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Barriers and Opportunities for Multifamily Building Electrification Retrofits in Sacramento

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Barriers and Opportunities for Multifamily Building Electrification Retrofits in Sacramento

By

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Abstract

Electrifying the built environment will be an important portion of economy-wide decarbonization efforts. However, significant barriers remain for electrifying existing multifamily buildings. This study focuses specifically on the reality of multifamily electrification in Sacramento Municipal Utility District (SMUD) territory. A review of existing literature uncovers qualitative studies on the barriers to multifamily building retrofits, including the number of stakeholders and aversion to new technologies, and also aims to identify optimal efficiency and load shifting measures to pair with electrification but finds conflicting results about the benefits of such measures. A study of pre- and post-electrification impacts on local electrical infrastructure finds that 10% of distribution transformers, 12% of main service building panels, and 2% of unit panels are currently loaded above their nameplate ratings and will need to be upsized during electrification, and that the specific impact of electrification on this infrastructure is negligible. The average total electrification project cost for buildings with all gas end uses and overloaded electrical infrastructure is projected to be $12,370 per unit, compared to $10,680 per unit for gas like-for-like replacement, but incentives of $3,700 per unit are currently available from SMUD to more than cover the gap. All other building tiers have more comparable electrification vs. gas project costs. The study projects that 92% of customers will see a decrease in total annual energy bills, and that average total energy bills will decrease by 11%. Finally, the study lays out a method for SMUD to target neighborhoods for electrification that will help reverse historic lack of investment into buildings and air quality in disadvantaged communities while avoiding overloaded electrical infrastructure and maximizing energy bill and emissions reductions. Ultimately, the study finds that the biggest barrier to multifamily electrification is not financial but rather the time and expertise required to perform electrification projects.

1. Introduction

1.1. Research Motivation

This study focuses on the barriers to and advantages of the electrification of the built environment. Buildings, the spaces that protect, comfort, and provide many basic goods and services, are entering a new age of opportunity. For the energy industry, buildings have historically been nothing more than energy sinks, black boxes that simply consume fossil fuel energy while occasionally sickening or hurting those within, and even state of the art building technologies and design strategies targeted harm mitigation – reducing energy use and operating costs, building with less toxic materials, decreasing fire risk (Nicol, Roys, and Garrett 2015; Allen et al. 2015). With the advent of affordable distributed energy resources (DER) in California like rooftop photovoltaics (PV) or storage systems and a better understanding of the variable greenhouse gas (GHG) and health impacts from different energy systems, buildings not only have better harm mitigation tools at their disposal but can provide a net benefit to occupant health and wealth, strained energy grids, and carbon neutrality plans (Krieger, Casey, and Shonkoff 2016; Lukanov and Krieger 2019).

These benefits can come in the form of heat pumps, which can replace gas appliances that contribute to unhealthy indoor and outdoor air quality levels and have magnitudes lower lifetime GHG emissions, especially when scheduled to run more during peak renewable electricity generation (Pistochini 2021). They can come in the form of electric vehicles (EV) paired with rooftop PV – if the EV charging is smartly or automatically managed, the PV will provide free, near-zero GHG emission transportation fuel while reducing local pollutant emissions (Coffman, Bernstein, and Wee 2017). Technologies with health, GHG emission, and grid co-benefits are available and affordable for many homes and businesses today. However, there are segments of the California building stock, and thus California resident and worker population, that have many barriers to accessing these DERs. This study focuses on existing multiunit shared spaces that are not owner-occupied, referred to here as “multifamily buildings". These buildings have proportionally less space for rooftop PV and EV charging than single-family homes, more technical challenges for installing all-electric retrofitted appliances, and split incentives between owners trying to minimize costs and occupants trying to minimize rent, bills, and negative health impacts. To ensure that occupants of these buildings experience the same benefits of electrification as the rest of the population, it is crucial to identify the biggest barriers to electrification and develop strategies and policies that make electrification the path of least resistance for multifamily buildings.

The goal for this research is to provide a granular analysis of what full multifamily electrification would look like on a local scale, specifically the territory of the Sacramento Municipal Utility District (SMUD). SMUD, a publicly owned electric utility serving most of Sacramento County and parts of Placer and Yolo Counties, offers a good case study for statewide electrification with a mid-sized urban center and suburban and rural surrounding areas and a climate with just slightly more heating and cooling needs than the population-weighted average for the state. Hopefully, this research can be used as a model for studying the potential for multifamily electrification in other localities, as each region will face similar challenges but may have different priorities, infrastructure, demographics, and building stock.

1.1.1. Existing Relevant Policy

California lawmakers have been focused on eliminating GHG emissions in all sectors for decades, enacting Assembly Bill 32, also known as the California Global Warming Solutions Act of 2006, which added a division to the Health and Safety code that required reporting and verification of greenhouse emissions while setting emissions targets in 2020 equivalent to 1990 levels (Nunez 2006). This was followed up by Senate Bill 32 a decade later that enacted into law, via the same Health and Safety code, that California was to reduce their total economy emissions by 40% of 1990 levels by 2030 (Pavley 2016). Around the same time, Senate Bill 350 was passed to ensure that electric utilities were similarly bound by law to purchase 33% of their electricity from renewable sources by 2020 and 50% by 2030 (De León 2015). In an effort to speed up the decarbonization of the electric grid, Senate Bill 100 followed a few years later in 2018 by setting the 2030 Renewable Portfolio Standard up from 50% to 60%, with the added goal of reaching 100% of electricity from carbon-free sources by 2045 (De León 2018).

These policies were helpful for spurring investment into grid decarbonization and even transportation electrification but did not attempt to directly eliminate carbon emissions from buildings. However, Assembly Bill 3232 addressed this issue outright by acknowledging that gas combustion in buildings lead to 10% of California's GHG emissions and requires that the building sector specifically reach the economy-wide goal set in SB 32 of a 40% emissions reduction by 2030 (Friedman 2018). Senate Bill 1477, signed on the same day, provides direct funding for this effort with the development of the Building Initiative for Low-Emissions Development (BUILD) Program, which requires gas companies to fund deployment of zero emission technologies, and the Technology and Equipment for Clean Heating (TECH) Initiative, which would require gas companies to advance the markets for zero emission technologies specifically for new and *existing* residential buildings as well as training and employment opportunities in the building decarbonization effort (Stern 2018). The TECH program would have specific funds and programs set aside for multifamily buildings.

Until the development of the TECH program, not much of an emphasis has been placed on existing buildings. The California Air Resources Board, which is charged with regulating local pollutant emissions including those from gas appliances, offers no policy or recommended strategies to increase existing building electrification, only a single page of basic information about the benefits ("Existing Buildings - Building Decarbonization" 2021). Most of the advances in electrification policy in California have been made through the California Energy Code and local "reach" codes, which both generally only apply to new construction. However, their development has been no small effort and will likely inform future efforts to implement stronger electrification retrofit policies. The energy code is a part, specifically Part 6, of the California Building Standards Code, which is known as Title 24 and also includes parts on mechanical and fire codes, to name a few. The energy code establishes standards for energy efficiency in new construction of both low-rise residential buildings as well as non-residential and high-rise residential buildings. In the 2019 update, there were two baselines to compare new home energy efficiency against: all-electric and mixed fuel ("2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings: Title 24, Part 6" 2018). This makes it easier to build all-electric buildings, as the code takes into account differences in the fuel used for energy services and applies efficiency standards appropriately. As of the writing of this, the 2022 update has not been ruled on, and there is a push to require new buildings to be all-electric to meet the code. Regardless of whether this is put into place, the code only applies to new construction, additions, and alterations. "Additions and alterations" potentially offer an opportunity to define retrofit standards, but they are very specifically defined for multifamily buildings: the standards do not apply to air and water conditioning systems expanded to new units or building additions. As of writing this, it is possible that heat pumps will become the baseline for the prescriptive option when installing a new HVAC or water heating system, meaning that the building owner would have to prove that a gas furnace or water heater would use less energy than the heat pump before installing, but even if this does get put into the 2022 code, enforcement may be challenging. A stronger solution may be to require electrification upon tenant change in multifamily rental buildings, but this would likely receive a lot of pushback from building owners and would be hard to implement through the energy code.

California cities and counties may adopt enhanced building codes in addition to the energy code, which are known as "reach codes". There are different types of reach codes: "electric preferred" codes tend to require stricter efficiency performance metrics, on top of the energy code, for new buildings built with gas and have been implemented by eleven California cities; "all-electric" codes requires specific end uses in new buildings to be serviced with electric appliances and have been implemented by 22 California cities; "natural gas ban" codes prohibit any new natural gas building hookups and have been implemented by eight California cities ("2020 Building Electrification & EV Infrastructure Reach Code Initiative" 2019; "Reach Code Paths: Building Efficiency/Renewables - Whole Building Equipment-Specific" 2021). This last reach code is not added through the energy code but usually through modification of the health and safety or other municipal code. The city of Sacramento, which contains 68% of SMUD's multifamily units, is in the midst of moving some version of a "natural gas ban" reach code, with significant caveats, through city council at the time of this research, likely starting with new low-rise buildings built after 2023. However, new buildings higher than three stories will not see this requirement until 2026 ("New Building Electrification – Proposed Framework & Timeline" 2020). This leaves even more multifamily buildings to retrofit from gas to electric in the future, and neither Sacramento nor any other city in California has moved to implement an existing building electrification policy, although the California Codes & Standards has outlined what that might look like, with the potential to require upgrades upon tenant change, at a specified date, or at phased intervals. Without a clear electrification enforcement mechanism for existing multifamily buildings, the final decision to electrify a building lies squarely with the building owner, which amplifies the importance of understanding every potential cost or loss of service associated with multifamily electrification and structuring incentives and project support around them.

1.1.2. Health and Welfare Impacts

Leaving existing multifamily buildings out of electrification policy makes centering an equitable electrification transition challenging – most multifamily residents are renters, and if the capital cost of electrifying a building requires increasing rent, the lower income tenants may be priced out of the building. If efficient all-electric buildings become unattainable for low-income residents, they will also see their gas bills increase as fewer Californians share the cost of the gas transmission system. In many cases, these low income residents may live in disadvantaged communities, which are defined by CalEnviroScreen, a tool developed by the California Environmental Protection Agency, as "census tract[s] that are disproportionately burdened by, and vulnerable to, multiple sources of pollution" (*CalEnviroScreen 3.0* 2018). Leaving these residents to pay higher utility bills while being even more disproportionately impacted by pollution would be a devastating scenario for the building energy transition.

With or without building electrification, gas rates are projected to increase. Because of the Low Carbon Fuel Standard regulating carbon emissions from fuels (*Low Carbon Fuel Standard Regulation* 2020), the natural gas used in California buildings will increasingly be made up of renewable natural gas, which is more expensive to procure. A California Energy

Commission study projects that even with no building electrification, residential gas rates will rise statewide from an average of around $1 per therm today to between $3 per therm and $4 per therm by 2040 (Aas et al. 2020). With heating, cooking, and light-duty vehicle equipment sales reaching 100% electric by 2040, the study predicts that rates would rise to $5 per therm and increase exponentially from there.

Gas appliances, especially gas cooktops, have also been shown to significantly increase air pollutant concentrations in homes, occasionally above the standards for outdoor air. In a study conducted by researchers at Lawrence Berkeley National Laboratory (LBNL), of the California homes that were sampled, 10% had 6-day NO_2 levels above outdoor limits set by the California Ambient Air Quality Standards (CAAQS), and although exhaust fans should have reduced the impacts from stoves, there was no statistically significant difference between the air quality in homes with exhaust hoods and without (Mullen, Li, and Singer 2012). If a multifamily building owner has actually gone to the trouble to make energy efficiency upgrades in the building to improve performance, it could actually lead to worse air quality and health outcomes for occupants in units with gas appliances. A study by researchers at Boston University modeled multifamily buildings with natural gas appliances before and after adding building insulation and sealing measures and found that air quality-related healthcare costs from trapping pollutants indoors far outweighed any energy-saving cost benefits from the measures (Underhill et al. 2020). If California hopes to see an equitable transition to all-electric buildings that centers environmental justice, it must focus on reducing the barriers to electrifying existing multifamily buildings.

1.2. Thesis Design and Layout

Both a quantitative and qualitative approach must be used to fully understand what currently prevents multifamily electrification. The bulk of the research and analysis performed for this thesis centers on the financial and technical barriers facing building owners and the impacts on tenants; however, to supplement the qualitative discussion, I perform a literature review in Chapter 2 to identify the social and organizational barriers as well. The literature review also includes hard-to-quantify impacts of multifamily building renovations on occupants and surrounding populations as well as a discussion of the lack of access to clean energy technology in low-income and disadvantaged communities. Additionally, the literature review aims to identify the most effective efficiency and load shifting measures to pair with electrification to increase cost effectiveness.

In Chapter 3, I outline the methodology and data sources used to model what systems currently consume gas in each multifamily building in SMUD territory, and then describe the methodology used to estimate electrification impacts on electrical infrastructure, building owner and tenant bills, and total project costs compared to a like-for-like gas equipment replacement. I also design a targeting method for optimizing electrification rollout to minimize costs and maximize beneficial impacts.

In Chapter 4, I describe the results of matching multifamily units to given fuel types for different end uses and determine potential electrification impacts at the household, building, and distribution grid level. I consider and model different solutions to avoid electrical infrastructure overloading, estimate the cost of upsizing any overloaded electrical infrastructure, and predict the financial implications for both building owners and tenants. Finally, I outline the results from targeting areas to focus electrification resources on.

In Chapter 5, I discuss potential utility programs, funding opportunities, design best-practices, and targeting strategies that will reduce the barriers shown in the results of Chapter 4 while discussing the magnitude and significance of each of the barriers studied.

In Chapter 6, I summarize the main findings of the study, make final recommendations, and suggest future work to expand on and verify these findings.

2. Literature Review

2.1. Qualitative Studies on Barriers to Multifamily Retrofits

Doing any sort of retrofit project in multifamily buildings has always involved more inertia than in single family homes, as the competing motivations and sheer number of stakeholders are much higher (Vogel et al. 2016). At minimum, the building owner will be the final decision maker for opting to do a retrofit and will likely be trying to minimize upfront capital costs and maximize rental rates and property value. The building manager, who may sometimes but not always be the same stakeholder as the owner, will likely be interested in decreasing the ongoing maintenance, energy, and water costs at the building level. The tenants will likely be interested in decreasing utility bills and rent while maintaining or improving the services and air quality in the unit but will have very little leverage aside from choosing to rent elsewhere. Developers are almost always separate from building owners and will not necessarily design the building so that resources are used efficiently or that the building is easily retrofitted. Even if a building owner decides to retrofit a building, the party that implements the retrofit will likely be trying to minimize time and resources spent on the project and may not optimize the retrofit design for performance or service quality.

Through interviewing thirteen stakeholders in roles related to multifamily buildings such as building owner, planner, estate manager, and contractor,, along with a literature review, a Swedish group of researchers was able to organize barriers into six main categories (Vogel et al. 2016). “Organization & Knowledge” barriers center around differences in knowledge – each stakeholder has different information and motivation, and no stakeholder has the right information to make a rational decision about technology implementation – and weak feedback structures – there is little interest and understanding of long-term economic impacts of retrofits. “Rules & Regulations” barriers center around the complexity, ambiguity, and weakness of energy codes and certifications; these barriers exist in California just as much if not more than Sweden. “Agreements & Building Process” barriers are focused on project planning processes that disincentivize new technology and utility payment by building owners instead of the end consumers. “Energy System” barriers involve the lack of interest in energy systems by building owners as well as lack of involvement of buildings in the energy system by most utility planning strategies with the increase in focus on distributed energy resources (DERs) in California, this category is becoming less of an issue. “Techniques & Design” barriers mainly focus on the lack of new technology and system designs in building energy systems due to resistance to change. “Economy” barriers center around more classic issues: perceived cost of new technologies and inaccurate or misaligned life cycle cost benefit analysis methods. These categories are not comprehensive but very well characterize the main barriers that exist to a building installing any new energy technology.

In general, barriers to retrofits often arise as a consequence of societal structure, not technological or even financial hurdles. It is crucial to understand how new technology interacts with different levels of the built environment, and the same group from Sweden has created four levels to organize the 38 barriers characterized in the study above: component level, project level, sector level, and contextual level (Vogel, Lundqvist, and Arias 2015). Given that the component level has already been resolved for new energy technologies – i.e. the technology works and is efficient – the focus is on the last three levels. The eleven barriers in the project level focus on lack of information, transparency, interest, and economic incentive for building owners. The eleven barriers in the sector level focus on the lack of incentive and motivation to use the newest technologies and the length of feedback time. The sixteen barriers in the contextual level revolve around confusing energy codes and planning processes as well as split incentives between building manager and occupant. This study highlights how many barriers are out of control of the building owner, who is the stakeholder in charge of opting for retrofits. Good policy & codes as well as widely available training, education, and funding will be crucial for a comprehensive energy transition.

Even when multifamily tenants are able to own their unit, they face challenges in performing retrofits. A qualitative study performed in Australia consisting of thirteen interviews with strata – similar to condominiums in America – managers as well as building committee members found that a big barrier for performing energy and water retrofits was the lack of individual meters for each unit for some services, as any savings at the unit level would be spread out to all building units (Altmann 2014). With more individual accountability for energy consumption, tenants would be more likely to opt for energy saving retrofits and even change their behavior, but this can be expensive for resources like central water heating and hydronic space conditioning. On the other hand, billing utilities for an entire building give the building manager more incentive to opt for energy saving retrofits. The study also found that unit owners did not want to spend time lobbying for retrofits nor spend money upfront on retrofits that they will not be around to see the benefit of and that have little to no resale impact, as most strata have high turnover rates. Because most multifamily residents in SMUD territory are renters – only 2% of multifamily units are condominiums – these issues are exacerbated, as renters are not as likely to stay in the same unit for as long as a single-family homeowner and thus will not receive energy saving benefits for very long; building owners may see even fewer resale or property value benefits from these retrofits if renters are not interested in the retrofits.

A study performed on strata in Switzerland found that financial issues are not even necessarily the key barriers for retrofits, finding that imperfect processes, communication, and information cause a good amount of the challenges surrounding retrofits (Ehrbar et al. 2019). However, when around 500 chairmen of cooperative housing facilities in Sweden – similar to strata or condos – were polled on effectiveness of various measures to encourage implementation of energy retrofits, the measures deemed most effective were investment subsidies (73% found effective) and tax deductions (64%) (Nair, Gustavsson, and Mahapatra 2011). The participants were not polled on higher level issues like confusing codes or lack of installer training, which speaks to the fact that most research focuses on the project level barriers noted in Vogel et al. (2015). Another study performed interviews in Australia with both strata owners who were on a building leadership committee and owners who were not and found that the owners who had more agency in building decision making were more likely to have the interest and ability to initiate beneficial energy retrofits; this suggests that including building occupants in decision making can increase the likelihood of implementing retrofits, although does not solve the challenge of including occupants who simply do not have the time or interest to be involved in such processes (Rex and Leshinsky 2016). It is worth noting that none of these studies were performed on European or Australian housing populations – there is a lack of qualitative multifamily housing research in the US. However, this thesis assumes that the basic human decision-making detailed in these studies relating to retrofit adoption and energy consumption are representative of multifamily housing stakeholders in Sacramento, even if some policies and living arrangements may be slightly different than in Europe or Australia.

2.2. Impacts from Retrofits on Multifamily Tenants

If building owners are able to overcome the hurdles in their way to retrofitting multifamily buildings, the impact of these retrofits is not always strictly positive for the tenants. First, it is important to put in context the energy burden that different demographics of Americans currently face and try to understand the root causes of the inequity in this burden. A meta-study looking at discussion of low-income energy affordability in scientific literature found that major stakeholders mentioned in papers were mainly governments, utilities, and NGOs with almost no representation of building owners, landlords, and building managers, despite the latter groups playing the largest role in investing in multifamily energy affordability and indoor air quality improvements (Brown et al. 2020). The group also found that there has been an increase in studies focused on the health implication of energy retrofits, which aligns with the general increase in interest in gas-to-electric building fuel conversion, although no terms similar to electrification show up in their bibliometric analysis, and they recommend moving towards an inter-agency approach to better target equitable energy burden reduction programs.

Another study was able to use small area, high resolution multifamily building energy data required to be reported by five major American cities to look at the energy cost burdens and energy use intensities across different income brackets (Kontokosta, Reina, and Bonczak 2020). The study found that energy burdens in minority communities are higher for all low-income brackets compared to white communities in similar brackets, although this result cannot be stated for the building or household level. The group also determined that energy retrofits have the highest potential for energy burden reduction in the lowest income brackets and encourage shifting energy efficiency investments towards targeted reduction of energy burdens for disadvantaged households and communities. A study in Europe found that government-owned multifamily buildings tend to be under-renovated compared to privately owned buildings, and that disadvantaged groups are overrepresented in buildings with poor energy performance (Mangold et al. 2018). These studies highlight the need to target electrification efforts and better understand how electrification will impact low-income and disadvantaged households.

Energy retrofits, and electrification for that matter, in energy burdened and disadvantaged households are only beneficial if the households are able to remain in the retrofitted unit. One reason that building owners may opt for energy retrofits is to increase the value of the property and, in turn, increase rent; this may even just be an indirect byproduct of the decision to perform a retrofit. The concern is then that an increase in rent would force out low-income households. Additionally, electrification offers air quality improvements that may be a selling point for renters with the financial mobility to move to buildings or neighborhoods for reasons other than economics. Banzhaf & Walsh (2013) suggest that investment in public goods such as environmental cleanup can lead to an increase in segregation. However, in a study that specifically looked at the change in neighborhood demographics, housing prices, and rents in the years after air quality changed, Lang (2015) discovered that rents take around six to ten years to respond to any changes, much longer than owner-occupied capitalization rates, which respond immediately; perhaps more relevantly, Lang also found that although there is an increase in rental unit turnover due to air quality change, the new occupants are from similar income, racial, and educational demographics, which refutes the first study's findings somewhat and hopefully indicates that electrification will equitably benefit the communities that it is implemented in.

The previous study's results specifically reference significant air quality improvements, a benefit unique to electrification compared to other energy retrofits. However, it is worth understanding the impact that different energy retrofits have on rent and affordability. A study performed on cost-of-living impacts in the Netherlands from energy retrofits attempted to model rent increases strictly based on capital costs of projects meted out to 30 years of increased rent (Konstantinou et al. 2019). The study suggests that installing a heat pump in a multifamily building will increase rent by 16%, with larger increases for retrofits such as heat recovery systems; however, there is no validation of this model and based on the results from the previous study it seems unlikely that a rent price would change that drastically, and it is more likely that a building owner would simply not choose to install a retrofit that could increase rent by that much. Additionally, the study did not make an effort to find the most recent costs of heat pumps, and it seems plausible that the results would change using the prices of both rent and heat pumps in California in the present day.

A study using a hedonic estimation of urban rental prices based on data from the American Housing Survey (AHS) suggests that each Energy Star appliance included in a unit contributed to a 1.6% increase in rent premium, which could mean that property managers can successfully market energy retrofits as a justification for rent increases (Hopkins, Carswell, and Love 2020). However, the authors suggested that the increase in rent could also be partially attributed to renovations or improvements not captured in the AHS; it seems that the results are too inconclusive to apply to this research. Another study investigating the impact of green building certification on tenants' willingness to rent showed that prospective tenants were willing to pay higher rent for buildings with certifications such as LEED but did not distinguish between different levels of certification (Jang, Kim, and Kim 2018). Additionally, low-rent buildings saw a higher increase in prospective tenant willingness to rent after the addition of a green building certification compared to high-rent buildings, and tenants with higher interest in “eco-friendliness” had a higher willingness to rent in certified buildings. These two results could end up being very important in the energy transition, suggesting that if electrification is strictly marketed as a “green” or “eco-friendly” retrofit, that tenants in affordable, if not low-income, housing may be priced out by higher income tenants willing to pay a premium for a more environmentally friendly all-electric home. This is an important implication to consider as different marketing strategies are tested out for electrification.

2.3. Optimal Measures for Energy and Peak Demand Reduction

2.3.1. Passive Efficiency & On-Site Solar

One of the main concerns surrounding building electrification is the additional strain that the newly electrified loads will put on the local grid and electrical infrastructure. Not only will more electric generation be required if consumption increases, but transformers, wires, and electrical panels may all need to be upsized to accommodate larger instantaneous demand. In both California and specifically Sacramento County, space cooling tends to drive the peak load in the hot summer months, which is what electrical infrastructure should be sized to, although it remains unclear how large the winter peak will be after electrifying space and water heating as well as transportation. There are a number of existing and developing strategies to avoid upsizing, including increased levels of passive efficiency measures, load shifting with behavioral and technological demand response measures, and on-site energy generation. One study modeled the potential residential peak load reduction in Las Vegas, another cooling-dominated climate, due to various efficiency and generation upgrades (Sadineni and Boehm 2012). The authors projected that a home with energy efficiency upgrades such as insulation, sealing, and a high-performance HVAC system would manage to decrease peak load from 1:00 PM to 7:00 PM by 37% compared to a home of the same size that meets but does not exceed the code standard, and that the energy-efficient home with on-site PV decreased the average demand another 9%. They also found that raising the thermostat setpoint on the peak day from 75°F to 79°F between 4:00 PM and 7:00 PM reduced the average demand an additional 24%.

Heating-dominated climates are more at risk of a large spike in peak demand from electrification, and much more research has been done on energy and electrification retrofits in Europe, which has many more cold-weather climates. Finnish researchers designed optimal electrification retrofits for four multifamily buildings of different vintages on fossil fuel-powered district energy systems to minimize carbon emissions (Hirvonen et al. 2019). In doing so, they also estimated impacts on peak demand in January and found that the percent increase in peak power demand from electrification of heating was greater than the increase in average hourly energy use, even with passive efficiency measures used in combination, meaning that electrification may drive more severe load spikes than total load increase. They also found that more advanced strategies like heat recovery and rooftop PV were more helpful in the summer but did very little to reduce peak power in January. Despite the SMUD grid currently having a summer peak, a post-electrification winter peak could start driving electric infrastructure sizing on a more local, building-specific level, so the results of this study should caution against passive efficiency or PV being a catch-all solution for avoiding peak impacts.

The question of what the “optimal” energy retrofit looks like is elusive and will clearly change depending on building type, vintage, and location, but a group in Barcelona, home to another mild climate similar to Sacramento, attempted to select the lifecycle cost-optimal energy efficiency measures for both single and multifamily buildings across building vintages (Garriga, Dabbagh, and Krarti 2020). In older multifamily buildings, they suggested that medium-level roof insulation, maximum wall insulation, maximum efficient AC split units, complete replacement of appliances and lighting with the most efficient new technology, and solar thermal hot water systems were the most cost-efficient options, while in newer buildings wall insulation and solar thermal were not necessary. In all multifamily buildings, window, cooking, and heating system improvements were not found to be cost effective, but they did not consider any heat pump technology. Upon implementing these measures, older buildings were projected to reduce energy consumption by 44% but peak load demand by only 26%; in newer buildings, energy savings were only projected to decrease by 15% and peak demand by 16%. Once again, efficiency measures are shown to be less effective at avoiding peak demand than saving energy.

A similar study by researchers in the United Kingdom found that solid wall insulation is the most impactful and cost-effective retrofit to reduce heat pump consumption in semi-detached housing, with other measures such as glazing and roof & floor insulation being less so, but only with all measures would the heat pump demand stay under 1 kW of demand, a key metric for the study (Lingard 2021). This essentially indicates that to avoid peak load issues, efficiency retrofits will have to be deeper than only what is cost effective; this adds another cost-benefit analysis to any electrification project to determine whether it is more cost effective to install efficiency retrofits or upsized electrical infrastructure.

A study of existing high-rise buildings in different climates in Turkey shows that in the mild and hot-weather climates, the most cost-effective energy retrofit is the installation of a more efficient and central domestic hot water distribution along with window glazing and LEDs, and occupant behavior changes such as opening windows instead of using conditioned air significantly increased the benefits from the retrofits in these climates (Sağlam et al. 2017). Notably, they found that envelope retrofits have limited effect on high rise buildings compared to previous studies of low-rise and single-family buildings. These studies do not agree on which specific energy retrofits are the most cost effective when combined, which means it is important to design a retrofit specifically for an individual building or complex. However, the key takeaways from these studies are that, for multifamily buildings, passive efficiency and rooftop PV usually lead to energy cost savings but not necessarily significant peak demand reduction; efficient equipment and system design, such as heat pumps and central water heating, will offer the most energy savings; and load-shifting technology or behavior will be an important aspect of electrification projects from a grid perspective, if not a building performance perspective.

2.3.2. Thermal Storage

With more efficient heating technology, using material heat capacity as a form of storage offers a promising method of peak demand reduction. A study by researchers in the UK simulated the impacts of different load shifting strategies using a thermal energy storage tank (TES) charged by a heat pump water heater based on real data from five homes that currently have hydronic space and water heating fueled by gas (Marini, Buswell, and Hopfe 2019). They found that hot water consumption behavior was a major factor in determining the effectiveness of different strategies, and that a peak load shifting strategy of charging TES tanks on either side of the 4:00 PM to 8:00 PM peak, as opposed to avoiding both the morning and night peak or using a night-only charging strategy, would allow the smallest volume tanks. Two of the five homes could use a 160-gallon TES tank to ensure sufficient service, one would require at least a 210-gallon TES tank, one would require at least a 260-gallon TES tank, and one would never reach acceptable service levels with any size of tank based on their current consumption patterns. The size of these tanks is impractical for individual units in a multifamily complex, but because a central water heating system has a much smoother demand profile due to the diverse consumption patterns it services, it is likely that the per unit volume needed for a TES tank on a central water heating system would be reduced compared to individual systems. The study also showed that energy costs would increase for the homes, but with a time-of-use (TOU) rate heavily encouraging shifting load from the peak, bills in homes that could utilize the TES charging would be closer to the baseline.

TES tanks are not the only thermal storage solution to smooth or shift peak load, however. A study by researchers in Portugal explored the concept of using apartment buildings as a thermal battery by simply automatically increasing the thermostat setpoint during hot days and “discharging” at night by reducing the setpoint, with the buildings ranging from a typical 1980s construction to a Passive House certified building (Oliveira Panão, Mateus, and Carrilho Da Graça 2019). Based on their thermal capacitance models, they found that the buildings with high thermal inertia and effective insulation can have a storage efficiency of around 80%, which compares to 40% to 60% in more typical buildings. The mild winters of Portugal are likely similar to those of Sacramento, so this is a promising result, but requires occupants to hand over control of their thermostats; additionally, many Sacramento multifamily buildings are older and poorly insulated, so making the retrofits necessary for the building to act as an efficient thermal storage source could be costly.

2.3.3. Measure Financing

Of course, the biggest barrier to these retrofits is not determining which specific retrofits to implement but figuring out how to pay for them. One study developed a financing system for multifamily retrofits and clean energy generation that relies on a fixed, per-resident fee to pay for a loan on energy efficiency, renewable energy, and storage investments; optimized demand response sold to a utility coupled with the energy cost savings would more than pay for the fee, and this would help overcome the split incentive issue present in many multifamily buildings (Raziei, Hallinan, and Brecha 2016). This is somewhat similar to a Pay-As-You-Save (PAYS) system but specifically designed for clean energy on multifamily buildings. However a building owner goes about paying for the project – whether it is with direct financing from tenants, indirect rent increases, incentives, or a combination – any additional costs from electrical infrastructure upsizing would impact the likelihood of completing a project. The next section will lay out methods to identify and quantify these barriers while targeting buildings in the communities who are generally underserved by efficiency and clean energy retrofits.

3. Methodology

3.1. Building Attribute & Load Data

Before any impact analysis on projected electrification can take place, each multifamily unit and building needs to be characterized by location, building ownership type and size, demographics and utility rates, transformer connection, and fuel type for different end uses. First, I define multifamily housing as either a parcel with four or more units or a condominium parcel in a building with four or more units, not including mobile home parks. In SMUD territory, this represents 110,898 meters. The Sacramento County parcel numbers have previously been matched to each meter which also allowed the matching of number of units, census tract, address, parcel area, building classification – fourplex, garden style, low-rise, or high-rise – year built when available, and whether the building receives government subsidies for low-income housing. Each meter can be matched to its SMUD rate – time-of-day or energy assistance program (EAPR) – and distribution transformer, which includes information on type – polebolt, padmount, or other – size in kVA, and voltage. This study also used hourly electricity consumption data at the meter level for all of 2019 instead of 2020, meaning there are no impacts due to COVID-19 in the data.

In this study, I only consider the impact of electrifying space heating, water heating, and cooking in multifamily buildings. This is not comprehensive, as pool heating and laundry are two other end uses that could use fossil fuels, but according to the 2009 California Residential Appliance Saturation Survey (RASS) organized by the CEC, water heating accounts for 49% of residential gas consumption, space heating accounts for 37%, cooking accounts for 7%, dryers account for 3%, and pools, spas, and miscellaneous uses account for the final 4% (Palmgren et al. 2010). Specifically for multifamily homes, the RASS projects that 88% of units have gas space heating, 69% have gas water heating, 66% have gas cooking, 22% have gas dryers, and 1% have gas pool heating. Additionally, it is much harder to determine which buildings have gas laundry and pool heating from the resources available. Given the minimal adoption of heat pumps and induction stoves at this point in time, if a building has electric water heating, space heating, or cooking, it is assumed to use electric resistance elements for heating (Palmgren et al. 2010). In addition to fuel type, I also consider the system type of space and water heating. Water heating can be done with individual storage or tankless water heaters in each unit, “multi-central” storage water heaters that serve four to ten units but do not recirculate unused hot water, and central water heaters that can serve part of a building, one building, or one complex. For the sake of simplicity, this study assigns a water heating system type of either individual, multi-central, or central to each building. Space heating can be done with a variety of technologies, such as wall furnaces, packaged A/C and heating units, central forced air heating and cooling, or central hydronic radiators. The specific technology type is too granular of a level to predict using the methodology laid out in this section, so this study simply assigns a space heating system type of either individual or central to each building.

One issue caused by the way that parcels are divided is that one parcel does not necessarily equal one building. As seen in Figure 1, there may be one building per parcel, there may be multiple buildings per parcel, or, in the case of condos, there may be multiple parcels per building. We are specifically interested in the fuel types and attributes of buildings, not parcels, so the two must be differentiated – we want the collections of meters in red, not blue, in the figure below. For this study, if a parcel had meters attached to more than one transformer, I deemed the meters on each transformer to be in one building. If a transformer had multiple parcels with one meter attached to it, as would be the case in a condo, I deemed those meters to be one building. Otherwise, I deemed the meters on a single parcel to be part of one building. Each building was assigned a unique identifier similar to the parcel or transformer identifiers. There are 6,232 multifamily parcels in SMUD territory and 5,315 transformers that have multifamily meters attached, which led to 6,722 unique buildings.

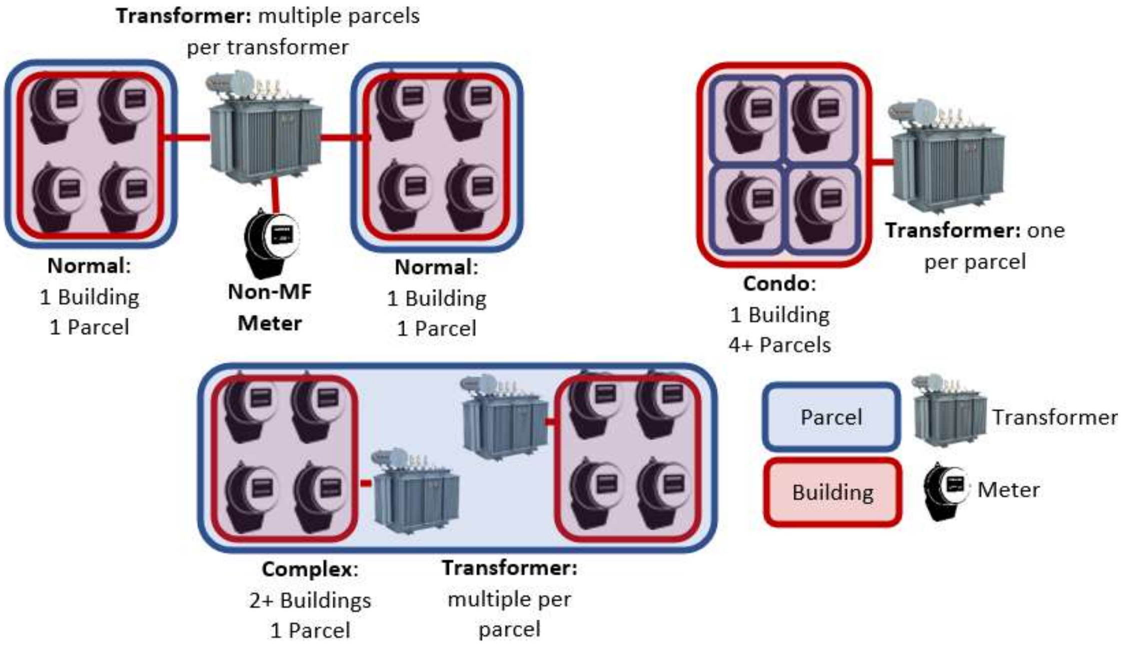


Figure 1: Examples of Possible Parcel, Building, and Transformer Layouts

The data for fuel and system types were pulled from three sources: Sacramento County building permit data, the California Tax Credit Allocation Committee's (TCAC) low-income housing capital needs assessments, and the former contractor of SMUD's multifamily energy efficiency program ("Permits" 2021; "Project Mapping" 2021). The county had every permit pulled since 2007 with a description of work and a parcel number. Fuel and system types for around 600 parcels were determined by searching for key phrases such as "gas water heater" in the description, although rarely did a parcel have permits showing fuel or system type for multiple end uses. TCAC, which provides funding for government subsidized low-income housing, requires capital needs assessments to be completed when the buildings are re-syndicated, which happens about every 20 years. The capital needs assessments contain detailed information on building attributes, including all fuel and system types for the three end uses studied here. Unfortunately, TCAC was only able to provide records for around 25 parcels. Finally, the former contractor was able to provide records for around 200 energy efficiency projects that included fuel and system types for most or all of the end uses, but due to customer privacy policies could not share the parcel numbers of the projects. It was possible to match up some of the projects with a parcel based on ZIP code, number of units, and vintage, however. Figure 2 shows the percent of buildings missing data for different variables after matching up as much of the end use fuel and system type data to buildings as possible using these three sources. Note that many buildings are missing year-built records. Table 1 shows the breakdown of fuel and system type across meters with known variables. “Type” refers to the style of housing – fourplex, low-rise, high-rise, condominium – “Tract” refers to an area of land smaller than the ZIP code but larger than a parcel, and “Space” refers to the size of the parcel.

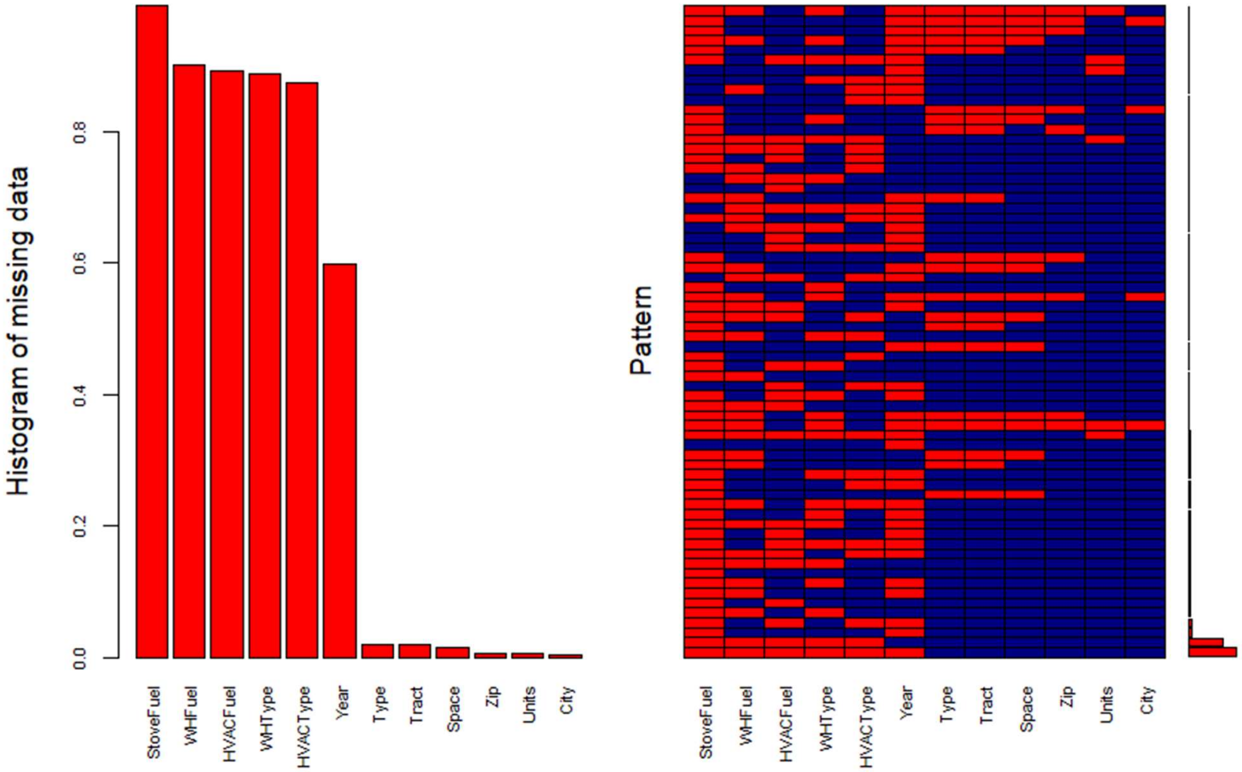
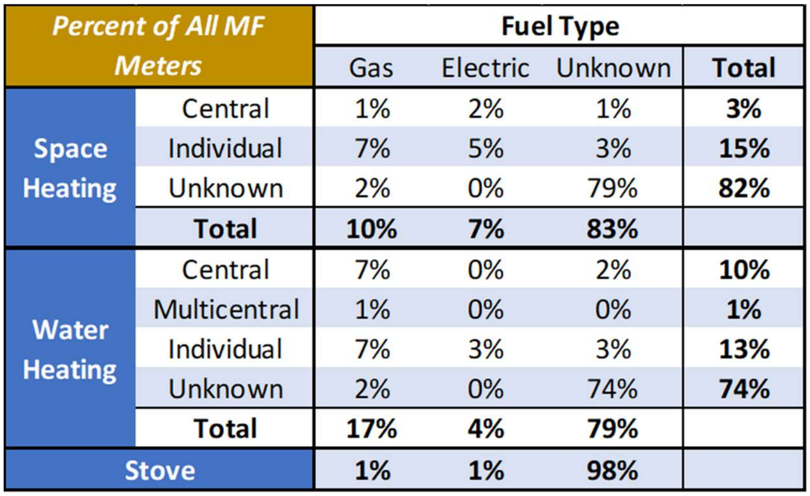


Figure 2: Missing Data and Most Common Combined Variable Availability

Table 1: Breakdown of Fuel and System Type by Meter Before Prediction



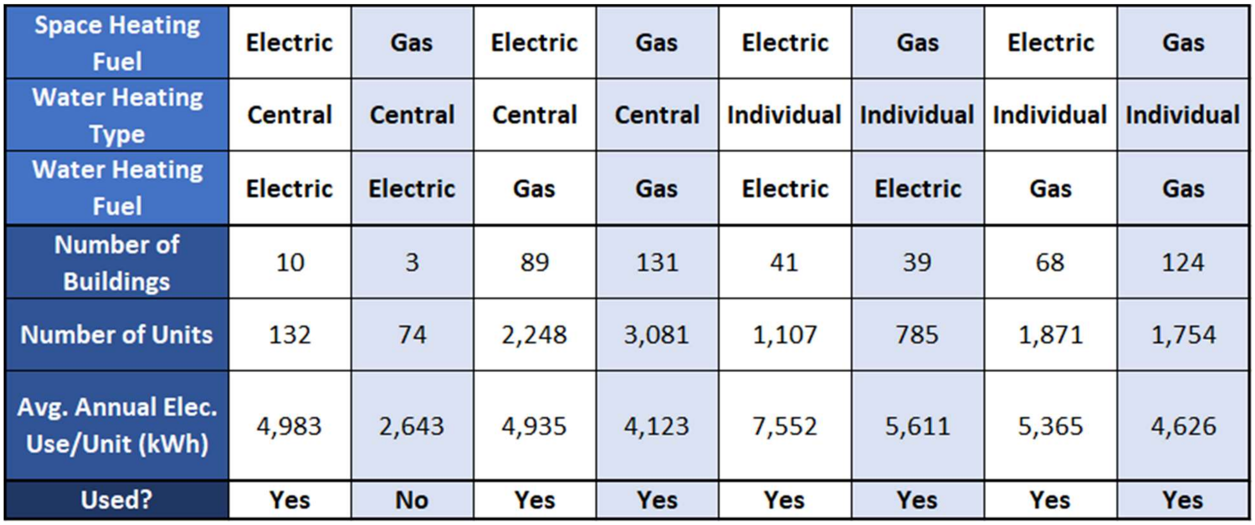
Percent of All MF Meters		**Fuel Type**			
		Gas	Electric	Unknown	**Total**
Space Heating	Central	1%	2%	1%	**3%**
	Individual	7%	5%	3%	**15%**
	Unknown	2%	0%	79%	**82%**
	Total	**10%**	**7%**	**83%**	
Water Heating	Central	7%	0%	2%	**10%**
	Multicentral	1%	0%	0%	**1%**
	Individual	7%	3%	3%	**13%**
	Unknown	2%	0%	74%	**74%**
	Total	**17%**	**4%**	**79%**	
Stove		**1%**	**1%**	**98%**	

3.2. Building Attribute Prediction & Imputation

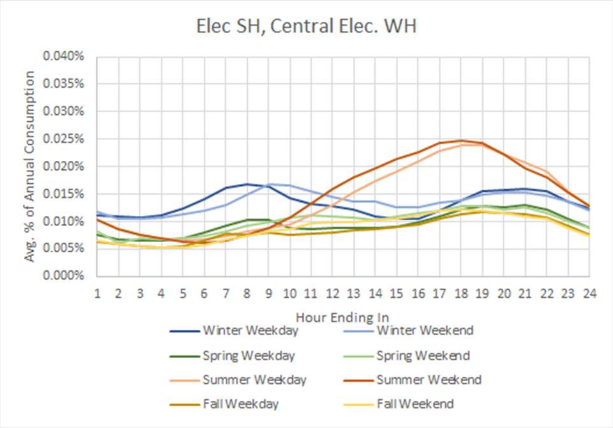
To predict the fuel and system types of the remaining multifamily building stock, one strategy is to create average normalized annual load shapes of the buildings with known fuel and system types and then match the unknown buildings to these load shapes. This method will not be effective for predicting stove fuel type, as stove fuel type has a minimal impact on overall load shape. Additionally, there is minimal difference in the load shape of central space heating compared to individual space heating. For the purpose of this study, central and individual space heating are assumed to have the same impacts on load shape. Multicentral water heating was treated the same as individual water heating in terms of load shape, as they have more similar load shapes than recirculating central water heating. This leaves three variables to determine for each building using the methodology summarized previously: space heating fuel, water heating fuel, and water heating system type.

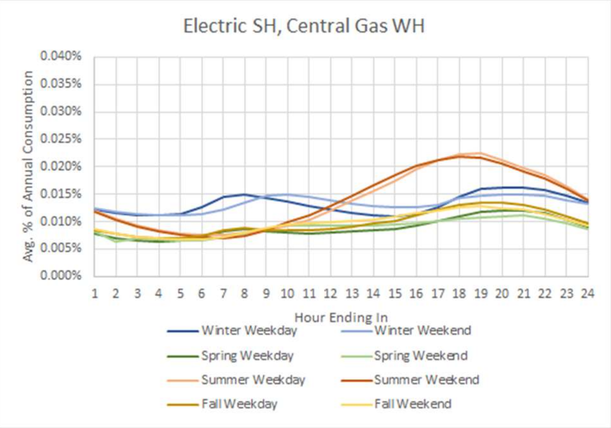
To create normalized load shapes at the building level, hourly energy consumption for each meter was aggregated to the building level so that any central or master meter consumption was included as well. The aggregated building load for each of the 8,760 hours in 2019 was then divided by the aggregated annual building electricity consumption to get the normalized load shape for each building, where the value for each hour represents the percent of annual electricity consumption consumed in that hour. The load shapes for buildings with known values for each of the three variables mentioned above were averaged to create distinct load shapes for each variable combination. Table 2 below shows the number of buildings and units with a given space heating fuel, water heating type, and water heating fuel. Because of the low number of buildings and outlier average annual electricity consumption per unit, buildings with both gas space heating and electric central water heating were not included as an option when matching unknown attributes to buildings. This means that buildings with these specific characteristics were matched incorrectly but, based on the known data, this should not affect a significant amount of the building predictions. Figure 3 shows summaries of the known load shapes.

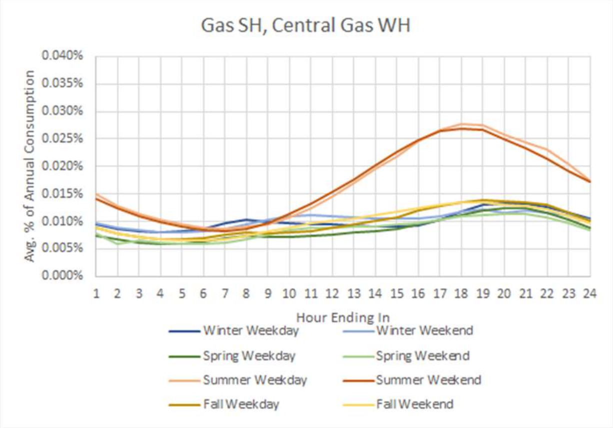
Table 2: Population of Buildings with Known Water and Space Heating Attributes

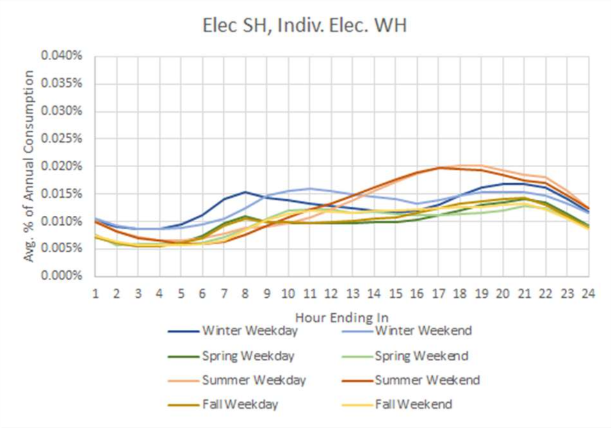


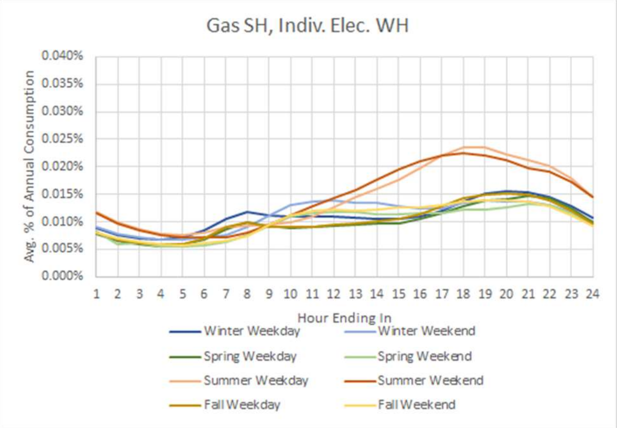
Space Heating Fuel	**Electric**	**Gas**	**Electric**	**Gas**	**Electric**	**Gas**	**Electric**	**Gas**
Water Heating Type	**Central**	**Central**	**Central**	**Central**	**Individual**	**Individual**	**Individual**	**Individual**
Water Heating Fuel	**Electric**	**Electric**	**Gas**	**Gas**	**Electric**	**Electric**	**Gas**	**Gas**
Number of Buildings	10	3	89	131	41	39	68	124
Number of Units	132	74	2,248	3,081	1,107	785	1,871	1,754
Avg. Annual Elec. Use/Unit (kWh)	4,983	2,643	4,935	4,123	7,552	5,611	5,365	4,626
Used?	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

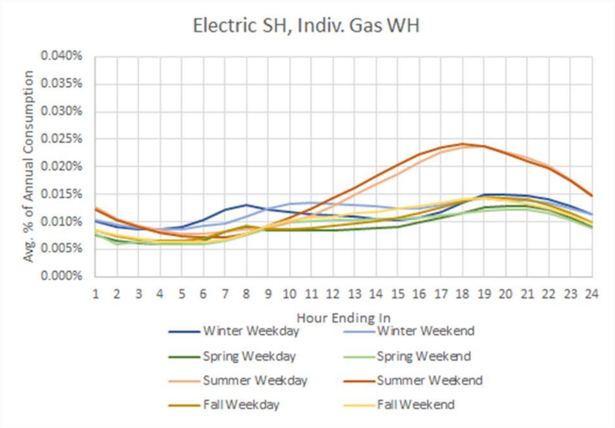

Elec SH, Central Elec. WH


Electric SH, Central Gas WH


Gas SH, Central Gas WH


Elec SH, Indiv. Elec. WH


Gas SH, Indiv. Elec. WH


Electric SH, Indiv. Gas WH

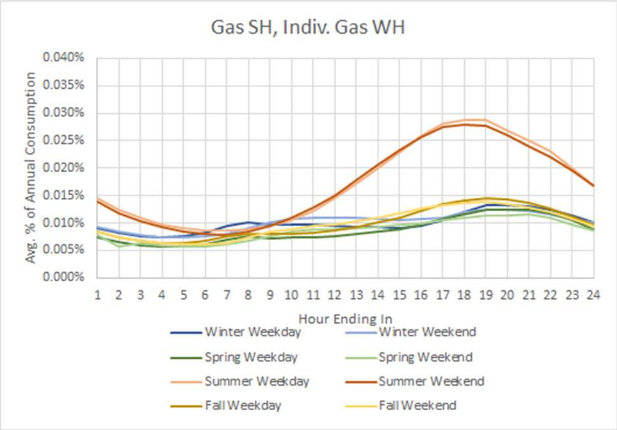


Figure 3: Average Load Shape Summaries for Different Known Fuel and System Types

To match the normalized load shapes of the buildings with unknown variables, the sum of squared errors for each hour between each building and each known load shape was calculated. The minimum sum of squared errors across all seven potential load shapes determined which combination of variables was assigned to each building. The predicted variables for buildings that have some but not all variables already known can be compared to the known values, resulting in the match success rate shown in Table 3. 72% of incorrect space heating fuel values were predicted to be electric instead of gas, 52% of incorrect water heating system type values were predicted to be individual instead of central, and 71% of incorrect water heating fuel values were predicted to be electric instead of gas. This suggests that the matching methodology is over-predicting the number of electric space heating as well as individual and electric water heating buildings.

Table 3: Success Rate of Load Shape Matching Based on Known Values Compared to Predicted Values

	SH Fuel	WH Type	WH Fuel
Buildings Correct	701	762	960
Buildings Incorrect	259	473	171
Successful Match Rate	**73%**	**62%**	**85%**

To strengthen confidence in the matching results as well as predict the stove fuel for all buildings, a second method was used called multivariate imputation by chained equations (MICE), which is a method of imputing, or predicting, missing values in a dataset based on other variables. It is an alternative to regression analysis when too much data is missing to create a meaningful model. There are different model types that can be used in the MICE function in R, but I used classification and regression trees (CART), which is a form of machine learning that splits outcomes into different partitions based on combinations of the predictor variables with the goal of creating similar outcomes for similar combinations of variables (Burgette and Reiter 2010). The variables used in the models to impute the missing fuel and system type data, if available, were Year Built, Number of Units, and Parcel Area. The model was run five times for each fuel and system type variable.

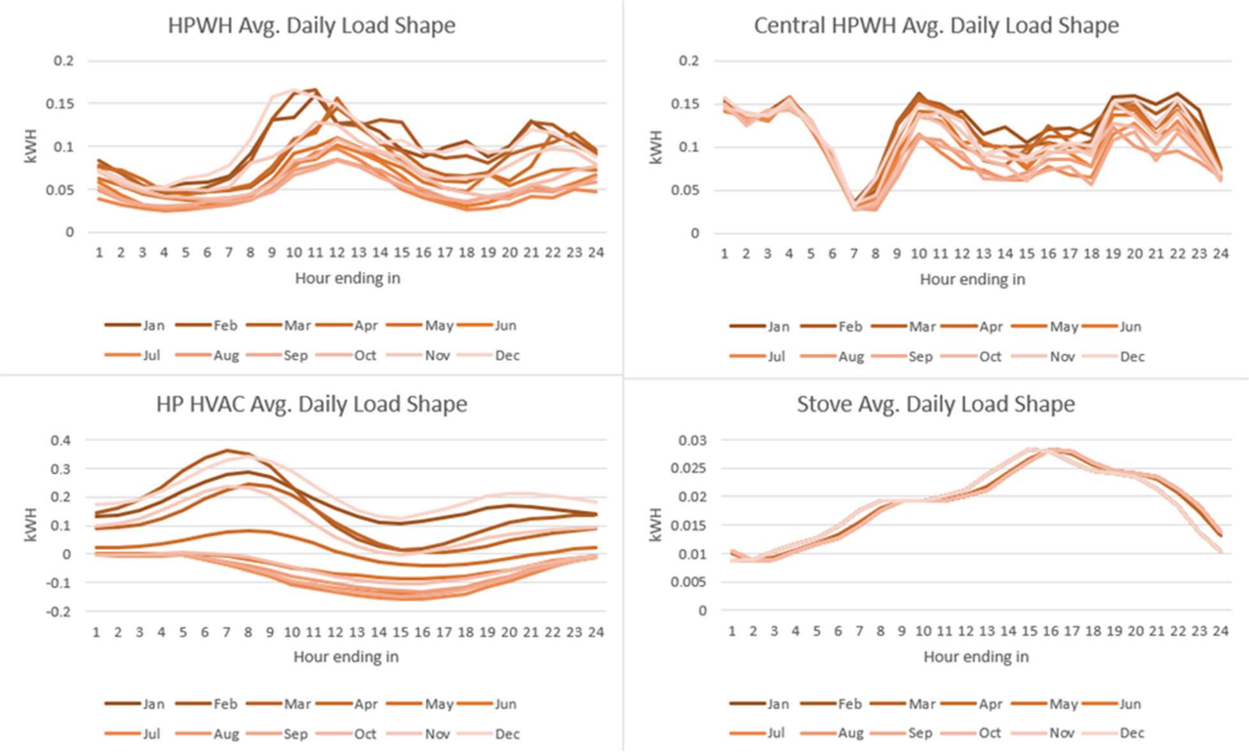
Stove fuel was simply determined by the fuel type that was selected in three or more of the five iterations. For space and water heating variables, if 1) all five iterations produced the same value, 2) it was different than the predicted value from the matching process, and 3) the minimum sum of squared errors from the matching process was in the top 20% of sum of squared errors – in this case, greater than 8.4e-7 – then the value of the variable was changed to what was predicted by the MICE methodology. In sum, this led to the values in Table 4. There are sure to be incorrect variable predictions from this methodology, but without better initial data from physical inspections of the buildings, this should be sufficient for the territory-wide analysis. These data align well with the statewide data in the RASS study mentioned previously, which estimated that, in multifamily units, 69% of space heating is gas, 88% of water heating is gas, and 66% of cooking is gas.

Table 4: Final Breakdown of Predicted Fuel and System Types, Including Known Values

Percent of All MF Meters		**Fuel Type**		
		Gas	Electric	**Total**
Space Heating	Central	5%	5%	**10%**
	Individual	55%	35%	**90%**
	Total	**60%**	**40%**	
Water Heating	Central	29%	1%	**29%**
	Individual/ Multicentral	59%	12%	**71%**
	Total	**88%**	**12%**	
Stove		**58%**	**42%**	

3.3. Electrification Load Shapes

The next step in understanding the impacts of electrification is adding on the load shapes of the gas-to-electric measures to the existing load profiles for each unit. Figure 4 shows the electrification load shapes to be added. For the individual heat pump water heater (HPWH) load shape, I aggregated unpublished simulations of individual storage HPWH energy use in SMUD's climate zone for different household sizes and HPWH models obtained from the Natural Resource Defense Council (Delforge 2020). For the central HPWH load shape per unit served, I aggregated results from simulations run in California's building compliance software, CBECC Res (Wilcox 2019). As discussed earlier, individual and central space heating are treated as having the same impact in this study, so only one load shape is used for both. Because the new HVAC heat pump (HP) can operate in both directions and is replacing not only the existing gas space heating system but also the existing AC cooling system, there are typically efficiency gains as a new high performance, better-sized cooling system replaces an older and potentially larger system. This reduction from the baseline is represented in the negative load in the warmer months. The HVAC HP load shape was developed through internal SMUD measurements and models based mostly on typical heating and cooling degree days in SMUD territory. The induction cooktop load shape was developed through internal SMUD estimates. Note that the magnitude of the induction cooktop load shape is much smaller than the heat pump load shapes.


HPWH Avg. Daily Load Shape

Central HPWH Avg. Daily Load Shape

HP HVAC Avg. Daily Load Shape

Stove Avg. Daily Load Shape

Figure 4: Electrification Average Daily Load Shape Summaries

An additional load shape was used to estimate the impact of passive efficiency measures on electrical infrastructure loading. Based on the energy efficiency measures that SMUD offers incentives for, namely roof and wall insulation, duct sealing, and efficient windows, and the hours that SMUD estimates that these measures effectively decrease load, SMUD developed the load shape summarized in Figure 5. In sum, the annual energy impact of all of these measures is summarized in Table 5. I assume that every building can achieve these passive efficiency measures, which is demonstrably false, as some buildings have already installed these retrofits; however, the purpose of this scenario is to identify the maximum bound for possible passive efficiency benefits, not to target individual buildings for retrofits.

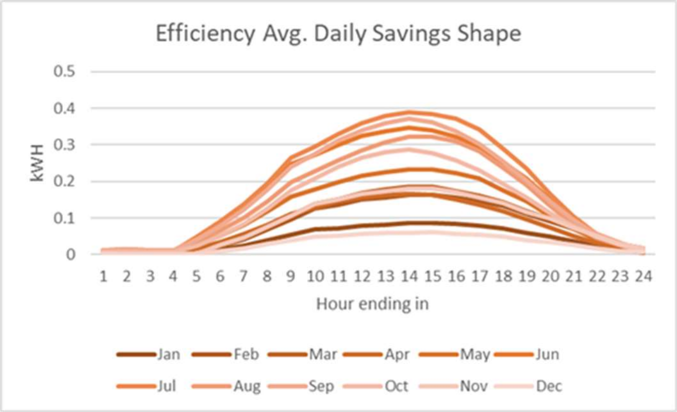


Figure 5: Passive Efficiency Average Daily Load Shape Summary

Table 5: Annual Electricity Impact Per Unit of Given Measures

	HPWH	Central HPWH	HP Space Heat	HP A/C Efficiency	Induction Stove	Passive Efficiency
Annual Added Energy Use (kWh)	628	942	694	-400	165	-980

These load shapes are suitable as base or average impacts per multifamily unit. However, each building has different envelope and use profiles. To account for this, a simple temperature dependent model was created for each aggregated normalized building load shape. The only variables used were heating degree days (HDD) and cooling degree days (CDD), which are calculated based on the difference between the average outside air temperature in a given hour and 65 degrees Fahrenheit, which is used as the desired interior temperature for a building. HDDs are zero for any hour if the temperature is above 65° F, and CDDs are zero for any hour if the temperature is below 65° F. The dependent variable in the models was hourly percent of annual electricity consumption, and the model produced a slope for HDD and CDD and an intercept for when HDD and CDD are zero (i.e., at 65 degrees). Each building was then assigned a percentile for their variable slopes and intercepts compared to all of the buildings with the same space and water heating characteristics – e.g., a building with gas space heating and central gas water heating was given a percentile for its HDD and CDD slopes and intercept compared to all other buildings of that type.

For buildings with gas space heating, the base heat pump electrification load shape detailed previously was scaled by assuming that the current CDD slope will similarly reflect the HDD slope after electrification, as the electricity used for space cooling is likely to be similar to the electricity used for space heating for the same degree day value. The potential range of the scaled load shape is from 0.5 times to 1.5 times the original load shape magnitude, with the CDD slope percentile from 0% to 100% dictating the scaled annual heat pump load within that range, as shown in Equation 1.

$$\begin{gathered} Scaled\ Annual\ HP\ Load\ \left(\frac{kWh}{yr}\right) = \\ Base\ HP\ Load\ \left(\frac{kWh}{yr}\right) \times (50\% + CDD\ Slope\ Percentile) \end{gathered} \qquad \text{Equation 1}$$

For buildings with gas water heating, the base HPWH load shape was scaled by assuming that the current intercept represents the baseline consumption for the building. Of the three variables available for each building, this represents the best estimate for scaling the HPWH consumption magnitude, as hot water is consumed year-round, regardless of temperature, although HPWHs will tend to use more electricity per unit of water in the colder months. A similar method was used to scale the HPWH load as the HP load but using the model intercept percentile instead, as shown in Equation 2.

$$\begin{gathered} Scaled\ Annual\ HPWH\ Load\ \left(\frac{kWh}{yr}\right) = \\ Base\ HPWH\ Load\ \left(\frac{kWh}{yr}\right) \times (50\% + Intercept\ Percentile) \end{gathered} \qquad \text{Equation 2}$$

After being scaled, these load shapes are added to each unit and result in three electric load shape scenarios for each unit: before electrification (current), after electrification, and after electrification with passive efficiency upgrades. These load shapes are then aggregated to different levels to predict the loading on different electrical infrastructure, as detailed in the following section.

3.4. Transformer & Panel Loading Analysis

This study considers loading scenarios on three different types of electrical infrastructure: distribution transformers, building panels, and unit panels. These are the levels that building owners are responsible for upgrading if needed; anything farther upstream on the grid is the responsibility of SMUD and not in the scope of this study. Distribution transformers may service multiple buildings, including non-multifamily buildings. They also may be connected to a building using a method called “direct bury”. This is an older practice that involves burying the wires from the transformer to the building underground and requires additional trenching to replace the wire if a transformer needs to be upsized. The building panel serves all units in a building and is the level that central HPWHs will be aggregated to. The unit panel serves all end uses in a single unit and is assumed to have the same load that is seen by the unit’s meter. Figure 6 shows a sample connection of electrical infrastructure.

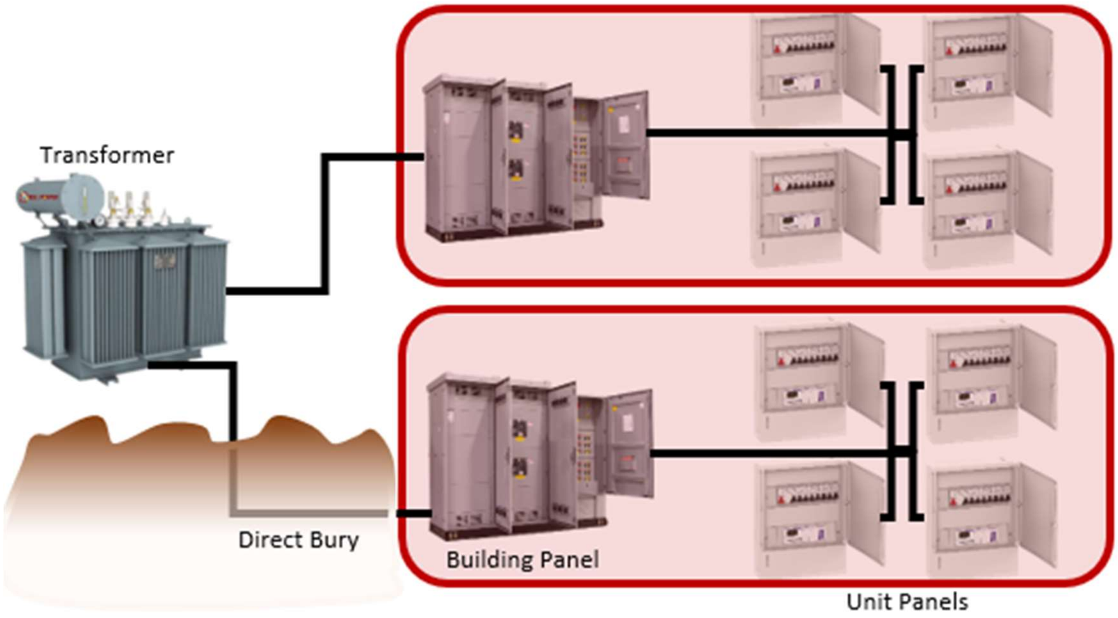


Figure 6: Sample Layout of Different Levels of Electrical Infrastructure

The transformer and panel sizes are necessary for determining which are currently overloaded and will be overloaded with electrification. SMUD keeps a database of distribution transformer sizes, and the histogram of multifamily transformer (abbreviated often as XFMR) sizes is shown in Figure 7, as well as the histogram of units on transformers of given sizes.

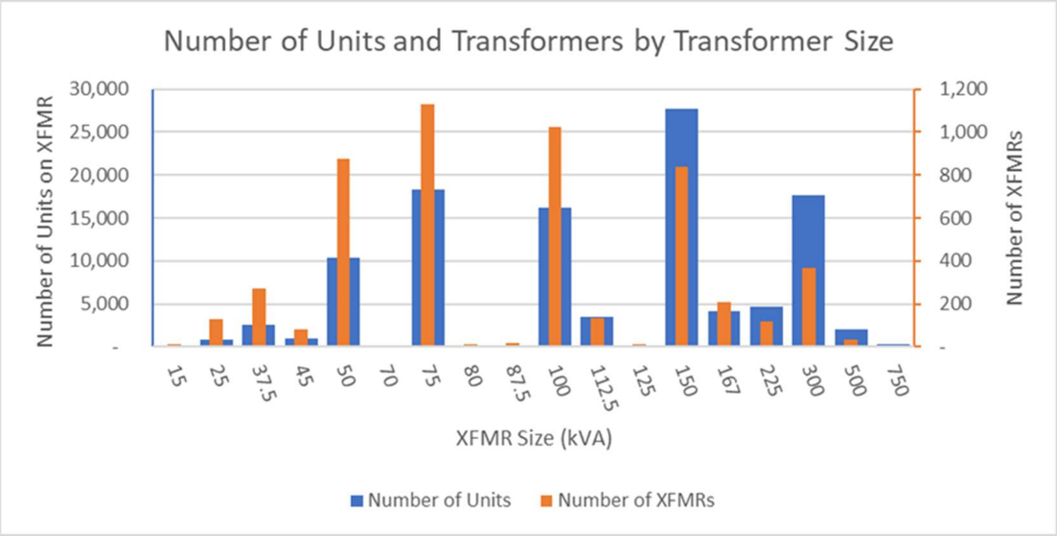
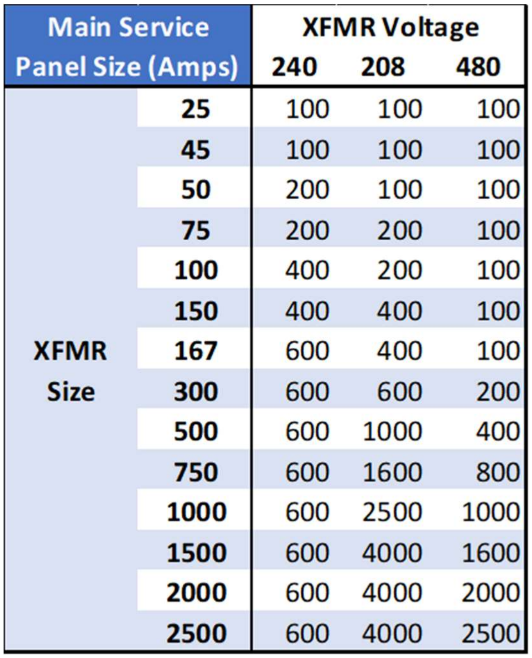


Figure 7: Multifamily Transformers and Units on Transformers by Size

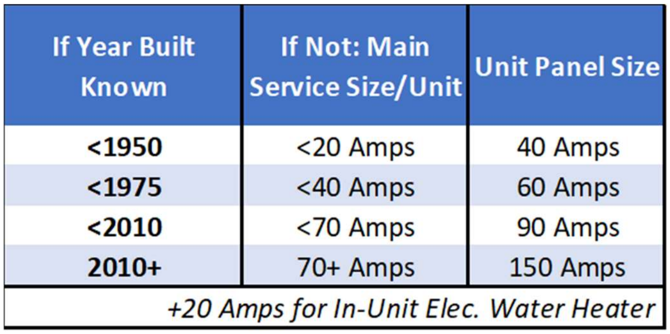
Panel sizes are much more difficult to determine. There is no central database for such data, and the only source used that had even a few records of building and unit panel sizes was the capital needs assessments from the TCAC database. SMUD does have a methodology for designing transformer sizes based on building panel sizes, so using that information I was able to reverse engineer the methodology to predict building panel size based on transformer size, as shown in Table 6. For unit panels, there is much more uncertainty; based only on informal interviews with multifamily electrification project managers at the Association of Energy Affordability (AEA) and the aforementioned TCAC data, I produced the methodology for determining unit panel size in Table 7. Figure 8 and Figure 9 show the breakdown of sizes across units and buildings. Even if the panel sizes are not predicted exactly correctly, hopefully they are representative of the correct magnitudes and distributions of panel sizes.

Table 6: Main Building Panel Size by Transformer Size (kVA) and Voltage



Main Service Panel Size (Amps)		XFMR Voltage		
		240	**208**	**480**
XFMR Size	**25**	100	100	100
	45	100	100	100
	50	200	100	100
	75	200	200	100
	100	400	200	100
	150	400	400	100
	167	600	400	100
	300	600	600	200
	500	600	1000	400
	750	600	1600	800
	1000	600	2500	1000
	1500	600	4000	1600
	2000	600	4000	2000
	2500	600	4000	2500

Table 7: Unit Panel Size by Year or Building Panel Size per Unit



If Year Built Known	If Not: Main Service Size/Unit	Unit Panel Size
<1950	<20 Amps	40 Amps
<1975	<40 Amps	60 Amps
<2010	<70 Amps	90 Amps
2010+	70+ Amps	150 Amps
+20 Amps for In-Unit Elec. Water Heater		

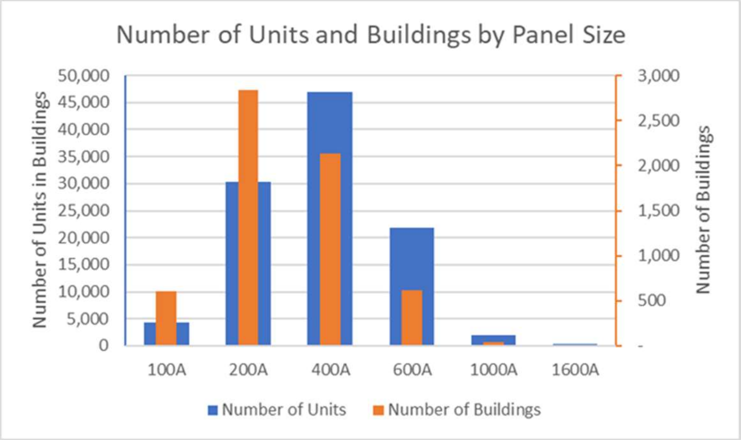


Figure 8: Building Panels and Units on Building Panels by Panel Size

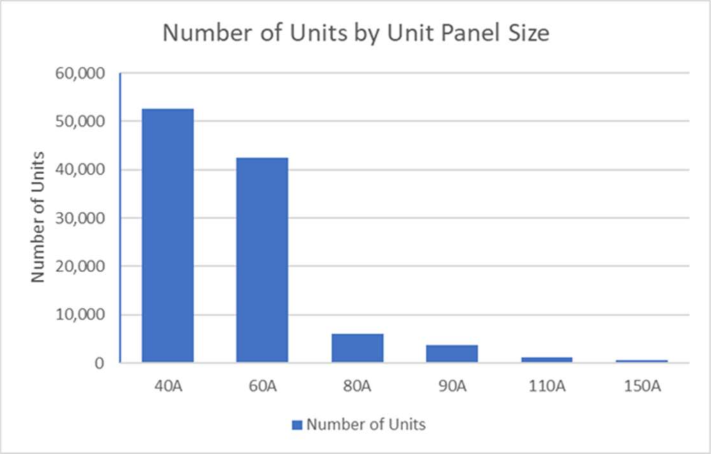


Figure 9: Unit Panels by Panel Size

According to SMUD transmission and distribution planning staff, transformers are deemed to be overloaded if the cumulative load for any hour on the transformer is above the rated size in kVA. This assumes that average hourly demand is a good enough proxy for actual demand and that the transformer load has a power factor of 100%, meaning that kVA is equal to kW. This is shown in Equation 3, which is used for the three loading scenarios previously described.

$$Peak\ XFMR\ Load\ (kVA) = 100\% \frac{kVA}{kW} \times \frac{max(\sum_{all\ meters\ on\ XFMR} hourly\ kW\ )}{1\ hour} \qquad \text{Equation 3}$$

Panels are deemed to be overloaded in a similar manner, but because their sizes are listed by amperage, the service voltage must be considered. I assume that building level panels use the same voltage that is used for the transformer and that unit level panels use 120V for all in-unit appliances. This is shown in Equation 4, which is used for the three loading scenarios.

$$Peak\ Panel\ Load\ (A) = \frac{max(\sum_{all\ meters} hourly\ Wh)}{1\ hour} \div service\ voltage \qquad \text{Equation 4}$$

This method of calculating panel loading is the most accurate for understanding true impacts seen by the panels and is allowed by the National Electric Code (NEC). However, the most common method currently used by electricians, also allowed by the NEC, uses deemed nameplate loads for each appliance and then applies a loading factor, usually around 75%, if there are more than four loads on a panel. Using this methodology often overestimates the necessary panel size, as there are many safety factors built in at different steps – this has been pointed out by many in the energy industry, so this study will only focus on overloading using the more accurate loading methodology.

Although slightly out of the scope of this study, electric vehicle (EV) charging at multifamily buildings is an important part of an equitable energy transition and may also have impacts to the grid that dwarf those from building electrification. After modeling the building electrification impacts to the transformer, I determined the remaining capacity on the transformer at peak hour to predict how many EV chargers would be able to utilize the existing transformer at the multifamily building. I assume that the chargers are 7.2 kW Level 2 chargers that would all be utilized at the peak time for each transformer.

3.5. Estimating Total Project Costs

In the early years of building electrification, the cost differential between business-as-usual projects that simply replace gas appliances upon burnout with the same gas appliance and electrification projects that replace gas appliances with heat pumps and inductions stoves as well as upgrade any necessary electrical infrastructure will be a deciding factor. The cost of replacing transformers that are overloaded is relatively well-established – the SMUD transmission and distribution planning staff has detailed information on upgrade costs that include materials, labor, and overhead depending on the type, location, and size of the transformer. These costs are summarized in Figure 10 and Figure 11, and the linear regression that is applied in both is used to estimate costs of the upgrades. Obviously, the fit of these lines is not perfect, but it should serve as a reasonable estimate. For projects that require unearthing direct bury lines, an extra \$6,000 per project was added plus \$100 per kVA of transformer size.

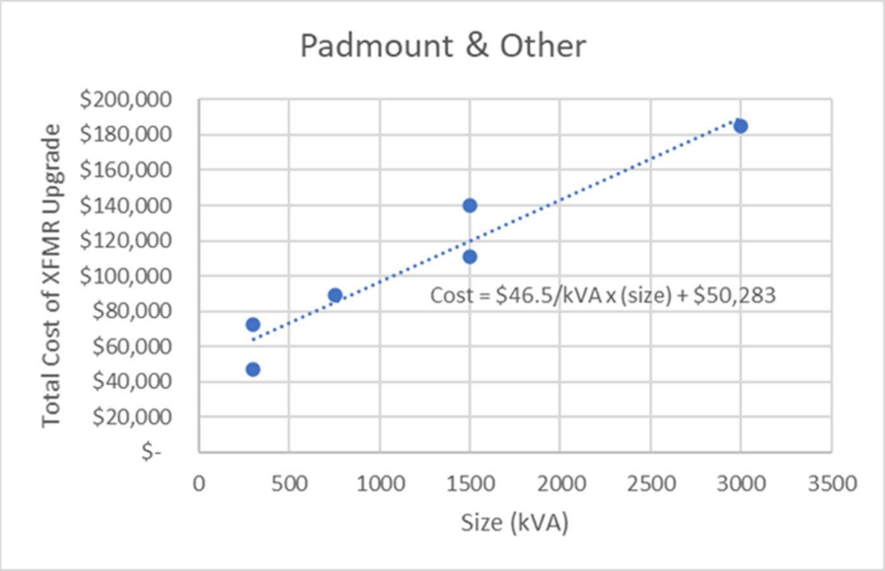


Figure 10: Costs of Padmount & Other Transformer Upgrades

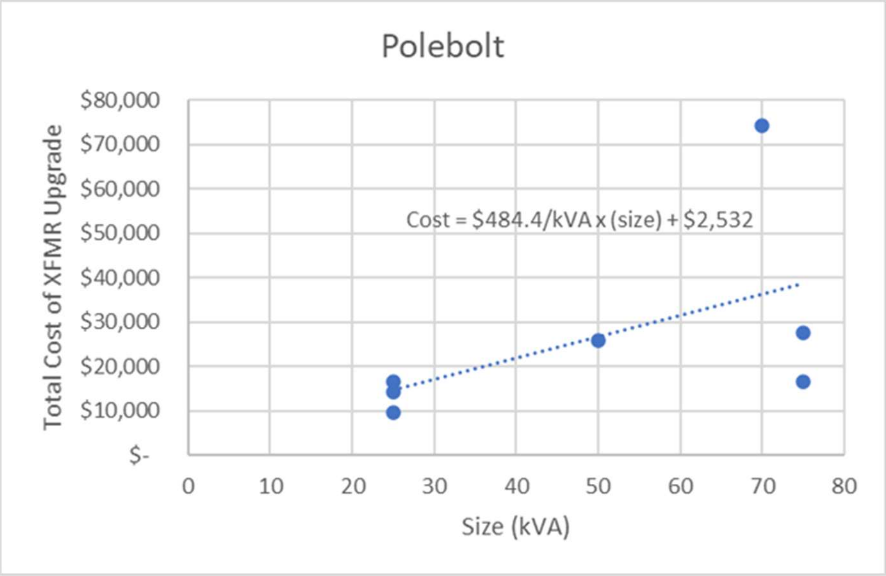
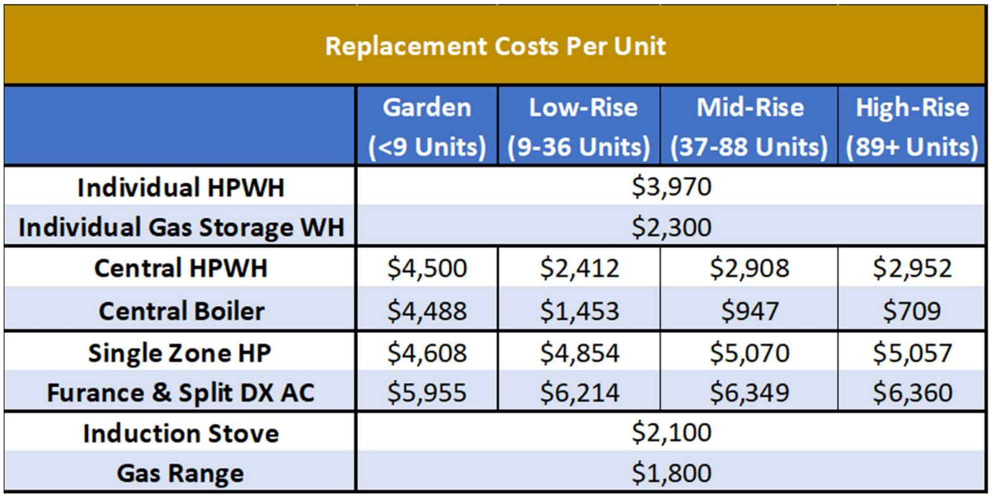


Figure 11: Costs of Polebolt Transformer Upgrades

Panel cost estimates are harder to pin down, but after interviewing project managers and utility experts at SMUD and AEA, I assume that main building panels cost $8,000 per project plus $50 per amp of panel size and unit panels cost $2,000 per project plus $25 per amp of panel size.

The bulk of project costs will be allocated to the actual equipment and installation of the equipment for electrification. Table 8 shows the base cost per unit served for each piece of equipment that may be needed for an electrification project and the corresponding gas equipment replacement cost as well. For space heating, the cost of both the gas furnace and the cost of the air conditioner are included in the gas equipment cost, as the heat pump would replace both and should be compared as such. The individual HPWH project costs are collected from a SMUD report compiled in 2020; the gas storage water heater, induction stove, and gas range costs are collected from an E3 study on building electrification (Mahone et al. 2019); the central water heating and space heating costs are collected from the 2022 Title 24 CASE report on multifamily buildings (Pande et al. 2021).

Table 8: Base Equipment Costs Used to Compare Business as Usual Case vs. Electrification



Replacement Costs Per Unit

	Garden (<9 Units)	Low-Rise (9-36 Units)	Mid-Rise (37-88 Units)	High-Rise (89+ Units)
Individual HPWH	$3,970			
Individual Gas Storage WH	$2,300			
Central HPWH	$4,500	$2,412	$2,908	$2,952
Central Boiler	$4,488	$1,453	$947	$709
Single Zone HP	$4,608	$4,854	$5,070	$5,057
Furance & Split DX AC	$5,955	$6,214	$6,349	$6,360
Induction Stove	$2,100			
Gas Range	$1,800			

These base costs were then scaled using a similar method as the scaled added electrification loads, but with slightly smaller range of potential values – 0.75 times the base cost to 1.25 times the base cost, as shown in Equations 5 and 6. These costs were then added to any predicted electrical infrastructure costs to get total project costs per unit.

$$Scaled\ HP\ Cost\ = Base\ HP\ Cost \times \left(75\% + \frac{CDD\ Percentile}{2}\right) \qquad \text{Equation 5}$$

$$Scaled\ HPWH\ Cost\ = Base\ HPWH\ Cost \times \left(75\% + \frac{Intercept\ Percentile}{2}\right) \qquad \text{Equation 6}$$

3.6. Bill Impacts

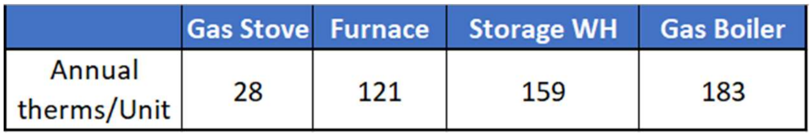
Utility bills are another factor impacting the decision to electrify. Although most multifamily tenants pay their own bills, there are costs like central water heating that are usually covered by the building owner. Additionally, there is political and market pressure for building owners to choose the appliances that have the lowest bill impacts on tenants. To estimate the change in total utility bill costs to multifamily customers due to electrification, I used the current SMUD time-of-day rates and Pacific Gas & Electric's (PG&E) monthly gas rates from 2019 (*Residential Time-of-Day Service Rate Schedule R-TOD* 2019; "Gas Rates" 2021). I calculated the current bill for each customer for each month based on the SMUD rate in Table 9 to get their annual costs, and then recalculated it for the second loading scenario, post-electrification. If a customer is on the EAPR rate, I subtracted $32 from their monthly bill, which is the median SMUD EAPR bill deduction across different low-income classes (*Residential and Commercial Industrial Energy Assistance Program Rate Schedule EAPR* 2018).

Table 9: SMUD Time of Day Rate

Winter ($/kWh)	8pm-5pm, weekends, and holidays	5pm-8pm	Fixed Charge ($/Month)	
	$0.1061	$0.1465	$22.25	
Summer ($/kWh)	12am-12pm, weekends, and holidays	12pm-5pm	5pm-8pm	8pm-12am
	$0.1277	$0.1765	$0.3105	$0.1765

To get the estimated current gas bill – household PG&E gas bills were not available for this study – the base annual therm consumption from the various gas appliances shown in Table 10 were used; these values are based on internal SMUD estimates. The same method of scaling electric consumption for water and space heating was applied to these values for each building.

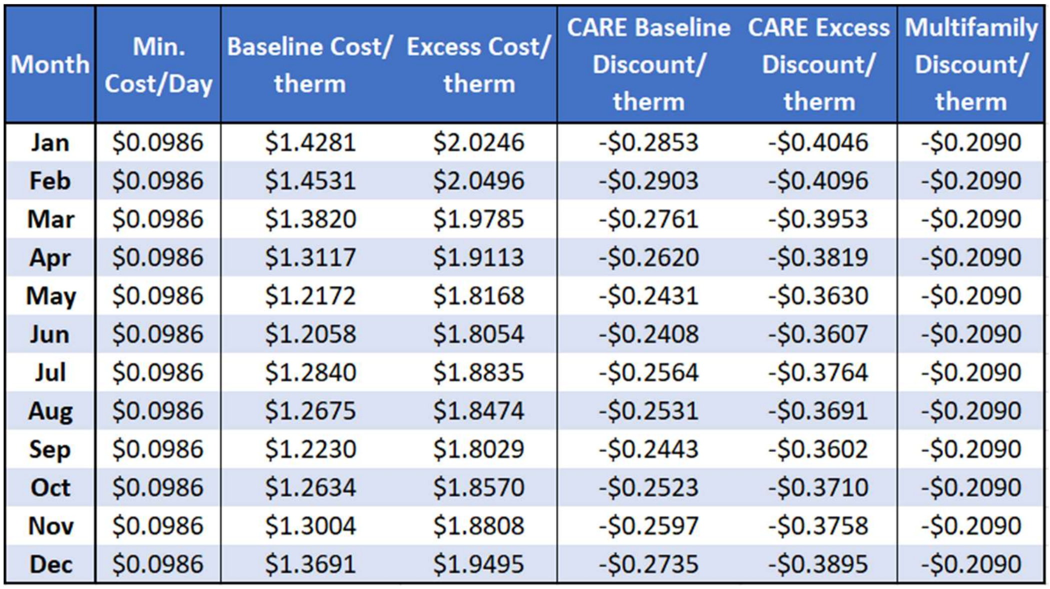
Table 10: Base Annual Therms per Unit for Gas Appliances



	Gas Stove	Furnace	Storage WH	Gas Boiler
Annual therms/Unit	28	121	159	183

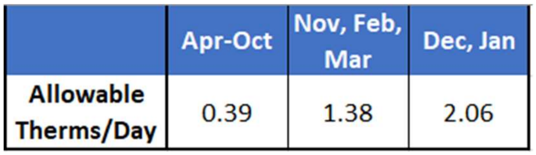
I used the 2019 PG&E gas rates in Table 11 to calculate the monthly gas bills before electrification. To determine if a customer went into the “Excess” tier in a given month, I used the values in Table 12, which also comes from the PG&E gas tariff. I assumed that if a customer was on the EAPR rate that they were also on the California Alternate Rates for Energy (CARE) rate, an analogous low-income rate for other California utilities.

Table 11: PG&E 2019 Gas Rates by Month



Month	Min. Cost/Day	Baseline Cost/ therm	Excess Cost/ therm	CARE Baseline Discount/ therm	CARE Excess Discount/ therm	Multifamily Discount/ therm
Jan	$0.0986	$1.4281	$2.0246	-$0.2853	-$0.4046	-$0.2090
Feb	$0.0986	$1.4531	$2.0496	-$0.2903	-$0.4096	-$0.2090
Mar	$0.0986	$1.3820	$1.9785	-$0.2761	-$0.3953	-$0.2090
Apr	$0.0986	$1.3117	$1.9113	-$0.2620	-$0.3819	-$0.2090
May	$0.0986	$1.2172	$1.8168	-$0.2431	-$0.3630	-$0.2090
Jun	$0.0986	$1.2058	$1.8054	-$0.2408	-$0.3607	-$0.2090
Jul	$0.0986	$1.2840	$1.8835	-$0.2564	-$0.3764	-$0.2090
Aug	$0.0986	$1.2675	$1.8474	-$0.2531	-$0.3691	-$0.2090
Sep	$0.0986	$1.2230	$1.8029	-$0.2443	-$0.3602	-$0.2090
Oct	$0.0986	$1.2634	$1.8570	-$0.2523	-$0.3710	-$0.2090
Nov	$0.0986	$1.3004	$1.8808	-$0.2597	-$0.3758	-$0.2090
Dec	$0.0986	$1.3691	$1.9495	-$0.2735	-$0.3895	-$0.2090

Table 12: PG&E Therms/Day Limit Before Entering Excess Tier



	Apr-Oct	Nov, Feb, Mar	Dec, Jan
Allowable Therms/Day	0.39	1.38	2.06

Using these methods, I was able to calculate current electricity and gas bills as well as projected electric bills after electrification. I assumed that the gas lines would be disconnected from an electrified building and thus there would be no outstanding gas bill costs. I also assumed that central water heating would be paid by the building owner, not split across individual units.

3.7. Electrification Project Targeting

Using the methods laid out in this section, I am able to project the local loading scenarios, project costs, bill impacts, and greenhouse gas emission impacts from multifamily electrification. This information may be useful to individual building owners, but if they are considering electrification, they are likely to get more precise cost estimates than this study can provide after an initial exploration. The results of this study are more useful for regional and statewide parties who are either looking to target more electrification projects or better understand the barriers to and impacts from electrification. Because of this, it would be valuable to have a method for targeting neighborhoods to electrify based on the aggregated or average impacts in different categories. The method I create in this section relies on assigning a “score” to each census tract with multifamily units in SMUD territory based on an average of six scores from 1-100 across different categories, with 100 being the top score and 1 being the lowest.

3.7.1. Density & Timing Score

The first score focuses on targeting neighborhoods that are likely to be worthwhile for exploring electrification. All census tracts are assigned a percentile for how many multifamily meters are in the tract as well as how many multifamily meters that I predict have both gas space and gas water heating, which will indicate the density of potential benefits in the region. In addition, the likelihood of an upcoming renovation was factored in through data from the TCAC database. Generally, all multifamily buildings that receive government subsidies are required to go through a re-syndication process every twenty years, during which they must upgrade any inefficient or failing equipment. If SMUD could target these buildings prior to their re-syndication, they may be able to push electrification during the process. Based on this, each census tract with buildings in the TCAC database was assigned a percentile based on the average number of years since the last syndication date of the buildings in the TCAC database, with more years since last syndication leading to a higher score. These scores were all averaged to get the Density & Timing Score.

3.7.2. Equity Score

This score focuses on targeting neighborhoods that are historically disadvantaged and neighborhoods that have many lower income customers. First, the CalEnviroScreen 3.0 score for the census tract, which already ranges from 1-100, is used to characterize the disadvantages that the neighborhood faces. The census tracts were also assigned a percentile based on the percent of units in the tract that were on the SMUD EAPR rate as well as a percentile based on the percent of units that are in government-subsidized housing. These scores were all averaged to get the Equity Score.

3.7.3. Infrastructure Score

This score focuses on targeting areas with low potential for electrical infrastructure overloading and minimal potential infrastructure costs. First, a percentile is assigned to each census tract based on the average cost per unit of any predicted electrical infrastructure upgrades and then inverted so that low projected costs correspond to high scores. Another percentile is assigned based on the average peak loading percentage of transformers in the census tract and then inverted so that tracts with transformers that have a peak load much less than their rated size will have higher scores. These scores are averaged to get the Infrastructure Score.

3.7.4. Equipment Cost Score

This score is meant to target projects where the necessary electrification equipment, namely HPWHs, HVAC HPs, and induction stoves, is potentially smaller, or the end uses that need to be electrified have the best cost tradeoff with the gas replacement. The first part of the score is created by assigning a percentile to each tract based on the average total cost of equipment per unit, and the second is created by assigning a percentile to each tract based on the average percent difference between the costs of electrification and gas replacement equipment. A building with smaller equipment, more units, and electric equipment that replaces costly gas equipment – e.g., heat pumps replacing both furnaces and air conditioners – will have a higher Equipment Cost Score.

3.7.5. Bill Savings Score

This score will reward projects with optimal customer impacts from fuel switching. The first part of the score is the percentile assigned based on average bill reduction per unit, the second part is the percentile assigned based on the average percent bill reduction per unit, and the third part is the percentile based on what percent of customers in the tract will have lower bills after electrification. These are averaged together to create the Bill Savings Score.

3.7.6. Carbon Impact Score

This score is aimed at estimating the carbon impacts from electrification in each tract. The first part of the score is the percentile assigned based on total lifetime carbon emission reductions for each tract, and the second part of the score is the percentile assigned based on per-unit lifetime carbon emissions reductions for each tract. These are averaged together to create the Carbon Impact Score

Each of these scores was given equal weight and averaged together to create the total targeting score. The results from the loading scenarios, cost estimations, and targeting scores are detailed in the following section.

4. Results

4.1. Transformer Loading

4.1.1. Current Scenario

For each of the three loading scenarios – current, projected after electrification, and projected after electrification plus passive efficiency upgrades – the peak load as a percent of rated size was determined for each transformer. Figure 15 shows the distribution of peak loads on transformers as a percentage of the rated size. Figure 12 shows the distribution of peak load as percent of transformer size by month, with most transformers having the highest peak loads in June, July, and August, the hottest months of the year in SMUD territory, and the lowest peak loads in October and December, two of the mildest months in 2019 in SMUD territory.

4.1.2. Electrification Scenario

After electrification, overall electric consumption will likely be higher, but the peak impacts are dependent on the timing of added load as well as gained efficiency from the air conditioning of the heat pumps. As seen in Figure 15, the biggest shifts from the “current” scenario and the “electrification” scenario are from transformers in the 20% to 40% loaded range towards the 60% to 80% loaded range, which indicates that transformers that are closer to being overloaded are less likely to have gas infrastructure. Figure 13 shows the distribution of peak load as percent of transformer size by month; in comparison to Figure 12, the summer peaks remained about the same but the winter peaks, especially December, increased significantly, although not enough to get close to surpassing the summer peaks on average.

4.1.3. Electrification with Passive Efficiency Scenario

After adding passive efficiency to every building, overall electric consumption will decrease compared to the electrification scenario, but there will be varying impacts on the peak loads. As seen in Figure 15, the biggest shifts from the “electrification” scenario to the “electrification + passive EE” scenario are from transformers in the 70% loaded or greater range towards the 20% to 40% loaded range, which indicates that most transformers are seeing significant peak load benefits from passive efficiency, although fewer are actually avoiding overloading, as relatively few are actually near overloading to begin with. Figure 14 shows the distribution of peak load as percent of transformer size by month; in comparison to Figure 13, the summer peaks have decreased significantly while the winter peaks remain higher than the current scenario. This could indicate that some buildings may start to see winter peak loads, but this is all dependent on the load shape of the passive efficiency savings, which may vary widely from building to building.

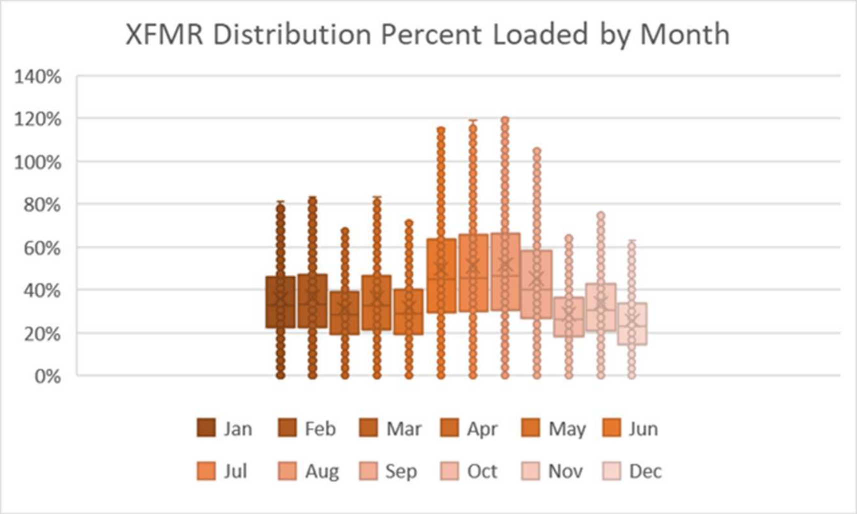


Figure 12: Current Peak Load as a Percent of Transformer Size by Month

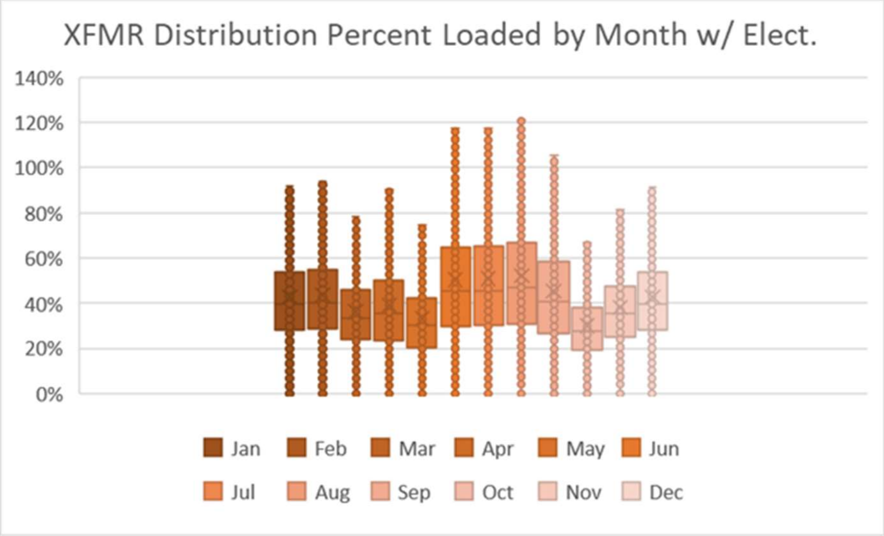


Figure 13: Peak Load with Electrification as a Percent of Transformer Size by Month

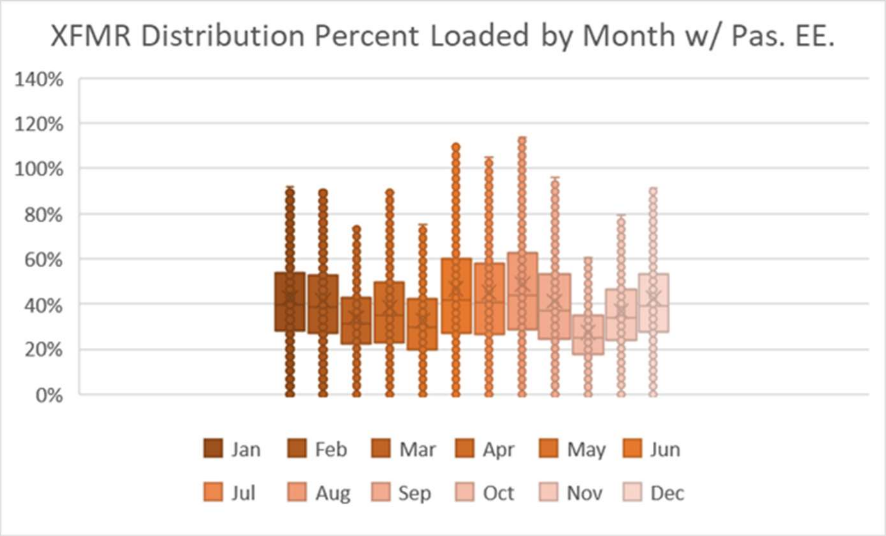


Figure 14: Peak Load with Electrification and Passive Efficiency as a Percent of Transformer Size by Month

Table 13 summarizes the results from the transformer loading study by describing the range of transformers with peak loading at both 95% or more of the rated size and 105% or more of the rated size to show the sensitivity of the study. Meters on overloaded transformers are relatively evenly distributed – overloaded transformers are not significantly more likely to have more meters than non-overloaded transformers – and only around 10% of meters are likely to be overloaded in the worst-case scenario. Efficiency gains from heat pump air conditioning have very small impacts on avoiding overloading, but passive efficiency could help avoid around 25% of transformer overloading cases.

Table 13: Number of Transformers with Peak Loads Above 95% and 105% of Rated Size

	Number of XFMRS					% of All XFMRs	% of All Meters
	Current	Electrif. Caused	Electrif. Avoided	EE Avoided	Total		
>95% Overloaded	555	34	17	129	589	11.1%	10.3%
>105% Overloaded	368	20	13	94	388	7.3%	6.9%

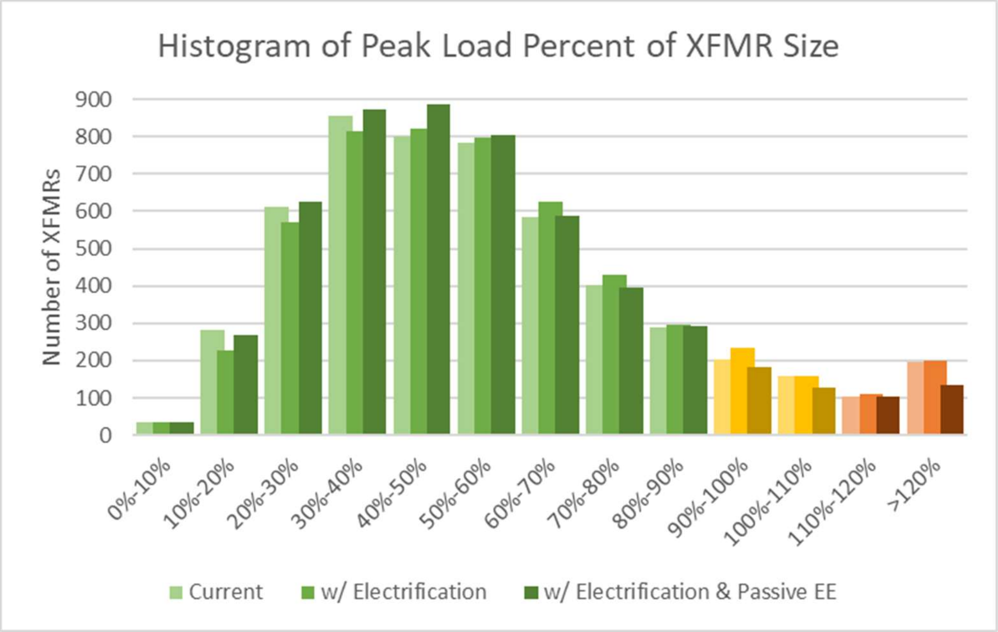


Figure 15: Peak Loads on Transformers by Scenario as a Percent of Rated Transformer Size

4.1.4. Potential EV Charging Space on Transformers

Figure 16 shows how many electric vehicle (EV) chargers could likely fit on the transformers after electrification before loading them above 100% of their rated capacities. Ideally, multifamily buildings would have at least one charger for every two units – at this moment, only around 25% of transformers meet this criteria, and passive efficiency does not have a huge impact. Ultimately, many of these transformers will have to be replaced when EV chargers are installed, but this may happen after a building is electrified.

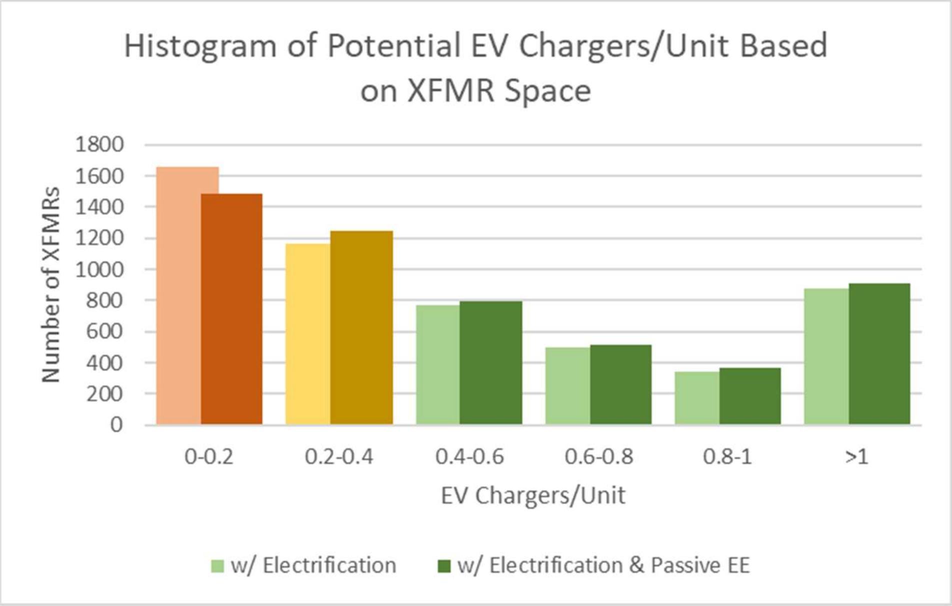


Figure 16: Distribution of Available Space on Transformers for EV Chargers After Electrification

4.2. Main Service Panel Loading

4.2.1. Current Scenario

The same results were produced for the main service panels in each building as the transformers. The results for the panels are more uncertain than the transformer results because the panel sizes are unverified and the exact meters on each panel are not confirmed. As mentioned previously, there are multiple accepted ways to calculate panel loading, so it is possible that an electrician working on an electrification project may come to different loading conclusions than those summarized in this study. Figure 17 shows the distribution of peak loads on the panels as a percentage of the rated size. Compared to the transformer overloading distribution profile, the main service panels tend to either be very far over the rated capacity or around 10% to 40% loaded at peak load.

4.2.2. Electrification Scenario

As seen in Figure 17, with electrification, some building panels move into the yellow and orange regions of overloading, but more of the panels in those regions are currently overloaded than incrementally overloaded from electrification.

4.2.3. Electrification and Passive Efficiency Scenario

As seen in Figure 17, the biggest gains from passive efficiency on loading seem to be in the buildings in the green range, as opposed to the buildings that are overloaded. Table 14 summarizes the building panel overloading. An important takeaway is that while the proportion of main service panels that are potentially facing overloading is not much more than the transformers – around 10% – the proportion of meters on main service panels facing overloading is much higher, around 25%. Passive efficiency measures are not significantly effective at avoiding overloading, as many of the potentially overloaded panels are over 120% loaded at their peak.

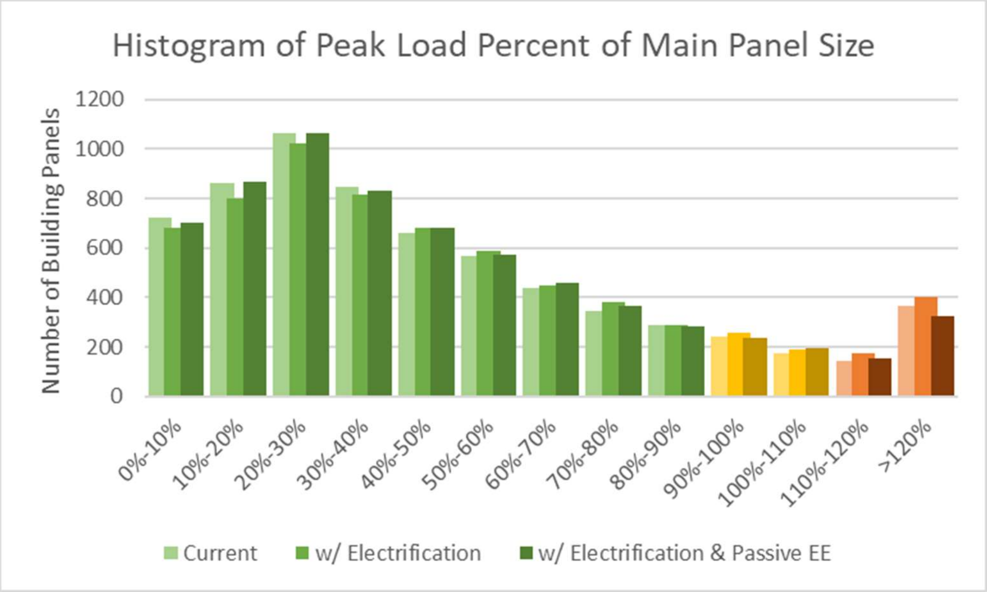


Figure 17: Peak Loads on Main Panels for Each Scenario as a Percent of Rated Main Panel Size

Table 14: Number of Main Service Panels with Peak Loads Above 95% and 105% of Rated Size

	Number of Building Panels						
	Current	**Electrif. Caused**	**HP EE Avoided**	**Passive EE Avoided**	**Total**	**% of All Panels**	**% of All Meters**
>95% Overloaded	787	101	13	30	888	13.2%	29.7%
>105% Overloaded	589	97	15	36	686	10.2%	24.2%

4.3. Unit Panel Loading

In the final loading analysis, the peak load on each unit's electrical panel was estimated. Figure 18 shows the distribution of peak loading as a percent of the predicted rated size of the panel. Virtually all panels are far from overloading, with the majority clustered around 20% to 70% loaded. As previously discussed, this level of electrical loading is most uncertain – the predicted panel size is an estimate mostly based on the estimate of main service panel size, if Year Built is not available. Because of this, the loading distributions for the electrification and passive efficiency scenarios are not shown, as the level of granularity in the changes would be misleading compared to the overall uncertainty. However, Table 15 summarizes the potential impacts of the scenarios. Around 0.05% of all unit panels are impacted by the electrification and passive efficiency scenarios, and only around 3% of panels would be overloaded in the worst-case scenario. Again, this study does not suggest that an electrician would come to the conclusion that most of these panels do not need to be upgrades, but instead that most panels are likely to physically be able to handle the increased loads of electrification because of the relatively small impact to the peak load and current predicted loading profiles of the panels.

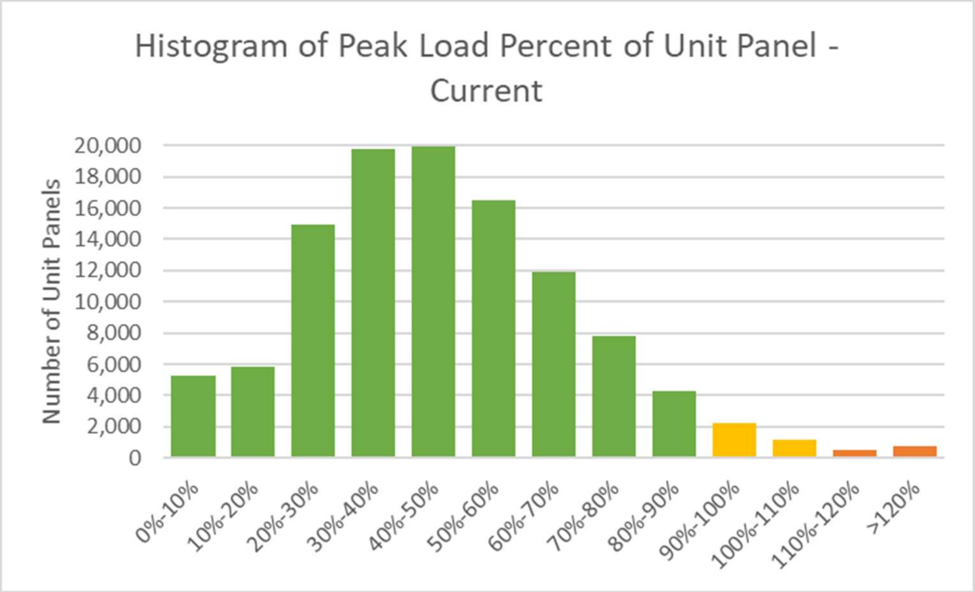


Figure 18: Current Peak Loads on Unit Panels as a Percent of Rated Panel Size

Table 15: Number of Unit Panels with Peak Loads Above 95% and 105% of Rated Size

	Number of Unit Panels					% of All Meters
	Current	Electrif. Caused	HP EE Avoided	Passive EE Avoided	Total	
>90% Overloaded	3,348	74	0	8	3,422	3.1%
>110% Overloaded	1,777	32	0	3	1,809	1.6%

4.4. Project Costs

Figure 19 summarizes the difference in total project costs per unit for electrification compared to the gas replacement baseline, assuming that projects happen upon equipment burnout. The group with the biggest project cost discrepancy is buildings with gas water and space heating that are required to upsize any electrical infrastructure. Even so, the average gap is less than $2,000 per unit, or around 15% to 20% of the total project cost per unit. At the moment, SMUD offers up to around $4,000 per unit of incentives for existing multifamily building electrification, depending on the necessary equipment and technical assistance, which would more than cover the difference. While this study was intended to be both comprehensive and conservative in regard to project costs, it is certainly feasible that there would be additional costs associated with the projects not covered in Figure 19. However, it is clear that the magnitude of costs for electrification are in the same range as the gas baseline. Because of the low likelihood and cost of electrical infrastructure upgrades, passive efficiency project costs were not estimated for any projects. They should be undertaken for reasons other than to avoid costs of electrical infrastructure, and this should not be considered as part of the electrification cost comparison.

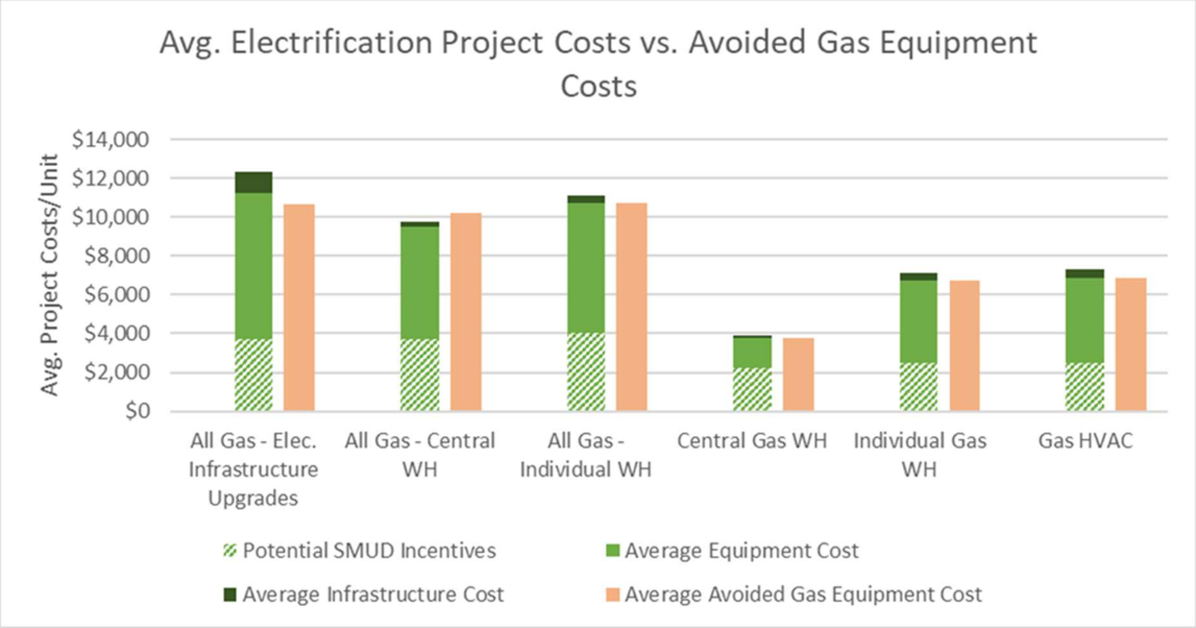


Figure 19: Electrification vs. Gas Project Costs by Category of Project Needs

Figure 20 shows the total electrification spending in SMUD territory that will need to happen over the next few decades for multifamily buildings to fully electrify. Mainly, this shows the magnitude of the market that needs to develop for heat pumps and heat pump water heaters – when combined with other building sectors across all of California, these markets will be in the billions of dollars range, which is incomparably larger than the current scale of investments in electrification equipment.

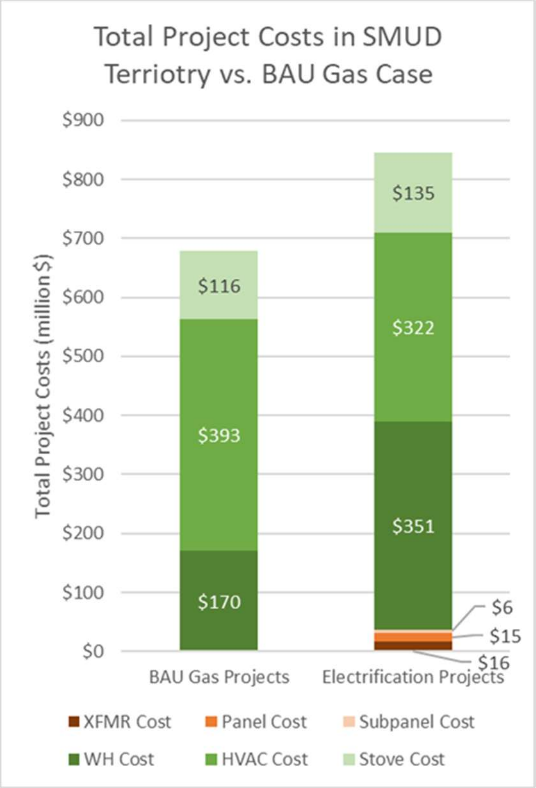


Figure 20: Total Electrification Project Costs in SMUD Territory Compared to Gas Baseline

4.5. Bill Impacts

Figure 21 shows the average energy bills before and after electrification for SMUD customers on the standard Time-of-Use rate in buildings with different water and space heating fuels. Because of the markedly better efficiencies of new heat pumps compared to any gas or existing air conditioning equipment, electricity bills decrease for every category. Additionally, for customers who use very little gas, having one energy bill instead of two will decrease bill costs due to the minimum daily costs that exist for natural gas bills from PG&E. Across all multifamily customers, only 8% are projected to see increased energy bills from electrification. Interestingly, the customers in all-electric buildings are currently paying the most for energy of all the subsets of customers, indicating that these buildings may have older, inefficient electric resistance appliances and perhaps poorer insulation or building performance. Although outside the scope of this study, it would be valuable to understand the impacts of newer heat pump technologies in these buildings.

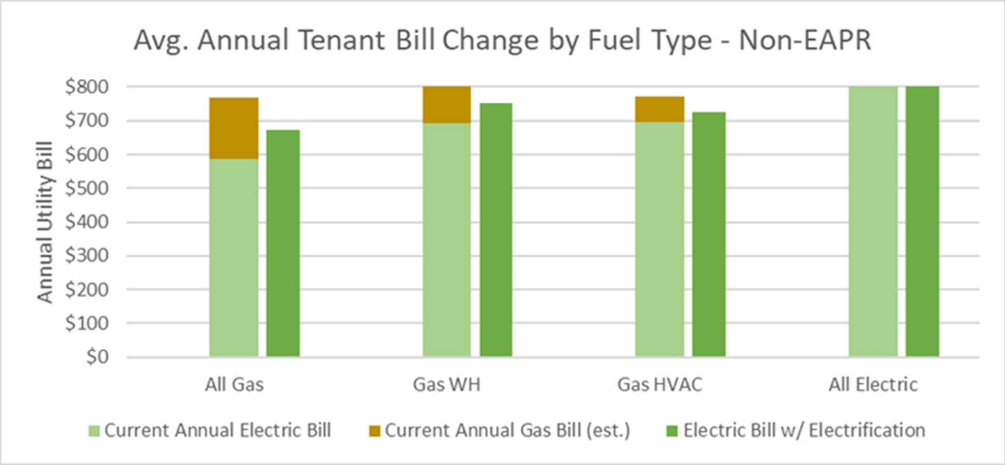


Figure 21: Average Energy Bills Before and After Electrification for Different Building Categories - Time-of-Day Rate

Figure 22 shows the average bills before and after electrification for customers on SMUD’s low-income EAPR rate. The same trends exist here as do for the non-EAPR customers, but the proportion of savings are even higher for the customers with more gas appliances.

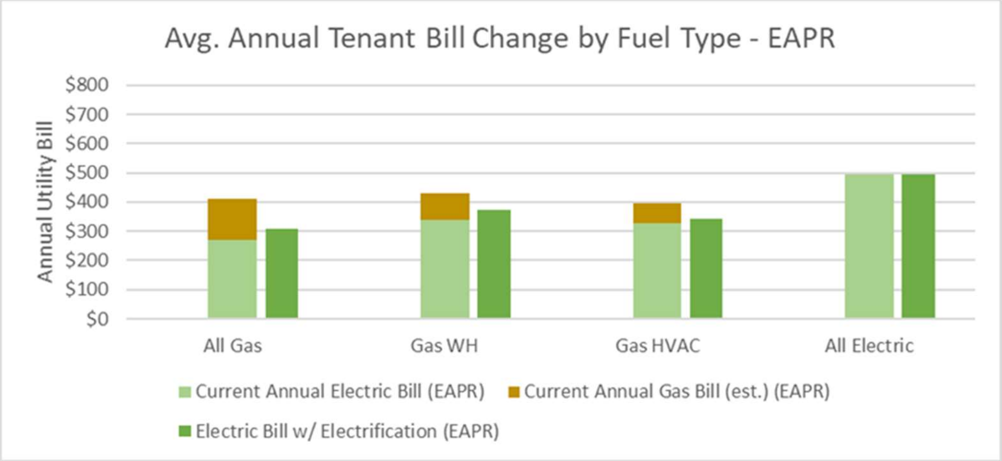
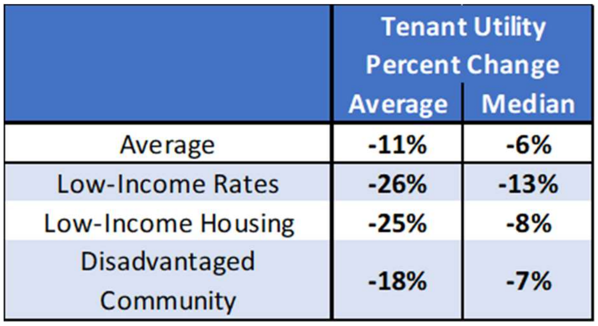


Figure 22: Average Energy Bills Before and After Electrification for Different Building Categories - EAPR Rate

Table 16 shows the average and median change in energy bills for different customer populations. Consistently, low-income customers and those in disadvantaged communities will tend to see larger benefits than the general population. This is likely due in part to the higher rates of gas equipment in those populations.

Table 16: Average and Median Energy Bill Change After Electrification for Different Populations



	Tenant Utility Percent Change	
	Average	**Median**
Average	**-11%**	**-6%**
Low-Income Rates	**-26%**	**-13%**
Low-Income Housing	**-25%**	**-8%**
Disadvantaged Community	**-18%**	**-7%**

4.6. Targeting

After applying the scoring methodology detailed in the previous chapter, Figure 23 shows the distribution of scores across SMUD territory by census tract. Tracts with no color had no multifamily units. Appendix A shows the distribution for each score as well as each census tract’s scoring breakdown. The majority of better scoring tracts are located in the Elk Grove, Arden Arcade, and Natomas areas, although there are above average tracts in most neighborhoods. The lower scoring tracts are mostly located around the outskirts of Sacramento County, in areas such as Folsom, Rio Linda, and Citrus Heights, although south downtown is also relatively low scoring. Table 17 and Table 18 show the best and worst scoring tracts, respectively. The best scoring tracts tend to have the best infrastructure, bill saving, and carbon scores, whereas the worst scoring tracts consistently have low density & timing and carbon scores.

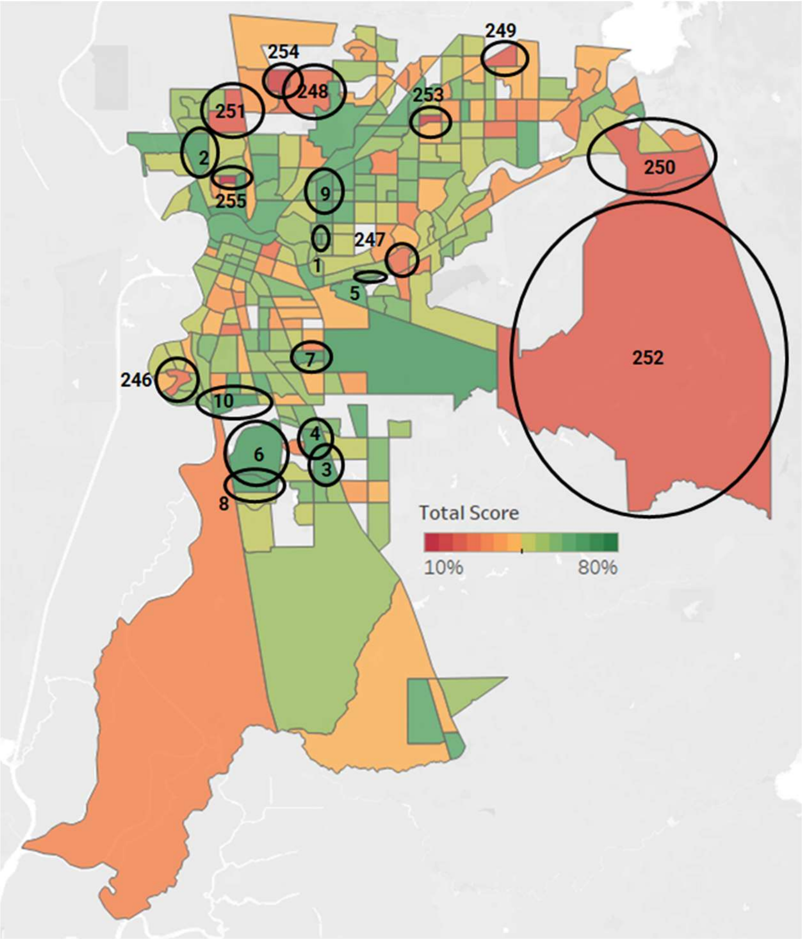
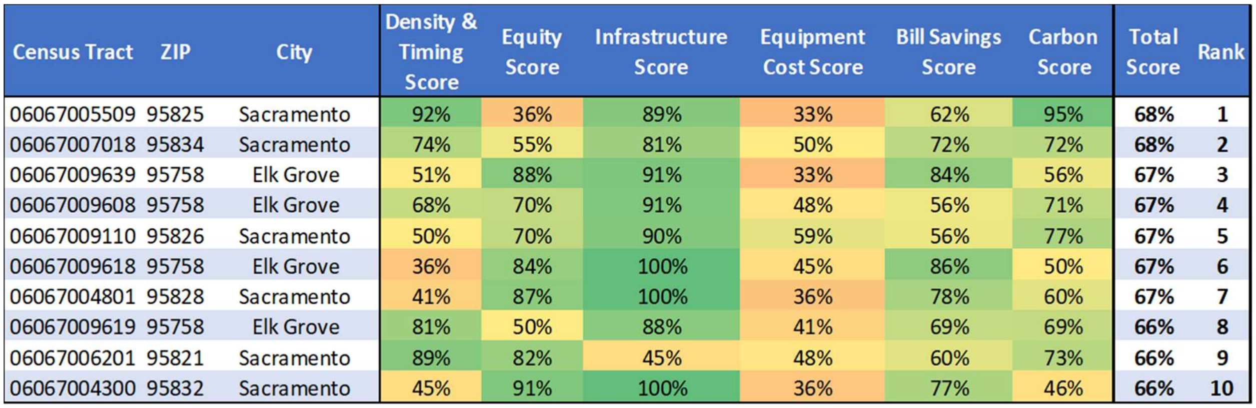


Figure 23: Location of Highest and Lowest Scored Census Tracts for Electrification

Table 17: Scoring Breakdown for Highest Scored Census Tracts for Electrification



Census Tract	ZIP	City	Density & Timing Score	Equity Score	Infrastructure Score	Equipment Cost Score	Bill Savings Score	Carbon Score	Total Score	Rank
06067005509	95825	Sacramento	92%	36%	89%	33%	62%	95%	**68%**	**1**
06067007018	95834	Sacramento	74%	55%	81%	50%	72%	72%	**68%**	**2**
06067009639	95758	Elk Grove	51%	88%	91%	33%	84%	56%	**67%**	**3**
06067009608	95758	Elk Grove	68%	70%	91%	48%	56%	71%	**67%**	**4**
06067009110	95826	Sacramento	50%	70%	90%	59%	56%	77%	**67%**	**5**
06067009618	95758	Elk Grove	36%	84%	100%	45%	86%	50%	**67%**	**6**
06067004801	95828	Sacramento	41%	87%	100%	36%	78%	60%	**67%**	**7**
06067009619	95758	Elk Grove	81%	50%	88%	41%	69%	69%	**66%**	**8**
06067006201	95821	Sacramento	89%	82%	45%	48%	60%	73%	**66%**	**9**
06067004300	95832	Sacramento	45%	91%	100%	36%	77%	46%	**66%**	**10**

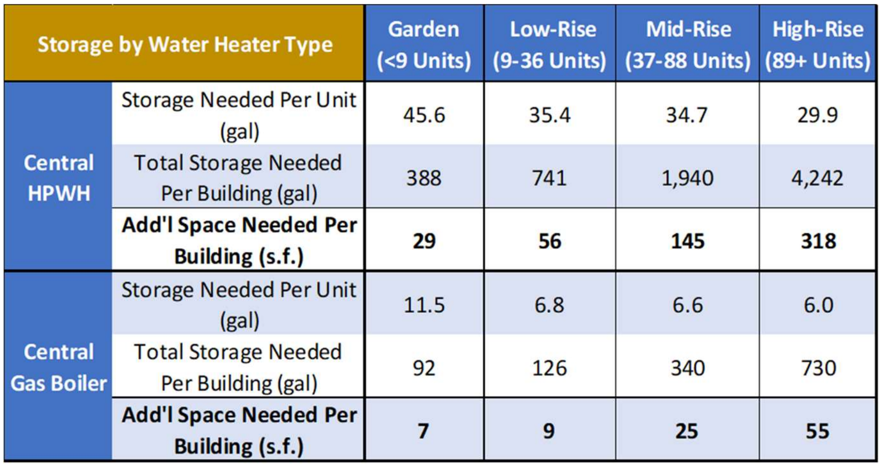
Table 18: Scoring Breakdown for Lowest Scored Census Tracts for Electrification

Census Tract	ZIP	City	Density Score	Equity Score	Infrastructure Score	Equipment Cost Score	Bill Savings Score	Carbon Score	Total Score	Rank
06067004009	95831	Sacramento	38%	8%	42%	48%	11%	26%	**29%**	**246**
06067009107	95827	Sacramento	6%	20%	65%	49%	1%	23%	**28%**	**247**
06067007202	95673	Rio Linda	25%	52%	8%	8%	44%	26%	**27%**	**248**
06067008125	95610	Citrus Heights	17%	13%	15%	63%	29%	13%	**25%**	**249**
06067008508	95630	Folsom	23%	4%	14%	49%	30%	29%	**25%**	**250**
06067007106	95835	Sacramento	13%	9%	62%	50%	7%	8%	**25%**	**251**
06067008600	95683	Sloughhouse	14%	9%	19%	77%	20%	8%	**24%**	**252**
06067008117	95608	Carmichael	16%	40%	13%	5%	36%	10%	**20%**	**253**
06067007209	95673	Rio Linda	13%	23%	54%	13%	11%	4%	**20%**	**254**
06067007013	95833	Sacramento	22%	28%	20%		2%	0%	**14%**	**255**

4.7. Heat Pump Water Heater Location

One additional consideration for building owners as they electrify is the storage space and air conditioning needed for heat pump water heating. Standard-sized individual HPWHs – typically 50 to 80 gallons – will generally be able to fit in the same spaces as gas storage water heaters but, during colder months, will see efficiency losses if they are outside or will decrease space heating efficiency if they are in conditioned spaces, as they will be removing heat from the air. However, this is a minor concern compared to the issues surrounding central HPWH storage. Because gas boilers are able to inject much more instantaneous heat into water compared to HPWHs, central HPWHs must compensate by continuously heating water and storing it for use in future hours, and thus require more storage to serve the same number of units compared to a gas boiler. Table 19 shows the estimated storage per unit needed for different building types and the corresponding space needed for hot water storage for each building type. For the smaller buildings, the additional storage space of 30 to 50 total square feet is not likely to be an issue, so this is specifically a concern for central HPWHs in large urban multifamily buildings. Storage space of 318 square feet, compared to that of the 55 needed for gas boilers, may mean needing to take out a wall or get rid of a row of parking spaces. However, this is a very specific issue that will only affect a few buildings – only nine buildings in SMUD territory have central gas water heating and 89+ units – so it will not be treated as a general barrier to electrification for the purpose of this study, although it is worth monitoring as more urban high-rise buildings attempt to electrify.

Table 19: Space Needed for Water Heating Storage by Fuel and Building Size (Pande et al. 2021)



Storage by Water Heater Type		Garden (<9 Units)	Low-Rise (9-36 Units)	Mid-Rise (37-88 Units)	High-Rise (89+ Units)
Central HPWH	Storage Needed Per Unit (gal)	45.6	35.4	34.7	29.9
	Total Storage Needed Per Building (gal)	388	741	1,940	4,242
	Add'l Space Needed Per Building (s.f.)	**29**	**56**	**145**	**318**
Central Gas Boiler	Storage Needed Per Unit (gal)	11.5	6.8	6.6	6.0
	Total Storage Needed Per Building (gal)	92	126	340	730
	Add'l Space Needed Per Building (s.f.)	**7**	**9**	**25**	**55**

5. Discussion

The results from the loading study suggest that multifamily electrification will not lead to widespread overloading of local distribution grids. In fact, multifamily electrification is likely to be cheaper per unit than single-family, as the costs of replacing infrastructure are spread across more households. However, it still remains a barrier, as the 10% of projects that will have to pay for upgrading the distribution transformer not only have to include it as a cost but will have to incur the hassle of potentially having to dig up any direct bury cables and temporarily shutting off power to units while completing the project. Owners of these buildings may rightfully turn down the opportunity to electrify their gas appliances strictly because of the time and hassle required, regardless of any cost incentives that make electrification more affordable than gas replacement. Additionally, while this study suggests that a similarly low number of main service building panels and virtually no unit-level panels are or will be technically overloaded, each electrification project will still require an electrician to calculate all of the loads on the panels, which takes additional effort compared to like-for-like replacements of gas equipment, and as mentioned earlier, if the deemed load calculation method is used, the panels are more likely to be considered overloaded when they are in fact not. SMUD should join with other utilities and state agencies to push for a change in the NEC calculations to ensure that estimates are accurate rather than conservative, which should be increasingly possible with the advent of smart meter technology in virtually every residence in California.

Passive efficiency measures such as insulation and window upgrades can significantly improve a building's ability to maintain a comfortable temperature while reducing energy use. However, as it relates to avoiding electrical infrastructure overloading, passive efficiency measures are not very likely to have an impact and even less likely to be cost effective if their only purpose is avoiding upgrades. This goes for more advanced load shifting measures like thermal energy storage tanks and centrally controlled thermostats as well as rooftop solar; their benefit is not likely to be in avoiding upsizing local electrical infrastructure or anything else relevant to building owners making decisions about electrification. However, all of these measures have value to other parties outside of the building owners: passive efficiency helps tenants have more comfortable homes and affordable energy bills, and load shifting measures provide flexibility and grid relief to utilities. Both of them are important for the welfare of building occupants and ratepayers in general but are better funded through programs such as the Low-Income Weatherization Program (LIWP) or a utility demand response program, respectively. Depending on how much SMUD values grid flexibility, they could even consider creating a program for Hot Water as a Service (HWaaS). This could mean SMUD taking ownership of some of the larger central HPWH systems the way that they own, maintain, and control energy generation and the grid. They would charge tenants or building owners a flat fee for hot water and in exchange they would have the ability to charge the hot water storage tanks at the times that provided the most benefit to the grid. There might be a slight decrease in service, as SMUD would be more likely to choose grid benefits over tenant service, but the flat fee should reflect less overall spending on hot water for tenants. This is very similar to some of the thermal energy storage and utility programs described in the literature review.

Based on the results of this study, project costs should not be what prevent most electrification projects. As mentioned, a few projects will have relatively high infrastructure costs in addition to the equipment costs or additional issues related to water heater storage space, but for the most part purchasing and installing electrification equipment is a similar magnitude of cost as the gas equipment, especially with current SMUD project incentives. Similar incentives should be available statewide soon with the onset of the TECH program. These results suggest that replacing gas equipment with electric equipment upon burnout is a viable and beneficial strategy. However, these installation costs and their underlying assumptions are dependent on a relatively standard cost of labor for installing heat pumps and heat pump water heaters. Because these systems, especially central heat pump water heaters, are relatively rare and new compared to gas furnaces and boilers, many contractors have little to no experience with them and will charge more, either because it takes longer to install or to factor in the risk of something failing due to a mistake during installation, which is more likely compared to a standard furnace or boiler installation. An additional barrier is the lack of industry experience with these sorts of installations – even if the installation costs are similar to the values used in this study, a building owner may go with the gas replacement simply because it is too hard to get a quote for an electrification project from a contractor. SMUD, along with other utilities, should continue efforts contributing to the development of an electrification workforce by providing training and funding for vocational schools.

If project costs do end up being significantly more than the gas replacement baseline, it is possible that those costs will be recovered indirectly through increased rent. Even if not, a few studies in the literature review suggested that building owners could offer slightly higher rents for units with efficient appliances and other “green” amenities compared to similar units lacking those amenities. It is not clear that this will be the case for multifamily buildings that electrify, but the results could be disastrous if so. Buildings with low-income residents and in disadvantaged communities should be electrified early in the transition to ensure these communities see energy burden and air quality benefits while avoiding increased gas rates. However, if by doing so these tenants are priced out and forced to move back to buildings with gas appliances, they will be stuck with worse air quality and, eventually, higher bills due to the projected increase of gas rates with more electrification. This would severely exacerbate the inequalities surrounding building energy systems. Again, it is not clear that this will happen, but SMUD should consider the possibility of these impacts as they discuss electrification with building owners.

One clear opportunity offered by electrification, especially in SMUD territory, is the impact on energy costs. This will mostly benefit tenants, but many building owners, especially in larger buildings, pay for central space conditioning and water heating; they will see huge benefits and can count the energy cost savings towards the life cycle value of switching to new efficient electric appliances. More focus should be placed on this benefit when encouraging building owners to electrify.

Targeting electrification projects is an effective way to go after buildings that are ripe for electrification in terms of project costs while ensuring maximum benefit to tenants and the climate alike. The targeting in this study provides decision makers at SMUD, local city governments, and state agencies like TCAC the ability to approach building owners in specific areas to suggest electrification and perhaps even provide additional funding or technical assistance.

An additional consideration for SMUD and others is how to increase the amount of public multifamily housing available in the region. Multifamily buildings are generally cheaper to electrify per unit than single-family homes but generally house renters who do not make decisions about electrification. With public housing, decisions about retrofits, electrification, and general building performance are more likely to be made based on tenant and general population wellbeing; examples of cities with more of these buildings can be found in many European countries. Much of this is out of the hands of SMUD, but they could support policies that increase housing in general and public housing specifically.

6. Conclusion

The goal of this study was to produce a more granular outlook than was previously available on the potential for and impacts from electrification in multifamily buildings in a utility region. In this case, the study was done in SMUD territory. The policy analysis determined that while California has been focused on cleaning up the electric grid and improving new building performance for decades, they have not yet developed an effective incentive or solution for retrofitting buildings with gas appliances that impact both air quality and GHG emissions, although the new TECH program may provide significant assistance. This study focused on the current landscape for retrofitting and electrifying buildings.

The literature review uncovered the many barriers that exist for multifamily building retrofits, including the relatively high number of stakeholders, high upfront costs, and aversion to committing to new or relatively unproven technologies. Additional studies showed the diverse array of efficiency and load shifting measures that can be cost effective in multifamily buildings. Across almost all studies, the most impactful and beneficial measures were efficient space conditioning and water heating technologies, which indicated that electrification technology such as heat pumps and induction stoves should be the main focus of a study such as this one.

The results determined that most buildings would not need to upsize their electrical infrastructure; overall, electrification project costs are relatively similar to gas project costs and electrical infrastructure costs do not represent a significant amount of the total costs that will be spent on electrification in multifamily buildings. Additionally, bills will be lower for nearly every customer and building owner after electrification. Buildings should be targeted by SMUD using a methodology similar the one laid out in this study, which considers density, timing, equity, infrastructure costs, equipment costs, bill savings, and carbon impacts related to electrification.

This study is useful for displaying a vision of what electrification will look like at a local scale for a small utility. SMUD can use the results of this study to develop programs, forecast impacts, and respond to equity concerns around the energy transition, perhaps starting by making a list of multifamily building owners in the top-scored census tracts to reach out to about electrification Some drawbacks of the study that could be improved in future studies are related to the data that are available: although some of the Sacramento County data such as permits and parcel information was very necessary and useful for determining building attributes, better data on number of stories, year built, and unit sizes would have significantly increased the ability of the models to correctly determine fuel and system types. It may have even been possible to consider more specific system types, such as wall furnaces vs. split DX gas heating, which would be more useful in understanding electrification impacts at the building and unit level. SMUD could work with the county to improve the availability and record-keeping of this data.

Originally, this study was going to include a section applying results from SMUD territory to the entire state. However, because of the uncertainties present in the data and vastly different building stocks and energy rates across the state, such an undertaking would have been either too general and extrapolated to be meaningful or too time-intensive to be feasible. Future studies in different regions can hopefully refer to this study and use or adapt some of the methodology to produce results specific to the region.

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Appendix A

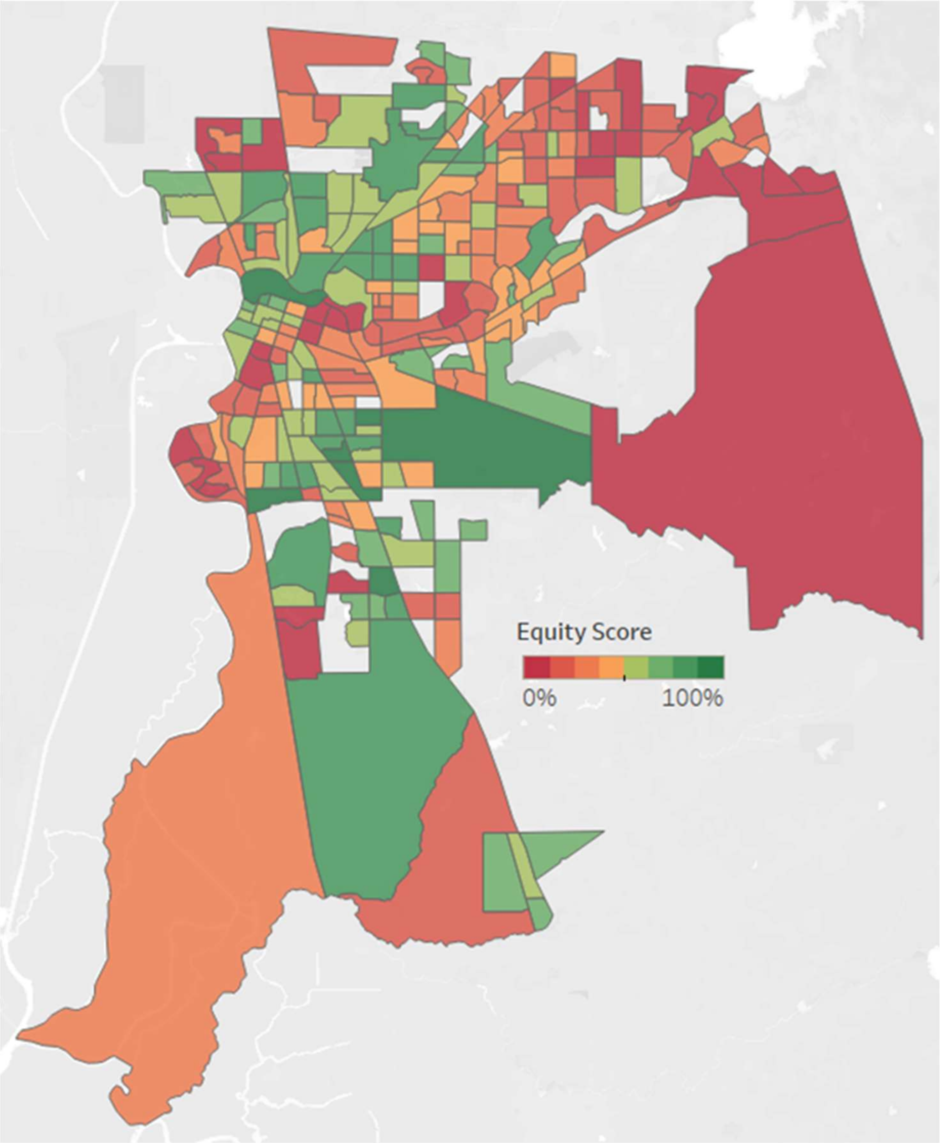

Figure 24: Equity Score for All Census Tracts

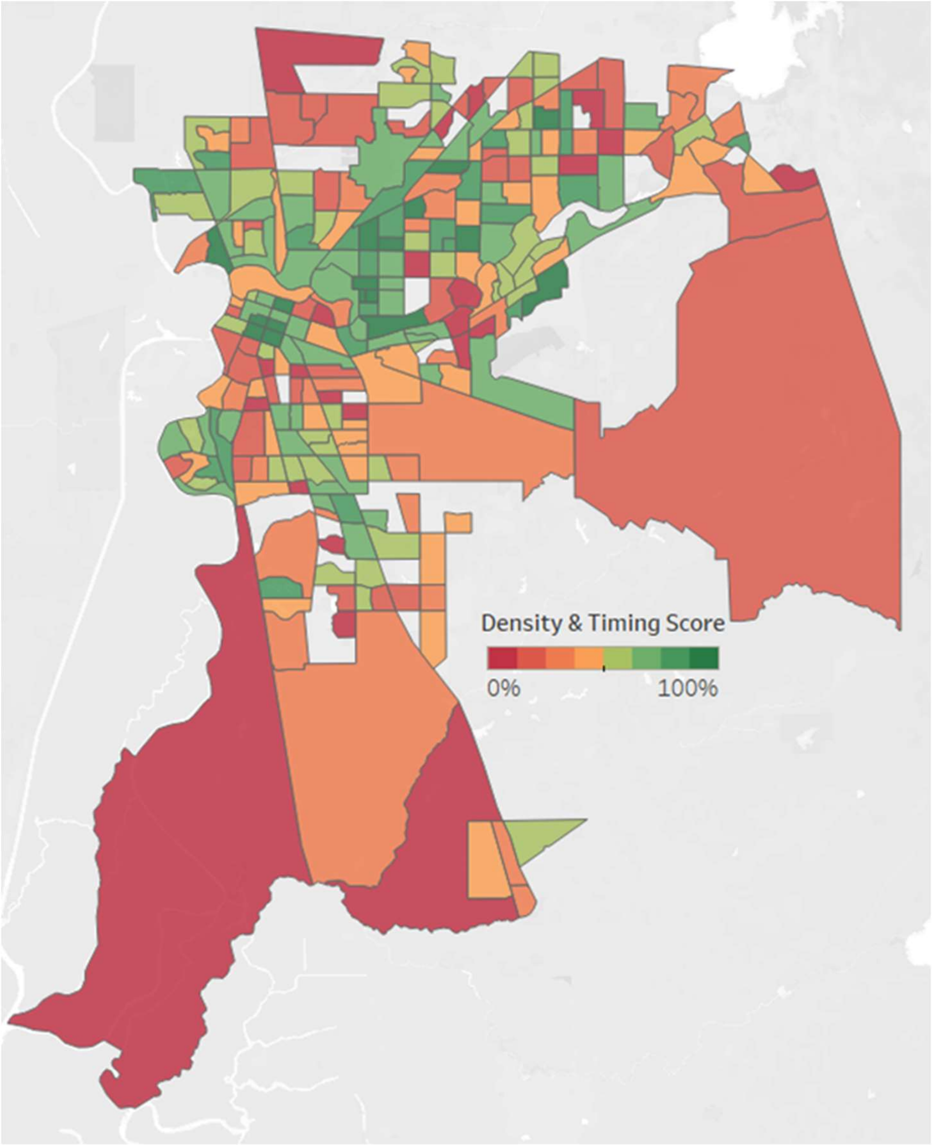

Figure 25: Density & Timing Score for All Census Tracts

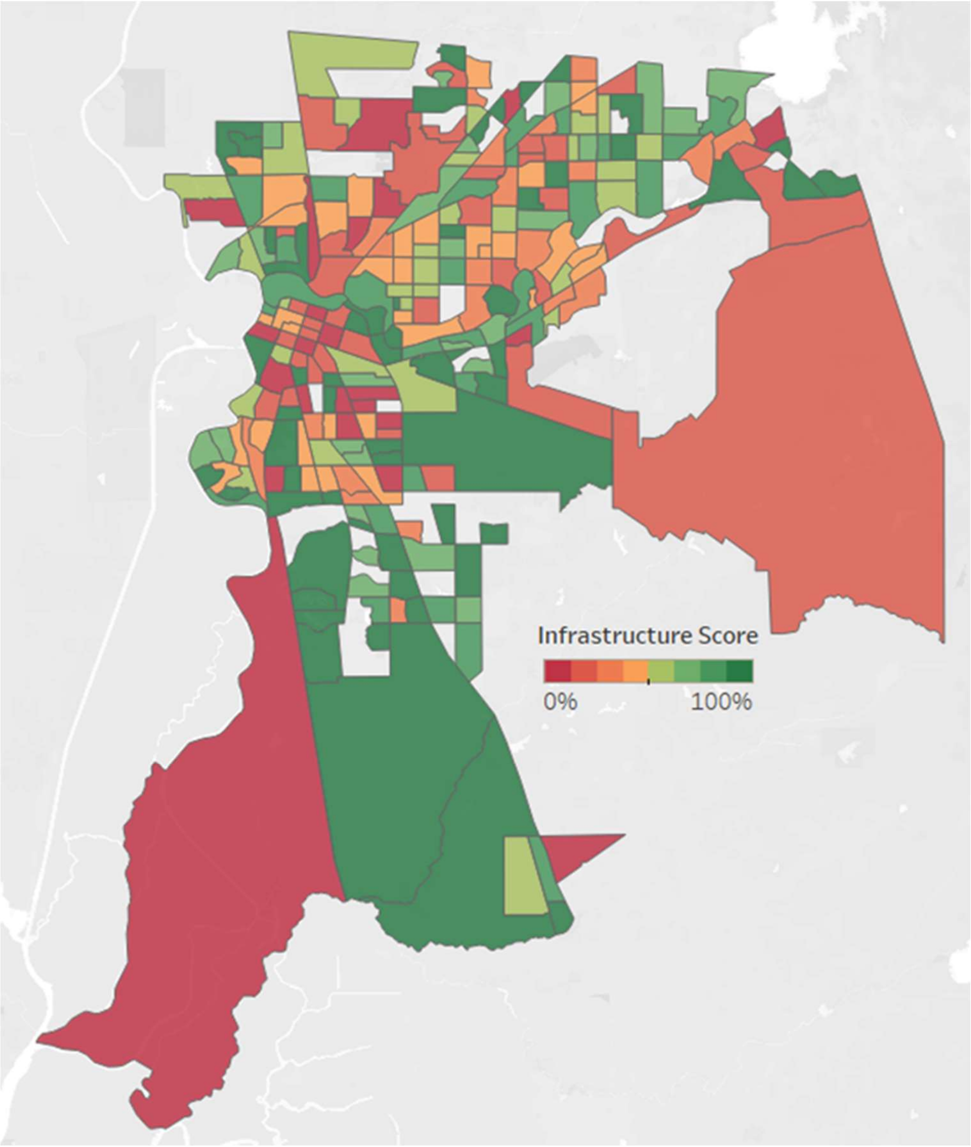

Figure 26: Infrastructure Score for All Census Tracts

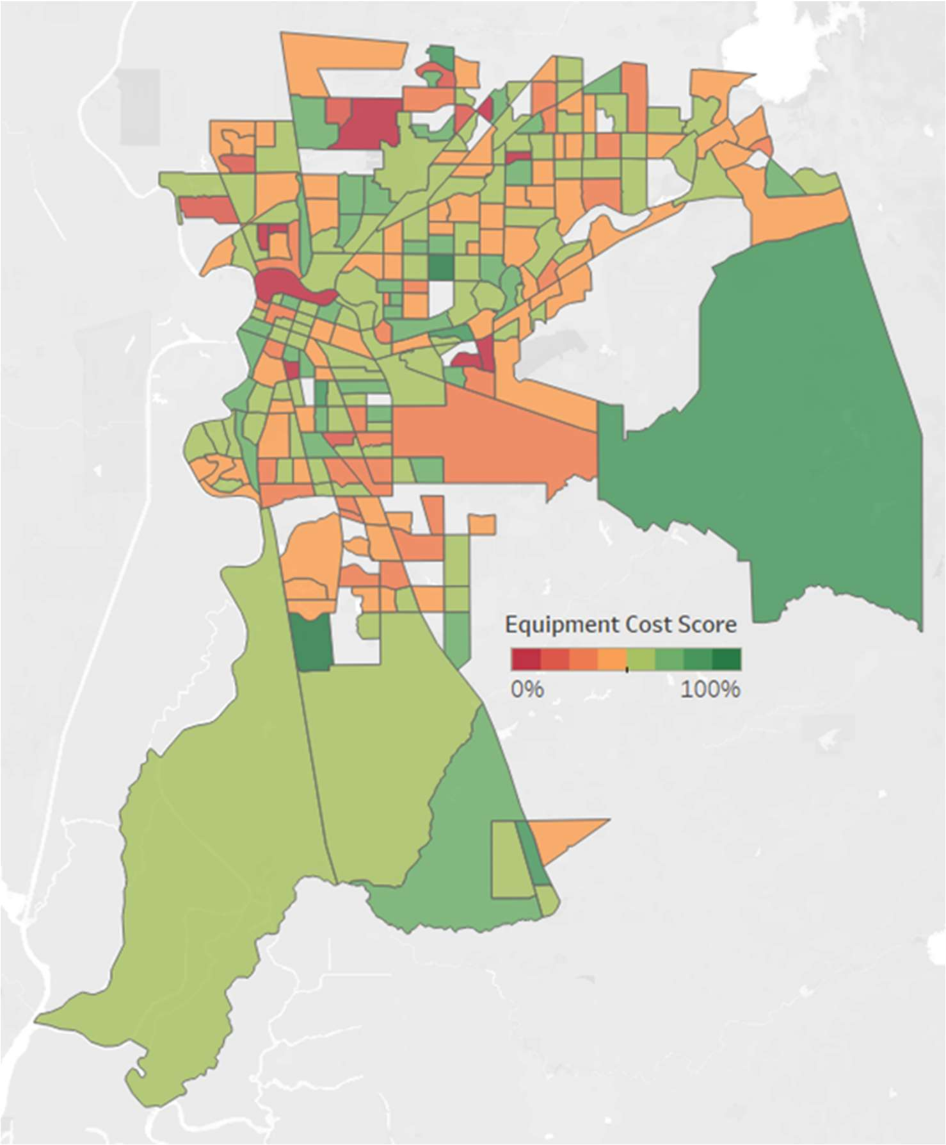

Figure 27: Equipment Cost Score for All Census Tracts

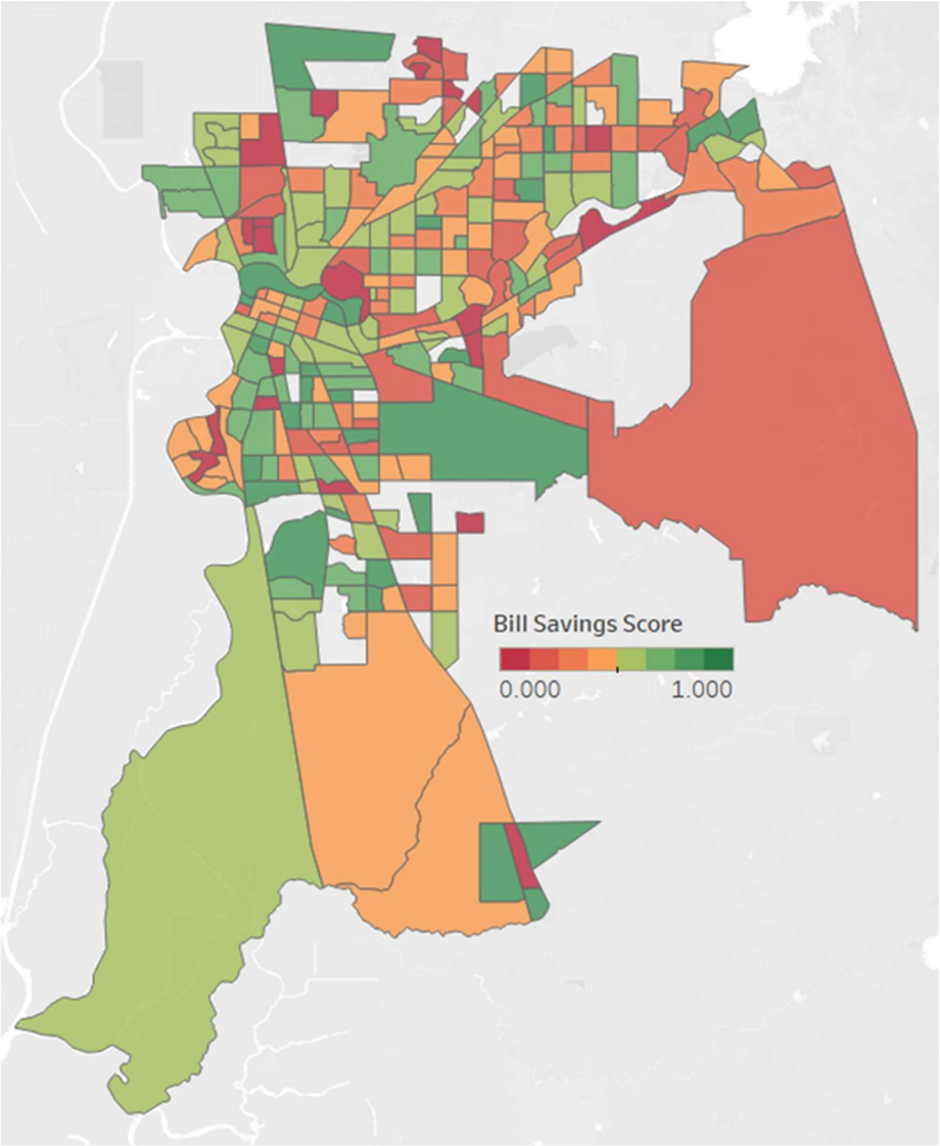

Figure 28: Bill Savings Score for All Census Tracts

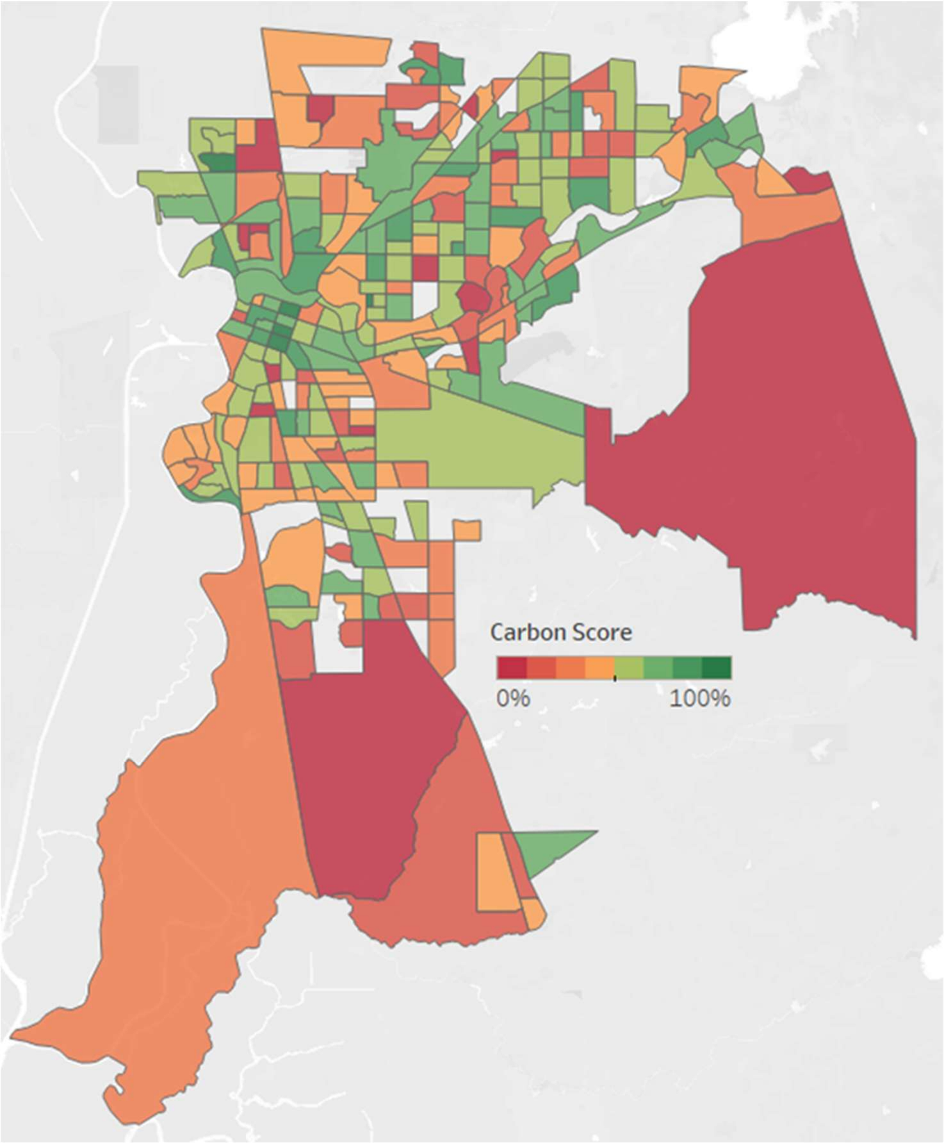

Figure 29: Carbon Score for All Census Tracts

Table 20: Score Breakdowns for All Census Tracts

Census Tract	City	Density & Timing Score	Equity Score	Infrastructure Score	Equipment Cost Score	Bill Savings Score	Carbon Score	Total Score	Rank
06067005509	Sacramento	92%	36%	89%	33%	62%	95%	**68%**	**1**
06067007018	Sacramento	74%	55%	81%	50%	72%	72%	**68%**	**2**
06067009639	Elk Grove	51%	88%	91%	33%	84%	56%	**67%**	**3**
06067009608	Elk Grove	68%	70%	91%	48%	56%	71%	**67%**	**4**
06067009110	Sacramento	50%	70%	90%	59%	56%	77%	**67%**	**5**
06067009618	Elk Grove	36%	84%	100%	45%	86%	50%	**67%**	**6**
06067004801	Sacramento	41%	87%	100%	36%	78%	60%	**67%**	**7**
06067009619	Elk Grove	81%	50%	88%	41%	69%	69%	**66%**	**8**
06067006201	Sacramento	89%	82%	45%	48%	60%	73%	**66%**	**9**
06067004300	Sacramento	45%	91%	100%	36%	77%	46%	**66%**	**10**
06067009201	Sacramento	32%	94%	100%	30%	83%	55%	**66%**	**11**
06067005505	Sacramento	86%	78%	40%	40%	68%	79%	**65%**	**12**
06067007007	Sacramento	65%	51%	93%	36%	73%	72%	**65%**	**13**
06067005601	Sacramento	72%	83%	62%	56%	62%	51%	**65%**	**14**
06067007015	Sacramento	77%	64%	57%	61%	69%	59%	**65%**	**15**
06067005301	Sacramento	49%	97%	84%	7%	80%	63%	**63%**	**16**
06067007413	Sacramento	77%	57%	69%	60%	47%	66%	**63%**	**17**
06067006702	Sacramento	64%	87%	50%	49%	60%	67%	**63%**	**18**
06067005204	Sacramento	47%	67%	100%	57%	63%	40%	**62%**	**19**
06067004202	Sacramento	36%	74%	91%	54%	63%	57%	**62%**	**20**
06067009317	Sacramento	26%	75%	100%	35%	86%	51%	**62%**	**21**
06067008006	Fair Oaks	66%	53%	81%	52%	70%	51%	**62%**	**22**
06067008506	Folsom	85%	33%	93%	33%	54%	75%	**62%**	**23**
06067004602	Sacramento	74%	56%	41%	66%	63%	70%	**62%**	**24**
06067008137	Citrus Heights	70%	60%	53%	40%	76%	70%	**62%**	**25**
06067000700	Sacramento	47%	63%	84%	31%	85%	60%	**61%**	**26**
06067005201	Sacramento	77%	31%	92%	51%	51%	66%	**61%**	**27**
06067007010	Sacramento	99%	27%	58%	50%	55%	77%	**61%**	**28**
06067004903	Sacramento	57%	86%	43%	59%	62%	59%	**61%**	**29**
06067008131	Citrus Heights	75%	30%	83%	50%	56%	72%	**61%**	**30**
06067007301	McClellan	67%	82%	21%	55%	69%	71%	**61%**	**31**
06067006900	Sacramento	74%	82%	24%	53%	56%	76%	**61%**	**32**
06067006101	Sacramento	85%	48%	40%	51%	57%	80%	**60%**	**33**
06067007501	Sacramento	74%	81%	32%	42%	64%	67%	**60%**	**34**
06067009502	Galt	45%	67%	62%	57%	84%	47%	**60%**	**35**
06067006003	Sacramento	93%	45%	58%	47%	53%	64%	**60%**	**36**
06067009504	Galt	27%	72%	90%	50%	82%	39%	**60%**	**37**
06067006202	Sacramento	80%	77%	30%	52%	52%	67%	**60%**	**38**
06067008133	Sacramento	46%	65%	85%	59%	49%	53%	**60%**	**39**
06067002000	Sacramento	90%	40%	13%	55%	72%	86%	**59%**	**40**
06067000400	Sacramento	97%	45%	5%	56%	60%	93%	**59%**	**41**
06067009314	Elk Grove	44%	74%	100%	54%	48%	35%	**59%**	**42**
06067006004	Sacramento	28%	41%	100%	41%	82%	62%	**59%**	**43**
06067001300	Sacramento	99%	28%	24%	57%	56%	90%	**59%**	**44**
06067006701	Sacramento	59%	78%	85%	40%	33%	59%	**59%**	**45**
06067004012	Sacramento	70%	13%	84%	45%	63%	79%	**59%**	**46**

06067004501	Sacramento	68%	51%	30%	45%	80%	76%	**58%**	**47**
06067007801	Carmichael	84%	30%	66%	54%	40%	75%	**58%**	**48**
06067001200	Sacramento	96%	54%	41%	54%	33%	71%	**58%**	**49**
06067007503	Sacramento	89%	71%	21%	42%	52%	75%	**58%**	**50**
06067003400	Sacramento	64%	62%	40%	61%	74%	47%	**58%**	**51**
06067006102	Sacramento	92%	46%	50%	65%	35%	61%	**58%**	**52**
06067006800	Sacramento	86%	44%	14%	58%	56%	87%	**58%**	**53**
06067005903	Carmichael	84%	35%	41%	48%	65%	75%	**58%**	**54**
06067007602	Carmichael	49%	60%	62%	48%	61%	66%	**57%**	**55**
06067009112	Sacramento	39%	31%	100%	35%	75%	64%	**57%**	**56**
06067004402	Sacramento	13%	47%	100%	78%	79%	25%	**57%**	**57**
06067005510	Sacramento	96%	31%	52%	70%	32%	61%	**57%**	**58**
06067008404	Folsom	54%	57%	27%	43%	82%	78%	**57%**	**59**
06067005506	Sacramento	89%	40%	51%	64%	42%	56%	**57%**	**60**
06067001700	Sacramento	68%	30%	61%	51%	59%	72%	**57%**	**61**
06067006002	Sacramento	58%	71%	64%	64%	34%	49%	**57%**	**62**
06067009111	Sacramento	68%	29%	86%	65%	38%	53%	**57%**	**63**
06067007423	Sacramento	67%	49%	66%	53%	42%	62%	**56%**	**64**
06067001900	Sacramento	92%	27%	7%	56%	65%	92%	**56%**	**65**
06067002800	Sacramento	11%	82%	100%	47%	80%	17%	**56%**	**66**
06067000500	Sacramento	70%	66%	22%	64%	41%	74%	**56%**	**67**
06067009612	Elk Grove	59%	65%	29%	38%	79%	66%	**56%**	**68**
06067009105	Sacramento	65%	29%	66%	60%	56%	58%	**56%**	**69**
06067007701	Carmichael	96%	36%	42%	49%	44%	67%	**56%**	**70**
06067009007	Rancho Cordova	83%	44%	50%	54%	37%	66%	**56%**	**71**
06067009633	Sacramento	26%	35%	100%	27%	84%	62%	**56%**	**72**
06067009320	Sacramento	65%	82%	30%	43%	52%	62%	**56%**	**72**
06067009616	Elk Grove	16%	73%	78%	43%	74%	48%	**55%**	**74**
06067008136	Citrus Heights	60%	23%	76%	35%	74%	64%	**55%**	**75**
06067009606	Sacramento	75%	46%	82%	47%	28%	53%	**55%**	**76**
06067008141	Citrus Heights	92%	24%	59%	52%	32%	70%	**55%**	**77**
06067002200	Sacramento	16%	61%	100%	68%	56%	29%	**55%**	**78**
06067001101	Sacramento	70%	62%	49%	29%	43%	77%	**55%**	**79**
06067005402	Sacramento	72%	59%	83%	59%	6%	48%	**55%**	**80**
06067001400	Sacramento	69%	60%	18%	61%	46%	73%	**55%**	**81**
06067007004	Sacramento	73%	73%	45%	50%	18%	67%	**54%**	**82**
06067000600	Sacramento	61%	77%	54%	61%	30%	43%	**54%**	**83**
06067003800	Sacramento	21%	41%	100%	47%	63%	54%	**54%**	**84**
06067005002	Sacramento	64%	92%	46%	33%	42%	49%	**54%**	**85**
06067009634	Sacramento	74%	34%	66%	33%	52%	65%	**54%**	**86**
06067009106	Sacramento	70%	15%	87%	77%	30%	46%	**54%**	**87**
06067008139	Citrus Heights	79%	19%	86%	60%	25%	56%	**54%**	**88**
06067007104	Sacramento	39%	29%	100%	38%	61%	56%	**54%**	**89**
06067009407	Galt	53%	72%	10%	39%	82%	67%	**54%**	**90**
06067005101	Sacramento	55%	53%	75%	52%	42%	47%	**54%**	**91**
06067000100	Sacramento	35%	10%	89%	55%	76%	59%	**54%**	**92**
06067005202	Sacramento	67%	22%	83%	46%	43%	61%	**54%**	**93**
06067002100	Sacramento	57%	63%	10%	66%	60%	66%	**54%**	**94**
06067007406	North Highlands	57%	85%	100%	31%	35%	13%	**54%**	**95**

06067009008	Rancho Cordova	59%	50%	28%	43%	69%	71%	**53%**	**96**
06067008009	Fair Oaks	77%	19%	53%	29%	62%	79%	**53%**	**97**
06067007433	Antelope	61%	68%	45%	47%	23%	76%	**53%**	**98**
06067005904	Sacramento	75%	38%	43%	56%	49%	57%	**53%**	**99**
06067008120	Citrus Heights	87%	8%	52%	38%	54%	79%	**53%**	**100**
06067007102	Sacramento	52%	9%	100%	42%	59%	55%	**53%**	**101**
06067001800	Sacramento	63%	60%	13%	38%	62%	79%	**53%**	**102**
06067009329	Sacramento	44%	69%	100%	48%	7%	47%	**53%**	**103**
06067005403	Sacramento	73%	13%	90%	31%	52%	57%	**52%**	**104**
06067002700	Sacramento	43%	62%	18%	63%	70%	58%	**52%**	**105**
06067004010	Sacramento	83%	21%	56%	47%	47%	61%	**52%**	**106**
06067008913	Rancho Cordova	59%	80%	45%	59%	47%	24%	**52%**	**107**
06067009010	Rancho Cordova	96%	27%	35%	40%	38%	77%	**52%**	**108**
06067004502	Sacramento	74%	54%	50%	69%	17%	49%	**52%**	**109**
06067009108	Sacramento	27%	71%	70%	10%	86%	48%	**52%**	**110**
06067009611	Elk Grove	13%	77%	100%	59%	45%	19%	**52%**	**111**
06067007424	North Highlands	46%	76%	51%	41%	47%	51%	**52%**	**112**
06067009638	Elk Grove	31%	84%	100%	54%	38%	5%	**52%**	**113**
06067007601	Carmichael	87%	32%	36%	56%	36%	64%	**52%**	**114**
06067005508	Sacramento	86%	23%	45%	67%	31%	59%	**52%**	**115**
06067004702	Sacramento	59%	80%	64%	22%	37%	49%	**52%**	**116**
06067004904	Sacramento	50%	52%	36%	33%	67%	72%	**52%**	**117**
06067008208	Orangevale	65%	14%	72%	51%	47%	59%	**51%**	**118**
06067004011	Sacramento	54%	5%	91%	53%	50%	54%	**51%**	**119**
06067008113	Citrus Heights	53%	15%	89%	48%	48%	54%	**51%**	**120**
06067004601	Sacramento	44%	79%	7%	54%	66%	58%	**51%**	**121**
06067007904	Fair Oaks	16%	20%	100%	47%	66%	57%	**51%**	**122**
06067006600	Sacramento	58%	52%	9%	69%	63%	53%	**51%**	**123**
06067008910	Rancho Cordova	59%	42%	13%	48%	68%	75%	**51%**	**124**
06067007103	Sacramento	84%	4%	50%	22%	57%	88%	**51%**	**125**
06067004701	Sacramento	55%	89%	63%	55%	19%	24%	**51%**	**126**
06067004802	Sacramento	38%	60%	92%	60%	17%	36%	**51%**	**127**
06067007105	Sacramento	36%	65%	64%	43%	48%	47%	**50%**	**128**
06067008907	Rancho Cordova	57%	65%	47%	55%	17%	62%	**50%**	**129**
06067009310	Elk Grove	41%	26%	85%	67%	51%	32%	**50%**	**130**
06067007504	Sacramento	37%	43%	79%	52%	54%	37%	**50%**	**131**
06067004001	Sacramento	75%	30%	31%	64%	47%	54%	**50%**	**132**
06067000200	Sacramento	10%	4%	100%	54%	81%	51%	**50%**	**133**
06067007011	Sacramento	68%	33%	65%	52%	28%	54%	**50%**	**134**
06067008905	Rancho Cordova	54%	40%	51%	35%	54%	64%	**50%**	**135**
06067007430	Antelope	40%	64%	88%	80%	4%	23%	**50%**	**136**
06067009615	Elk Grove	51%	9%	63%	33%	69%	75%	**50%**	**137**
06067009635	Elk Grove	29%	9%	93%	92%	55%	21%	**50%**	**138**
06067008010	Fair Oaks	42%	16%	81%	41%	56%	62%	**50%**	**139**
06067007905	Carmichael	40%	52%	22%	46%	76%	62%	**49%**	**140**
06067009622	Elk Grove	43%	4%	92%	39%	55%	61%	**49%**	**141**

06067005502	Sacramento	65%	77%	45%	38%	20%	48%	**49%**	**142**
06067008504	Folsom	43%	3%	100%	50%	37%	58%	**49%**	**143**
06067005801	Sacramento	51%	58%	31%	56%	41%	56%	**49%**	**144**
06067004004	Sacramento	63%	10%	68%	61%	43%	47%	**49%**	**145**
06067008007	Fair Oaks	60%	30%	36%	50%	64%	50%	**48%**	**146**
06067009005	Sacramento	64%	70%	25%	48%	14%	69%	**48%**	**147**
06067008134	Carmichael	77%	18%	22%	50%	50%	72%	**48%**	**148**
06067008143	Citrus Heights	57%	49%	29%	52%	44%	58%	**48%**	**149**
06067009632	Elk Grove	12%	57%	100%	51%	47%	20%	**48%**	**150**
06067005404	Sacramento	92%	20%	42%	64%	21%	48%	**48%**	**151**
06067006500	Sacramento	22%	57%	42%	75%	56%	32%	**47%**	**152**
06067008507	Folsom	47%	1%	88%	69%	38%	41%	**47%**	**153**
06067005605	Sacramento	63%	58%	62%	29%	37%	35%	**47%**	**154**
06067007416	Sacramento	9%	25%	100%	59%	50%	40%	**47%**	**155**
06067007016	Sacramento	54%	58%	8%	21%	69%	73%	**47%**	**156**
06067009006	Sacramento	31%	43%	84%	50%	38%	37%	**47%**	**157**
06067004203	Sacramento	61%	81%	41%	43%	30%	25%	**47%**	**158**
06067003900	Sacramento	50%	25%	57%	71%	39%	39%	**47%**	**159**
06067007906	Carmichael	67%	23%	92%	45%	16%	36%	**47%**	**160**
06067008909	Rancho Cordova	43%	42%	81%	69%	24%	20%	**46%**	**161**
06067008911	Rancho Cordova	53%	66%	48%	50%	27%	34%	**46%**	**162**
06067006300	Sacramento	39%	58%	28%	60%	42%	50%	**46%**	**163**
06067008111	Citrus Heights	18%	20%	71%	34%	78%	56%	**46%**	**164**
06067005606	Sacramento	65%	28%	14%	44%	61%	64%	**46%**	**165**
06067009322	Elk Grove	59%	61%	75%	36%	17%	28%	**46%**	**166**
06067007019	Sacramento	60%	76%	42%	38%	23%	37%	**46%**	**167**
06067007020	Sacramento	37%	20%	68%	45%	49%	56%	**46%**	**168**
06067008403	Folsom	49%	29%	23%	47%	53%	73%	**46%**	**169**
06067003202	Sacramento	60%	83%	42%	32%	35%	22%	**45%**	**170**
06067003501	Sacramento	39%	33%	17%	51%	74%	59%	**45%**	**171**
06067004906	Sacramento	5%	14%	100%	51%	54%	48%	**45%**	**172**
06067004005	Sacramento	52%	13%	69%	52%	41%	45%	**45%**	**173**
06067005701	Sacramento	3%	12%	87%	93%	65%	12%	**45%**	**174**
06067004006	Sacramento	72%	44%	40%	56%	12%	45%	**45%**	**175**
06067002900	Sacramento	15%	21%	63%	61%	64%	46%	**45%**	**176**
06067004100	Sacramento	45%	54%	45%	55%	40%	29%	**45%**	**177**
06067007403	North Highlands	24%	86%	20%	67%	55%	15%	**44%**	**178**
06067009503	Galt	32%	51%	78%	79%	12%	15%	**44%**	**179**
06067008140	Citrus Heights	33%	14%	42%	42%	71%	63%	**44%**	**180**
06067007001	Sacramento	39%	57%	7%	73%	54%	33%	**44%**	**181**
06067008129	Citrus Heights	22%	24%	100%	54%	37%	26%	**44%**	**182**
06067008138	Citrus Heights	48%	29%	70%	45%	33%	37%	**44%**	**183**
06067007429	Sacramento	67%	55%	32%	51%	7%	48%	**44%**	**184**
06067003204	Sacramento	11%	92%	2%	65%	45%	45%	**43%**	**185**
06067008142	Citrus Heights	58%	12%	39%	51%	37%	62%	**43%**	**186**
06067007414	North Highlands	59%	65%	57%	19%	25%	35%	**43%**	**187**
06067001600	Sacramento	45%	29%	21%	38%	61%	66%	**43%**	**188**
06067002600	Sacramento	52%	18%	20%	64%	47%	58%	**43%**	**189**

06067004008	Sacramento	13%	21%	100%	41%	44%	41%	**43%**	**190**
06067007014	Sacramento	57%	32%	80%	49%	6%	35%	**43%**	**191**
06067009501	Galt	7%	15%	100%	75%	40%	21%	**43%**	**192**
06067008203	Orangevale	23%	8%	71%	25%	70%	61%	**43%**	**193**
06067004905	Sacramento	72%	51%	30%	53%	6%	46%	**43%**	**194**
06067008206	Orangevale	46%	14%	77%	47%	13%	59%	**43%**	**195**
06067007206	Elverta	7%	18%	59%	49%	83%	40%	**42%**	**196**
06067008145	Orangevale	9%	17%	100%	57%	43%	29%	**42%**	**197**
06067005001	Sacramento	40%	48%	11%	27%	63%	65%	**42%**	**198**
06067002300	Sacramento	13%	12%	60%	37%	79%	53%	**42%**	**199**
06067003000	Sacramento	25%	36%	3%	73%	72%	43%	**42%**	**200**
06067007903	Carmichael	20%	39%	41%	67%	44%	37%	**42%**	**201**
06067005205	Sacramento	46%	39%	60%	52%	15%	37%	**41%**	**202**
06067009307	Elk Grove	29%	18%	72%	58%	39%	30%	**41%**	**203**
06067005804	Carmichael	11%	20%	100%	58%	49%	7%	**41%**	**204**
06067007802	Carmichael	75%	30%	31%	44%	19%	44%	**40%**	**205**
06067008210	Folsom	32%	4%	73%	48%	42%	42%	**40%**	**206**
06067003300	Sacramento	26%	16%	25%	54%	68%	53%	**40%**	**207**
06067008135	Citrus Heights	38%	25%	37%	71%	33%	33%	**40%**	**208**
06067008402	Folsom	26%	19%	3%	49%	76%	63%	**39%**	**209**
06067007208	Rio Linda	13%	34%	14%	69%	65%	41%	**39%**	**210**
06067004201	Sacramento	13%	44%	10%	34%	84%	49%	**39%**	**211**
06067007012	Sacramento	40%	77%	100%	11%	4%	1%	**39%**	**212**
06067007426	Antelope	40%	16%	67%	74%	1%	32%	**38%**	**213**
06067005102	Sacramento	33%	42%	15%	67%	44%	29%	**38%**	**214**
06067008119	Fair Oaks	54%	20%	20%	54%	27%	54%	**38%**	**215**
06067003600	Sacramento	15%	39%	4%	51%	72%	48%	**38%**	**216**
06067006400	Sacramento	29%	54%	3%	72%	30%	38%	**38%**	**217**
06067004401	Sacramento	25%	44%	10%	51%	44%	51%	**38%**	**218**
06067005803	Sacramento	19%	8%	32%	51%	58%	55%	**37%**	**219**
06067003102	Sacramento	7%	38%	2%	55%	78%	45%	**37%**	**220**
06067000800	Sacramento	23%	54%	48%	57%	22%	21%	**37%**	**221**
06067008908	Rancho Cordova	45%	38%	41%	48%	19%	29%	**37%**	**222**
06067001500	Sacramento	69%	10%	5%	48%	26%	62%	**37%**	**223**
06067009308	Elk Grove	22%	22%	85%	47%	19%	24%	**36%**	**224**
06067002400	Sacramento	22%	11%	11%	46%	72%	55%	**36%**	**225**
06067008209	Folsom	36%	5%	82%	56%	14%	26%	**36%**	**226**
06067008703	Rancho Cordova	70%	23%	13%	39%	6%	66%	**36%**	**227**
06067007427	Antelope	58%	18%	24%	15%	24%	78%	**36%**	**228**
06067008130	Sacramento	9%	25%	0%	70%	64%	46%	**36%**	**229**
06067002500	Sacramento	6%	65%	100%		2%	0%	**34%**	**230**
06067009004	Sacramento	8%	41%	2%	62%	54%	40%	**34%**	**231**
06067009609	Sacramento	8%	25%	66%	49%	34%	22%	**34%**	**232**
06067003203	Sacramento	39%	52%	20%	58%	22%	12%	**34%**	**233**
06067007702	Carmichael	41%	32%	14%	70%	24%	22%	**34%**	**234**
06067008513	Folsom	9%	0%	100%	58%	22%	12%	**34%**	**235**
06067008122	Fair Oaks	29%	8%	100%	37%	8%	13%	**32%**	**236**
06067009900	Walnut Grove	6%	35%	1%	53%	62%	32%	**32%**	**237**
06067008204	Orangevale	3%	9%	55%	59%	36%	20%	**30%**	**238**
06067009103	Sacramento	0%	49%	100%		2%	0%	**30%**	**239**

06067007422	Sacramento	15%	34%	100%		2%	0%	**30%**	**240**
06067008207	Orangevale	16%	17%	31%	55%	18%	44%	**30%**	**241**
06067005901	Sacramento	29%	35%	22%	46%	34%	16%	**30%**	**242**
06067008008	Fair Oaks	7%	4%	61%	53%	34%	17%	**29%**	**243**
06067000300	Sacramento	19%	10%	14%	68%	35%	30%	**29%**	**244**
06067003502	Sacramento	3%	17%	100%	42%	10%	2%	**29%**	**245**
06067004009	Sacramento	38%	8%	42%	48%	11%	26%	**29%**	**246**
06067009107	Sacramento	6%	20%	65%	49%	1%	23%	**28%**	**247**
06067007202	Rio Linda	25%	52%	8%	8%	44%	26%	**27%**	**248**
06067008125	Citrus Heights	17%	13%	15%	63%	29%	13%	**25%**	**249**
06067008508	Folsom	23%	4%	14%	49%	30%	29%	**25%**	**250**
06067007106	Sacramento	13%	9%	62%	50%	7%	8%	**25%**	**251**
06067008600	Sloughhouse	14%	9%	19%	77%	20%	8%	**24%**	**252**
06067008117	Carmichael	16%	40%	13%	5%	36%	10%	**20%**	**253**
06067007209	Rio Linda	13%	23%	54%	13%	11%	4%	**20%**	**254**
06067007013	Sacramento	22%	28%	20%		2%	0%	**14%**	**255**