PG&E Furnace Replacement Initiative Case Study

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Acronyms

Acronym	Definition
ACC	Avoided Cost Calculator
AMI	Automated Metering Infrastructure
CAISO	California Independent System Operator
CARB	California Air Resources Board
CARE	California Alternate Rates for Energy
CPUC	California Public Utilities Commission
CO2e	Carbon Dioxide Equivalent
CVRMSE	Coefficient of the variation of the root mean square error
CZ	California Climate Zone
DHW	Domestic Hot Water
FSC	Fuel Substitution Calculator
GHG	Greenhouse Gas
GWP	Global Warming Potential
IOU	Investor-Owned Utility
MWh	MegaWatt-hour
MUP	Multifamily Upgrade Program
MMBTUs	Metric Million British Thermal Units
nmecr	normalized metered energy consumption in r
RMP	Refrigerant Management Program

Executive Summary

Heat pumps are quickly becoming an important measure in the California IOUs' energy efficiency portfolios to address the need to save energy and decarbonize the built environment. Deemed savings estimates show heat pumps for space conditioning provide a lower annual energy use (in kBtu) than natural gas furnaces.[1] Heat pumps also represent an electrification and decarbonization opportunity as electricity production becomes cleaner due to expanded use of renewable energy generation and storage. However, few measurements have been made of actual energy use changes, customer bill impacts, GHG impacts, and occupant satisfaction where heat pump space conditioning systems replaced existing gas wall furnaces and air conditioners in multifamily buildings.

This report presents case study results from a space conditioning heat pump retrofit of 253 dwelling units at four multifamily sites in Northern California. The retrofits occurred during 2018 and 2019 as part of PG&E's Multifamily Upgrade Program (MUP) and replaced existing gas wall furnaces and air conditioners with ductless mini-split heat pumps. One of the buildings in the study did not have existing air conditioners and in that instance the heat pumps replaced gas wall furnaces for heating but also added space cooling when previously there was none. As detailed in the report, in addition to the heat pumps, two of the four sites conducted other significant upgrades (e.g., envelope improvements, efficient appliances), so reported savings include impacts of the heat pumps and other measures.

We used AMI data (provided by PG&E) for energy consumption for 2016 through 2021 to estimate energy savings, and "Average" Bundled Total Rate (provided by PG&E) to estimate billing impacts. (Refer to Billing Impacts section 5.1.2 for more details.) We completed property manager surveys at two sites, and resident surveys at one site (a senior housing facility) to evaluate equipment performance and occupant satisfaction. We interviewed HVAC contractors to estimate heat pump retrofit costs and refrigerant handling practices. In addition, we investigated the GHG impacts of refrigerant management, including the impact of reclamation rates for refrigerants in removed equipment and the impact of low-global-warming-potential (low-GWP) refrigerants in installed equipment.

Energy and Bill Impacts: The following table summarizes the total (gas and electric) energy use change at all four sites based on a comparison of pre- and post-retrofit consumption data. For each site, we aggregated the dwelling unit level data,[2] converted savings for natural gas (therms – typically positive savings) and electricity (kWh – typically negative savings) to kBTU, to calculate total energy savings (kBtu). As shown, total energy use decreased—i.e., generated positive savings, for three of the four sites. The table shows the site level savings divided by the number of dwelling units at that site for per-unit savings. Total energy use increased at one site (Sunnyvale), resulting in negative savings. However, this was the only site that did not have air conditioning pre-retrofit—i.e., where air conditioning was added. Using the CPUC's Fuel Substitution calculator, all sites resulted in GHG emissions reductions, so would pass the fuel substitution calculator test.

[1] The California eTRM https://www.caetrm.com/measure/SWHC045/01/, this measure passes the Energy Efficiency Three Prong Test Related to Fuel Substitution, whereby all fuel substitution measures must "not increase total source energy consumption when compared with the baseline comparison measure available utilizing the original fuel".

[2] Except for the gas consumption at the Yuba City site where only site level gas data were available.

Table 1: Summary of Site Energy and Bill Savings per dwelling unit

Site	Retrofit Measures Affecting Fuel Use	Normalized Savings (kBtu)/Unit/yr)	% Savings (% kBtu/ unit/ yr)	Bill savings ($/unit/yr), Non-CARE Rates	Bill savings ($/unit/yr), CARE Rates
Auburn	Heat pumps, ceiling and crawlspace insulation, in-unit lighting, efficient refrigerators	574	4.4%	$194	$162
Sunnyvale	Heat pumps, in-unit lighting, ceiling and wall insulation, windows, efficient refrigerators and dishwashers	(1,579)	-11.9%	-$24	$18
Yuba	Heat pumps, low-flow showerheads	1,394	8.8%	$298	$236
Campbell	Heat pumps, in-unit lighting	2,903	27.2%	$360	$254

In terms of annual customer bill impacts, our estimates show that the retrofits resulted in customer bill savings at all sites except Sunnyvale under non-CARE rates, and at all sites under CARE rates. We did not have the fraction of customers under CARE and non-CARE rates at each site, and we used average bundled rates (not actual customer bills) provided by PG&E. Consequently, the billing impacts are illustrative, but not the actual customer impacts.

One limitation of the study is that the projects had varying levels of energy efficiency measures installed in addition to heat pumps. The Yuba City site had only low-flow showerheads installed with the heat pumps, so almost all energy savings at that site are due to the heat pump retrofit. On the other hand, the Sunnyvale site involved a complete building rehabilitation with many energy efficiency measures installed. The other two sites had moderate retrofit scopes. Thus, it was difficult to isolate the savings attributable only to the heat pump. At the Yuba City site, where almost all savings were due to heat pumps, total natural gas use was cut in half (by 52%) after the retrofit, illustrating the impact of the fuel switch for space heating. That site's domestic hot water (DHW) continued to be fueled by natural gas.

Customer Feedback: The two property managers surveyed reported they are either "satisfied" or "very satisfied" with the heat pumps and perceived their residents' satisfaction as being "very satisfied". At the Auburn site, a senior housing facility, resident surveys indicated that 88% of residents are generally comfortable in terms of temperature, and most seniors reported satisfaction with their bills. The most common problem identified was that the heating or air conditioning was not balanced between rooms. This problem may be unique to the heating system configuration: At this site, the heat pump is located on an exterior wall of the living room, and a transfer fan circulates heated or cooled air between the living room and the bedroom.[3]

GHG emissions and Refrigerant Best Practices: HVAC contractors reported in interviews that California Air Resources Board (CARB) refrigerant management practices require specialized training and recycling of old refrigerant. Contractors suggested other best practices for refrigerant management, including the

[3] The pre-retrofit heating system configuration was one wall furnace in the living room. The transfer fan was added as part of the heat pump retrofit. While this is not ideal for comfort reasons, it is less expensive than adding a head to the bedroom and should provide better heat distribution than the pre-retrofit condition.

use of no-loss fittings, proper drainage techniques, and properly sizing refrigerant lines. Interviewees also reported that unlicensed contractors sometimes simply "cut the refrigerant lines", allowing it to leak directly into the atmosphere. The Avoided Cost Calculator (ACC) indicated GHG emissions from a standard heat pump refrigerant leakage—both during the life of the equipment and at equipment end of life—is higher than from a window A/C unit (the baseline condition) because heat pumps have more refrigerant. While most A/Cs and heat pumps use refrigerants with a Global Warming Potential (GWP) > 2,000, using a lower GWP (e.g., <750) refrigerant significantly reduces GHG emissions. But lower GWP refrigerants are not yet available for residential space heating heat pumps due to flammability concerns.

Program Implications:

This study found that:

- Efficiency and bill savings are achievable when gas wall furnaces and room air conditioners are replaced with heat pumps, particularly with other energy efficiency measures. Where heat pumps represent the first air conditioning system for the units, summer electricity bills may increase. Note these findings are based on projects in Climate Zones 4 and 11, so results for different climate zones may vary.
- Furnace to heat pump retrofits have a smoothing effect on customer bills. Monthly energy costs are more consistent and predictable.
- While energy savings from heat pumps translates into GHG reductions, the refrigerants in these systems cause GHG emissions, as refrigerant slowly leaks from pressurized refrigerant lines over time and at the end of life during removal. Traditional heat pump refrigerants have a high GWP (e.g., GWP for R410A= 2,088). Incentive programs are somewhat limited for how they can reduce refrigerant GHG emissions, particularly until lower GWP refrigerants are available. However, programs can encourage or require contractors to drain existing refrigerant lines using the best practices noted above, properly size and replace refrigerant lines in existing systems, and use no loss fittings. This study still found a net GHG reduction – i.e., that the GHG reductions from energy savings outweighed GHG increases from refrigerant leakage, but refrigerant impacts cut GHG reductions by one-quarter to one-third at each site compared to window A/Cs.

While the study found that heat pumps can provide significant natural gas savings, net energy savings, customer bill savings, and GHG savings,[4] the customer bill savings are low: approximately $15 to $30 per month per dwelling unit. This is likely too low to motivate most multifamily decision makers: multifamily property owners or condo associations. The State agencies and the IOUs will need to make significant market interventions to achieve large-scale space heating heat pump retrofits, such as offering large heat pump incentives, increasing natural gas rates, requiring a switch to heat pumps in code for certain types of alterations, or other mechanisms.

Overall, heat pumps can play a key role in CA's future decarbonization with continued incentives for heat pump retrofits along with other energy efficiency measures to support IOU electrification efforts.

[4] The exception was the Sunnyvale site, but this is because the heat pumps added air conditioning to a site that did not previously have air conditioning.

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1 Introduction

1.1 Motivation for the Study

Heat pumps are quickly becoming an important measure in the California IOUs' energy efficiency portfolios. Deemed savings estimates show heat pumps provide a lower annual energy use (in kBtu) than furnaces. They also represent an electrification opportunity to reduce carbon emissions. However, few measurements have been made of actual energy use changes from heat pumps installed in multifamily buildings. Factors such as actual versus modeled efficiency, occupant behavior, and equipment runtimes can result in significant differences between deemed and actual energy savings.

1.2 Study Scope

Through this case study, we measured the outcomes of fuel-substitution measures in a real-world scenario. In PG&E's MUP (implemented by TRC) heat pumps replaced natural gas wall furnaces and AC units in 253 dwelling units in four (4) multifamily projects from 2018 to 2019. This case study measured the energy, customer bill, and GHG impacts of those retrofits, based on billing data from before (pre) and after (post) the retrofit.

With these data we investigated the following questions:

- What are the energy (natural gas and electric) impacts of heat pump retrofits at these four sites?
- What are the customer bill impacts?
- What are the GHG emissions impacts, based on the Avoided Cost Calculator (ACC)?
- What are the lessons learned from customers, property managers, and contractors that can be applied to future heat pump programs?

1.3 Site Locations

All four study sites are located in suburban neighborhoods in the Northern California section of PG&E's service territory. We preserved the anonymity of the sites by only referencing the location city.

- The Auburn and Yuba City sites are in Climate Zone 11. This is a relatively arid region with hot summers and mild winters dropping sometime to below freezing.
- The Sunnyvale and Campbell sites are in Climate Zone 4. This region is less arid with warm/hot summers and mild winters that may include occasional nighttime frosts.

Figure 1: Site Locations below shows the sites and the number of dwelling units retrofitted at each site.

Figure 1: Site Locations

Map

1.4 Site Details

The following table provides an overview of the four retrofitted sites in the study.

Table 2: Site Details

Project City	Climate Zone	Number of dwelling units retrofitted with heat pump	Construction end date	Square footage	Market rate or affordable	Pre-retrofit A/C	Air Conditioning (AC) type
Auburn	11	48	10/2/2019	29,832	Affordable, and Senior Housing	Yes	Through wall AC
Sunnyvale	4	22	9/25/2019	20,907	Affordable	No	None, except one unit had window AC
Yuba City	11	25	6/30/2019	17,220	Market Rate	Yes	Through wall AC
Campbell	4	158	10/24/2018	117,312	Market Rate	Yes	Through wall AC

1.5 Retrofit Scope

All sites retrofitted gas wall furnaces with space heating heat pumps as part of an energy efficiency retrofit. The heat pumps for all sites were ductless mini splits with wall-mounted indoor heads (fan coils).

The heat pump retrofit was not the only energy efficiency measure adopted as part of PG&E's Multifamily Upgrade Program (MUP). Other measures ranged from nothing more than low-flow shower heads (Yuba City) to a full gut-rehab with ceiling, roof and crawlspace insulation, double-pane windows, efficient appliances, high-efficiency central domestic hot water (DHW), and LED lighting (Sunnyvale).

The table below summarizes the retrofit scope at each site. Three of four sites (Auburn, Sunnyvale, Campbell) have unit-level metering, so we analyzed data at the dwelling unit level for those sites. The fourth site (Yuba City) is centrally metered, so we analyzed data at the site level. All sites have central hot water. Consequently, the energy usage data does not reflect DHW usage or DHW retrofits at Auburn, Sunnyvale, or Campbell, but it does reflect DHW usage at Yuba City.

Table 3: Energy Efficiency Measures

Project City	Unit Level Measures[5]	Notes
Auburn	• Heat pumps • In-unit lighting • Ceiling and crawlspace insulation • Efficient refrigerators	We analyzed unit data. DHW measures are not included in measured energy usage because it was provided centrally.
Sunnyvale	• Heat pumps • Dual pane windows • Ceiling and roof insulation • LED lighting • Efficient refrigerators • Efficient dishwashers	We analyzed unit data. DHW measures are not included in measured energy usage because it was provided centrally.
Yuba City	• Heat pumps • Low-flow showerheads	Gas centrally metered, so we analyzed site-level data which included DHW usage.
Campbell	• Heat pumps • In-unit lighting	We analyzed unit data. DHW measures are not included in measured energy usage because it was provided centrally.

[5] Some sites also had DHW improvements. But for the 3 sites with centrally metered DHW, where we analyzed energy use at the unit level, we do not include this in the unit level measures. This is because DHW (and therefore DHW upgrades) did not impact unit level energy consumption.

2 Methods

The table below shows an overview of data collection methods. The Appendix has more details on methodology.

Table 4: Overview of Methods

Method	Purpose	Overview	Key Limitation
Analysis of AMI data of gas and electric energy consumption using nmecr[6]	Compute energy consumption and perform weather normalization.	Obtained monthly gas and hourly electricity consumption data from these sites, normalized it for weather, and developed regression models for pre- and post-retrofit usage using nmecr.	Because we used whole billing analysis, we could not disaggregate the impacts of the heat pumps from other efficiency measures at these sites. In particular, the results for the Sunnyvale and Auburn sites are significantly impacted by both the heat pumps and other measures. The primary measures at the Yuba City and Campbell sites were the heat pumps, so the analysis primarily reflects heat pumps at those sites.
Application of average billing rates to energy savings	Estimate customer bill impacts from the retrofits.	We used PG&E blended (average) rates, both with and without CARE bill assistance, to estimate bill impacts.	Actual bill impacts could be larger or smaller depending on a customer's rate structure and usage.
Property manager and resident surveys	Collect feedback on heat pump operation and residents' thermal comfort.	Conducted phone surveys with property managers at two of the four sites, and with residents at one of the four sites.	Could not reach property managers and residents at all sites. The one site where we surveyed residents, Auburn, is a senior living facility. The response rate was over 50% so results are a good representation of the seniors' opinions at this site but are not generalizable to other populations or other sites.
Contractor interviews	Estimate heat pump retrofit costs and discuss refrigerant management practices.	Interviewed five HVAC contractors who have experience with gas furnace to heat pump retrofits in single-family homes in California	Could not recruit contractors with experience retrofitting furnaces with heat pumps in multifamily residences, so interviewed single-family contractors instead. The cost estimates represent single-family home retrofits.

[6] normalized metered energy consumption in R. This is an open-source R package that analyzes building energy consumption using a meter-based, whole-building approach for site-specific measurement and verification (M&V) of energy efficiency projects. https://kw-engineering.com/nmecr-nmec-r-package-tool-energy-efficiency-project-savings-measurement-verification-analysis-amv/

Method	Purpose	Overview	Key Limitation
Greenhouse Gas (GHG) Impact Calculations	Estimate the impact of the retrofits on GHG emissions	Used the California Public Utilities Commission’s avoided cost calculators (ACCs) to estimate GHG impacts of heat pump retrofits – both from energy saved, and from refrigerant impacts. Also used the CPUC’s fuel substitution calculator to estimate lifetime GHG emissions saved.	Specifications for the new installed heat pumps were not available, so we used an assumption of average system size of 2 tons per unit and refrigerant charge of 2 lbs. per ton.

3 Findings

3.1 Energy Savings Analysis and Bill Impacts

This section provides savings analysis for each site, followed by estimates of customer bill impacts. We then provide an overview of energy savings and bill impacts for all sites. Note that the gas consumption graphs appear smoother (fewer mini-peaks) than the electricity consumption graphs, because we used monthly data for gas and daily data for electricity. Also, the curve (peaks and valleys) of the electricity use often looks similar pre- and post-retrofit, because the regression model uses the same weather file (for a typical meteorological year – TMY) for both.

3.1.1 Auburn

The Auburn location's modeled pre and post normalized annual consumption is shown below for both gas and electricity. The total difference in energy consumption (both electricity and gas) between pre and post case conditions for the Auburn site was a reduction of 27,566 kBtu, or an average annual savings of 574 kBtu per dwelling unit, **representing 4% of total energy savings[7]**. This is based on pre vs. post retrofit kBtu usage, as shown in Table 6.

Because this site's retrofit scope included heat pumps, in-unit lighting, ceiling and crawlspace insulation, and efficient refrigerators, the heat pumps likely contributed a significant portion of the energy savings, but the combined effects of other measures was also significant.

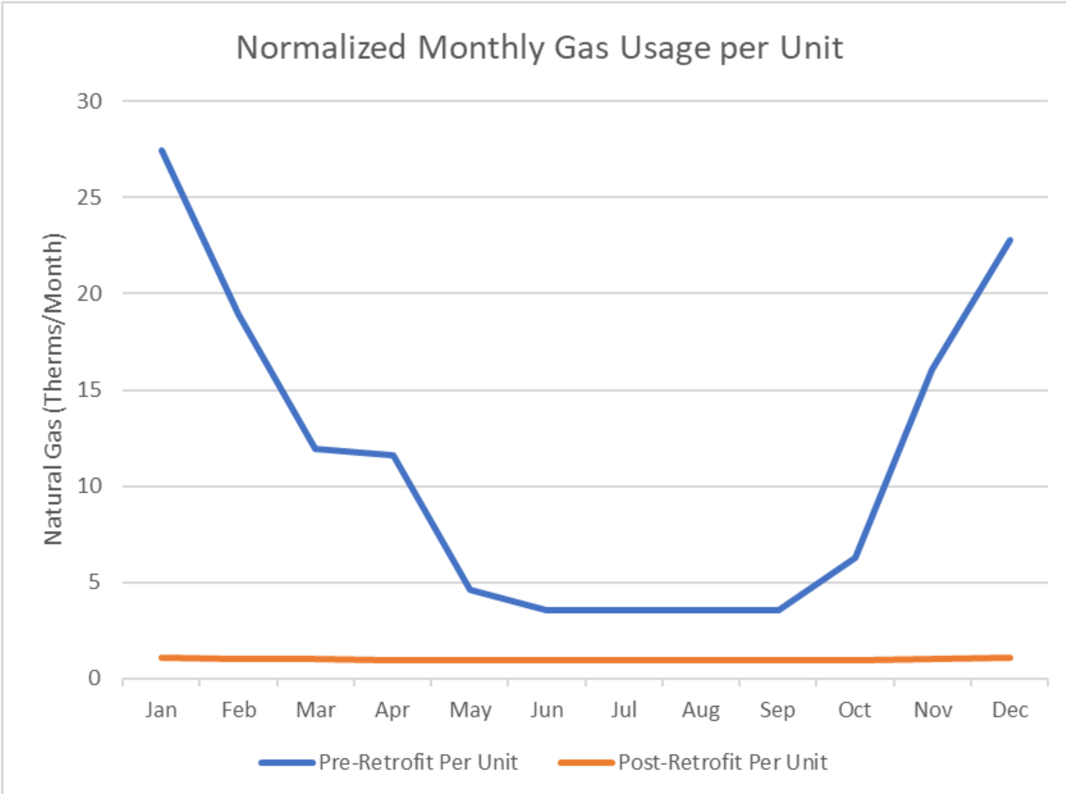
Gas Consumption Data

The plot below compares site level baseline vs post-retrofit modeled gas usage in therms. The baseline model has a r^2 value of 0.98 and a coefficient of the variation of the root mean square error (CVRMSE) of 8.5%, while the post case model has a r^2 value of 0.11 and a CVRMSE of 12.8%. The poor post-case r^2 value is due to the removal of weather-related heating loads. While the baseline data shows significantly higher usage in the colder winter months to represent gas heating, the post-retrofit plot is fairly flat throughout the year. This is consistent with no longer having gas-based heating. It is also worth noting that the summer gas usage dropped, which is not significantly affected by heating. This may reflect additional measures that improved the efficiency of other gas dependent uses,[8] The regression analysis resulted in an approximately 91% reduction in therm usage at the site level, with an average reduction of 122 therms per dwelling unit annually.

[7] Does not include usage from DHW, since that was centrally metered, and our analysis used unit-level consumption data.

[8] It was beyond the project scope to fully investigate gas savings due to upgrades or changes outside of heat pumps. However, the remaining gas loads (the orange line) could be "meter noise" aggregated to a monthly level, or a very small consistent gas load (such as a gas stove or gas dryer).

Figure 2: Auburn Site Gas Data (monthly)

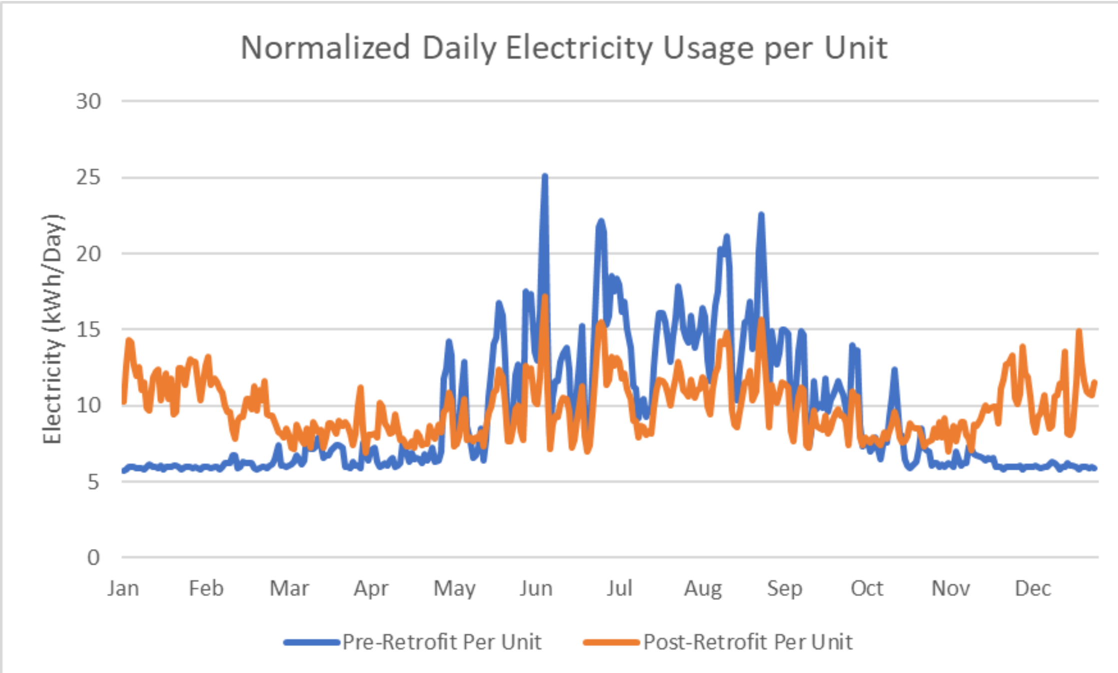


Electricity Consumption Data

The plot below compares site level baseline vs post-retrofit modeled electricity usage in kWh. The baseline model has a r^2 value of 0.87 and a CVRMSE of 21.5%, while the post case model has a r^2 value of 0.69 and a CVRMSE of 20.45%. In the same heating months where gas heating was originally seen in the pre-retrofit of the above plot, the post-retrofit electricity data now shows an *increase* from the pre-retrofit electricity period. This was an expected outcome and is consistent with converting to electric based heating. In the summer, or cooling months, the post-retrofit modeled consumption is less than the pre-retrofit modeled consumption. The post-retrofit electricity savings in the summer can be explained by a few factors: 1) The increased cooling efficiency of the heat pump compared to the original through-wall AC units, and 2) The other energy efficiency measures at this site, including LED lighting, crawlspace and ceiling insulation (which reduces heating and cooling needs), and efficient refrigerators, reduced electricity assumption.

The cooling savings from the summer help to mitigate the electricity penalty created by heating in the winter. The regression analysis resulted in an approximately 6% increase in electricity usage at the site level, with an average increase of 189 kWh per dwelling unit annually.

Figure 3: Auburn Site Electricity Data (daily)



3.1.2 Campbell

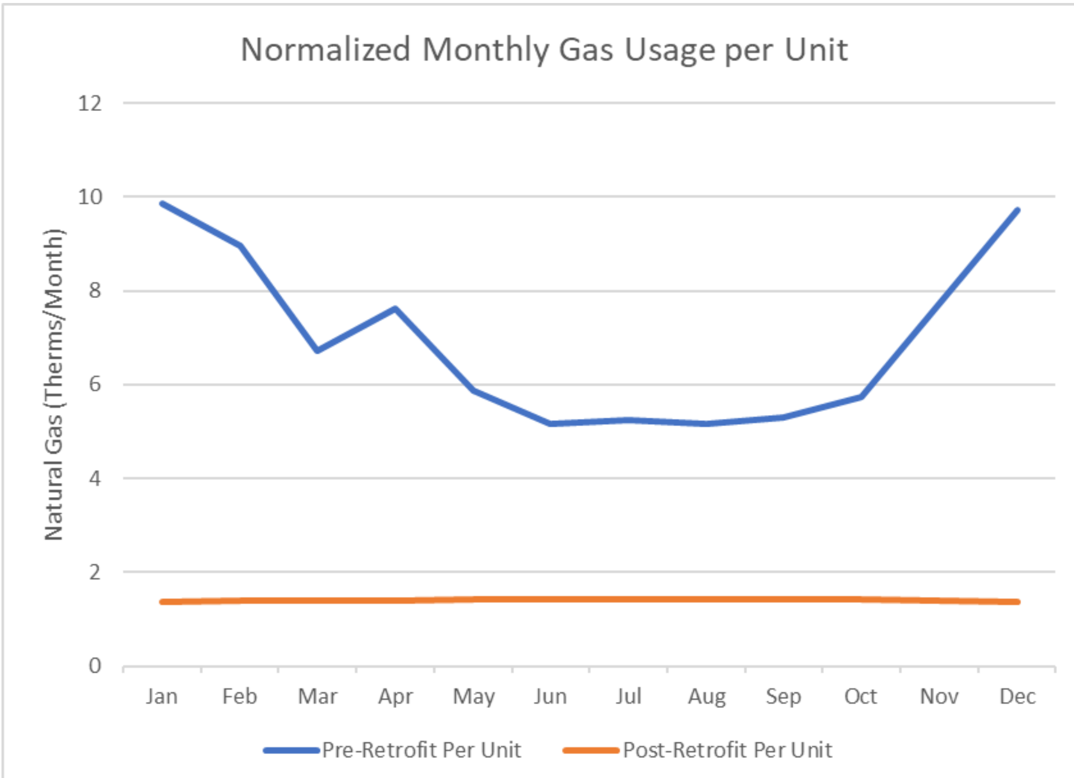
The Campbell location's modeled pre and post normalized annual consumption is shown below for both gas and electricity. The total difference in energy consumption between pre and post-retrofit conditions for the Campbell site was a reduction of 458,677 kBtu, or an average of 2,903 kBtu per dwelling unit, **representing 27% of total energy savings** per dwelling unit.

The high savings at this site are surprising, given the small scope of the retrofit implemented at this site through MUP: replacement of gas furnaces and window A/C units with heat pumps, and installation of high efficacy lighting. In addition, it is surprising that the summer natural gas savings dropped, since this should not be affected by heat pump installation or lighting changes. The high overall energy savings and the summer gas savings suggest that other efficiency upgrades were installed outside of MUP.

Gas Consumption Data

The plot below compares site level baseline vs post-retrofit modeled gas usage in therms. The baseline model has a r^2 value of 0.96 and a CVRMSE of 4.6%, while the post case model has a r^2 value of 0.03 and a CVRMSE of 9.4%. The poor post-case r^2 value is due to the removal of weather-related heating loads. While the baseline data shows significantly higher usage in the colder winter months to represent gas heating, the post-retrofit plot is fairly flat throughout the year. This is consistent with no longer having gas-based heating. It is also worth noting that the summer usage still significantly dropped, which is not affected by heating assuming there is no need to run the heaters in the summer. This would suggest that additional measures were employed to improve the efficiency of, or to fuel switch from gas to electric, for other gas dependent uses. The site likely implemented these measures outside of the program, since MUP program files only show in-unit lighting (in addition to the DHW measures that are not captured in our analysis). In addition, almost all residents had likely changed at this site pre vs. post-retrofit. The pre-retrofit data was from 2016, since there were many data holes (units with missing data) for 2017 and 2018. The post-retrofit data was from 2020 through 2021. The regression analysis resulted in an approximately 80% reduction in therm usage at the site level, with an average reduction of 66 therms per dwelling unit annually.

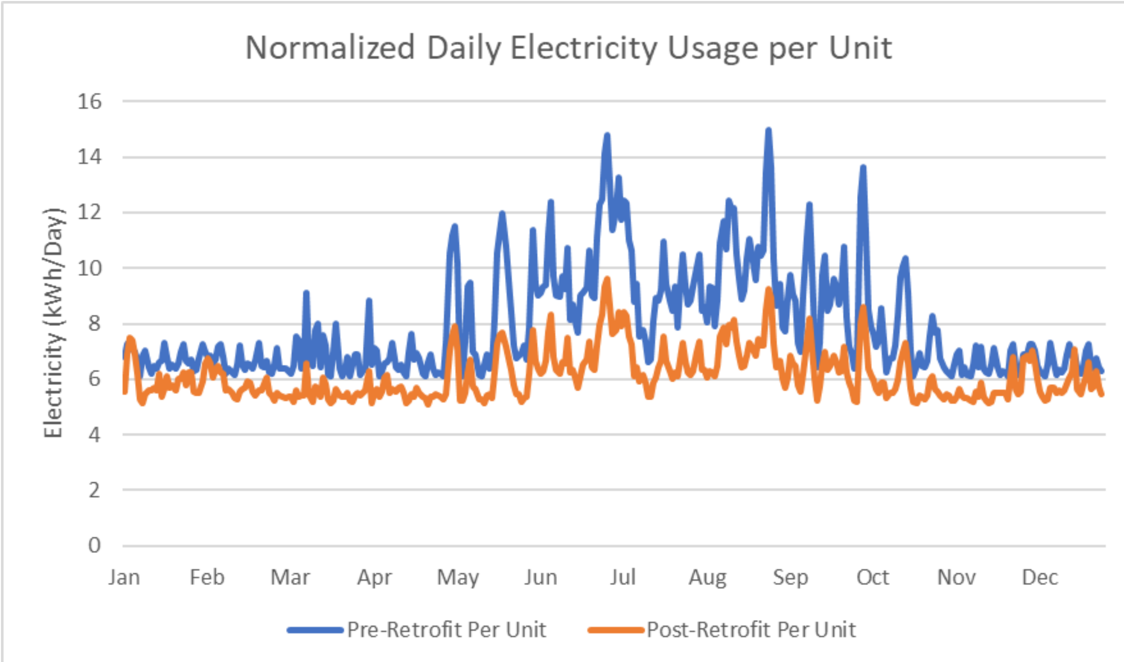
Figure 4: Campbell Site Gas Data (monthly)



Electricity Consumption Data

The plot below compares site level baseline vs post-retrofit modeled electricity usage in kWh. The baseline model has a r^2 value of 0.78 and a CVRMSE of 16.7%, while the post case model has a r^2 value of 0.75 and a CVRMSE of 14.0%. In the summer, or cooling months, the post-retrofit modeled consumption is less than the pre-retrofit modeled consumption. This can be partially explained by the increased cooling efficiency of the heat pump compared to the original through-wall AC units, and the cooling savings from the summer help to mitigate the electricity penalty created by heating in the winter. However, in the winter heating months, the expected increase in post-retrofit electricity associated with converting from gas heat to electric heat was not observed. This lack of electricity increase in the winter is surprising and suggests energy efficiency measures installed outside of the MUP program. In addition, the lighting upgrade should have reduced electricity usage, and changes in occupancy and occupant behavior may have contributed to electricity savings. The regression analysis resulted in an approximately 21% decrease in electricity usage at the site level, with an average decrease of 602 kWh per dwelling unit annually.

Figure 5: Campbell Site Electricity Data (daily)



3.1.3 Yuba City

The Yuba City location's modeled pre and post normalized annual consumption is shown below for both gas and electricity. The total difference in energy consumption between pre and post case conditions for the Yuba City site was a reduction of 34,845 kBtu, or an average of 1,394 kBtu per dwelling unit, **representing 9% of total energy savings**. Like all sites, this site has centrally metered hot water, but this is the only site where we analyzed site-level consumption data, instead of individual dwelling unit consumption data. Consequently, the percent savings results reflect DHW use.

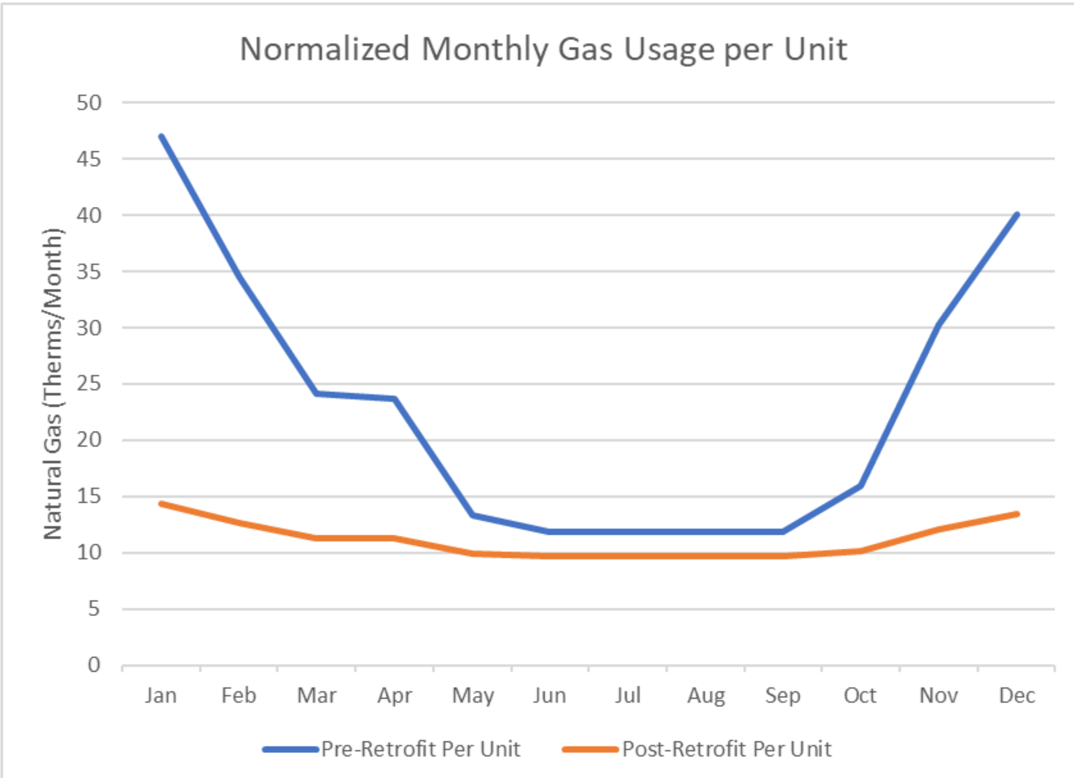
Because this site's retrofit scope included heat pumps and low-flow showerheads, the heat pumps likely contributed almost all of the energy.

We analyzed data at the site level for this project, so our analysis includes both dwelling unit consumption data and consumption for common areas. While this site has limited interior common areas, it does have a small pool. Any energy consumption for pool heating would be included in our analysis and spread out (divided by) the number of dwelling units. Consequently, it is likely that we slightly underestimated the savings of the heat pump retrofit on a percent of savings basis.

Gas Consumption Data

The plot below compares site level baseline vs post-retrofit modeled gas usage in therms. The baseline model has a r^2 value of 0.95 and a CVRMSE of 12.1%, while the post case model has a r^2 value of 0.45 and a CVRMSE of 14.4%. The poor post-case r^2 value is due to the removal of weather-related heating loads. While the baseline data shows significantly higher usage in the colder winter months to represent gas heating, the post-retrofit plot is fairly flat throughout the year. This is consistent with no longer having gas-based heating. The regression analysis resulted in an approximately 52% reduction in therm usage at the site level, with an average reduction of 143 therms per dwelling unit annually. Domestic hot water (DHW) is natural gas heated and provided through a central system to each dwelling unit. Because this is the one site where we analyzed site-level consumption data, the DHW use is likely the largest end-use of the post-retrofit gas usage. In addition, the Yuba City gas meter is a site aggregated meter, which means it also includes non-unit loads such as common areas, leasing office space, and the pool.

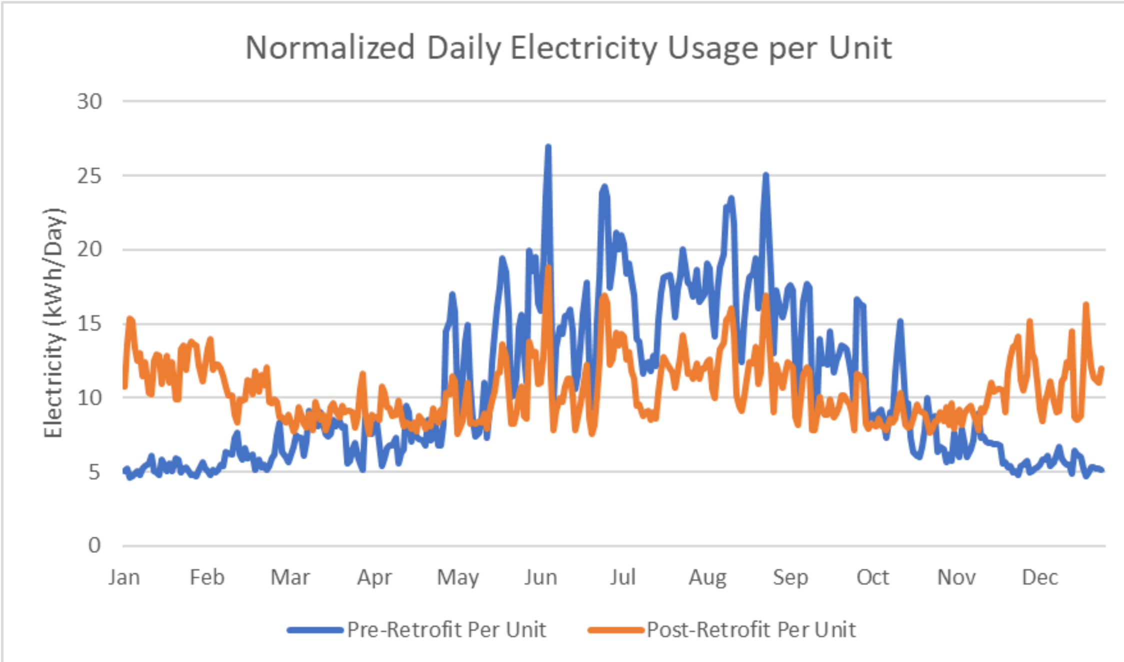
Figure 6: Yuba City Site Gas Data (monthly)



Electricity Consumption Data

The plot below compares site level baseline vs post-retrofit modeled electricity usage in kWh. The baseline model has a r^2 value of 0.79 and a CVRMSE of 31.6%, while the post case model has a r^2 value of 0.67 and a CVRMSE of 25.3%. In the same heating months where gas heating was originally seen in the pre-retrofit of the above plot, the post-retrofit electricity data now shows an *increase* from the pre-retrofit electricity period. This was an expected outcome and is consistent with converting to electric based heating. In the summer, or cooling months, the post-retrofit modeled consumption is less than the pre-retrofit modeled consumption. This can be explained by the increased cooling efficiency of the heat pump compared to the original through-wall AC units, and the cooling savings from the summer help to mitigate the electricity penalty created by heating in the winter. This electricity use increase was approximately 0.3% at the site level, with an average increase of 10 kWh per dwelling unit annually.

Figure 7: Yuba City Site Electricity Data (daily)



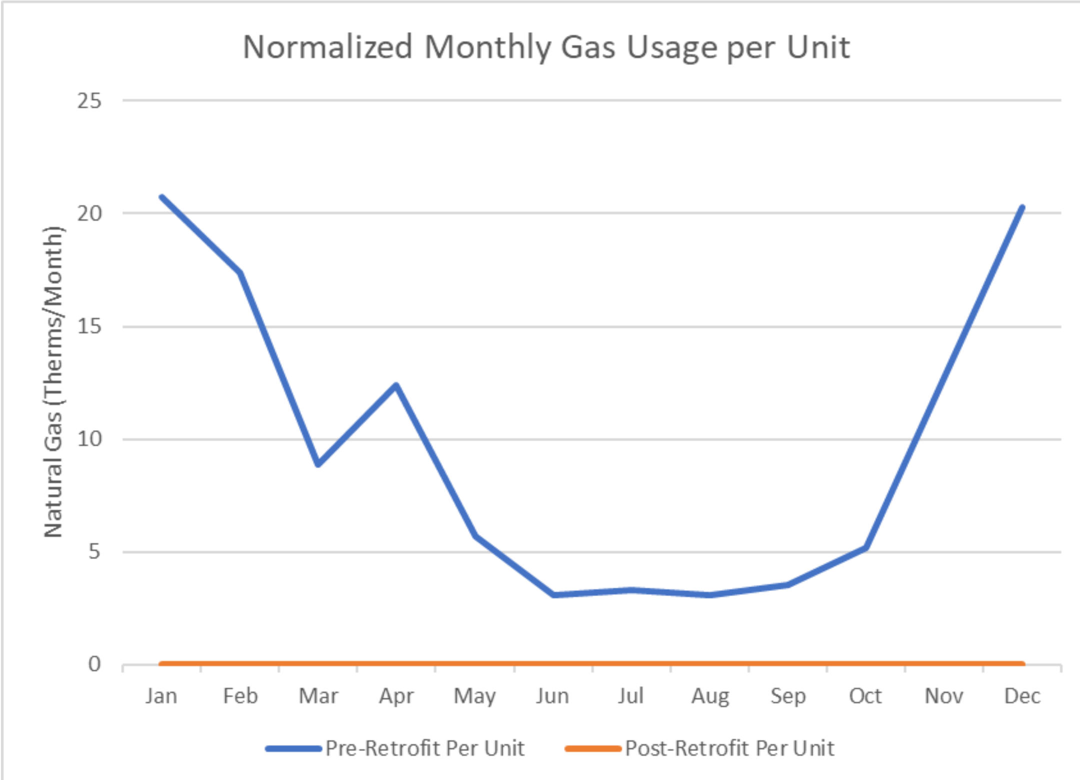
3.1.4 Sunnyvale

The Sunnyvale location's modeled pre and post normalized annual consumption is shown below for both gas and electricity. The total difference in energy consumption between pre and post case conditions for the Sunnyvale site was an increase of 34,727 kBtu, or an average of 1,579 kBtu per dwelling unit, representing **–12% of total energy savings per dwelling unit**. The energy increase (negative savings) was because the baseline units had no form of cooling.

Gas Consumption Data

The plot below compares site level baseline vs post-retrofit modeled gas usage in therms. The baseline model has a r^2 value of 0.95 and a CVRMSE of 14.2%. At the Sunnyvale site, all in-unit gas-fired appliances were removed in a major renovation, and the individual dwelling units now no longer have individual gas meters. The dwelling units still receive hot water from a central gas-fired boiler system, but that gas usage falls outside the scope of the analysis. The gas savings associated with these dwelling units are essentially 100%, or 116 therms per dwelling unit.

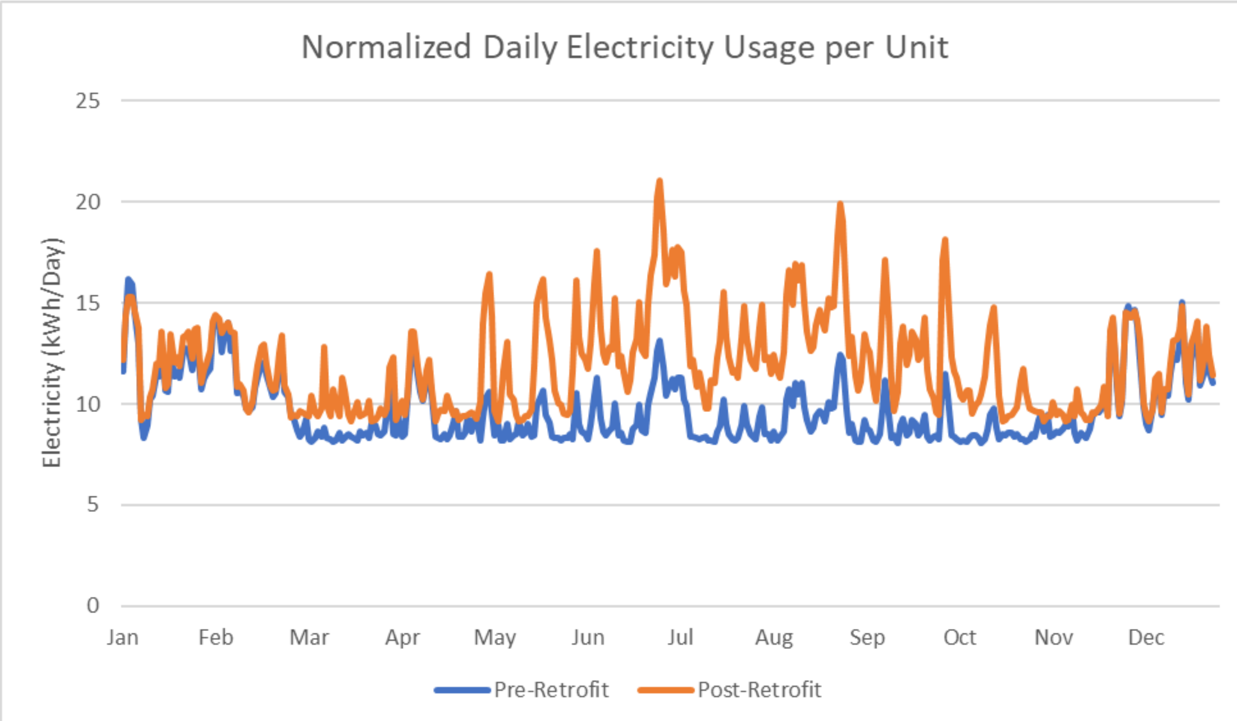
Figure 8: Sunnyvale Site Gas Data (monthly)



Electricity Consumption Data

The plot below compares site level baseline vs post-retrofit modeled electricity usage in kWh. The baseline model has a r^2 value of 0.58 and a CVRMSE of 22.1%, while the post case model has a r^2 value of 0.49 and a CVRMSE of 27.6%. In the summer, or cooling months, the post-retrofit modeled consumption shows an *increase* in electricity consumption. This is consistent with the site adding cooling where there was no cooling previously. (Recall this is the one site without air conditioning pre-retrofit.) Unexpectedly, the winter heating months do not show an increase in electricity consumption that would be consistent with going from gas to electric heat. There are a few possible reasons for this, but the most likely contributors are the addition of the comprehensive suite of other energy efficiency measures implemented at the site, including envelope measures (insulation and dual-pane windows) and efficient appliances. The regression analysis resulted in an approximately 7% increase in electricity usage at the site level, with an average increase of 245 kWh per dwelling unit annually.

Figure 9: Sunnyvale Site Electricity Data (daily)



3.1.5 Billing Impacts

All sites achieved overall net bill savings during 6 months of the year (summer, May through October) at non-CARE rates and three of four sites achieved net bill savings during every month when CARE rates are applied. This result suggests that at current gas and electric rates, a heat pump retrofit may be even more beneficial to CARE customers, who are more highly impacted by energy costs. At non-CARE rates, the Sunnyvale site saw increased annual net costs of $24 due to higher net cost between May and October that averaged $5 per month of net increase, which offset bill savings during the other months. This site is the only site in the analysis that did not have existing cooling, although it also underwent the most significant energy efficiency retrofit. Auburn and Yuba experienced net cost increases during the winter heating season. Fortunately, the increases were small, ranging from just $0.59 to $2.24 per dwelling unit per month during months a net cost increase. Total energy costs at each site varied less month-to-month than before the heat pump retrofit.

Table 5: Annual Energy Savings Cost

			Non-CARE Savings ($/unit/year)			CARE Rates ($/unit/year)		
Project	Retrofit scope	Dwelling Units Analyzed	Electric	Gas	Total	Electric	Gas	Total
Auburn	Heat pumps, ceiling and crawlspace insulation, in-unit lighting, efficient refrigerators	48	($63)	$257	$194	($41)	$203	$162
Sunnyvale [9]	Heat pumps, in-unit lighting, ceiling and wall insulation, windows, efficient refrigerators and dishwashers	22	($270)	$245	($24)	($175)	$194	$18
Yuba	Heat pumps, low-flow showerheads	25	($3)	$301	$298	($2)	$238	$236
Campbell	Heat pumps, in-unit lighting	158	$220	$140	$360	$143	$110	$254

3.1.6 Energy Savings Summary for All Sites

Table 6 shows energy savings for all sites, with

- Natural gas impacts in blue (in the first set of rows)
- Electricity impacts in orange (in the middle set of rows)
- Total energy (kBTU) impacts in green (in the final set of rows)

Not surprisingly, all sites show large gas savings. At Yuba City , total natural gas usage decreased by half (52%); that calculation includes natural gas used for domestic hot water (DHW). Since the site switched from natural gas to electric space heat, but retained natural gas for DHW, it is reasonable that natural gas usage was cut in half. Natural gas use dropped by 80-100% at the other sites; those calculations do not include DHW. Again, that decrease is reasonable, since (outside of DHW) space heating is typically the biggest natural gas end-use, particularly if the units have clothes dryers that are electric or located in common areas.

Total kBTU savings were positive at all sites except Sunnyvale, where air conditioning was added.

[9] The difference in results for Sunnyvale is because the CARE discount has a higher impact on electricity bills than natural gas bills. Consequently, CARE reduced the electricity bill increase, allowing the natural gas bill savings to exceed the electricity bill increase for CARE customers.

Table 6: Gas, Electric, and Total Savings for All Sites[10]

Fuel	Site	# of Units	Summary of Retrofit Measures Affecting Fuel Use	Pre-Retrofit/Unit	Post-Retrofit/Unit	Annual Normalized Savings/Unit	% Savings
				(therms)	(therms)	(therms)	
Natural Gas Impacts	Auburn	48	Heat pumps, ceiling, and crawlspace insulation	134	12	122.0	91%
	Sunnyvale	22	Heat pumps, ceiling and wall insulation, windows	116	-	116	100%
	Yuba	25	Heat pumps, low-flow showerheads	276.3	134	142	52%
	Campbell	158	Heat pumps	83	17	66	80%
				(kWh)	(kWh)	(kWh)	
Electricity Impacts	Auburn	48	Heat pumps, ceiling, and crawlspace insulation, in-unit lighting, efficient refrigerators	3,407	3,596	(189)	(5.6%)
	Sunnyvale	22	Heat pumps, in-unit lighting, ceiling and wall insulation, windows, efficient refrigerators and dishwashers	3,554	4,357	(803)	(23%)
	Yuba	25	Heat pumps	3,819	3,829	(9.7)	(0.3%)
	Campbell	158	Heat pumps, in-unit lighting	2,888	2,232	657	23%
				(kBtu)	(kBtu)	(kBtu)	
Total Energy (kBTU) Impacts	Auburn	48	Heat pumps, ceiling, and crawlspace insulation, in-unit lighting, efficient refrigerators	12,963	12,388	574	4.4%
	Sunnyvale	22	Heat pumps, in-unit lighting, ceiling and wall insulation, windows, efficient refrigerators and dishwashers	13,288	14,866	(1,579)	(11.9%)
	Yuba	25	Heat pumps	15,793	14,399	1,394	8.8%
	Campbell	158	Heat pumps, in-unit lighting	10,686	7,783	2,903	27.2%

More detail on the energy savings calculations is included in the Appendix.

[10] We conducted energy analysis using dwelling unit billing data. These sites had central DHW, so DHW is not included in the energy usage or savings data. Some sites had DHW retrofits, but we do not describe these since they are not reflected in the data.

3.2 Customer Feedback

3.2.1 Property Manager Survey Results

We conducted property manager surveys at the Yuba City and Auburn sites. Property managers at the other two sites in the study did not respond to multiple requests for a survey. The Yuba City site has multi-zone heat pumps with one indoor unit in the living room and indoor units in each bedroom. The Auburn site has single-zone heat pumps with the indoor unit in the main living space and a transfer fan to move conditioned air to bedrooms.

Satisfaction

At both sites, property managers indicated they are either “satisfied” or “very satisfied” with the heat pumps installed at their property. Both property managers perceived their residents’ satisfaction as being “very satisfied”.

Comfort

Both property managers indicated they had managed the property prior to the heat pump retrofit. However, the manager at Auburn came onboard just prior to the retrofit and did not have a sense of the nature of comfort complaints prior to the retrofit. At Yuba City, residents frequently complained that the apartments were either too hot or too cold prior to the retrofit. Both managers noted that they rarely receive complaints about the heat pumps but noted that the few complaints typically relate to operating the heat pumps’ remote control. At the Auburn site, some residents have complained about not getting enough heating or cooling in rooms that rely on the transfer fan to move conditioned air to other parts of the apartment. The pre-retrofit heating system configuration was one wall furnace in the living room and no means of moving heat to the bedroom. The transfer fan was added as part of the heat pump retrofit. While it is not ideal for comfort reasons to install one indoor heat pump unit and a transfer fan to move heat to another room, it is less expensive than adding a head to the bedroom and should provide better heat distribution than the pre-retrofit condition. As shown in Section 3.2.2, in the customer survey, 88% of residents reported their home was comfortable in terms of temperature.

Property managers were not aware of residents using any type of supplemental heating (e.g., space heaters) or cooling (e.g., window or portable air conditioning units).

Resident Training

According to the property managers, residents at both properties received training on how to operate the heat pumps and clean the filters.

Maintenance

When asked about whether they had experienced maintenance issues with the heat pumps, both property managers pointed to instances of units failing to provide heating or cooling shortly after installation (Auburn 10-15 units out of 48 total units, Yuba City 1 dwelling unit out of 25). These problems turned out to be a result of refrigerant leaks. Leakage problems were fixed by the onsite maintenance person. While we do not have additional information from property managers on this issue, a discussion of residential heat pump installation and service issues (from our interviews with

HVAC contractors) is included in Refrigerant Management Section 3.3.2 below. The Auburn site also experienced problems with condensate drains backing up on 8 dwelling units.

Resident Education

At both properties, property managers indicated that residents sometimes have questions about the use of their heat pump's remote controls, and they sometimes have questions about switching the system over from heating to cooling mode (multi-zone units at Yuba City). This feedback highlights the need for resident education at the time of installation and more thorough training of site maintenance staff to support new resident inquiries.

Property Manager Surveys Conducted through MUP Program

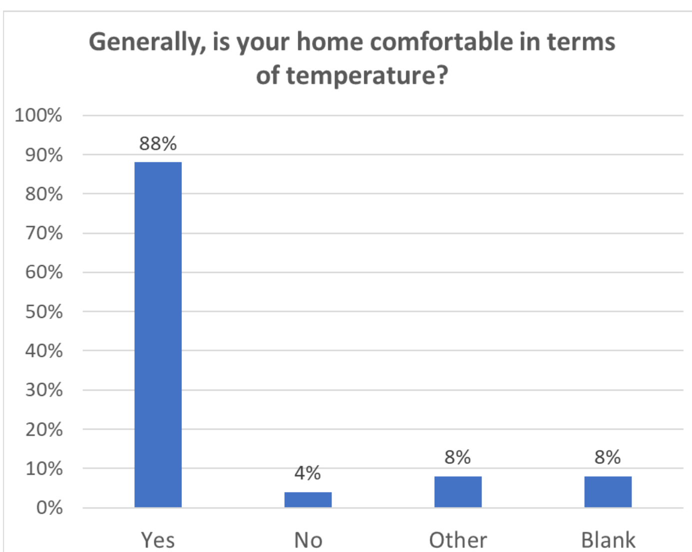
In addition to the surveys conducted through this study, the MUP program implementation team conducted surveys with property managers at the Sunnyvale and Yuba City sites three months after the retrofit. Results from post-retrofit surveys conducted as part of MUP (in 2018-2019) showed similar findings as survey responses collected for this case study (collected at the end of 2021). Property managers reported the frequency of heating and cooling complaints did not change after the retrofit. However, residents did ask questions about operating the heat pump during the transition between heating and cooling seasons.

3.2.2 Resident Survey Results

General Feedback on Heat Pump and Thermal Comfort

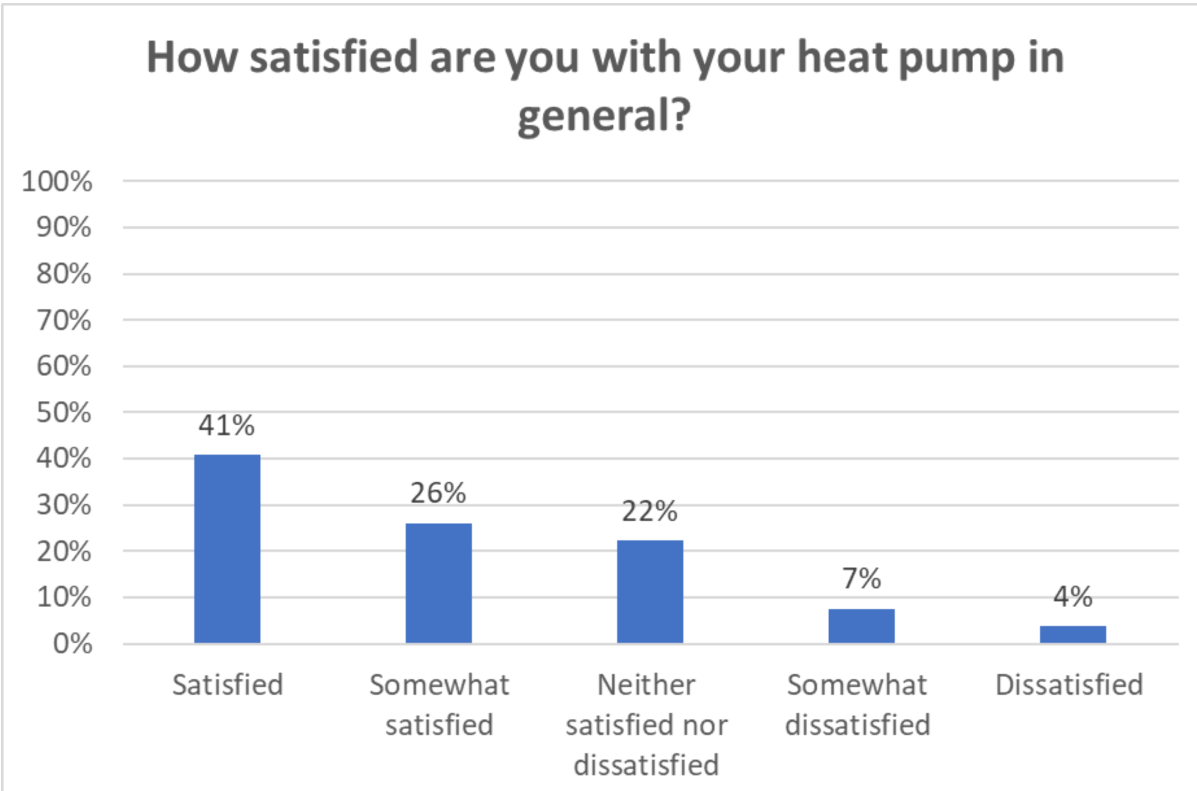
This section describes results from the resident survey at the Auburn site, which has ductless mini-splits controlled with remote-control type wands. Over 80% of the respondents indicated they have lived in their home more than 12 months and almost 90% reported their home was generally comfortable in terms of temperature. As a reminder, the Auburn site is a senior housing facility, so all respondents are senior citizens.

Figure 10: General Comfort and Satisfaction Results at Auburn (Senior Housing) Site



When we asked about general satisfaction with the heat pump, 67% said somewhat or very satisfied. Only one respondent indicated they did not know how to use it. Less than 15% did not know whom to call if they had questions or did not answer the question.

Figure 11: Satisfaction with Heat Pumps at Auburn (Senior Housing) Site

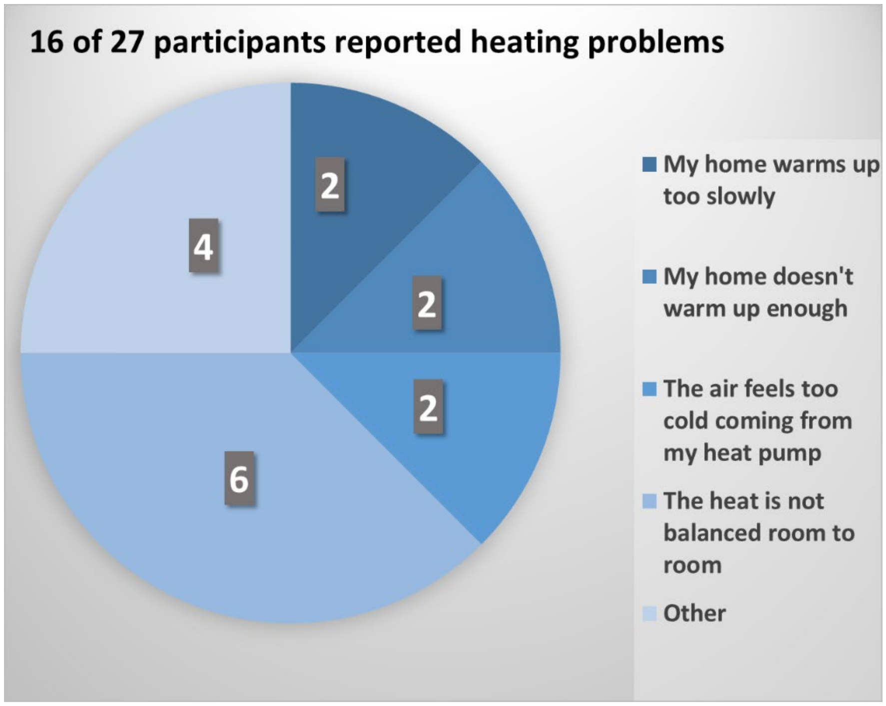


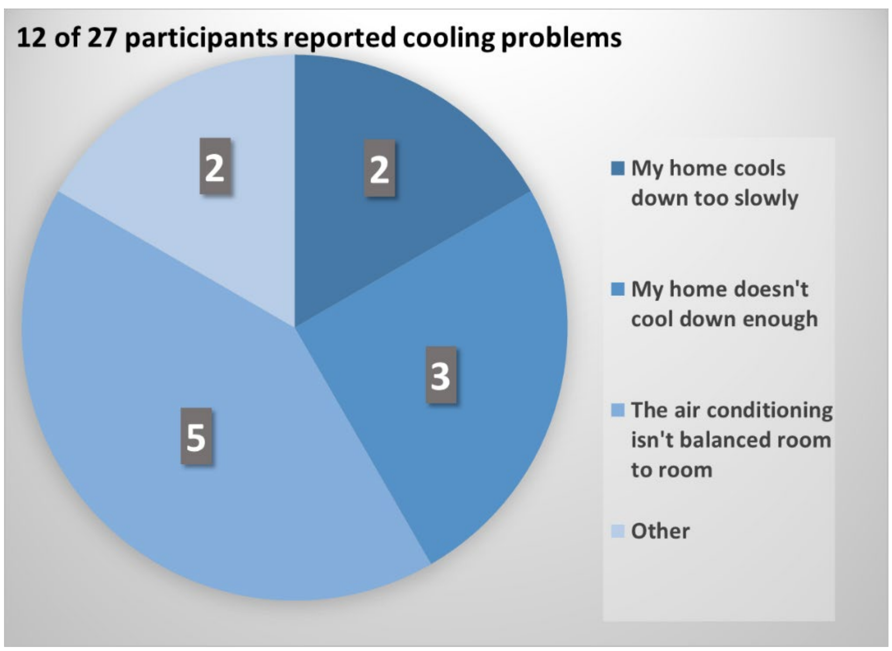
Two-thirds of respondents were satisfied with the heat pump for heating and cooling. There was no difference between satisfaction with the heat pump for heating and cooling. The same 66% of respondents were satisfied with the heat pump for both heating and cooling.

We also asked whether respondents had had any problems using the heat pump for heating or cooling. More respondents reported problems with heating (60%) than cooling (44%). The most common problem identified was that the heating or air conditioning was not balanced between rooms. At this site, the heat pump is located on an exterior wall of the living room. A transfer fan circulated heated or cooled air between the living room and the bedroom. Several participants reported dissatisfaction with the difference in temperatures between the two rooms. At least one uses an electric heater for supplemental heating and an electric fan for supplemental cooling when needed.

Note that the results likely have some response bias, since the survey asked, "Which of the following problems, if any, do you have" and provided a list of options.[11]

Figure 12: Reported Heating and Cooling Problems





[11] Because we administered a paper survey, instead of an online survey, we had space constraints and could not implement branching patterns. For example, in an online survey, we would have asked whether they have any problems and, only to those that selected yes, provided a list of potential problems.

Energy Bills

Two thirds (62%) of participants were “satisfied” or “somewhat satisfied“ with their energy bills during the heating season and another one-third (31%) were “neither satisfied nor dissatisfied“. Only 8% were dissatisfied. During the cooling season, satisfaction with energy bills decreased but only to the “neither satisfied nor dissatisfied” option. Few (8% again) were dissatisfied.

Summary

In general, the senior residents surveyed were satisfied with their heat pump their energy bills in both heating and cooling seasons. There were some problems reported with heating and cooling performance, particularly with balancing the heat or air conditioning between rooms.

Resident Surveys Conducted through MUP Program

In addition to the surveys conducted through this study at the Auburn site, the MUP program implementation team conducted surveys with residents at the Sunnyvale and Yuba City sites three months after the retrofit. Results from post-retrofit surveys conducted as part of MUP (in 2018-2019) showed similar findings as survey responses collected for this case study (collected at the end of 2021). Residents reported increased comfort and increased satisfaction with the heat pump operation although they did not receive training, only an instruction manual.

3.3 Contractor Interview Results

All of the contractors interviewed served the single-family home market, not multifamily. These contractors represented a range of customers in terms of income. One contractor serves the low-income market through the PG&E San Joaquin Valley Pilot Program while another contractor reported his affluent clientele relocate to a second home while work is being completed.

Likely because they serve single-family homes, most contractors reported switching out central furnaces (not wall furnaces) with heat pumps. Our contractor interview results are useful for establishing costs of central furnace removal, heat pump installation, and electrical work plus panel upgrades in general. But they are not directly applicable to wall furnace retrofits, particularly when delivered at scale in multifamily structures. One area of the interview that applies widely to the residential HVAC retrofit market is refrigerant management.

3.3.1 Job Costs

Table 7 shows the range of contractor job costs. As shown, most contractors estimated the cost of retrofitting from a central gas furnace to a central heat pump is approximately $10K to $15K. Note these reflect costs for central systems, which are typical for single-family homes. This is because we were not able to recruit a contractor that frequently retrofits wall furnaces with mini-split heat pumps, such as those in the multifamily units found in the four case study sites.

Contractors noted that electrical upgrades can vary depending on the site and can significantly increase costs. One contractor reported, “Usually if it’s a mild climate, you can get away with the existing panel. Upgrading is another world of hurt.” As shown, panel upgrade can double costs.

Table 7: Range of Contractor Costs

Contractor	Cost Range	Included in Cost Range	Not Included in Cost Range
A	$10K - $12K	Heat pump only	Electrical wiring not included. $1.5k - $2k if needed. If electrical panel upgrade needed, $10K-$12K extra
B	$12K - $15K	Heat pump only	
C	$10K - $12K	Heat pump only	Electrical wiring not included, $6k-$8k if needed
D	$10k - $15K	Heat pump only	Electrical wiring not included
E	$18K - $30K	Heat pump, heat pump dryer, all electrical wiring, new panel if needed, and electric car charger	

3.3.2 Refrigerant Management

Refrigerant Loss Prevention, Capture, and Recycling

California state law requires technical certification for professionals working on building systems containing refrigerants. While requirements for non-residential building systems vary depending on system size, an EPA Section 608 Technician Certification is the standard requirement for working on residential systems. This legal requirement flows down through the California Air Resources Board via its Refrigerant Management Program (RMP).

About half of the HVAC contractors interviewed handle refrigerant management in-house with certified refrigerant technicians on staff. The remainder subcontract the work to outside technicians. The interviewed contractors reported that best practices include:

- Use of 'no-loss' fittings to reduce the remaining gas in hoses when decommissioning old equipment.
- Replacement of existing refrigerant lines (required 85% of the time) if
  - Lines are over 10 years old.
  - Lines are incorrectly sized.
- Testing lines with nitrogen to uncover leaks before pressurizing with refrigerant.
- Using bubble-spray to detect leaks directly while nitrogen pressurized.
- After nitrogen leak testing, pulling a vacuum into the lines and holding a steady vacuum for at least 15 minutes.
- Capturing old refrigerant by pumping into a Department of Transportation-compliant refrigerant recovery cylinder and delivering to an approved recycling center.

The HVAC contractors we spoke with conveyed a strong distinction between licensed and unlicensed contractors when it comes to refrigerant management. Licensed HVAC technicians are required to have EPA certification and follow best practices. However, the interviewed contractors (all of whom were licensed) reported that unlicensed contractors will sometimes cut lines and allow refrigerant to escape. (One reported he occasionally finds that the old refrigerant lines have already been cut when he first arrives on a site.) Residential A/C systems require 2 to 4 pounds of refrigerant per ton of capacity. With a typical size of 4 to 5 tons, that represents a range of 8 – 20 pounds of refrigerant or ~17,000 to 42,000 pounds of CO_2 equivalent per system. Under-charging or over-charging a system is also a common problem. Some HVAC equipment suppliers have prevented equipment sales to un-licensed contractors.

Two contractors reported they use a digital multi-gas gauge in the process of commissioning the system. These gauges have long hoses. Even when used perfectly, the gas in the hoses escapes when the gauge is disconnected from equipment. If disconnection is done very carefully, the amount of refrigerant could be as low as three to five ounces. However, if the hose is pressurized when disconnected, up to one-half pound of refrigerant could easily be released. This is still considered a legal 'de minumus' amount because it is not released intentionally.

3.3.3 Electrical Upgrades

The contractors interviewed reported the following information regarding electrical upgrades. Generally, if there is an existing A/C window unit, a 20-amp service becomes available when that window unit is removed. Then, the A/C condenser electrical load can be simply replaced by the heat pump condenser load. If cooling is provided by central A/C equipment or there is no existing breaker in the panel for a window A/C unit, the solution is to add a 15-amp breaker to the panel and run a new circuit for the fan/coil. That upgrade costs between $1,500 to $2,000 for an electrician just to add the breaker and wiring. If the existing electrical panel is full or does not have enough amperage capacity, then the entire panel needs to be upgraded. That upgrade costs $10,000 to $12,000 and can be a source of significant additional delay because PG&E must be involved.

For an entire electrification package, one contractor pointed out that one of the biggest cost drivers is the kitchen range. In this contractor's experience, replacing the gas range with electric is the most commonly encountered trigger of an entire panel upgrade while mini-split heat pumps usually are not. The panel upgrade problem is compounded in certain communities by limited capacity in the existing electrical service in front of the meter.

3.3.4 Just a Heat Pump? Or a Multiple Systems Package?

Contractor B has the highest job cost range and almost never does a heat pump retrofit in isolation. Typically, for this contractor, a job includes multiple systems such as a heat pump, heat pump clothes dryer, all electrical wiring, a new panel if needed, and an electric car charger, all carpentry, and all electrical work. Another contractor also reported they typically install "an entire electrification package" which includes an electric vehicle car charger, a mini-split heat pump, and a heat pump dryer. Some contractors reported partnering with a solar voltaic vendor. After a solar system has been designed, the vendor often recommends a heat pump furnace A/C and DHW heat pump. In other cases, heat pump conversions occur because a customer already has a solar voltaic array and wants a heat pump.

3.4 GHG Impacts

3.4.1 GHG Impact of Energy Savings

The following table provides an estimate of the GHG reductions represented by the energy savings at each of the retrofitted sites, using the CPUC's Avoided Cost Calculators (ACCs). Note these do not include refrigerant GHG impacts, which are presented in the next subsection. All sites achieved some level of GHG emissions. This is not surprising for the three sites, with net energy savings (Auburn, Yuba, and Campbell). But it is interesting that Sunnyvale shows GHG savings, even though there was a slight energy increase at that site. The GHG emissions reductions were the lowest at Sunnyvale (3%), likely because air conditioning was added where it did not exist previously, and the highest at Campbell (33%), which had the highest total energy savings. Averaging results across the sites, the reduced GHG emissions by 0.6 tons of CO2e/year per dwelling unit (18%). The table below shows results for annual impacts and (at the unit level) the lifecycle impacts assuming a 15 year equipment life, and assumes the same CO2e impacts per year.

Table 8: GHG Impacts Based on Avoided Cost Calculator (ACC)

		Natural Gas Impacts		Electricity Impacts			Per Unit Impacts		
Site	Units	Annual Normalized Savings (Therms)	CO2e Reduction (tons/yr)	Annual Normalized Savings (kWh)	CO2e Reduction (tons/yr)	Total CO2e Reduction (tons/yr)	CO2e Reduction (Tons/yr/ unit)	Lifecycle CO2e Reduction (Tons/unit)	% CO2e Reduction
Auburn	48	5,855	34.2	(9,080)	(6.6)	27.6	0.6	9	18%
Sunnyvale	22	2,557	15.0	(17,671)	(12.9)	2.0	0.1	1	3%
Yuba	25	3,567	20.9	(243)	(0.2)	20.7	0.8	12	19%
Campbell	158	10,474	61.3	103,734	75.9	137.1	0.9	13	33%

Based on the annual energy savings that we calculated at each site, we used the CPUC's Fuel Substitution Calculator (FSC) to calculate the lifetime GHG impacts at each site. The results are presented below. As shown, all sites show positive GHG savings.

Table 9: Lifetime GHG Emissions Savings Using Fuel Substitution Calculator

Site	Units	Lifecycle emissions savings – Site level (Tons CO2e)	Lifecycle emissions savings – Per Unit (Tons CO2e)
Auburn	48	496	10
Sunnyvale	22	176	8
Yuba	25	317	13
Campbell	158	1,236	8

FSC estimates savings and GHG impacts over the lifetime of the measure, whereas the ACC analysis estimates the annual GHG impacts. Please refer to Section 5.1.4 for the key differences between FSC and ACC analysis.

Comparing the lifecycle results from the Avoided Cost Calculator (ACC) and the Fuel Substitution Calculator (FSC), results are very similar for two of the sites (Auburn and Yuba), but different for the other two (Sunnyvale and Campbell). While it was beyond the scope to thoroughly investigate the differences between the calculators, the FSC assumes a lower-carbon electricity grid over time so assumes lower emissions per kWh for 2022 vs. later years, whereas our calculations using the ACC assumed the same emission rate per year. The FSC may also assume a higher efficiency power plant than the ACC. For lifecycle calculations, TRC views the FSC as more accurate because it uses different emission factors based on the year, so used the FSC results in Section 3.4.3 Total GHG Impacts.

3.4.2 Refrigerant GHG Impacts

The following table shows the refrigerant GHG impacts under different scenarios using the CPUC's Refrigerant ACC. Note these values indicate a net GHG *increase* from the refrigerants. The Refrigerant ACC estimates the GHG emissions (in equivalent tons of CO2 – or CO2e) from the refrigerant in the air conditioning system—either the window or through wall A/C unit for the base case or in the heat pump for the proposed case. The Refrigerant ACC assumes there is some leakage of refrigerant over the life of the equipment, and it assumes (as a default assumption) that 80% of the remaining refrigerant is leaked at the end of equipment life (i.e., is not captured when the equipment is removed). We show four different heat pump retrofit scenarios, all compared with the base case of the existing condition—window air conditioning units with R-22.

Retrofit scenarios 1 and 2 represent the standard retrofit and a retrofit with a high refrigerant reclamation rate, and both have higher GHG emissions (4.0 and 3.5 CO2e) than the baseline case (1.4 CO2e). Scenario 2 reduces GHG emissions slightly compared to Scenario 1, since it assumes that 80% of the refrigerant in the heat pump is reclaimed at the end of equipment life instead of 20% reclamation (Scenario 1). Scenarios 1 and 2 assume R-410A, which is industry standard practice and has a high GWP of 2,088. If the heat pump uses a refrigerant with a medium GWP such as R-454B (GWP = 466, shown in scenario 3), the heat pump has much lower GHG emissions (0.9 CO2e) – even lower than the baseline. The heat pump has even lower GHG emissions if it both uses a medium GWP and has a high reclamation rate for the refrigerant at the end of equipment life (scenario 4: 0.8 CO2e).

Table 10: Refrigerant GHG Impacts from Retrofits under Various Scenarios

Device type	Average lifetime (years)	Average charge size (amount of refrigerant) in lbs. per unit	Refrigerant	Refrigerant GWP	Annual leakage per unit (tons CO2e)	End-of-life leakage per unit (tons CO2e)	Total lifetime leakage per unit (tons CO2e)	GHG Impact per unit (% Reduction)
Baseline – Existing condition Window/Room/Wall AC and Packaged Terminal AC (PTAC) Units with R-22	12	1.54	R-22	1810	0.03	1.04	1.4	N/A
1. Standard Retrofit Heat Pumps - 20% Refrigerant reclaimed	15	4.0	R-410A	2088	0.22	0.68	4.0	-191%
2. Retrofit with High Refrigerant Reclamation Rate Heat Pumps - 80 % Refrigerant reclaimed	15	4.0	R-410A	2088	0.22	0.17	3.5	-153%
3. Retrofit with Medium GWP Refrigerant Heat Pumps (Med GWP) - 20% Refrigerant reclaimed	15	4.0	R-454B	466	0.05	0.15	0.9	35%
4. Retrofit with Medium GWP Refrigerant and High Refrigerant Reclamation Rate Heat Pumps (Med GWP) - Refrigerant reclaimed	15	4.0	R-454B	466	0.05	0.04	0.8	43%

These results highlight the importance of the refrigerant GWP, and they show that recycling or capturing refrigerant at the end of equipment life can also reduce GHG impacts.

Unfortunately, medium GWP refrigerants such as R454B are not currently available in the U.S. market because it is considered mildly flammable. According to DNV (2021),[12] HVAC contractors are not permitted to install mildly flammable refrigerants in most common HVAC equipment today, including R-32, R-454B, and R-452B. According to DNV 2021, "State fire marshal delays indicate building and fire codes most likely will not be updated to allow these mildly flammable refrigerants for use in most California HVAC equipment until January 1, 2024. Web survey responses indicate the HVAC supply chain will likely take around two years from when building and fire code requirements are finalized to have a representative selection of <750 GWP HVAC refrigerant equipment offerings." However, California Air Resources Board (CARB) promulgated regulations requiring new room or window air conditioners to use refrigerants with <750 GWP beginning in 2023, and all new residential air conditioners to use refrigerants with <750 GWP beginning in 2025[13]. Programs should consider incentivizing heat pumps with medium GWP refrigerants (<750 GWP) when they become available, while also ensuring that installations meet a high rigor for safety.

3.4.3 Total GHG Impacts

The following table combines results of the GHG reductions from energy savings, based on the fuel substitution calculator (FSC) and the refrigerant impacts (which have negative GHG reductions) based on the Avoided Cost Calculator (ACC) for a net lifetime GHG reductions impact. The GHG reductions from refrigerants assumes the standard retrofit case (Scenario 1) compared to a window A/C (baseline) in Section 3.4.2: 1.4 - 4.0 = -2.6 tons CO2e. The table presents results on a per-unit basis for each site. All sites show net GHG reductions. However, the GHG emissions reductions from energy savings are significantly eroded by GHG refrigerant impacts. This highlights the importance of exploring best practices for refrigerants, such as using low-GWP refrigerants, reclaiming refrigerant at end of equipment life, and designing compact refrigerant line sets to reduce refrigerant charge (and therefore refrigerant leakage).

Table 11: Total Lifecycle GHG Impacts Per Unit

Site	Lifetime GHG Reductions from Energy Savings, based on FSC (tons CO2e)	Lifetime GHG Reductions from Refrigerants, based on ACC Refrigerant Calculator (tons CO2e)	Net lifetime GHG Reductions (CO2e)
Auburn	10.3	-2.6	7.7
Sunnyvale	8.0	-2.6	5.4
Yuba	12.7	-2.6	10.1
Campbell	7.8	-2.6	5.2

[12] DNV 2021, "A Roadmap for Accelerating the Adoption of Low-Global Warming Potential HVAC Refrigerants". https://pda.energydataweb.com/api/downloads/2506/CPUC%20HVAC%20Refrigerants%20-%20PDS_05032021_FinalReport.pdf

[13] https://ww2.arb.ca.gov/our-work/programs/california-significant-new-alternatives-policy-snap/air-conditioning-equipment

3.5 Potential COVID impacts on the study

The effect of the Covid pandemic on the study is unknown, but it likely led to a slight underestimation of energy savings and consequently, bill savings and GHG reductions.

Qualitatively, if residents spent a greater proportion of their day at home than pre-pandemic due to workplace or school closures, actual savings from the heat pump retrofits may be under-estimated by this study.

4 Conclusions and Lessons Learned

4.1 Conclusions

Heat pumps are quickly becoming an important measure in the California IOUs' energy efficiency portfolios. Deemed savings estimates show heat pumps provide a lower annual energy use (in kBtu) than natural gas furnaces. Heat pumps also represent an electrification and decarbonization opportunity. However, few measurements have been made of actual energy use changes, customer bill impacts, and occupant satisfaction where heat pump retrofits replaced gas wall furnaces in multifamily buildings.

This report presents billing analysis from a heat pump retrofit of 253 dwelling units at four multifamily sites in California. We used property manager and resident surveys to evaluate equipment performance and occupant satisfaction, and HVAC contractor interviews to estimate heat pump retrofit costs and refrigerant handling practices. In addition, we investigated the GHG impacts of different refrigerant outcomes.

Energy and Bill Impacts: The following table summarizes the total energy use change at the four sites based on a comparison of pre- and post-retrofit consumption data. These represent site-level savings – i.e., savings seen at the site, not source-level savings that also account for savings at the generation source (e.g., power plant). We combined the changes to natural gas (therm) and electricity (kWh) data, for total energy savings at each site (kBtu) and then divided by the number of dwelling units to estimate per-unit savings. As shown, total energy use decreased—i.e., generated positive savings, for three of the four sites. Savings were similar for Auburn and Yuba City. Savings were the highest at Campbell; this was surprising, since this site had a relatively modest retrofit scope within the program.

Total energy use increased at Sunnyvale, resulting in negative savings. However, this was the only site that did not have air conditioning pre-retrofit—i.e., where air conditioning was added.

Table 12: Summary of Total Savings and Bill Savings

Site	Retrofit Measures Affecting Fuel Use	Normalized Savings (kBtu)/Unit/yr)	% Savings (% kBtu/ unit/ yr)	Bill savings ($/unit/yr), Non-CARE Rates	Bill savings ($/unit/yr), CARE Rates
Auburn	Heat pumps, ceiling and crawlspace insulation, in-unit lighting, efficient refrigerators	574	4.4%	$194	$162
Sunnyvale	Heat pumps, in-unit lighting, ceiling and wall insulation, windows, efficient refrigerators and dishwashers	-1,579	-11.9%	-$24	$18
Yuba	Heat pumps	1,394	8.8%	$298	$236
Campbell	Heat pumps, in-unit lighting	2,903	27.2%	$360	$254

In terms of annual customer bill impacts, our estimates show that the retrofits saved customers with their bills in all sites except Sunnyvale under non-CARE rates, and at all sites under CARE rates. The difference in results for Sunnyvale between CARE and non-CARE customers is the CARE discount has a higher impact on electricity bills than natural gas bills. Based on PG&E's average bundled rates, CARE reduces electricity bills by approximately 35% and natural gas bills by 21%. This should be helpful to ensures that electrification programs result in bill savings for low-income customers, since electrification should reduce natural gas usage but increase electricity usage. For example, at Sunnyvale, the CARE discount "chipped away" at the electricity bill increase, allowing the natural gas bill savings to exceed the electricity bill increase for CARE customers. Since these are annual bill savings, and given the assumptions made in the estimates, the Sunnyvale bill savings of -$24 and $18 per year are almost negligible.

We found:

- Natural gas for space heating dropped to almost zero, while electricity use decreased at 3 of the four sites. One site had no existing A/C and electricity use increased slightly at that site.
- All sites achieved overall net bill savings during at least six months of the year (summer, May through October) at non-CARE rates and during every month when CARE rates are applied.

Separating the savings from the heat pump retrofit from the other energy efficiency measures at all study sites proved difficult with site level data. Load analysis at the dwelling unit level might isolate the heat pump but is beyond the scope of this study. The Yuba City site had the fewest measures installed through the program besides the heat pumps, so almost all savings are attributed to heat pumps.

Customer Feedback: The two property managers surveyed reported they are either "satisfied" or "very satisfied" with the heat pumps and perceived their residents' satisfaction as being "very satisfied". At one of those sites (Auburn, a senior housing facility), we conducted resident surveys and found that 88% are generally comfortable in terms of temperature. Most seniors reported satisfaction with their bills. The most common problem identified was that the heating or air conditioning was not balanced between rooms. At this site, the heat pump is located on an exterior wall of the living room. A transfer fan circulated heated or cooled air between the living room and the bedroom. Several participants reported dissatisfaction with the difference in temperatures between the two rooms.

Contractor Cost Estimates: Contractors reported that, in single-family homes, cost estimates ranged from $10k to $15k for replacing a central gas furnace with a central heat pump using existing wiring. Full electrical panel upgrades can double the job cost. Note that we were not able to complete interviews with contractors that retrofit wall furnaces with mini-split heat pumps. So, while these cost estimates are useful for single-family home retrofits, they do not reflect the retrofit scope at the four case study sites; all of which replaced gas wall furnaces with mini-split heat pumps.

Refrigerant best practices and GHG impacts: Contractors reported that:

- CARB mandated refrigerant management practices require specialized training and EPA certification. Licensed contractors should be capturing old refrigerant by pumping it into a Department of Transportation-compliant refrigerant recovery cylinder and delivering it to an approved recycling center.

- There is a need for regulation enforcement regarding refrigeration management. Unlicensed contractors sometimes do not follow refrigerant recycling practices and sometimes simply "cut the refrigerant lines", allowing refrigerant to leak directly into the atmosphere. This has massive GHG impacts, since refrigerants have a high GWP (typically about 2000 times more potent than CO2).

Contractors also suggested as best practices

- Use of no-loss fittings to reduce the remaining gas in hoses when decommissioning old equipment.
- Replacement of existing refrigerant lines if lines are old or incorrectly sized.
- Testing lines with nitrogen to uncover leaks before pressurizing with refrigerant, using a bubble-spray to detect leaks directly while nitrogen pressurized, and (after nitrogen leak testing), pulling a vacuum into the lines and holding a steady vacuum for at least 15 minutes.

For the retrofitted sites, our ACC calculations showed that the energy savings resulted in approximately 0.1 to 0.9 CO2e per year per dwelling unit. However, the GHG emissions from a standard heat pump refrigerant leakage—both during the life of the equipment and at equipment end of life—is higher than from a window A/C unit (the baseline condition). If a medium GWP refrigerant is used in the heat pump, GHG emissions are lower than from a window A/C unit, but medium GWP refrigerants are not yet available due to flammability concerns. Recovering almost all of the refrigerant at the end of the heat pump life further reduces GHG emissions

4.2 Lessons Learned and Program Implications

- Efficiency and bill savings are achievable when gas wall furnaces and room air conditioners are replaced with heat pumps, particularly with other energy efficiency measures. Where heat pumps represent the first air conditioning system for the units, summer electricity bills may increase. Note these findings are based on projects in Climate Zones 4 and 11, so results for different climate zones may vary.
- Furnace to heat pump retrofits have a smoothing effect on customer bills. Monthly energy costs are more consistent and predictable.
- While energy billing impacts may be low, utility programs can gain traction only when the high upfront costs of a heat pump are sufficiently offset, particularly in the split-incentive case often found in multifamily buildings.
- While energy savings from heat pumps translates into GHG reductions, the refrigerants in these systems increase GHG emissions through leakage of refrigerant. Traditional air conditioners and heat pump refrigerants have a high GWP (e.g., GWP for R410A= 2,088), and refrigerant slowly leaks from pressurized refrigerant lines over time and at the end of life during removal. Heat pumps have more refrigerant than window A/C units, so result in more emissions. Heat pump incentive programs are somewhat limited for how they can reduce refrigerant GHG emissions, particularly until building codes identify a compliance path for low-flammability, medium GWP refrigerants. However, in addition to encouraging lower GWP refrigerants, programs can encourage or require contractors to drain existing refrigerant lines using the best practices noted above, properly size and replace refrigerant lines in old or oversized systems and use no loss fittings. In general, this study still found a net GHG reduction – i.e., that the GHG reductions

from energy savings outweighed GHG increases from refrigerant leakage, although the refrigerant impacts eroded GHG reductions by one-third to one-half at each site.

While the study found that heat pumps can provide significant natural gas savings, net energy savings, customer bill savings, and GHG savings,[14] the customer bill savings are low: approximately $15 to $30 per month per dwelling unit. This is likely too low to motivate most multifamily decision makers (multifamily property owners or condo associations). The State agencies and the IOUs will need to make significant market interventions to achieve large-scale space heating heat pump retrofits, such as offering large heat pump incentives, increasing natural gas rates, requiring a switch to heat pumps in code for certain types of alterations, or other mechanisms.

Overall, heat pumps can play a key role in CA's future decarbonization with continued incentives for heat pump retrofits along with other energy efficiency measures to support IOU electrification efforts.

[14] The exception was the Sunnyvale site, but this is because the heat pumps added air conditioning to a site that did not previously have air conditioning.

5 Appendix

5.1 Detailed Description of Methods

5.1.1 Data for Determining Site Level Energy Savings

AMI Energy Data

The TRC team obtained AMI data from PG&E's metered energy usage database. We provided dwelling unit level address data and a date/time range to PG&E. PG&E retrieved the associated gas and electric consumption for each address. We analyzed the hourly data for electricity and monthly data for gas usage, since daily gas data was not accurate. This is because, for PG&E daily gas data, values less than one (1) therm per day are rounded down to zero in the AMI database. A single-family home can easily exceed one therm per day, but the dwelling units in multifamily buildings in this study rarely exceeded it (~5% of the time). Consequently, we relied on monthly data for the natural gas analysis.

Data Review and Cleaning

PG&E provided usage files (one for each site), including hourly kW data for every meter associated with the site address from 2016 to early 2022. These data included meters for individual apartment dwelling units, as well as miscellaneous meters for solar panels and common areas. We aligned timestamps and data for each site chronologically, and tagged meter data not associated with dwelling units.

We discovered significant gaps in the electric data, timestamps with zero kWh values or gaps with no timestamps at all. In many cases, the time gaps clearly represented unoccupied periods because no service agreement was in place. In other cases, a service agreement was in place, but the unit may have been unoccupied during construction or tenant turnover. We identified dwelling units with larger proportions of zero and or missing data and excluded those from the analysis. The natural gas data did not require the same level of scrutiny, since we were provided with monthly data instead of hourly.

For the Yuba City site, the dwelling units did not have individual gas meters so one site-wide gas meter provided aggregate data. For the Sunnyvale site, the dwelling units no longer had gas-fired appliances and the meters were removed, so post-retrofit dwelling unit-level gas data were unavailable.

Site maps created from on-site visit records and/or Google maps provided unit locations, floors, and building orientation. We defined *orientation* as the direction normal to the main exterior wall. We defined a perimeter unit as a unit with adjacent units on either side and a corner unit as a unit with two or more adjacent exterior sides.

nmecr Software

We used weather-based regression analysis to compare post-implementation operation against baseline operation. This allowed us to create annualized energy usage profiles normalized for weather variation. We then applied an R-based package known as Normalized Metered Energy Consumption in R (nmecr) nmecr was developed by kW Engineering and is well-suited for utility based energy consumption analysis. The nmecr package processes input energy data and corresponding weather data to establish an algorithmic relationship between energy usage and outside air temperature. This algorithm is then applied to both the baseline and post-implementation weather data periods to model energy savings from the retrofit without the influence of weather.

The nmecr package comes with functions that fit the data according to different regression models and calculate *goodness-of-fit* statistics (such as CVRMSE and R-squared values). Once we had a well-fit model, we used it to predict energy usage based on a weather file.

Once space heating loads were converted from gas to electricity, the remaining gas loads were predominantly independent of outside air temperature, and as such, the r^2 goodness of fit values for natural gas usage were significantly worse in the post-case regression analysis. This does not mean that the annual normalization is inaccurate, just that outside air temperature is not a strong independent variable for determining the expected post-case natural gas usage.

Weather Normalization

We used typical meteorological year (TMY) weather files to create annual energy usage profiles normalized for weather for both the baseline and post case periods. The TMY weather files selected were the DEER2023 Climate Zone (CZ) 4 and 11 '.bin' files. CZ4 corresponds to the Sunnyvale and Campbell locations, while CZ11 corresponds with the Auburn and Yuba City locations.

We obtained Actual Meteorological Year (AMY) weather data from the California Measurement Advisory Council (CALMAC) website (http://www.calmac.org/weather.asp). The timespan of the data begins January 2016 and runs through the end of the available post-retrofit time period, January 2022. We used local hourly outside air dry-bulb temperature for both Auburn and Yuba City locations. For Sunnyvale and Campbell, we chose the nearest approximations from available CALMAC files: the weather station in Mountain View for Sunnyvale, and the San Jose International Airport for Campbell.

5.1.2 Billing Impacts

For each site, we estimated billing impacts using the total pre- and post-retrofit energy use for each site. We applied blended PG&E residential electricity and gas rates to the AMI energy data, since analyzing individual customer billing data was beyond the scope of this project. In addition, the average turnover in these units was high—approximately six different tenants on average over a period of six years for at least one site. The residents in most dwelling units pre-retrofit were different from those in the same dwelling units post-retrofit, with a mix of customers that were eligible and ineligible for CARE. Consequently, we applied simple multipliers to address these variations.

For electricity, we used the PG&E E-1 rate schedule,[15] current as of March 01, 2022, which has an average bundled total rate of $0.336 per kWh. CARE customers receive a 34.944% discount, translating to a blended rate of $0.218 per kWh.

Residential gas rates are split into two tiers based on monthly usage: Baseline and Excess. A blended rate is not provided in the rate schedule and could not be estimated without billing data. To estimate

[15] https://www.pge.com/tariffs/Res_Inclu_TOU_Current.xlsx

the blended gas rate, we used the PG&E Total Residential Schedules[16] charge from tariff rates applicable as of January 1, 2022, plus the Schedule G-PPPS charge and interpolated between the Baseline and Excess rates, matching the blended electricity rate's position between the Baseline and High Usage rates. This approach provides an estimated blended rate of $2.111 per therm for non-CARE customers and $1.667 per therm for CARE Customers, which is a 21% discount. See Table 12 below for rates used in the analysis that we applied for the customer bill impacts.

Table 13: Blended Electric and Gas Rates

Rate Schedule basis	Energy Type	Blended Rate ($)	Unit
E-1, non-CARE	Electricity	$0.336	kWh
E-1, CARE	Electricity	$0.218	kWh
G-1, non-CARE	Gas	$2.111	Therm
G-1, CARE	Gas	$1.667	Therm

PG&E's rate structures offer a multifamily discount in the form of dollars per dwelling unit per day of service. We are unsure if customers received this discount, so it is difficult to predict whether minimum service charges would be applicable after the retrofits. Therefore, the multifamily discount was not considered for the analysis. If applied, we estimate total bills would decrease less than 10%.

5.1.3 Surveys and Interviews

Table 14: Survey Details

Project City	Post-retrofit Resident survey conducted by MUP team (2018-19)?	Property manager survey conducted by MUP team (2018- 19)?	Property manager survey Conducted for this Case Study (2021-22)?	Resident Survey Conducted for this Case Study (2021-22)?
Auburn	No	No	Yes	Yes
Sunnyvale	Yes	Yes	No	No
Yuba City	Yes	Yes	Yes	No
Campbell	No	No	No	No

16 https://www.pge.com/tariffs/Res_Current.xlsx

Property Manager Survey

We surveyed property managers at two of the sites (Yuba City and Auburn) to learn about their experience with the heat pumps installed at their property. At the other two sites (Sunnyvale and Campbell), the property managers did not respond to survey requests.

The goal of the surveys was to determine the level of satisfaction with new units installed in PG&E's MUP. We asked questions regarding:

- Overall satisfaction with the new units
- Maintenance issues
- Resident thermal comfort
- Resident complaints
- Resident training on operating the units
- Prevalence of supplemental sources of heating or cooling after the retrofit.

A complete list of questions and responses is in the Appendix. As part of the MUP program, attempts were made to survey property managers with a similar set of questions three months after the retrofit occurred. Only two property managers were reached at that time.

Senior Housing Resident Survey

We attempted to survey residents at all four sites. However, because we did not have resident email or phone numbers, our approach was to ask property managers if they would be willing to send out an online resident survey on our behalf. This was only possible at Yuba City and Auburn, where we had completed property manager surveys. The property manager at Yuba City never responded despite repeated requests. Consequently, the only site with resident responses was Auburn, a senior housing facility.

The senior housing property manager at the Auburn site indicated that many of the seniors did not have computers, and if they had email addresses, a list was not maintained. We prepared a paper version of the survey, which the Auburn property manager distributed directly to the dwelling units.

We had a high response rate to the paper survey from the Auburn site residents. Of the 48 total residents, 27 completed the survey, representing a 56% response rate.

As part of the MUP program, attempts were made to survey residents three months after the retrofit occurred. At only two sites was a resident survey successfully completed, the senior housing site was not one of the sites surveyed at that time, so no comparisons are possible.

Contractor Interviews

We interviewed five HVAC contractors who have experience with gas furnace to heat pump retrofits in single-family homes in California. We identified contractors for the interviews using a mix of:

- Attendees of a heat pump training webinar that TRC co-hosted.
- PG&E Referrals

    - One contractor is an active participant in utility programs. The other was a subject matter expert with field experience and a track record of teaching classes on heat pumps and refrigerant reclamation as part of PG&E educational outreach.

While we aimed to reach contractors who have experience with furnace to heat pump replacement in multifamily residences, we were not able to recruit any for interviews. We conducted the contractor interviews via one-on-one phone interviews. We developed an interview guide (see Appendix) which includes questions regarding:

- Description of typical furnace-to-heat pump retrofits
  - Prevalence and type of existing air conditioning system
  - Typical scope of work required for a furnace-to-heat pump retrofit, including:
    - Any work required for the wall cavity
    - Any work required for electrical upgrades, including scenarios where a panel upgrade is required
  - Other work that is typically requested by customers (just a furnace to heat pump, or a multi-equipment package)
  - Retrofit costs, broken out by labor and materials, and split out by the HVAC replacement compared to electrical upgrades
  - Typical refrigerant management
  - Practices to prevent refrigerant release, and general advice for refrigerant best practices

5.1.4 GHG Impacts

We estimated the impacts on GHG emissions from two types of emissions:

- First, we estimated GHG impacts from energy savings by applying GHG multipliers[17] to the savings at each site to determine CO2 equivalent (CO2e) impacts. This estimates the avoided GHG emissions from the energy savings, that is, the embodied GHG emissions from natural gas and electricity generation. We applied the GHG multipliers from the 2021 ACCs at the site-level.
  - For the electricity model, the CO2 equivalent (CO2e) multiplier assumes a low efficiency power plant.
  - For the gas model, the CO2e multiplier assumes a residential furnace.
- Second, we used the CPUC's ACC for Refrigerants[18] to investigate the impacts of refrigerants on GHG emissions. This estimates the impacts of refrigerants—both in the removed equipment (window air conditioning units) and installed equipment (heat pumps). Refrigerants are chemicals that typically have a high global warming potential (GWP).[19]

[17] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/energy-efficiency/idsm
[18] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/energy-efficiency/idsm
[19] GWP is a number that represents how much energy the emissions of one ton of a gas will absorb, relative to the emissions of one ton of CO2. For example, a typical HVAC refrigerant is R410A, which has a GWP of 2,088, meaning that one ton of R410a released to the atmosphere will cause warming approximately 2,088 times more than one ton of CO2.

Table 15: Methods for Computing GHG Impacts

GHG Component	Description	Tool	Method
Electricity	GHG Impact with electricity savings from using more efficient equipment	2021 ACC Electric Model V1b	Applied the GHG multipliers from the tool for a low efficiency power plant to the annual electricity savings for each site
Natural Gas	GHG Impact with natural gas savings from replacing gas heating furnace to heat pumps	2021 ACC Gas Model v1b	Applied the GHG multipliers from the tool for a residential furnace to the annual natural gas savings for each site
Refrigerant	GHG Impact with refrigerant change and leakage rates with new heat pumps	2021 ACC Refrigerant v1b	Calculated the GHG impacts for different system types and refrigerants using

For the refrigerant impacts calculated using the using the ACC for Refrigerants, we assumed a baseline case is a window A/C unit with R-22 refrigerant. We assumed a refrigerant charge per unit based on the California Air Resources Board (CARB) average, and an annual leakage rate and end of life from refrigerant leakage using the default values in the ACC. We then calculated the GHG impacts under several refrigerant management scenarios, as shown below. These varied the refrigerant reclamation rate—i.e., the percent of the HVAC refrigerant that was pumped out of equipment and refrigerant lines at the end of the equipment life and the GWP of the refrigerant in the heat pump.

Table 16: Proposed Refrigerant Scenarios

Case		Scenario
Base	Existing Condition	Window/Room/Wall and Packaged Terminal A/C unit with R-22 refrigerant charge (quantity = ARB average)
1	Standard Retrofit	Residential Split Heat Pump with R-410A refrigerant[20] (high GWP) and 20% refrigerant reclaimed at EOL[21]
2	Retrofit with High Refrigerant Reclamation Rate	Residential Split Heat Pump with R-410A refrigerant (high GWP) and 80% refrigerant reclaimed at EOL.
3	Retrofit with Medium GWP Refrigerant	Residential Split Heat Pump with R-454B refrigerant (med GWP) and 20% refrigerant reclaimed at EOL
4	Retrofit with Medium GWP Refrigerant and High Refrigerant Reclamation Rate	Residential Split Heat Pump with R-454B refrigerant (med GWP) and 80% refrigerant reclaimed at EOL

We also estimated the impacts from leaked refrigerants if contractors do not properly drain existing refrigerant out of the refrigerant lines per California Air Resources Board requirements, and instead simply cut the lines. From our contractor interviews, we heard that this was a practice of some

[20] Assume 2 lbs. of refrigerant charge per ton for a 'typical' 2-ton residential split heat pump system
[21] Annual leakage rate for refrigerants from CARB

unlicensed contractors. If contractors cut fully charged refrigerant lines, all refrigerant is released to the atmosphere. We used an online calculator[22] to estimate refrigerant charge in a 35-foot line set (typical for a single-family home) for a system using R-410A.

We have also included lifetime GHG impacts at the each of the retrofitted site using CPUC's Fuel Substitution Calculator (FSC). The FSC calculates lifetime energy savings (MMBTUs) and lifetime emissions savings (Tons of CO2e) for fuel substitution measures like residential heat pumps, DHW, electric cookers for custom/deemed measures. Here are some key differences between FSC and ACC analysis:

- In ACC analysis, we are calculating the annual GHG impacts using ACC Emission factors for a low efficiency plant
- FSC estimates savings and GHG impacts over the lifetime of the measure
- FSC uses CAISO Projected emissions Intensity (0.21 tCO2/MWh) in the first year. In ACC analysis we are using low efficiency plant emissions rate (0.73 tCO2/MWh)
- FSC does not account for GHG impacts from refrigerant emissions.

Lastly, the most recent version of FSC was developed in 2019, while the ACC was updated in 2021.

5.1.5 Study Limitations.

We encountered some clear limitations during this case study. Some limitations point to further work while others are not addressable with the data provided.

Isolation of Heat Pump Effects

While the energy and bill savings are verified by this case study, it proved difficult to separate the savings from the heat pump retrofit from the other energy efficiency measures across all the sites using site level analysis. On one end of the spectrum, the Yuba City site had almost no additional energy efficiency measures (only low flow showerheads) so almost all energy savings came from the heat pumps. At the other end of the spectrum, the Sunnyvale site was completely rehabilitated with many energy efficiency measures installed (See Table 3: Energy Efficiency Measures). In addition, three of the four sites (Auburn, Campbell, and Sunnyvale) had centrally-metered DHW that is not reflected in our savings analysis (which used unit-level consumption data at those sites). Consequently, our percent savings estimates for these sites do not include DHW energy use.

Contractor Interview Sample

We had difficulty finding any contractors with a history of furnace to heat pump replacements in multifamily buildings. Single-family home furnace replacements are far more common. Consequently, our interview results on job costs are likely not applicable to retrofits in multifamily buildings. However, our findings regarding refrigerant management practices are comprehensive and broadly applicable.

[22] Refrigerant Line Charge Calculator - Inch Calculator

Property Manager and Resident Recruitment

We had difficulty reaching some property managers for interviews and also with facilitating access to resident for surveys. In two cases, the property managers were willing to be interviewed, but at the other two sites, repeated attempts to contact them produced no response. Ultimately, we were only able to obtain resident surveys from one site, and that site was a specific demographic: all senior citizens. Still, results provide valuable information of senior citizens' opinions of mini-split heat pumps.

5.2 Regression Model Goodness of Fit and Normalized Savings

Table 17: Goodness of Fit

Site	Units	Fuel	Pre-Retrofit			Post-Retrofit		
			Date Range	CVRMSE (%)	R-Squared	Date Range	CVRMSE (%)	R-Squared
Auburn	48	Natural Gas	Jan 2016 - Nov 2018	8.46	0.98	Nov 2019 - Dec 2021	12.8	0.11
Sunnyvale	22	Natural Gas	Jan 2016 - Oct 2018	14.15	0.95	Oct 2019 - Dec 2021	No Data	
Yuba	25	Natural Gas	Jan 2016 - Nov 2018	12.07	0.95	July 2019 - Dec 2021	14.44	0.45
Campbell	158	Natural Gas	Jan 2016 - Dec 2016	4.6	0.96	Jan 2020 - Dec 2021	9.4	-0.03

Site	Units	Fuel	Pre-Retrofit			Post-Retrofit		
			Date Range	CVRMSE (%)	R-Squared	Date Range	CVRMSE (%)	R-Squared
Auburn	48	Electricity	Jan 2016 - Nov 2018	21.51	0.87	Nov 2019 - Dec 2021	20.45	0.69
Sunnyvale	22	Electricity	Jan 2016 - Oct 2018	22.14	0.58	Oct 2019 - Dec 2021	27.64	0.49
Yuba	25	Electricity	Jan 2016 - Nov 2018	31.35	0.79	July 2019 - Dec 2021	25.26	0.67
Campbell	158	Electricity	Jan 2016 - Dec 2016	16.73	0.78	Jan 2020 - Dec 2021	14.02	0.75

Table 18: Detailed Savings Calculations

Site	Normalized Pre-Retrofit (Therms)	Normalized Post-Retrofit (Therms)	Annual Normalized Savings (Therms)	Pre-Retrofit/Unit	Post-Retrofit/Unit	Annual Normalized Savings (Therms/Dwelling Unit)	% Savings
Auburn	6,423	568	5,855	133.8	11.8	122.0	0.9
Sunnyvale	2,557	-	2,557	116.2	-	116.2	1.0
Yuba	6,907	3,340	3,567	276.3	133.6	142.7	0.5
Campbell	13,130	2,656	10,474	83.1	16.8	66.3	0.8
Site	Normalized Pre-Retrofit (kWh)	Normalized Post-Retrofit (kWh)	Annual Normalized Savings (kWh)	Pre-Retrofit/Unit	Post-Retrofit/Unit	Annual Normalized Savings (kWh/Dwelling Unit)	% Savings
Auburn	163,535	172,614	(9,080)	3,407	3,596	(189)	(6%)
Sunnyvale	77,334	82,729	(5,394)	3,515.2	3,760.4	(245.2)	(7%)
Yuba	95,473	95716	(243)	3,819	3,829	(10)	(0.3%)
Campbell	448,902	353,840	95,062	2,841	2,239	602	21%

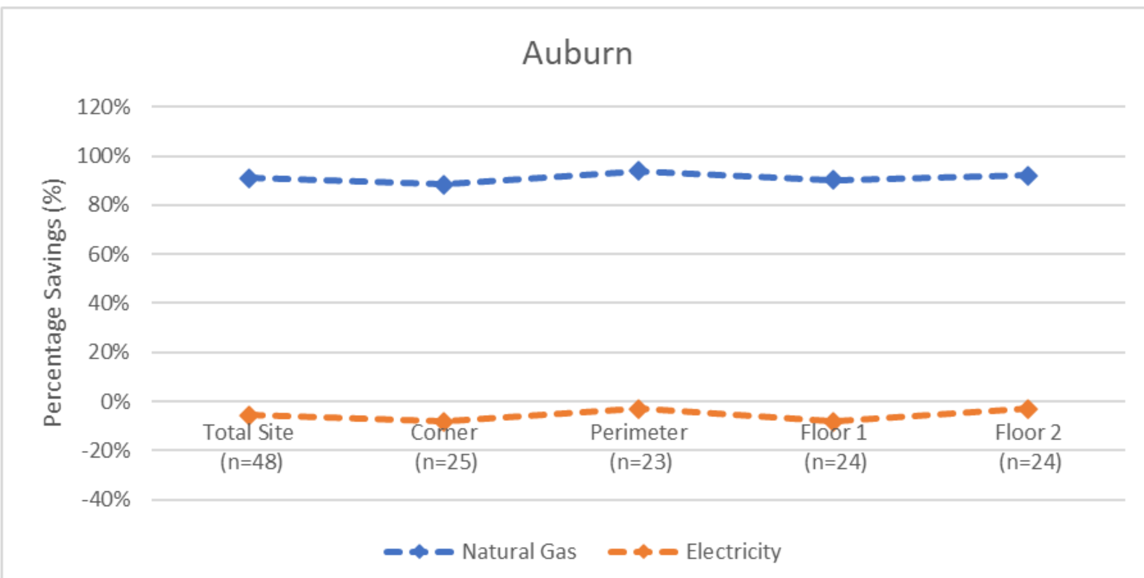
5.3 Energy Use by Dwelling Unit Location and Orientation

We also analyzed energy savings at the sub-group levels of floor 1 vs floor 2, corner vs perimeter dwelling units, and primary dwelling unit orientation where possible. We conducted this analysis at the request of PG&E to inform residential programs (such as potentially setting different incentive levels for different units). Note that for Yuba City, it was impossible to break out the gas usage per dwelling unit, so we excluded Yuba City from the dwelling unit location and orientation analysis.

Auburn

The chart below shows the gas savings percentage and electric penalty percentage for the total Auburn site, as well as corner vs perimeter and floor 1 vs floor 2. As shown, there was very little difference in dwelling unit savings by floor or corners vs. perimeter for this site, with the savings mostly consistent across all group. As floor 1 and floor 2 have equal population sizes, and the corner and perimeter dwelling units are also nearly equal population sizes as well, there is little variation in total site savings versus savings in each separately defined group. Most units at this site had a mix of north-facing and south-facing orientations, so we did not analyze energy use by orientation.

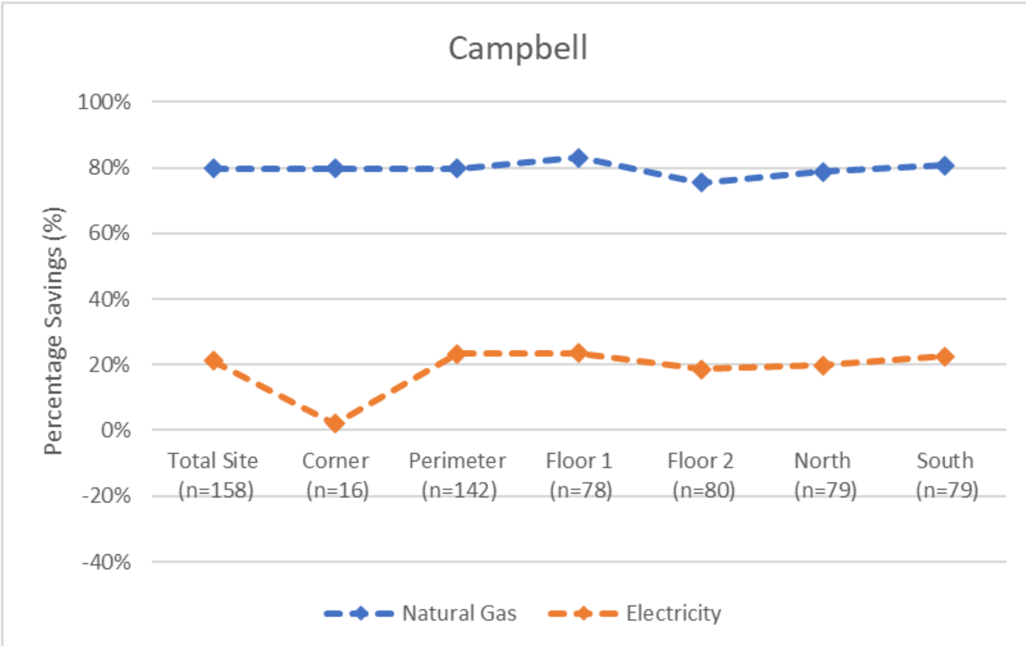
Figure 13 Auburn Site: (corner, floor, and perimeter differences)



Campbell

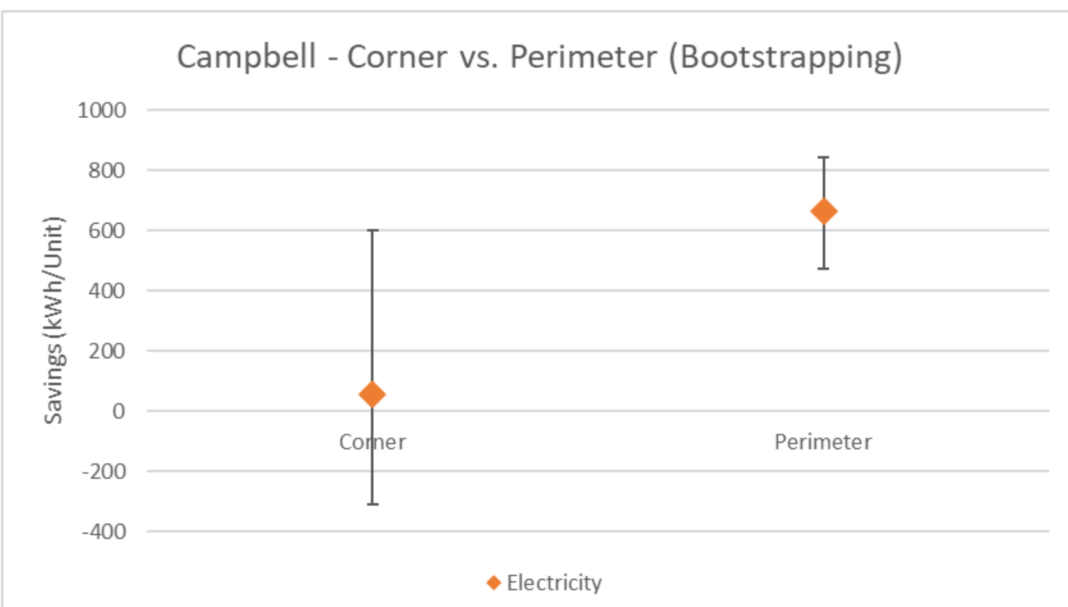
The same patterns observed with the Auburn site are present in the Campbell site data as well. There was minimal difference in gas savings across dwelling units split by floor, corner vs. perimeter units, and north vs. south facing units. This was the case with electricity savings as well, with the exception of the corner dwelling units. The data from the corner dwelling units showed lower electricity savings compared to the other dwelling unit types. We identified the individual corner dwelling units and found the group to contain multiple dwelling units that are outliers with atypical energy usage and low population size compared to other units.

Figure 14: Campbell Site (corner, floor, and perimeter differences)



To investigate whether the difference in energy use between corner and perimeter units was statistically significant (or more likely to be due to coincidence), we conducted a bootstrapping error analysis for Campbell between the corner and perimeter dwelling units. This check was necessary, as corner savings/unit data showed a high variation across a small population size. We determined that the 95% confidence intervals of the electricity savings per dwelling unit for corner and perimeter dwelling units overlap, indicating that the difference in savings is not statistically significant, falling more in line with the Auburn results.

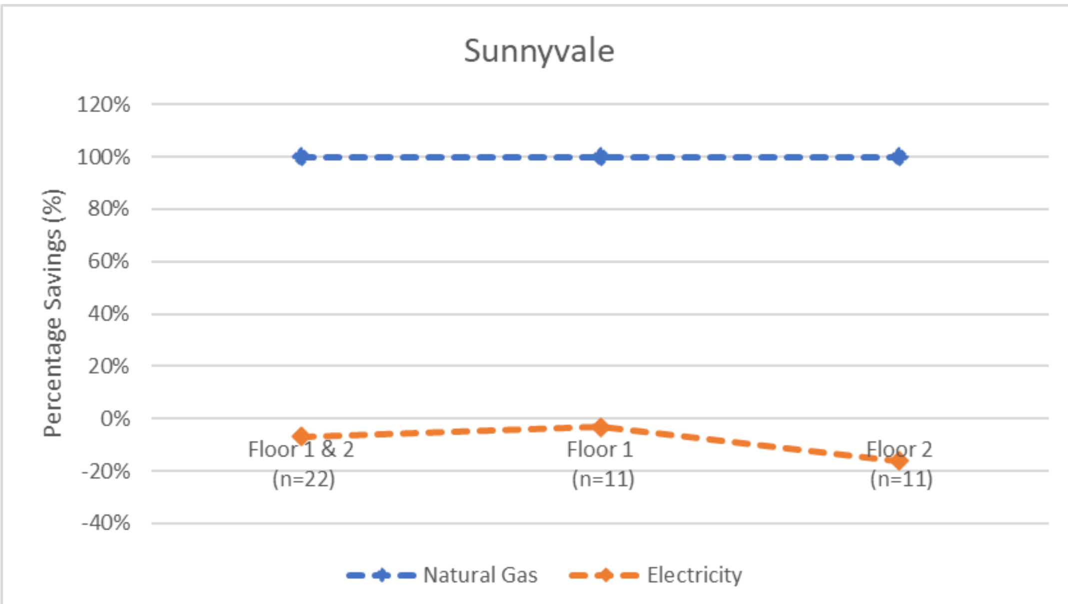
Figure 15: Campbell Site (bootstrap method for significance testing)



Sunnyvale

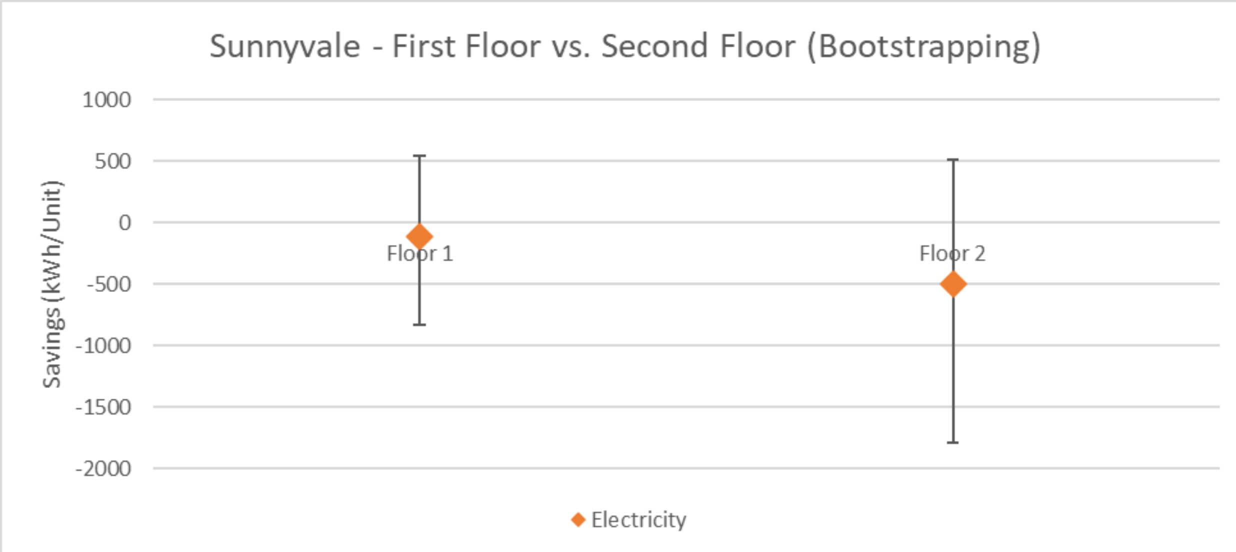
For the Sunnyvale location, we did not have sufficient dwelling unit location information to break them down into groups like corner vs perimeter or orientation, but we were still able to conduct the floor analysis. For the Sunnyvale locations, it does appear that the second-floor dwelling units incurred a slightly larger electricity penalty. A possible explanation could be poor roofing insulation, which would result in more summer cooling and winter heating in the second-floor dwelling units.

Figure 16: Sunnyvale Site (floor differences)



We repeated the bootstrapping error analysis for the Sunnyvale floor comparison as well. While the 95% confidence intervals do overlap (indicating savings do not differ with statistical significance), we would need a larger sample size to confirm that the second-floor units used more energy (had a greater electricity usage penalty) compared to the first-floor dwelling units.

Figure 17: Sunnyvale Site (bootstrap method for significance testing)



5.4 Tabulated Property Manager Survey Results with Comments

Table 19: Property Manager Survey Results (2021)

#	Question	Auburn	Yuba City
1	Have you experienced any maintenance issues with the heat pumps?	Yes	Yes
2	On a scale of 1 to 5 with 1 being not satisfied and 5 being very satisfied, how satisfied are most residents with their heat pump?	5	5
3	On a scale of 1 to 5, with 1 being not satisfied and 5 being very satisfied, how satisfied are you with your building's heat pumps?	4	5
4	How frequently do you receive questions or complaints from the residents about their heat pump?	Rarely	Rarely
5	What specific feedback or questions have you received from residents about the heat pumps?	Display screen is small, not back lit (5 complaints). The equipment is in one room with transfer fan, heat / cooling not getting to room. Disabled and elderly population.	Most love that they can control 2 or 3 zones. Have a cool bedroom, and a warmer living room. Before, residents, I would see windows open in the living room (where wall furnace is) and blasting furnace to heat the bedrooms. It's much quieter walking down the courtyard than previously with the old ACs.

#	Question	Auburn	Yuba City
6	When you receive comfort complaints from the residents, what is the issue (typically)?	Only complaints about the bedrooms not getting enough cooling / heating via the transfer fan – about 4 total.	Only complaints from residents if they don't know how to use the remote. All remotes/units must be in same mode (heat or cool) to work
7	Did you manage the property before the furnaces were retrofitted with heat pumps?	Yes	Yes
8	If Yes to Q7: Has the frequency of comfort complaints changed since the heat pumps were installed?	Yes, fewer	Yes, fewer
9	If Yes to Q7: What were the most common comfort complaints with the furnaces (so the old equipment)?	Unknown	Less, virtually nothing. We had more complaints about pilots, about pilots being lit in each year than I have in the entirety since installing [heat pumps].
10	Do the tenants receive training on how to operate their new heat pumps?	Yes	Yes
11	Do residents understand how to operate their new heat pumps?	Yes	Yes
12	Are residents expected to clean the air filters on the heat pumps?	Yes	Yes
12b	If yes, were they taught how to do so?	Yes	Yes
12c	If yes, do they receive reminders?	-	Yes
13	Approximately what percent of residents currently use window air conditioners or portable air conditioners (this kind uses a hose that sticks out the window)?	0%	0%
14	Approximately what percent of dwelling units currently use plug-in space heaters in their apartments?	0%	0%

5.5 Interview Guide and Survey Instruments

5.5.1 HVAC Contractor Interview Guide

PG&E Furnace Replacement Initiative Case Study
HVAC Contractor
Your goal is to learn about installation nuances and challenges associated with this conversion.

1. Do you do mainly single family or multifamily furnace replacements?
   a. What percentage are multifamily?

2. How many days does the job typically take per dwelling unit?

3. Do the projects typically have existing AC units (central, window or portable)?

4. What work is involved to remove the wall furnace and renovate the cavity?

5. What, if any, electrical upgrades do you typically make to install the heat pumps?

6. Do you usually retrofit one electrical appliance based on a heat pump or do you find that your customers prefer a package of multiple appliances? Examples include electric vehicle chargers, mini-split heat pump for space conditioning, and a heat pump clothes dryer.

7. What is a typical cost for a gas furnace to heat pump replacement, roughly broken down by materials and labor? Feel free to give a range.
   - Removal?
   - Install of new equipment?
   - Electrical?

8. Finally, I'd like to ask about your refrigerant management practices. First, what do you do with the refrigerant in any systems removed, such as old air conditioning systems?

9. When charging the heat pump with refrigerant, what practices do you follow to avoid refrigerant releases? For example, any steps to reduce remaining gas in the hoses from escaping?

10. Do you have any suggestions on refrigerant management best practices, either for your team or for the industry at large?

5.5.2 Property Manager Survey

PG&E Furnace Replacement Initiative Case Study

Property Manager

Audience: Property manager, *because they have day-to-day interaction with the residents and access to dwelling unit addresses (which is essential for the PG&E data request).*
Survey to be conducted over the phone.
Hello. This is [full name] with TRC, calling on behalf of PG&E. The [name of multifamily property] at [address of property] participated in the PG&E Multifamily Upgrade Program a few years ago and received several energy efficient upgrades, including replacing wall furnaces with heat pumps.

Now that the new heat pumps have been in place for a while, we would like to conduct a 10 to 15-minute phone survey with you (the property manager) to find out how the equipment is working. We would also like to know a bit more information about [name of property] so we can conduct some energy savings analysis to understand the equipment's energy and greenhouse gas impacts. To show our appreciation, we would like to offer you a $100 electronic Visa gift card for participating in the survey.

Is now a good time for the survey? If not, please let me know a better time for the survey. [*If the property manager is available now, continue script. If not, schedule the survey as needed.*]

1. Have you experienced any maintenance issues with the heat pumps? (Y/N)
   a. Yes
   b. If yes, what type of maintenance issues?
   c. No
2. On a scale of 1 to 5 with 1 being not satisfied and 5 being very satisfied, how satisfied are most residents with their heat pump?
   a. 1 – Not satisfied
   b. 2 – Somewhat not satisfied
   c. 3 – Neutral
   d. 4 – Somewhat Satisfied
   e. 5 – Very Satisfied
3. On a scale of 1 to 5, with 1 being not satisfied and 5 being very satisfied, how satisfied are you with your building's heat pumps?
   a. 1 – Not Satisfied
   b. 2 – Somewhat Not Satisfied
   c. 3 – Neutral
   d. 4 – Somewhat Satisfied
   e. 5 – Very Satisfied
4. How frequently do you receive questions or complaints from the residents about their heat pump?
   a. Never
   b. Rarely (during change from heating to cooling season)

c. Frequently (multiple times each season)

5. What specific feedback or questions have you received from residents about the heat pumps?
   a. Enter comments:
6. When you receive comfort complaints from the residents, what is the issue (typically)?
   a. Apartment is too hot
   b. Apartment is too cold
   c. Don't receive comfort complaints from residents
   d. Other:
7. Did you manage the property before the furnaces were retrofitted with heat pumps?
   a. Yes
   b. No
8. If Yes to Q7: Has the frequency of comfort complaints changed since the heat pumps were installed?
   a. Yes
   b. If yes, more or less?
   c. No
9. If Yes to Q7: What were the most common comfort complaints with the furnaces (so the old equipment)?
   a. [open ended]

[If yes to Q7]: Thanks for that feedback on the old equipment. I have a few more questions about the heat pumps, so what's installed now.

10. Do the tenants receive training on how to operate their new heat pumps?
    a. Yes
    b. If yes, what topics did the training cover?
    c. No
11. Do residents understand how to operate their new heat pumps?
    a. Yes
    b. No
    c. If no, what operations or functions do they not understand?
12. Are residents expected to clean the air filters on the heat pumps?
    a. Yes
    b. If yes, were they taught how to do so? (Y/N)
    c. If yes, do they receive reminders? (Y/N)
    d. No
13. Approximately what percent of residents currently use window air conditioners or portable air conditioners (this kind uses a hose that sticks out the window)?
    a. #:
14. Approximately what percent of dwelling units currently use plug-in space heaters in their apartments?
    a. #:

15. We are working with PG&E to compare energy use before and after the retrofit. All results will be strictly confidential. Can you please help us by sharing the following information with us? [If needed, you can also offer to send this list in an email.]
    a. Dwelling unit address list, so we can request energy info (by meter number) from PG&E
    b. A site map showing where dwelling units are located within the building(s) and the dwelling unit types.
    c. Square footage and number of bedrooms for each dwelling unit (or a floor plan of each dwelling unit type with this information).

5.5.3 Resident Survey

PG&E Furnace Replacement Initiative Case Study

Resident

Fill out this survey to support the net zero carbon transition, improve PG&E programs, and receive $20!

On behalf of PG&E, TRC is conducting a survey at apartment buildings that received heat pumps with PG&E incentives. The survey captures feedback from residents on heat pumps, which provide heating and air conditioning.

The survey takes just 5 minutes to complete, and we are offering a **$20 Visa electronic gift card** to thank you for your time. We will keep all of your answers confidential.

About your home:

1. About how long have you lived in your home? (please circle) Less than 3 months 3 to 6 months 6 to 12 months More than 12 months

About your heat pump (providing heating and cooling/air conditioning to your home):

2. On a scale of 1 to 5, **1 = Dissatisfied, 5 = Satisfied**, how satisfied are you with your heat pump **in general**? (please circle)	1 2 3 4 5

3. On a scale of 1 to 5, **1 = Dissatisfied, 5 = Satisfied**, how satisfied are you with your heat pump **for heating** (in the winter)? (please circle)	1 2 3 4 5
4. On a scale of 1 to 5, **1 = Dissatisfied, 5 = Satisfied**, how satisfied are you with your heat pump **for cooling** (in the summer)? (please circle)	1 2 3 4 5
5. Who do you ask when you have questions about your heat pump? (please write in your answer)	_______________________

About your comfort:

6. Do you have any problems using your **heat pump for heating**?
   Yes / No / Don't know

If "Yes" or "don't know", which of the following problems do you have? Circle all that apply.

My home warms up too slowly

My home doesn't warm up enough

The air feels too cold coming from my heat pump

The heat isn't balanced room to room

Other, please specify: **[OPEN END]**

None: No problems during heating.

7. Do you have any problems using your **heat pump for cooling**?
   Yes / No / Don't know

If "Yes" or "don't know", which of the following problems do you have? Circle all that apply.

My home cools down too slowly

My home doesn't cool down enough

The air feels too hot coming from my heat pump

The air conditioning isn't balanced room to room

Other, please specify: **[OPEN END]** None: No problems during cooling.
Generally, is your home comfortable in terms of temperature? Yes/ No / Other: Please explain

About your energy bill:

8. On a scale of 1 to 5, **1 = Dissatisfied, 5 = Satisfied**, how satisfied are you with your energy bills during the **heating** season (in the winter)? (please circle)	1 2 3 4 5
9. On a scale of 1 to 5, **1 = Dissatisfied, 5 = Satisfied**, how satisfied are you with your energy bills during the **cooling** season (in the summer)? (please circle)	1 2 3 4 5

Anything else:

10. What, if anything, is surprising about your heat pump?
11. Is there anything else you would like to tell us about your home, your heat pump, your comfort, or your energy bill? (Please explain)

Please enter your email address to receive a $20 gift card. (Limit of one per household.). Your email will only be used for the purpose of sending a gift card:

____