Field Deployment of Window Heat Pumps in Multi-Family and Single-Family Low-to-Medium Income Homes

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ABSTRACT

California's ambitious greenhouse gas reduction goals necessitate innovative solutions for residential space heating and the inclusion of low-to-medium income communities for clean energy equity. Although heat pumps are commonly seen as the solution for decarbonizing residential space heating, they often come with barriers such as high upfront costs, lack of qualified technicians, and the need for electrical upgrades that may further exacerbate inequities in access to electrification technologies. As such, this project aimed to work with low-to-medium income communities to facilitate the development and adoption of a product to fit the needs of these residents. This paper summarizes the deployment of 100 units of easy-to-install 120V window heat pumps in disadvantaged residential communities in the California Central Valley, through funding by the California Strategic Growth Council. The project emphasized community engagement and participant feedback as key pillars of success. Local community organizations, "the trusted messenger", were leveraged to foster trust and participation and surveys were conducted to understand perception of the product. Overall, users were satisfied with the efficacy of the product, with an average rating of 3.78 out of 5 (after 6+mths use) and over 75% of participants saying they would recommend the product. Some areas for improvement include app connectivity and window sealing. A trend in utility bills was not obvious but effort is ongoing to collect metered data and utility bill information. This study demonstrates that with strategic support and community involvement, window heat pumps can be a useful technology for electrification within low-to-medium income communities.

Introduction

California has some of the most aggressive energy and greenhouse gas (GHG) emission reduction goals in the U.S. Specifically, the 2022 scoping plan from California Air Resource Board mandates the reduction of gas emissions to zero in every sector by 2045. In the California residential building sector, over half of the GHG emissions come from burning natural gas or propane in space and water heaters since this is the predominant heating fuel in 90% of homes (Hopkins et al, 2018). As more renewable resources are integrated into the electric grid, space and water heating will make up an even larger portion of building emissions if fossil fuel remains as the predominant heat fuel. Heat pump deployments can be an efficient method to electrify and decarbonize space conditioning loads in buildings and meet GHG reduction targets.

However, the adoption of heat pumps faces several barriers, particularly in low-to-medium income (LMI) and disadvantaged communities (DAC): higher upfront costs than competing technologies, lack of qualified technicians, and requirements for electrical upgrades (Elkind et al, 2022). The difference in upfront cost between heat pumps and other heating, ventilation, and air conditioning (HVAC) technologies is decreasing because of the surge in heat pump demand, but efficient systems still come at higher cost premiums. Additionally, technicians are less familiar with heat pumps compared to air conditioner (AC) and furnace combos, so they are less likely to recommend heat pump products at the time of installation. The potential requirement for electrical service upgrades is another concern with upfront cost for low-to-medium income communities. While there are incentive programs that aim to lower the financial burden for customers, an underutilized approach is for manufacturers to design these efficient products with these communities in mind.

This paper summarizes the deployment and testing of 100 units of window heat pumps in LMI/DAC residences s in the California Central Valley, funded by the California Strategic Growth Council's (SGC) Climate Change Research Program (Award CCR#20013). A key grant objective was to address how to improve access, acquisition, and adoption of low-GWP energy efficient heat pumps for the low-to-medium income customers (LMI) and disadvantaged communities (DAC). To do this, the project team worked with two communities in the California Central Valley: a multi-family complex in Tracy, CA and a largely single-family home neighborhood in Fresno, CA. Both sites have similar climates with cool, wet winters and long, hot summers. The existence of both heating and cooling seasons in the two locations made the sites ideal for testing the window heat pump units.

Both selected sites are supported by local community organizations. These organizations host events such as neighborhood tours, support initiatives including local scholarships, and provide communication services between residents and city regulators. As community engagement partners are the critical thread for establishing a trusted messenger, especially in LMI/DAC communities, these organizations are what allowed the project to be successful. Throughout the project demonstration period, these organizations helped organize recruiting events, provided spaces for equipment storage, and facilitated communication between the residents and project team.

Throughout the project, 40 units were deployed for testing in multi-family affordable housing and 60 units were deployed in single-family residential homes in low-to-medium income households. The project entailed surveying the participants once during installation and twice throughout the usage period, collecting energy usage data when possible, and assessing the participants' behavior and their usability of the product for primary heating and cooling benefits.

Technology Overview

The technology deployed in this project was Gradient Comfort's window heat pump that uses a low-GWP refrigerant (R-32), with a rated cooling capacity of 8600 Btu/h. Each heat pump is powered by a standard three-prong 120V outlet. The heat pump is installed in vertically hung sash-style windows at least 24" wide and 24" from the floor. Figure 1 shows an installed Gradient heat pump. Each Gradient heat pump comes with an expandable bracket system of either size "large" or size "small", which allows the system to fit windowsill depths between 5"-15". The bracket saddles the window frame and supports the indoor and outdoor components. A high-density foam piece is used to create a seal around the installation bracket and bridge between the indoor and outdoor sides of the Gradient heat pump. Figure 2 shows the installation bracket and high-density foam seal. Each Gradient is designed to condition an individual room sized up to 450 sqft, enabling modular, room-by-room heating and cooling. A simple digital temperature dial on the unit allows users to adjust the temperature set point, mode, and fan speed manually. The mobile app can also be used for remote control and increased functionality such as scheduling and multi-unit operation.

The Gradient window heat pump presents potential advantages over centrally ducted HVAC systems as no structural or electrical alterations are needed for installation. Gradient's variable capacity compressors can provide efficient cooling and heating operation compared to existing modular HVAC technologies such as window ACs or space heaters. Additionally, Gradient users do not lose functionality of windows where units are installed.

Figure 1: Gradient heat pump indoor unit (left) and outdoor compressor unit (right) installed at demonstration sites.

Figure 2: High density foam seal (left) and installation bracket (right).

Project Objectives

This demonstration study was conducted with the objective of gathering a wide range of LMI/DAC residents' user feedback to assess how well the Gradient heat pump technology serves these communities' space conditioning needs. The project team followed a strategy that is focused on community engagement at the demonstration site: (1) site outreach and selection, (2) participant enrollment, (3) technology installation, and (4) collection of participant feedback.

Site Outreach and Selection

Two communities in the California Central Valley participated as host sites for the deployment of the Gradient heat pump units: a multi-family complex in Tracy, CA and single-family homes in a neighborhood near downtown Fresno, CA. These sites were selected because many homes within them have windows compatible with the Gradient heat pump specification and the community organizations that support the sites were willing to actively engage with the project team. Both locations experience similar climate conditions. In the winter, daily highs are commonly in the mid 60ºF and daily lows around 40ºF. In the summer, daily highs are frequently above 90ºF, with Fresno experiencing some hot daily highs closer to 100ºF, and daily lows around mid 60ºF.

In Tracy, the multi-family affordable housing complex is located in a DAC. The community is in a mixed-use residential and commercial area in the northeast part of Tracy. The complex was built ca. 2000 and features a combined community center and management office surrounded by several one- and two-story apartment buildings, with dwelling units ranging from one- to four-bedroom apartments. This site was identified by the project team after engaging two affordable housing developers in the Central Valley and examining 10 potential multifamily complexes. The complex is desirable as a demonstration site because most dwelling units had uniform vertical windows suitable for the Gradient heat pump. The existing HVAC technology at the complex were central ducted heat pump systems with outdoor compressor units for each apartment installed sometime in the last five years. The Gradient heat pumps could provide an advantage over the central ducted systems as they can be controlled on a room-by-room basis, better accommodating the needs of the residents. A total of 40 Gradient heat pumps were demonstrated in 22 participating households at the Tracy site.

In Fresno, the project team leveraged SGC's network and Transformative Climate Cities project and connected with the Fresno Metropolitan Ministry and Lowell Community Development Corporation (CDC), a local community benefit organization. The neighborhood is a DAC near downtown Fresno. Many homes in this neighborhood are of single-family construction, built in the early-to-mid 20th century. These homes have various window types, but many have vertical-sliding windows compatible with the Gradient heat pump. Members of Lowell CDC helped to find eligible single-family homes as host sites, which were inhabited by a mix of homeowners and renters. Lowell CDC's connections, their committed involvement with the project, and the close-knit nature of the Lowell community was a major part of the project's success in recruiting participants. Participating households often did not have central ducted heating and cooling, instead a mix of evaporative coolers, window AC, space heaters, and floor radiators were used. A total of 60 Gradient heat pumps were installed in 23 participating households in and around the Fresno neighborhood.

Participant Enrollment

In Tracy, the project team coordinated with personnel from the community's management team to distribute project materials such as door hanger brochures and fliers to notify tenants of the demonstration opportunity. The project team organized recruiting events in the community center on four different evenings to maximize the number of residents who would be available to attend. A functional Gradient heat pump was installed in a window in the management office, and a demonstration Gradient heat pump was installed on a mock window for showcasing to interested residents. The project team engaged interested residents, answered questions, and signed up participants for the study. Residents who signed up were also encouraged to refer their friends and neighbors to the program.

In Fresno, the team worked with Lowell CDC to distribute program information through paper fliers and e-mail bulletins. The fliers were distributed in both English and Spanish. Lowell CDC hosted a community meeting at their office, where the project team set up a demonstration Gradient heat pump on a mock window and described the project to those in attendance. After the initial flyer distribution and open house event, the news of the study traveled by word-of-mouth throughout the community. A second event was hosted at the CDC office one month later with much greater attendance.

Gradient Heat Pump Installation

The installation team for this project was largely made-up of the authors of this paper. Most of the team are researchers or analysts and no one is a licensed HVAC technician or contractor. Despite this, the Gradient heat pump installations were relatively straightforward. No drilling or building alternations are required for installation and each unit is powered by a standard three-prong 120V outlet. A team of at least two is need for the installations as two people are needed to move and install the 90-pound outdoor compressor unit. Installation of the Gradient heat pumps took place in January and February of 2023 in Tracy and February and March of 2023 in Fresno. In most cases, residents were at home during the time of installation and were able to observe the process and ask the project team questions. Installations were an opportunity for the project team to speak one-on-one with participants, gather feedback candidly, and identify challenges that don't exist in lab settings.

One common challenge during installations was with the high-density foam seal. The compression and tension forces on the high-density foam seal made it difficult to prevent gaps from occurring. Direct feedback from participants in Tracy included draftiness, water intrusion, and noise penetration through the seal. Another challenge was with the window locks used to secure the sliding windows. Some installations used metal track locks, but the majority used plastic adhesive locks. Both lock types were procured by third-party manufacturers. In both sites, the adhesive window locks tended to loosen over time, especially if exposed to direct sunlight. The reduction in adhesive strength lessened the downward pressure on the foam seal and subsequently affected the performance of the seal and the security lock. Some participants also expressed safety concerns over the use of window locks.

Installation in Tracy. Installations in Tracy went smoothly due to the uniformity of windows and apartment floorplans, as well as the ability to store the Gradient heat pumps in a central location on site and distribute them to apartments. Grounded three-prong outlets were consistent throughout the complex, thus all electrical systems in the participating households were compatible with the Gradient heat pump. The windows at Tracy had vertically hung blinds which extended from the top of the window frame down to the windowsill. These blinds had to be cut to allow participants to close their blinds for privacy and security after the Gradient heat pump installation. The project team became responsible for providing the complex with a replacement stock of vertical blinds.

Some heat pumps were installed on the first and second floors on the same side of the building, and thus were located directly above one another. This resulted in condensation from the upstairs outdoor unit falling on the downstairs outdoor unit, and a drain line was added to the upstairs unit to redirect the condensate away from the downstairs unit. One participant in Tracy did not have access to Wi-Fi nor a smartphone to use the Gradient app, which prevented them from using certain features of the unit, such as remote control and scheduling. In addition, at this residence new versions of the firmware had to be manually updated using a mobile hotspot during continued site visits.

Installation in Fresno. Installations in Fresno were more challenging since the host sites covered a much larger geographic area that required more transportation coordination. While most windows in the participating homes were made of solid wood, they were of varying size, age, and condition. Some windows designated for installations had been painted shut and required cutting the windows free before they could be opened, and some windows had window AC units that had to be removed ahead of time to install the Gradient heat pumps. Many windows were wider than 36 inches, the dimension Gradient configures their foam seal package for, so extra foam had to be used to seal these windows. Windowsills were of varying depth and required different bracket sizes to install Gradient heat pumps. Adhesive window locks were exclusively used in Fresno since windows usually did not have a track suitable for using aluminum track locks.

Finding adequate power outlets for Gradient heat pumps was another challenge in Fresno. Home electrical systems were often dated, and many homes had only ungrounded, two-prong outlets near the windows. Extension cords rated for the Gradient heat pump were used in homes with three-prong grounded outlets farther from the window, and some windows were unable to be used due to insufficient power access. Participants in Fresno also had concerns about break-ins, as many of them had previous experiences with break-ins in the downtown neighborhood.

Follow-up visits. After the installations, participants who experienced difficulties with the Gradient heat pumps reported issues to the project team. While some issues were able to be resolved remotely, others required in-person troubleshooting, and two heat pumps required full unit replacements. A total of six follow-up visits were made to perform check-ins and address requests for service of installed units. Many units were fully functional throughout the duration of the study.

Six participants in Tracy elected to exit the study for various reasons. For example, one participant forfeited from the study after just one week of participation, citing noise and security concerns from an encampment adjacent to the complex. Another had one of their two Gradient heat pump units removed due to an intrusion of insects through the window seal. As of the date of this paper, no participants in Fresno have elected to leave the study. Fresno participants have generally been more patient with any issues that occurred with the Gradient heat pumps, likely because the existing HVAC systems were not as reliable as those in Tracy.

Participant Feedback

Surveys were the main method of collecting community feedback on the Gradient heat pump. Three surveys were administered throughout the study to capture both the initial and long-term experience with the demonstration. The surveys were administered on paper in English, but verbal and written Spanish translations were provided when needed. Where possible, in-person verbal communications also occurred concurrently to clarify questions and gather additional feedback.

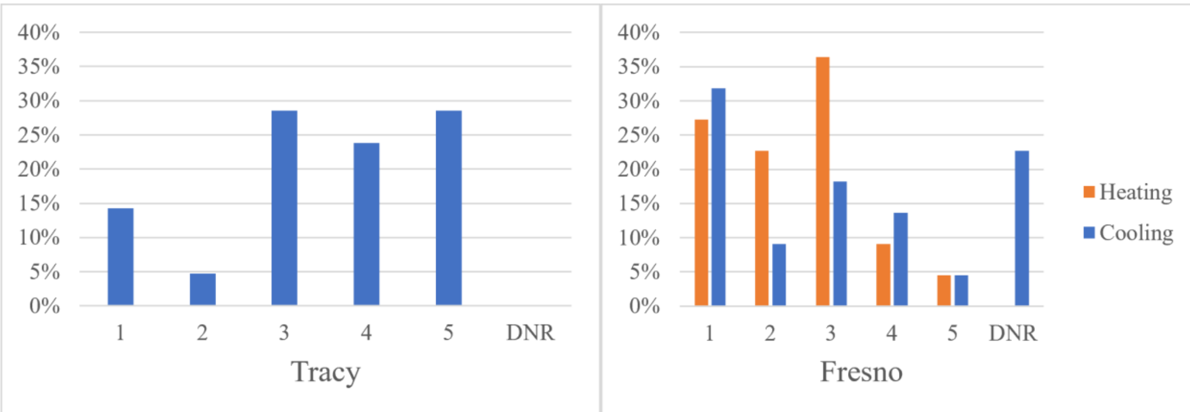
The first survey was conducted during the installation of the Gradient heat pump in the residence of each participant. At the Tracy site, installation and surveying began in mid-January of 2023 and continued through mid-February. At the Fresno site these efforts began in late February of 2023 and continued through late March. The first survey was designed to capture demographic data as well as first impressions of the unit's appearance, the installation process, and initial experience with the unit's performance. Information obtained from the installation surveys also included residents' perception of their existing HVAC systems. The second survey was conducted 1-2 months after the Gradient heat pump installations. This survey was designed to solicit feedback on the unit's performance and user experience. The third and final survey was conducted at the end of summer and was designed to track any changes in the perceived performance and user experience since the second survey. Many questions were included in all surveys in attempt to account for subjectivity in the perception of the Gradient heat pump over time. Table 1 shows the number of participants that responded to each of the three surveys in the Tracy and Fresno locations.

The first two surveys issued a reward (Visa gift card) for completion whereas the final survey did not. As a result, the team had difficulty communicating with participants towards the end of the demonstration period and the final survey had significantly fewer responses than total participating households which may skew results and understanding. In the future this could be mitigated through more consistent communication and a more appealing reward structure. Additionally, on each of the three surveys there were questions that certain participants did not respond to. The reason for this is unclear, but it could be because the answer was unknown or irrelevant to the participant, or in some cases language barriers could have made answering the questions difficult. On Figures 3-12, the percentage of participants who did not respond to the relevant question are shown as "DNR".

Table 1: Number of participating households and respondents for each survey at Tracy and Fresno

	Installation survey	Second survey	Final survey	Total participating households
Tracy	21	19	13	22
Fresno	22	22	14	23

Installation survey responses. The first survey asked participants about their satisfaction with their previously existing HVAC systems to ascertain the baseline space conditioning efficacy. This is important as the baseline may impact the perception of the newly installed Gradient heat pumps. The existing HVAC systems were rated on a scale of 1 to 5, with 5 being the most satisfied. In Tracy, where the existing systems performed both cooling and heating, overall satisfaction ratings were collected. In Fresno the satisfaction data was separated into heating and cooling as many homes in the study had different devices for each. As shown in Figure 3, over 80% of participants in Tracy gave a rating of 3 or above for the overall rating of the existing centralized HVAC system installed only 5 years ago. For Fresno, most participants were neutral to unsatisfied with their existing systems, reflecting the lack of adequate or cost-effective space conditioning systems found in homes across the site. As shown in orange on the right plot of Figure 3 over 25% of participants in Fresno gave their existing heating systems the lowest rating



and as shown in blue over 30% gave their existing cooling systems the lowest rating.

Figure 3: Resident satisfaction of the currently installed system with 1 being least satisfied and 5 being most satisfied for each demonstration location – Tracy and Fresno.

The survey also asked participants to evaluate the operating cost of their existing system as a multiple-choice question with the following options: “Expensive”, “Neutral”, and “Inexpensive”. Figure 4 shows that participants in both sites predominantly felt that the cost of heating and cooling was too high at their residence. A bias in responses to this question may exist since residents who were not satisfied with their utility costs may be more likely to participate in this demonstration of a new efficient HVAC system.

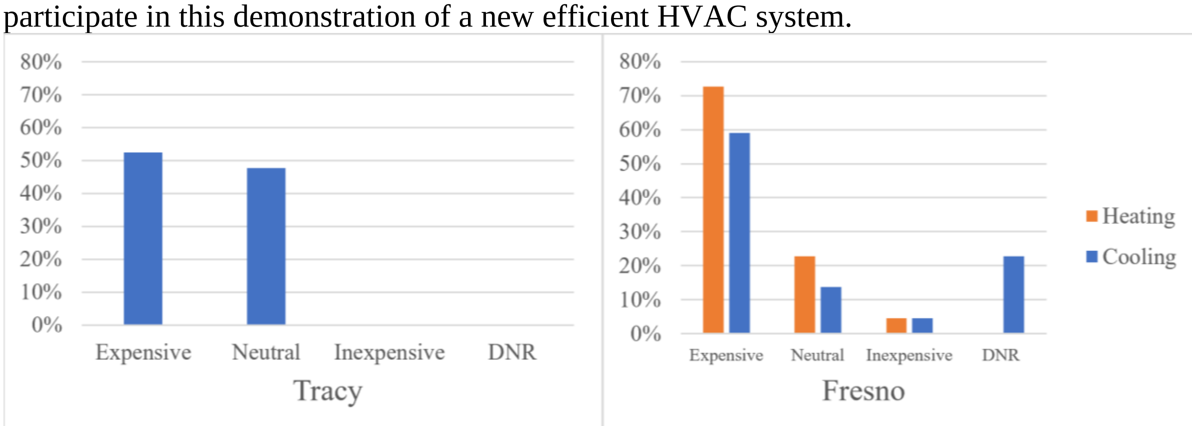


Figure 4: Resident cost evaluation of the current system by for each demonstration location – Tracy and Fresno.

Another question on the survey sought to determine if additional HVAC appliances were being used to supplement space conditioning in the household. Figure 5 shows that only 20-30% of the participants in Tracy needed additional heating or cooling. Conversely, in Fresno approximately 60% needed some form of additional cooling and heating when using their existing system. The higher summer temperatures in Fresno can account for some of this discrepancy. A common survey response in Fresno is the dissatisfaction with the efficacy and reliability of the existing cooling system, which also indicates a difference in baseline cooling system performance across the two sites.

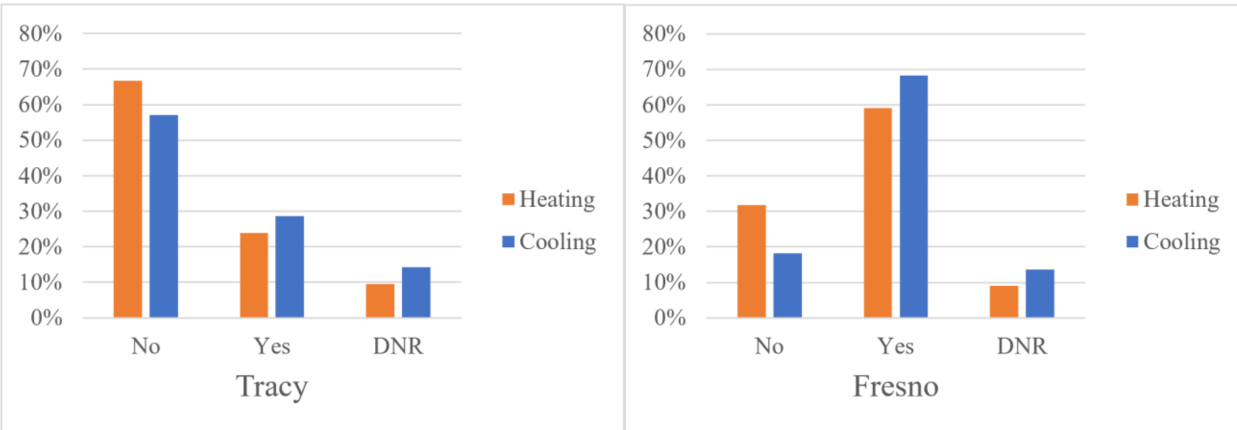


Figure 5: Percentage of residences that currently use additional plug-in appliances such as space heaters or window ACs to supplement space conditioning for each demonstration location – Tracy and Fresno.

Second and final survey responses. The second and final surveys asked participants to rate their overall satisfaction with the Gradient heat pump on a scale of 1 – 5, with 5 being the most satisfied with the unit. When the second survey was conducted, the participants had only experienced the unit for a few weeks on average. This also coincided with more mild spring weather. On the other hand, the final survey was conducted after the participants had used the Gradient heat pump in the summer months, and sufficient time had passed to remove short-term bias from having a new system in their home.

Figure 6 shows the responses for this question. For the second survey (in orange), the most common rating for both sites was 5, the highest possible rating, with 53% at Tracy and 41% at Fresno. In Tracy, the satisfaction trended downward on the final survey (blue). 31% of participants gave ratings of 3, and the number of participants rating 5 reduced to 31% as well. In Fresno, the percentage of participants giving a rating of 5 decreased to 21%, and the majority (57%) gave a rating of 4. Across both sites, participants who gave ratings under 3 also provided qualitative responses that highlighted both perceived shortcomings in design - such as difficulty with the app control and a lack of child-proofing measures - and issues with performance stemming from malfunctions that occurred in some units in the deployment batch - such as firmware glitches and intermittent shutoffs.

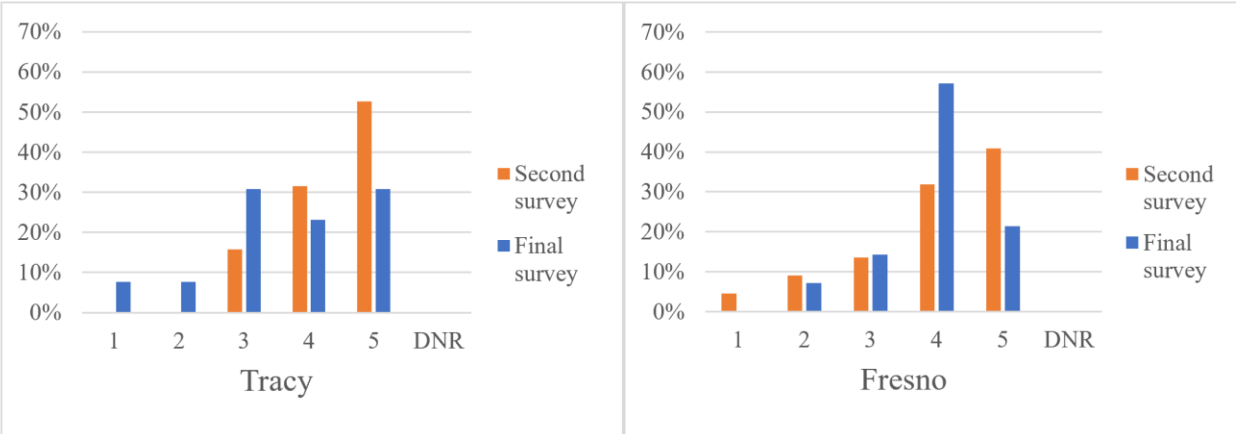


Figure 6: Ranking of Gradient heat pump performance by participants after a few weeks (Second survey) and again after over 6 months of use (Final survey) for Tracy and Fresno, with 1 being worst performing and 5 being best performing.

The participants were surveyed on how frequently the Gradient heat pump maintained a comfortable temperature at their residence. Figure 7 illustrates the responses on the second (in orange) and final surveys (in blue) for both sites. In Tracy, the percentage of participants who answered "All the Time" decreased from nearly 90% in the second survey to 54% in the final survey, indicating a decrease in perceived comfort and satisfaction with the heat pump's performance over the demonstration period. Similarly, in Tracy ~30% more participants answered "Sometimes" on the final survey. In Fresno, the distribution of responses stayed nearly constant over time.

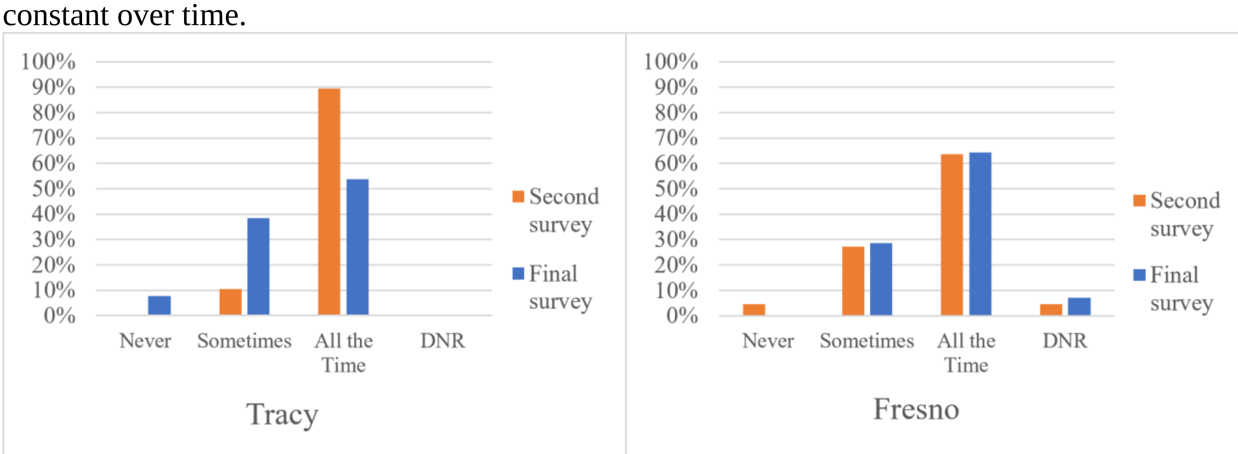


Figure 7: Response distribution for frequency that the Gradient heat pump maintains a comfortable temperature as stated by participants at each demonstration location – Tracy and Fresno.

Participants were also asked a series of questions regarding the ease-of-use of the Gradient heat pump, as well as their preferred method of controlling the unit (app vs on-unit dial). One question specifically asked participants whether they had success using the app, since many of the negative responses from the installation survey related to app connectivity and operation. In both Tracy and Fresno, results from the second survey showed that around 35% of participants were unable to reliably control the heat pumps with the app. By the final survey, over 50% of participants across both sites were unable to use the app to control the Gradient heat pumps. Despite the app related issues, ~62% of the Tracy participants and 36% of the Fresno participants said they would rather use the app than the physical dial on the device to control their system, which highlights the need for further development of the unit's control systems.

Another survey question asked participants to rate the ease of operating the Gradient heat pump on a scale from 1 – 5, with 5 being the best and easiest to operate. Figure 8 highlights the spread of user difficulty at both sites. In Tracy, most respondents selected 5 – meaning that the unit was easy to operate – in both the second survey (orange) and the final survey (blue). In Fresno as a function of time, there appeared to be slight middling effect on this question, with less extreme responses on either end (1 or a 5) for the Final Survey. This could have been due to more exposure to the device enabling people to become more comfortable operating it, while also allowing for more complications with the device, or glitches with the app, to occur.

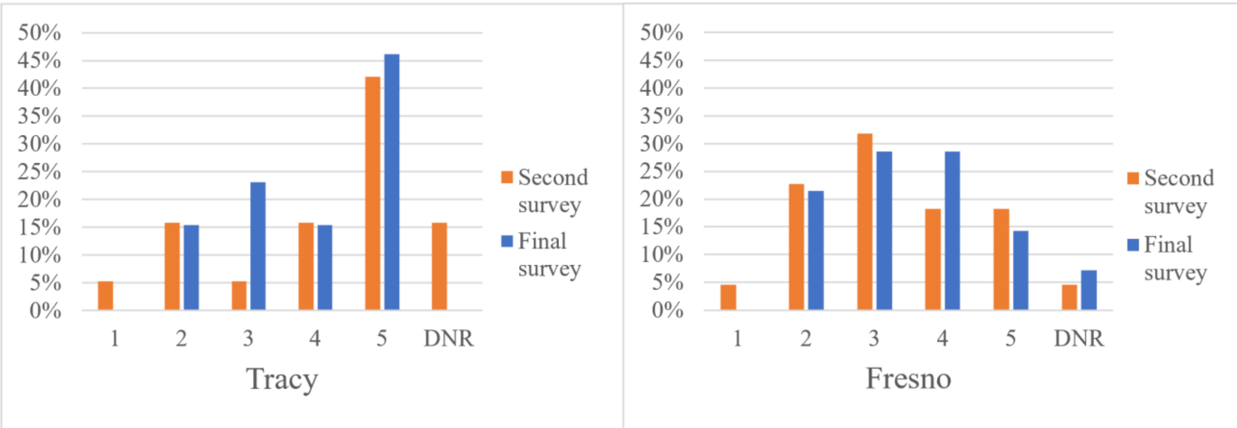


Figure 8: Ranking of how easy it was to operate the unit either through the app or by using the dials on the unit itself with 1 being most difficult and 5 being easiest at each demonstration location – Tracy and Fresno.

Most of the 23 participants who completed the final survey had more than one unit installed in their home. These participants were surveyed on whether they preferred to use the Gradient heat pumps in a modular "room-by-room" fashion or to use all installed units simultaneously. Result of this survey question are shown in Figure 9. Most participants used the Gradient heat pumps in a modular fashion, controlling each unit individually as needed. This could suggest energy saving opportunities, but comprehensive analysis that includes evaluation customers' utility billing to verify changes in energy usage is needed for more conclusive results.

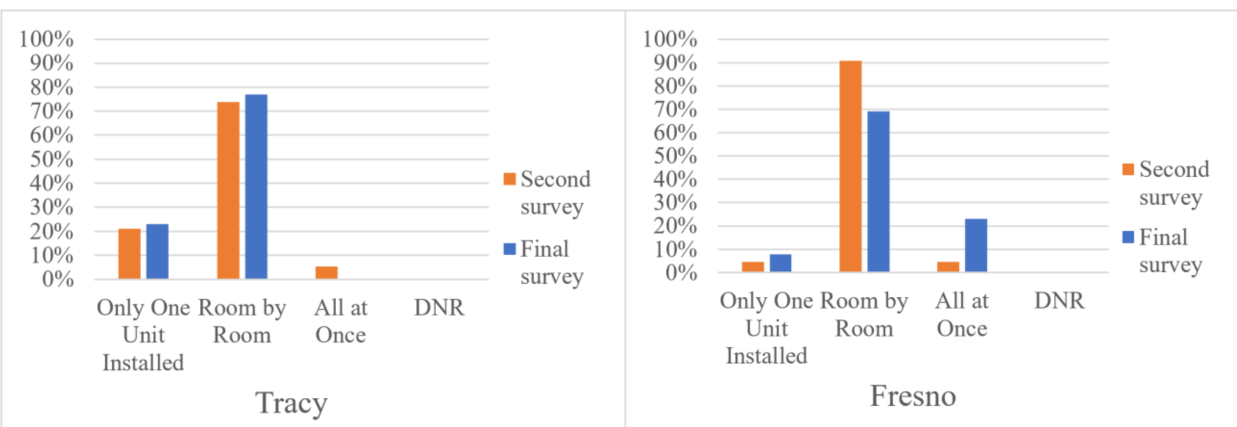


Figure 9: Results of how the residents preferred to use multiple Gradient heat pumps within the home at each demonstration location – Tracy and Fresno.

The residents were asked to report on the perceived effect that the Gradient heat pump had on their utility bill, as shown in Figure 10. From the second survey, it appeared that the window of time was too short to make any assessment given that the participant being "Unsure" of the effect was the most common response. After the final survey, there was a roughly 25% increase in participants observing an increase in their utility bill at Tracy, which is expected for the summer months. At Fresno, there were higher percentages of participants claiming their utility bill increased as well as decreased. Overall, the results of this question did not seem to elucidate any trend in the impact of the Gradient heat pump on a participant's bill. Analysis is ongoing, including power metering and collecting utility data, to better assess the impact of Gradient heat pumps on utility bills.

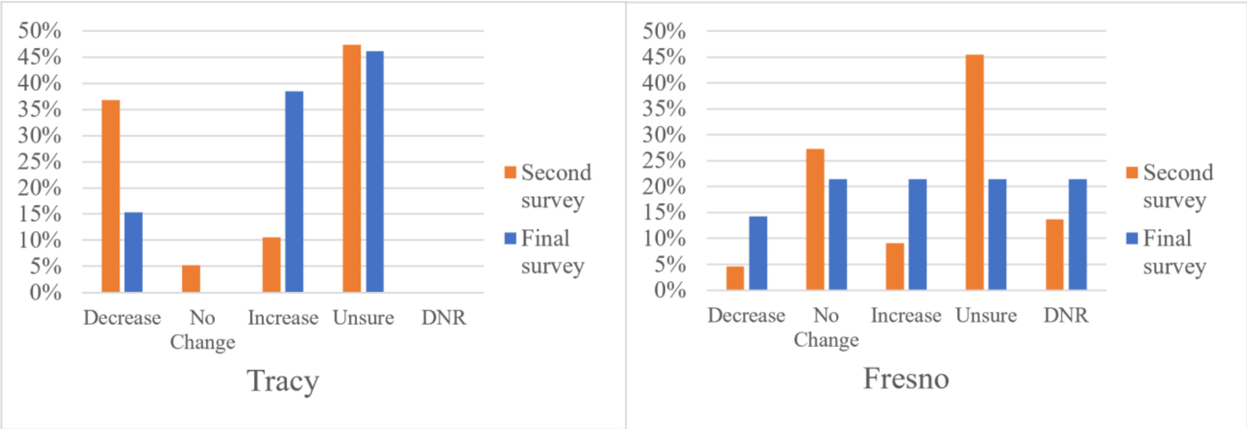


Figure 10: Resident evaluation of how their utility bill changed with the installation of the Gradient heat pumps at each demonstration location – Tracy and Fresno.

The participants were also asked if they would refer a friend or family member to get a Gradient heat pump, and whether they would like to continue with the study or end the study. Based on the results of the answers collected, most participants of the survey would recommend the device to friends or family, as seen in Figure 11. Similarly, most participants agreed to continue the study, particularly at the Fresno site, as seen in Figure 12.

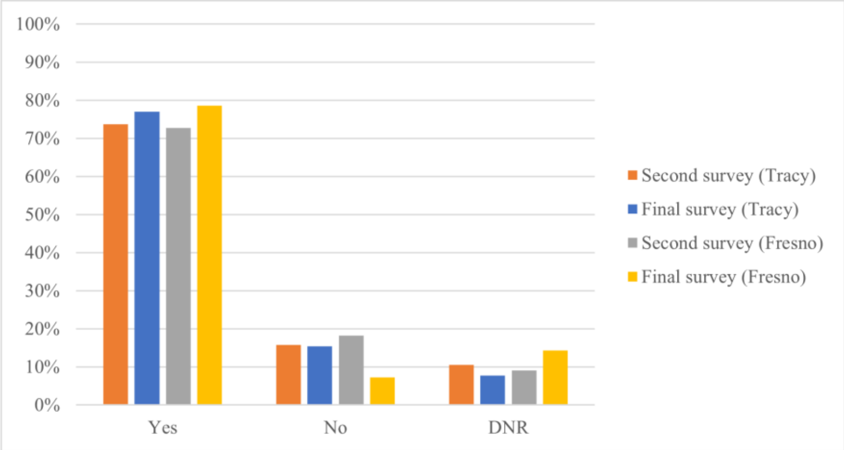


Figure 11: The percentage of participants that would recommend a Gradient heat pump to a friend.

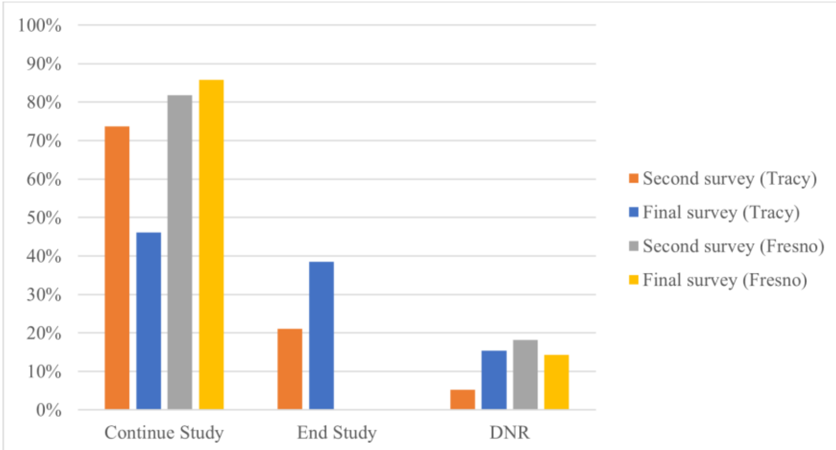


Figure 12: The percentage of participants that agreed to continue the study after the survey was conducted.

Discussion

The demonstration of 100 units represents the largest field study of 120V Gradient heat pumps to date, and the large quantity of participants and units can accelerate the process of gathering feedback and making product improvements. This study also enabled 45 households to transition to an electrified source of heating and reduce GHG emissions in a tangible way. With the inevitable transition to a low-carbon future, a technology that can be easily installed without technicians and electrical upgrades holds tremendous potential in electrifying homes in CA and across the U.S. Additionally, this study's focus on DAC provides invaluable insights on program and product design which will benefit countless homes in the Central Valley.

In general, when asked to rank their overall satisfaction with the heat pumps after over 6 months of use, the average score from Tracy participants was a 3.62 out of 5, and for Fresno it was slightly higher at 3.93 out of 5. This seems to reflect that most participants were satisfied with the performance of the unit but acknowledge there is some room for improvement. Additionally, across both sites, over 75% of the participants said they would recommend the Gradient heat pump to a friend. This demonstration project was largely successful, there are key areas for improvement that have been identified and natural next steps for the project.

Gradient App Connectivity

One particularly common challenge was with the Gradient heat pump's control app. As described in the previous section, many participants experienced issues with operating the Gradient heat pump through the app, with nearly a third of all participants having consistent issues during the study. Even with these setbacks, most participants still preferred to control the unit with the app as compared to the physical dial on the unit. This suggests that a heat pump system with a well-functioning app can immensely improve the deployment of heat pumps as a means of electrification.

Even though the app issues created hurdles in this demonstration, the Gradient heat pump's connectivity also provided a simple and effective avenue for software updates that address the participant's feedback. During the first three months of the study period, two significant software updates were released that added features to the user interface, enabling greater customization of temperature control and fan speed, all developed from user feedback.

Follow up engagement with the participants after these updates confirmed a better user experience as a result.

Installation and Foam Sealing

Feedback about the installation process was generally positive, with participants commenting about the speed of installation and not needing to puncture walls. This was very well-received by landlords and homeowners. The expandable bracket system proved to be very versatile, and the modular sealing foam enabled installations on a wide range of window widths. However, the positive feedback during the installation is contrasted with some negative feedback during the demonstration on the effectiveness of the foam sealing. Up to 35% of participants across both sites stated that a draft was present at least part of the time, which likely resulted in some negativity towards the product. Poor sealing not only creates drafts indoors, but also creates security risks and vulnerabilities for water and insect intrusion. The leakage of conditioned air can also result in higher economic burden and the unit operating much more frequently.

While the simple installation process of the Gradient heat pump is a huge benefit since it does not require licensed technicians, additional research should be invested in the seal strategy to ensure quality installations. Installation team training and post installation walk throughs maybe low-hanging fruit solutions. The installation phase of the project also saw several participants that enrolled with windows that are incompatible with the Gradient heat pump. Future deployments should consider site assessments during the enrollment phase, which can result in a more efficient enrollment and installation process.

Cost Analysis

Another area for improvement within the study is to perform an in-depth utility bill and usage analysis. As cost effectiveness is often seen as the most important factor in adoption, it is critical to holistically understand the economic implications of the Gradient heat pump. For LMI/DAC communities, utility bills may be especially burdensome, and conversations with participants of the demonstration study highlighted this concern. Ensuring that electrification products and programs are designed with this in mind could better enable equitable electrification. The surveys administered did ask participants how they perceived their change in utility bills after the installation of the Gradient heat pumps, but the surveys failed to capture further details such as usage patterns, change in weather, or occupancy alterations. Accordingly, no conclusions were able to be made about the impact of the Gradient heat pump on utility bills. The project team is currently collecting and analyzing utility bill and usage data from participants to gain a better understanding of how the heat pumps may financially affect users. In addition, for future work, more consistent check-ins with participants on how they are using the installed units and how the conditions affecting the usage may be changing, would allow for clearer understanding of bill impact.

Future work should also include additional cost analysis for completeness. This should include the upfront cost of competing systems, installation costs, electrical service costs if applicable, maintenance costs, and any utility bill impacts. The project team will continue to work on these analyses in further efforts to ensure the product and any programs supporting it are designed to accommodate the needs of LMI/DAC communities.

Community Engagement

The community engagement strategy employed in this demonstration project was largely successful and allowed for valuable insights about working with LMI communities. Collaborating with community organizations to host events and engage with residents helped to foster more trusting relationships between the project team and the participants. Using surveys as the primary method of feedback was also largely successful, but a few small changes could have introduced significant results. For example, the two surveys where a cash reward was issued upon completion had a much greater response rate than the survey with no reward. Altering the incentive program such that rewards were issued with each survey may have seen a greater number of respondents and more cohesive feedback. The team also saw that some of the most detailed responses were recorded when the surveys were issued verbally during an in-person visit. In these instances, the residents were able to ask questions to the project team if the survey question was not clear to them and the project team was able to ask questions to the resident if their response needed additional clarifications. In future projects issuing surveys in-person or fine-tuning questions to reflect what information was gathered through in-person interactions may allow for more detailed and relevant feedback.

Community outreach was noticeably more successful in Fresno than Tracy. Two potential explanations for this difference are 1) the nature of the community, and 2) the existing HVAC equipment. The community in Fresno is very tight-knit and many participants referred their friends and neighbors to the study. In contrast, there seemed to be fewer interpersonal connections between neighbors at the Tracy multifamily complex. The existing HVAC systems in Fresno were also much less reliable than the central HVAC system installed in Tracy. Many of the Fresno participants were eager to have access to better cooling performance during the summer, thus boosting community interest in the project. This seems to suggest that closer-knit communities and communities with dated HVAC systems may be more receptive to similar demonstrations in the future.

Conclusion

This paper describes the field demonstration of 100 120V window heat pumps in LMI/DAC in California's Central Valley. The demonstrated heat pump utilizes low GWP refrigerant, does not require professional technicians for installation, and offers participants dual heating and cooling Community engagement was emphasized as the key component in this project and resulted in effective participant recruitment and insightful feedback. This holistic approach is effective and impactful for technology development and adoption. While there were some issues with app connectivity and window foam sealing, the demonstration is largely a success with positive and constructive feedback from most participants. This deployment represents the start of a two-year test period, and the project team will continue to monitor power consumption and utility bills to understand the energy savings impact through different seasons and demands. Future analyses will also aim to evaluate changes in quality of life and comfort in conjunction with utility bills. The goal of this will be to understand economic and societal impacts simultaneously. This quantitative analysis will be foundational to designing appropriate utility programs that focuses on LMI/DAC.

Future research with the Gradient heat pump can also investigate the unit's performance in different settings, such as cold climate applications and urban environments. The Gradient heat pump's built-in connectivity, variable speed compressor, and accompanying app gives it excellent potential as a distributed energy resource and should be comprehensively evaluated in future studies.

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