

The new low-carb diet: an assessment of California’s new fuel substitution decarbonization policy in practice

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ABSTRACT

Avoiding the most detrimental impacts of climate change requires that we decarbonize our economy quickly. Heat pumps are one of a few market-ready and scalable technologies that can significantly and efficiently reduce climate changing emissions from residential space and water heating. Demand side management programs are a potential mechanism through which to influence end users and market actors. However, we are only starting to understand the costs and impacts of decarbonization efforts through these programs.

The focus of the paper is a recent evaluation of residential HVAC fuel substitution measures incentivized by California investor-owned utilities (IOU) in program year 2020. In this case, the fuel substitution involves residential gas-to-electric conversions of furnaces to heat pumps. This represents the first evaluation of IOU energy efficiency portfolio funded residential HVAC fuel substitution claims under the newly revised California Public Utilities Commission fuel substitution policy following Decision 19-08-009 in August 2019.

The paper reviews the application of a gross savings evaluation methodology that uses broad scale web-based surveys and advanced metering infrastructure based normalized metered energy consumption with a matched comparison group to analyze midstream fuel substitution measures at scale and remotely. Ultimately, the paper presents keys to success for enabling rapid market adoption of low-carbon heating and high efficiency cooling in existing residential buildings. Research results include carbon and other GHG savings, utility customer bill impacts, a breakdown of participation by customers in disadvantaged communities, as well as drivers or barriers for adoption and satisfaction.

Introduction

The paper presents DNV’s energy savings estimates (impact evaluation) of residential heating, ventilating, and air conditioning (HVAC) heat pump fuel substitution technology groups (measures) that are part of the California Public Utilities Commission (CPUC) HVAC Research Roadmap (DNV 2022). These measures are evaluated under the CPUC’s Group A contract, which is focused on deemed measures in the energy efficiency portfolio. The primary results of this evaluation are the estimated site energy savings (in kWh and therms), source energy savings (in Btu), and greenhouse gas emissions reduction (in metric tons of CO₂) achieved by two selected HVAC measures—residential ductless HVAC heat pump fuel substitution and residential central HVAC heat pump fuel substitution—in program year 2020 (PY2020).

Heat pumps are a type of reversible air conditioning technology that transfer thermal energy using the refrigeration cycle. HVAC heat pumps can provide both space cooling when operating as an air conditioning system, and space heating when the refrigeration cycle is operated in reverse. HVAC heat pumps therefore provide an opportunity for fuel substitution for

existing gas-fired furnace and one-way direct expansion air condition systems. Space heating using heat pumps is less carbon emissions intensive when fueled with fully or partially emissions-free electricity sources compared to gas-fired furnaces. Heat pumps are also more efficient at providing space heat than electric resistance powered systems, which may be used to supplement central gas-furnaces. Heat pumps are an integral technology for building electrification undertaken to meet decarbonization goals, and thus these fuel substitution measures aim to accelerate the adoption of heat pumps replacing gas-fired heating equipment.

A southern California investor-owned electric utility program administrator (PA) offered incentives that offset the cost to convert existing residential gas space heating and electric AC cooling equipment to electric heat pumps in PY2020. The program is implemented as a midstream design, targeting participation of HVAC equipment distributors for enrollment, as opposed to a downstream design aiming to directly engage the utility customers. The PA offered these electrification measures following the 2019 CPUC Decision 19-08-009 that permits the inclusion of fuel substitution measures in the energy efficiency portfolio of regulated investor-owned utilities so long as they meet the two-pronged fuel substitution test calculations (CPUC 2019a). The fuel substitution test requires that the lifecycle source energy consumption (Btu) and emissions intensity (CO₂ metric tons per unit) of the fuel substitution measure must be less than the baseline technology it is replacing. These requirements are driven by decarbonization policies including AB 32, the California Global Warming Solutions Act of 2006 (California State Legislature, Assembly 2006).

HVAC Fuel Substitution Measure Description

The two residential HVAC fuel substitution heat pump measures — residential ductless HVAC heat pump fuel substitution (measure package ID SWHC044) and residential central HVAC heat pump fuel substitution (SWHC045) — were the only two HVAC fuel substitution measures claimed by the PAs in PY2020. The two residential HVAC fuel substitution heat pump systems measure groups, when combined, had the highest gross lifecycle gas savings claim in the residential sector and in the prescriptive portfolio overall in PY2020 as well as the largest contribution to lifecycle gas savings in PY2020. While they reduce the use of the fuel they substitute away from (gas), they necessarily increase the fuel they use in its place (electricity). Of the two measure groups, the PA reported nearly six times as many ductless HVAC fuel substitution measure claims (4,494) as they did central HVAC fuel substitution measure (763).

The ductless HVAC heat pump fuel substitution technology is intended to replace the use of an existing residential ductless natural gas furnace such as a gravity wall furnace, either with or without a separate existing residential ductless window air conditioner unit. The heat pump provides high efficiency electric heating and cooling as a substitute for gas heating system and perhaps standard efficiency cooling system as well. In general, relative to central ducted systems, ductless systems are more compact and have lower heating and cooling capacities, so they are usually installed in smaller residential dwelling units.

The central HVAC heat pump fuel substitution technology is intended to replace the use of an existing residential central ducted natural gas furnace and air conditioning HVAC system. Like the ductless technology, the central heat pump provides high efficiency electric heating and cooling as a substitute to existing central gas furnace and AC systems.

Methodology

The methodology section provides high level descriptions of the data collection activities and the methods used to evaluate site energy consumption impacts, source energy consumption impacts, CO₂ GHG emissions reductions, utility customer bill impacts, and program participant characteristics. Principally, the site energy impacts were derived from an analysis of advanced metering infrastructure (AMI) energy consumption records for periods before and after the fuel substitution measures. Source energy and CO₂ GHG impacts were determined using the site-level impacts and the CPUC's Fuel Substitution Calculator tool (CPUC 2019b). Similarly, utility customer bill impacts were calculated from the applying blended residential rate schedules to the calculated changes in site energy consumption. End-user utility customer participant self-report surveys served to provide the basis of analysis for understanding baseline conditions, energy use behavior, and site characteristics. Table 1 provides a summary of the study's data sources and the purpose of their inclusion.

Table 1. Summary of data sources and purposes

Data sources	Description	Purpose in evaluation
Program Tracking Data	PA Program data includes number of records, savings per record, program type, name, measure groups, measure description, incentives etc.	To identify program participants, installed measures, installation dates, and claimed (ex ante) savings
Detailed Program Participation Data	Site level information including customer addresses, names, and contact information, installation dates, and details on installed equipment, distributor and contractor names and contact information	To identify participating sites (including customer and premise IDs), contact information for end-user, contractor, and distributor surveys
Energy Use Data	PA monthly billing electric and gas data, and hourly electric and daily gas interval (AMI) data	To construct comparison groups, estimate energy savings, and construct pre-post-participation daily load shapes
Customer Data	Customer location (zip code), climate zones, and household-related information (household size, age composition, income, ownership status)	To construct comparison groups and estimate ex post measure savings estimates
Manufacturer Specification Sheets	Data sheets that include equipment specifications such as horsepower (HP), efficiency, capacity, etc.	To inform installed HVAC unit characteristics
Weather Data	Hourly temperature and dew points for the relevant analysis period and locations, and typical meteorological year (normal) weather data	To weather normalize energy consumption

Data sources	Description	Purpose in evaluation
Telephone/ Web Surveys	Surveys of participating utility customers, contractors, and distributors, and PA program staff.	To determine net-to-gross ratios (NTGRs) and net savings To inform baseline conditions, energy use behavior and site characteristics

AMI analysis

The study's gross energy savings analysis is based on a two-stage modeling approach that estimates the effect of program measures on energy consumption of homes receiving the measures. The first-stage uses site-level models to weather normalize energy consumption. The second stage uses a difference-in-difference (DID) approach based on the pre-to-post difference of weather normalized energy consumption of participant and matched comparison households to estimate savings. The first-stage models control for the effect of weather on energy consumption while the second stage models control for the effect of non-program changes on energy consumption.

The two-stage approach has a long track record in energy program evaluation and is attractive for a variety of reasons including:

- Site-level focus
- Full use of weather information at the daily level
- Separation of the weather-normalization process from savings estimation
- Use of a comparison group as a proxy for non-program-related change

This methodology is consistent with the approach laid out in the Uniform Methods Project (UMP) Chapter 8 modeling approach, which provides energy savings estimation protocols for energy efficiency interventions that have whole-home impacts like heat pumps (Agnew and Goldberg 2017). It is also consistent with CalTRACK, which involved efforts to develop agreed upon steps for site-level modeling (CalTRACK 2022).

Results

This section presents the results of the AMI analysis of site energy impacts, the subsequent source energy and CO₂ emissions impacts, the estimated impacts to participating utility customers' energy costs, and the characterization of the program's utility customer participants.

Site Energy Impacts

Site energy savings are the energy consumption reductions at the utility customer site and are the values the PAs report as savings. The PAs report both gross and net savings. Gross savings are the changes in energy consumption resulting from the installation of energy efficient technologies offered by PA programs, regardless of what factors may have motivated program participants to install these measures. Net savings are the portion of gross savings attributable to a program's influence. The focus of this paper is gross savings impacts.

Ductless HVAC systems. DNV estimated the changes in annual weather normalized electricity and gas consumption of participating sites to evaluate the magnitudes of the decrease in gas and increase in normalized electricity consumption (NAC) from the installation of ductless heat pumps. Table 2 below illustrates the consumption change estimates. The results indicate a statistically significant but modest 3% annual savings in annual gas consumption. On the other hand, there is a statistically significant increase of 3% in annual electricity consumption. The savings in gas consumption is associated with an estimated 7% savings in gas heating load, while the estimated annual increase in electricity consumption is associated with an estimated 21% addition in electric heating load. Sites with ductless heat pumps also appear to have a modest electric cooling savings of 2%.

Table 2. Evaluated annual energy change¹ per site for ductless heat pump systems

Fuel	Model	Baseline consumption (therms)	Change (therms)	% Change	P-value	Relative Precision ²
Gas	NAC	415	11	3%	0.00	40%
	Heating load	182	12	7%	0.00	28%
Fuel	Model	Baseline consumption (kWh)	Change (kWh)	% Change	P-value	Relative Precision
Electric	NAC	9,035	-315	-3%	0.00	26%
	Cooling load	1,947	32	2%	0.00	138%
	Heating load	326	-70	-21%	0.00	34%

Central HVAC systems. Table 3 provides the estimated gas and electricity consumption changes per sites for central heat pumps systems. The results indicate normalized annual gas consumption (NAC) savings of 35% and gas heating load savings of 59%. Annual electricity consumption increases by 7% with an electric heating load addition of over 200% and cooling load reduction of almost 20% from the installation of central heat pumps. Gas consumption savings from central heat pumps are over ten times higher than such savings from ductless systems. Similarly, central heat pumps have electric heating increases and electric cooling savings that are ten times those of ductless systems.

Table 3. Evaluated annual energy change³ per site for central heat pump systems

Fuel	Model	Baseline consumption (therms)	Change (therms)	% Change	P-value	Relative Precision ⁴
Gas	NAC	436	152	35%	0.00	12%
	Heating load	199	118	59%	0.00	12%

¹ Positive values indicate savings or decrease in consumption and negative values indicate increase in consumption

² Relative precision values with 90% confidence.

³ Positive values indicate savings or decrease in consumption and negative values indicate increase in consumption

⁴ Relative precision values with 90% confidence.

Fuel	Model	Baseline consumption (kWh)	Change (kWh)	% Change	P-value	Relative Precision
Electric	NAC	9,640	-715	-7%	0.00	27%
	Cooling load	2,422	459	19%	0.00	30%
	Heating load	272	-562	-207%	0.00	25%

Overall site energy impacts. Table 4 and Table 5 compare the evaluated gas and electric savings per site and per ton against reported values. Evaluated electric consumption increases from both technology types are about two-thirds of what is reported; gross realization rates (GRR) for these measures are approximately 65%. On the other hand, the ratios of evaluated to reported gas consumption savings are different for the two technologies. Central heat pumps delivered 75% of reported gas savings while ductless heat pumps delivered only 5% of reported gas savings.

Table 4 Reported and evaluated annual gas energy change and relative precision

Measure	Gas savings (therms) ⁵					
	Per site		Per ton		GRR, evaluated to reported	Relative precision ⁶
	Reported	Evaluated	Reported	Evaluated		
Ductless	243	11	86	4	5%	40%
Central	202	152	46	35	75%	12%

Table 5. Reported and evaluated annual electric energy change and relative precision

Measure	Electric savings (kWh)					Relative precision
	Per site		Per ton		GRR, evaluated to reported	
	Reported	Evaluated	Reported	Evaluated		
Ductless	-465	-315	-165	-112	68%	26%
Central	-1,118	-715	-255	-163	64%	27%

Principally, these site energy impact results suggest the ductless heat pump systems are not serving to sufficiently displace the existing gas-fired heating load in the same manner as the ducted, central heat pump systems are in this application.

Source Energy Impacts

The reported and evaluated source energy savings is based on the outputs of the CPUC's Fuel Substitution Calculator v1.1, using the total gross reported and evaluated site energy savings and other pertinent measure details as the inputs into the custom calculator segment. In reviewing the source energy savings, it is important to understand that in the fuel substitution test "only the source energy from depletable fossil-fuel resources are currently considered" by the CPUC. The CPUC approach considers "the source energy and emissions for renewable

⁵ Positive values indicate savings or decrease in consumption and negative values indicate increase in consumption

⁶ Relative precision values with 90% confidence

generation, such as solar, wind, and hydro-electric generation, to be zero.” Thus, source energy savings are the savings only from natural gas combustion “either through power generation or in direct combustion for the end-use” (CPUC 2019c).

Table 6 below presents the evaluated and reported first-year full energy savings and the lifecycle source energy savings, in MMBtu, for both the ductless and central HVAC technologies.

Table 6. Reported and evaluated first-year and lifecycle source energy savings

Measure and result source	First year Full Energy Savings (MMBtu equivalent)			Lifecycle Primary Energy Savings (MMBtu at generation source)		
	Per site	Per cooling ton capacity	Program total	Per site	Per cooling ton capacity	Program total
Ductless, evaluated	0.02	0.01	209	1.04	0.40	7,851
Ductless, reported	21.8	7.8	153,629	328	117	2,311,384
Ductless, ratio of evaluated to reported	0.11%	0.14%	0.14%	0.32%	0.34%	0.34%
Central, evaluated	12.8	2.9	14,326	193	44.0	216,588
Central, reported	16.4	3.7	18,383	248	56.6	278,411
Central, ratio of evaluated to reported	77.9%	77.9%	77.9%	77.7%	77.8%	77.8%

The results for ductless HVAC systems show a very small first year source average energy savings of 0.02 MMBtu per site, 0.01 MMBtu per ton capacity, and 209 MMBtu in total, compared to the calculated reported equivalent of 21.8 MMBtu per site, 7.8 per ton, and 153,629 MMBtu program total first year source energy savings. Lifecycle source energy savings, 1.04 MMBtu per household, 0.40 per ton, and 7,851 MMBtu total, are also modest in comparison to the reported equivalent savings (328 MMBtu per site, 117 per ton, and 2,311,384 MMBtu total). As a result, ductless HVAC systems barely pass the source energy savings test for fuel substitution. However, accounting for measurement uncertainty, the evaluation finds the lifecycle source energy savings impact of this technology application questionable, and it falls short of meeting reporting expectations for achieving source energy savings.

This first-year result is driven by the low evaluated gas savings and the moderate evaluated electric consumption increase from the site-level savings analysis, whereas the lifecycle measurement benefits from the calculator’s assumed lowering of electric source energy intensity (Btu/kWh) over the lifetime of the technology. The ductless HVAC system claims will have to achieve higher gas savings in future program years to reach the source energy savings expected from these heat pump fuel substitution technologies.

Compared with the ductless HVAC technology group, the central HVAC technology group exhibits much greater first-year source energy savings of 12.8 MMBtu per site on average, 2.9 MMBtu per ton capacity, and 14,326 MMBtu in total. Therefore, the central HVAC technology group passes the source energy savings test for fuel substitution with a considerable margin. Relative to the reported first-year source savings of 16.4 MMBtu per household, 3.7 per

ton, and 18,383 MMBtu for the program, the evaluated result for this technology comes much closer to meeting source savings expectations. The central HVAC technology group falls a little short of expectations for source energy savings because the evaluation result does not achieve as much gas savings as expected, but it does achieve this gas savings at a lower electric energy increase than anticipated. The lifecycle source energy savings result for the central HVAC technology is also significant at 193 MMBtu per site (44.0 per ton) and 216,588 MMBtu in total.

CO₂ Emissions Impacts

As with the source energy savings methodology, the evaluated carbon dioxide (CO₂) emissions savings is based on the outputs of the CPUC's Fuel Substitution Calculator v1.1 that use the total gross evaluated site energy savings and other pertinent measure data as the inputs into the custom calculator segment. Emissions savings results are "total CO₂ emissions over the EUL of the measure technology," as identified in the CPUC's Fuel Substitution Guideline document (CPUC 2019c). Table 7 provides reported and evaluated CO₂ reductions at per site, per cooling ton capacity, and at the program level.

Table 7. Reported and evaluated lifecycle emissions impacts

Measure and result source	Lifecycle Emissions Savings (Metric tons CO ₂)		
	Per site	Per cooling ton capacity	Program total
Ductless, evaluated	0.06	0.02	417
Ductless, reported	17.4	6.19	122,666
Ductless, ratio of evaluated to reported	0.32%	0.34%	0.34%
Central, evaluated	10.2	2.3	11,494
Central, reported	13.2	3.0	14,775
Central, ratio of evaluated to reported	77.7%	77.8%	77.8%

The emissions saving results are similar to the source energy findings in that the ductless HVAC systems produce a very small individual emissions benefit (0.06 tCO₂ evaluated versus the 17.4 tCO₂ reported) and very limited total emissions benefit given the volume of the reported systems. On the other hand, the central systems achieved a substantial reduction in lifecycle emissions (10.2 tCO₂ evaluated versus the 13.2 tCO₂ reported per site) per site as well as at the program level and provide 77% of the expected CO₂ reductions. This is a direct result of the difference in achieved gas savings between the ductless and central HVAC heat pump technologies. Like with the source energy savings findings, the ductless HVAC system claims will have to achieve higher gas savings in future program years to reach the CO₂ emissions savings expected from these heat pump fuel substitution technologies.

Utility Customer Bill Impacts

The results of the participant utility customer's bill impact assessment are presented in Table 8. Central heat pump measures that replaced less efficient heating systems provided utility customers an average annual bill savings of \$95. The gas bill savings associated with these systems outweighed cost increases from their increased electric load. On the other hand, ductless heat pump measures that supplemented existing HVAC equipment led to total average annual bill increases of \$86. The gas cost savings from these systems did not outweigh the cost increase associated with their higher electric load. Overall, the program resulted in an average annual bill increase of \$58 since most installations were ductless HVAC rather than central HVAC fuel substitution heat pumps. The estimated total program first-year utility bill increase for these measures was \$471,929.

Table 8. Average annual bill impacts⁷ per site from fuel substitution heat pumps

Measure	Average Annual Bill Impact			Total Participants	Total Bill Impact
	Electric	Gas	Total		
Ductless HVAC	\$151	-\$66	\$86	7,043	\$604,177
Central HVAC	\$170	-\$265	-\$95	1,122	-\$106,669
Overall	\$154	-\$97	\$58	8,165	\$471,929

Participant Characteristics

Survey responses from participating utility customers also provided insight into household characteristics, energy use attributes, and experience with heat pump installations.

Household characteristics. Table 9 provides a summary of household characteristics for participants who installed central and ductless heat pumps. It indicates that households that participated in the program have relatively high incomes. The majority reported more than \$150,000 in annual income with homes installing central systems being marginally better off than those installing ductless systems. In addition, participants are also well educated with 73% and 50% of those with central and ductless systems, respectively, reporting college or higher level of educational attainment. Further, most participating households have two to three members, which is typical for single family homes.

Table 9. Household characteristics: education, income, and household size

Characteristics	Central Heat Pump Participants (n=171)	Ductless Heat Pump Participants (n=394)
Income		
Less than \$50,000	*7%	10%
More than \$50,000 and less than \$150,000	*27%	21%
More than \$150,000	*37%	33%
Education		

⁷ Negative values indicate a cost reduction while positive values indicate an increase.

College or higher	*73%	50%
High school or less	*4%	15%
Household size		
1 person	13%	14%
2-3 people	*59%	45%
4 or more people	*20%	31%

* Statistically significantly different from ductless installation responses, at least at the 90% confidence level.

Table 10 provides a breakdown of the percent of heat pump capacity that is reported to be installed within a recognized disadvantage community (DAC), based on the utility provided installation zip code and the CalEnviroScreen 3.0 DAC definition (OEHHA 2022). Across all the climate zones, 43% of the total ductless heat pump system capacity was reported to be installed in a zip code within a DAC, whereas only 13% of the total central heat pump system capacity was found to fall within a DAC.

Table 10. Percent of heat pump capacity (tons) claimed within and outside of a designated DAC, by California Energy Commission building climate zone

Technology	Climate Zone	Zip code within a DAC	Zip code outside a DAC
Ductless	6	4%	12%
	8	15%	8%
	9	9%	9%
	10	11%	10%
	13	2%	0%
	14	1%	8%
	15	0%	8%
	16	0%	2%
	All CZs	43%	57%
Central	6	1%	12%
	8	5%	19%
	9	2%	10%
	10	5%	7%
	13	0%	0%
	14	0%	2%
	15	0%	35%
	16	0%	1%
	All CZs	13%	87%

Heating system attributes. A summary of the attributes of the previous and the new heating systems as well as participant behavior related to both is provided in Table 11. Based on the summary, most participants reported still receiving gas service (94% for central and 89% for

ductless) indicating that there has not been complete electrification for almost all participants despite the addition of electric heat pumps for heating and cooling purposes. Further, all installed heat pumps (of both kinds) are still in use.

Table 11. Heating system characteristics and changes

Characteristics	Central Heat Pump Participants (n=171)	Ductless Heat Pump Participants (n=394)
Heating System		
Heat pump still in use	100%	100%
Homes with gas service	*94%	89%
Percent utility gas	*93%	81%
Percent propane	1%	8%
Replacing existing heating system	*98%	33%
New heating load	*2%	66%
Installed in previously unheated space	*1%	22%
Installed in a new room added to home	*0%	4%
Added without removing existing system	*1%	30%
Part of home renovation	*0%	10%
Previous Heating System⁸		
Central furnace system	*78%	50%
Existing heat pump system	*15%	13%
Floor/wall heater	*2%	21%
Previous heating system did not work well	*40%	25%
Previous heating system worked well	*58%	70%
New Heat Use⁹		
More heat use	*23%	44%
About the same heat use	*63%	34%
Less heat use	*10%	17%

*Statistically significantly different from ductless installation responses, at least at the 90% confidence level.

The results also show that almost all those with central heat pumps (98%) reported replacing their existing (mostly central furnace) heating systems that were fueled by natural gas. On the other hand, only about a third (33%) of those who installed ductless heat pumps reported replacing their existing system. Most (66%) of those with ductless heat pumps reported keeping

⁸ Answers from a subset of respondents (n = 162 (central); n = 242 (ductless)).

⁹ Answers from a subset of respondents (n = 162 (central); n = 242 (ductless)).

their natural gas-fired heating systems when they added the heat pump. The low gas savings estimated for those with ductless heat pumps reflects this limited fuel substitution and apparent load building by this group of participants who installed their ductless heat pumps in previously unheated space (22%), as part of a new room addition (4%), or as part of a home renovation (10%). Moreover, a greater proportion (44%) of those who installed ductless systems compared to those with central heat pumps (23%) reported using more heat after installing their heat pumps.

Of those who added ductless heat pumps without replacing their existing heating system, about one-fifth (21%) had an existing ductless furnace (floor/wall furnace), 50% had a central furnace, and 13% already had a ductless heat pump.¹⁰ In addition, a majority of participants who installed their heat pumps as a replacement or in addition to their existing system reported that their previous heating system worked well indicating a high incidence of early replacement than the normal replacement intended for this type of program.

Cooling system attributes. Findings on the previous and new cooling systems of participants are provided in Table 12. As the table indicates, a small percentage (13%) of those with central heat pump installations reported adding new cooling load compared to those with ductless heat pumps, 78% of whom reported adding cooling load. These results line up with the findings of higher cooling savings for those with central heat pumps compared to those with ductless systems. Further, a higher percentage of those with ductless heat pump installations reported using more cooling (44%) than those with central heat pump installations (26%) after receiving their heat pumps. These results support the notable cooling savings (19%) estimated for participants with central heat pumps compared to cooling savings of 2% for those with ductless systems.

Of participants who installed heat pumps as a replacement or an addition to their existing cooling system, a much higher percentage with central systems (93%) had central AC compared to only 55% of those installing ductless heat pumps. Further, 19% of those with ductless systems reported having windows and portable ACs while none of those with central heat pumps had such end uses prior to installing their heat pumps.

Table 12. Cooling system characteristics and changes

Characteristics	Central Heat Pump Participants (n=171)	Ductless Heat Pump Participants (n=394)
Cooling System		
New cooling load	*13%	78%
Replacing existing cooling system	*86%	19%
Previous Cooling System¹¹		
Central A/C	*93%	55%
Heat Pump A/C	*6%	10%

¹⁰ The proportions of previous heating systems are the same for those who replaced their existing systems with ductless heat pumps. The survey question about participants' prior heating systems was asked of those that either replaced their existing system (98% for central heat pumps and 33% for ductless systems) or installed the heat pumps without such replacements (2% for central heat pumps and 30% for ductless systems). Participants who reported installing their heat pumps in a previously unheated space, in a new room added to the home, or as part of a home renovation were not asked this question and these responses do not represent their existing heating systems.

¹¹ Answers from a subset of respondents (n = 149 (central); n = 150 (ductless)).

Window or Portable A/C	0%	19%
Old A/C not working well	*59%	28%
Old A/C working	*41%	66%
New Cooling Use ¹²		
More cooling use	*26%	44%
About the same cooling use	*63%	37%
Less cooling use	*8%	14%

Participant program experience. Participant satisfaction with various aspects of the program that delivered heat pumps is provided in Table 13. All participants are generally satisfied with their equipment and contractor, which is reflected in high overall levels of satisfaction of at least 85%. The one area that respondents reported having lower levels of satisfaction is the amount of savings generated by their heat pumps. The respondents reported varying perceptions of changes in annual energy costs with central heat pump respondents reporting slightly higher perceived energy costs decreases than those with ductless HVAC systems. This perception among those with central heat pumps accords with DNV's assessment of the bill impact from the installation for the typical participant in this group. Our estimates indicate that this group, on average, saved \$95 which is about 3% of their pre-installation cost.

Table 13. Participant satisfaction with heat pump installations

Characteristics	Central Heat Pump Participants (n=171)	Ductless Heat Pump Participants (n=394)
Satisfaction		
Satisfaction overall	85%	87%
Satisfaction with contractor	91%	91%
Satisfaction with equipment	*89%	89%
Satisfaction with savings	*67%	76%
Reported Change in Annual Energy Costs		
Noticed energy costs increase a lot	*10%	7%
Noticed energy costs increase a little	*18%	23%
Noticed energy costs decrease a little	*31%	25%
Noticed energy costs decrease a lot	13%	13%
Did not notice a change in energy costs	17%	17%

* Statistically significantly different from ductless installation responses, at least at the 90% confidence level

Table 14 provides the motivations and barriers reported by participants. A majority (61%) of those with central heat pumps reported the desire to save energy and reduce carbon emission for motivating their installations while the majority of those with ductless heat pumps (69%) reported safety and comfort as their motivation for installing their system. These motivations explain the load building and lower savings estimated at the meter for the latter group. Recommendations, saving money, equipment failure, and better use of renewable energy round out the other top motivations for installing the heat pumps. The majority of both groups (54% and 59% for those with central and ductless heat pumps, respectively) reported no barriers

¹² Answers from a subset of respondents (n = 149 (central); n = 150 (ductless)).

or challenges in connection with their heat pump installation. But for those that did experience barriers, installation and cost posed challenges.

Table 14. Participant motivations and barriers to installation

Characteristics	Central Heat Pump Participants (n=171)	Ductless Heat Pump Participants (n=394)
Motivations		
Save energy/reduce carbon emissions	*61%	47%
Improve safety and comfort	*43%	69%
Based on recommendation	*37%	33%
Save money	*34%	32%
Equipment Failure	*31%	16%
Better use of renewable energy	*30%	15%
Based on reputation of heat pumps	21%	20%
Adding air conditioning	*13%	44%
No other options	*2%	14%
Barriers		
No barriers or challenges	*54%	59%
Installation Barriers	*23%	16%
Cost Barriers	*21%	18%
Availability of equipment	*3%	4%
Knowledge Barrier	*6%	5%
Qualified contractors	5%	4%

* Statistically significantly different from ductless installation responses, at least at the 90% confidence level

Conclusions and Recommendations

The midstream focused program delivery of central heat pump measures achieves most of the expected gas energy and CO₂ emissions reductions with slightly better ratio of electric energy increases to gas energy decreases than reported. Surveys indicate a high prevalence of central heat pumps replacing existing central gas heating systems and AMI analysis results demonstrate a cooling efficiency improvement as well.

The evaluated energy and emissions reductions impacts for the midstream program delivery of ductless heat pump measures fail to substantially decarbonize space heating while still increasing electric energy consumption. Survey results indicate this is most likely because the ductless heat pump is more commonly serving a new heating load rather than decarbonizing an existing gas heating system load. The versatility of the ductless split systems likely makes them attractive equipment options for adding space conditioning to previously unheated spaces, renovated spaces, or as supplemental to existing heating systems.

The results of the central heat pump measure indicate residential HVAC fuel substitution measures can deliver considerable decarbonization of space heating in existing buildings when these heat pumps fully replace existing system and therefore achieve the intended fuel substitution. Our study findings suggest this is possible to achieve with a midstream focused program delivery for central heat pump systems, but this might not be possible for ductless split

heat pump systems because their versatility requires considerable oversight and limitations on their application to ensure substantial decarbonization through fuel substitution.

For the ductless heat pump fuel substitution measure to rapidly achieve its intent of displacing existing gas-fired heating in residential applications, it will likely require a program design that provides the implementer with greater access to the utility customer in order to meaningfully enforce measure application requirements that ensures complete fuel substitution will result from the ductless heat pump technology adoption. The additional implementation costs of downstream delivery program design could be justified if it enables the program to ensure fuel substitution is achieved and accurately recorded through data collection and controls that verify retirement and replacement of the existing gas heating equipment.

Future research into the effectiveness of residential heat pump fuel substitution for decarbonization could focus on where ductless heat pump applications can achieve the most beneficial decarbonization and what program delivery and control mechanisms can best ensure these applications are achieved.

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