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Maximizing Mini Split Performance: a Meta, Market, and Measure Study

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Definitions of Acronyms

AMI	Advanced metering infrastructure
COP	Coefficient of performance
DHP	Ductless mini-split heat pump
eFAF	Electric forced air furnace
ETO	Energy Trust of Oregon
HSPF	Heating season performance factor
HVAC	Heating, ventilation, and air conditioning
IFTTT	If This Then That
NEEA	Northwest Energy Efficiency Alliance
NEEP	Northeast Energy Efficiency Partnerships
NREL	National Renewable Energy Laboratory
QA	Quality assurance
QC	Quality control
RFP	Request for proposal
RTF	Regional Technical Forum
SEER	Seasonal energy efficiency ratio
TRM	Technical reference manual

Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) contracted with Sustainabilist to review and document ductless heat pump research and evaluations (aka DHPs, or mini split heat pumps) conducted over the past 15 years. This study explores why utility programs are not achieving the level of savings that were achieved in pilot programs and field tests, and presents a set of enhancement measures that could improve program level savings of DHPs to be closer to their technical potential.

Key findings include multiple program improvements, which if combined could double DHP program savings. These solutions are not primarily "widget-based" enhancements but are mostly approaches to program delivery that use existing incentives to ensure that DHPs are installed and used properly in the right part of the right homes. Integrating the identified enhancement measures into program measures can increase the amount of electric resistance heat displaced by a DHP.

This report contains three core sections:

1. A **meta study** of all related DHP program evaluations, field studies, and case studies
2. A **market study** of information about products that exist in the market
3. A **measure study** with detailed information about the calculations performed to determine the measures suggested herein

The research team, led by Sustainabilist, reviewed 82 papers on the subject of DHPs and related work. The team interviewed 27 experts and held many more informal discussions. The team found that the underperformance of DHPs is not a mechanical failure, but the structure of the efficiency program that pays to maximize the number of installed units rather than to maximize delivered savings. Through these efforts, the team arrived at recommendations for five enhancement measures (EMs) it felt were defensible, practical, cost-effective, and implementable, as follows:

- EM1: Targeting homes with significant electric heating loads
- EM2: Designing for displacement
- EM3: Integrated control of backup heating system
- EM4: Consumer education
- EM5: Quality assurance

Implementation of these enhancement measures would yield annual combined improvements of approximately 2,500 kWh and 3,400 kWh for DHPs that displace zonal systems and electric forced-air furnace (eFAF) systems, respectively. However, resolving the problem is not as simple as some might hope, and no widget or magic wand exists that solves the problem in all applications. The team's research repeatedly reinforced the challenge of retrofitting a second heating system whose controls and distribution systems only partly overlap with those of the pre-existing system, in buildings with different layouts and HVAC systems, by installers who are neither equipped nor compensated to perform a full analysis and design. Almost all of these enhancement measures increase savings by increasing the amount of heating load displaced by the DHP system from electric resistance (or other baseline HVAC systems) since this was identified as the root cause for most evaluated underperformance. Table 1 shows the respective savings in each category for eFAF and zonal replacement. The authors have designed each measure to be additive and have built in derate factors for measures that may have overlap. In general, the reader should feel comfortable "stacking" the savings from measures, as they come from different usage or savings categories.

Table 1. Summary of Enhancement Measure Savings

	eFAF*		Zonal**	
Enhancement	**Expected Savings Improvement (kWh/year)**	**Percent of baseline**	**Expected Savings Improvement (kWh/year)**	**Percent of baseline**
Evaluated baseline savings	**2,560**	**--**	**1,709**	**--**
Targeting homes with significant electric heating loads	2,169	85%	1,449	85%
Designing for displacement	309	12%	309	18%
Integrated control of backup heating system	660	26%	441	26%
Consumer education	125	5%	22	1%
Quality assurance	255	10%	170	10%
Total Enhancement Improvements	**3,518**	**137%**	**2,390**	**140%**

* *From https://nwcouncil.box.com/v/ResDHPonFAFv2-1*
** *From https://nwcouncil.box.com/v/ResDHPforZonal-v5-1*

Targeting Homes with Significant Electric Heating Loads

Targeting has by far the most potential to improve the cost effectiveness of DHP programs, increasing savings by around 85% per unit. Even if programs do not invest in additional marketing to the highest-potential homes, they can take simple steps to eliminate those homes with little or no electric heating, that are more likely to increase rather than decrease energy use as a result of DHP installation. While this strategy can be implemented without the use of sophisticated energy data-analysis software, even those tools are becoming more affordable and can further boost results. Targeting is a known and proven practice in utility programs. Just as commercial lighting programs are designed to limit eligibility to avoid adding unnecessary new lighting loads, DHP programs aimed at reducing electric heating consumption should limit their application to displacing existing electric resistance heating.

BOX 1 - Final Recommendation Preview for Targeting

Practical recommendation: Target homes with significant electric heating loads, based on analysis of billing data.
 	
Other options: Target homes with significant heating season load by performing weather regression analyses from monthly-read or AMI utility meters will avoid missing out on small homes or homes with small annual loads that still have significant heating loads. Recommended analytical methods include:
 	
• Utilize advanced metering infrastructure (AMI) data to determine how much heating energy the building uses based on regression models against outdoor temperature data. For this method, daily models are recommended over monthly models.
 	
• If using monthly data, several options exist:
   o Good: Compute the average of three peak winter months of monthly data
   o Better: Compute the ratio of usage in winter to shoulder months
   o Best: Develop weather-regression models to disaggregate heating and cooling from base loads
 	
• Additional data can be used to increase the targeting method's utility. For example, real estate parcel data can be used to normalize heating and cooling loads by square foot of conditioned area.

Designing for displacement

In an ideal scenario, DHPs would be installed only after a thorough analysis of a home's heat loss and air flow to determine the ideal location(s) and control strategy for the DHP, as well as any needed modifications to the existing HVAC system. In practice, this is probably beyond the time and ability of most installers, and the best that most programs can do to address this is to provide more training in best practices. The only simple fix available is to limit incentives to those cases that are most likely to shift a significant proportion of the home's heating load to the DHP: When they are installed in living rooms. This also eliminates most projects where the DHP is installed in previously unconditioned areas such as garages, where they will only increase energy use.

BOX 2 - Final Recommendation Preview for Design
Practical recommendation: Only pay incentives on DHPs installed in spaces designated as "living rooms." **Other options:** Designate high airflow regions of each specific house, or a set of rules to place DHPs in areas that will guarantee optimal air dispersal. Do not pay any incentives for DHPs installed in previously unconditioned spaces.

Integrated control of backup heating system

The closest thing to a widget-based enhancement is the use of integrated controls. The study team identified several examples, but found no perfect solution. This report describes the solution needed and suggests incenting superior integrated control systems to motivate manufacturers to accelerate their development and focus on energy impacts as well as on consumer comfort and convenience. The cost effectiveness of this enhancement is highly dependent on the percentage of homes that not only install the controls, but set them up correctly and use them consistently. The authors are conservatively estimating that only 30% will do so. For this reason, consumer education could be paired with an integrated controls program to deliver far more savings than either would alone.

The report covers a number of products, many of which can simply be lumped into the "smart thermostat" category. A few products are genuine integrated controls, further described in Box 3. To read the detailed comparison of products and capabilities, please refer to the Market Study.

BOX 3 - Final Recommendation Preview for Integrated Controls
Practical recommendation: For eFAF houses, install connected or communicating thermostats on both the DHP and the existing system, where at least one of them coordinates both systems like a two-staged heater. This might be achieved by a single-manufacturer solution, or by a smart thermostat that can control compatible third-party thermostats on the other system. **Other options:** • A totally stand-alone controller that can be added to the existing HVAC system to prevent it from running when outside temperatures are mild enough that the DHP should be able to carry the whole load • Connected or communicating thermostats installed on both the DHP and the existing system, then integrated through a third-party service such as IFTTT, SmartThings, Hubitat, etc.

Consumer education

While both consumers and installers could be better educated about how to get the most energy savings out of DHPs, the study team's recommendation is focused on the former. As previously mentioned, providing guidance about how to operate DHP controls (whether integrated or not) could provide at least a small amount of increased savings to many consumers. However, for the savings estimate in this report, the team focused on the small portion of homes where misunderstandings about DHPs result in consumers not using them at all for heating, thus generating little to no savings. In these few cases, a small amount of education can result in a large increase in savings. It would be advantageous to use any educational opportunities to address not only this problem, but also to encourage appropriate setbacks, coordination with existing HVAC systems, regular cleaning and other maintenance, and other operational savings best practices.

BOX 4- Final Recommendation Preview for Consumer Education
Practical recommendation: Educate consumers on basic facts about their new DHP, such as: • DHPs can heat as well as cool. A small but significant number of consumers do not recognize that their DHP is a heater. • Maintaining heat pump use for heating as much as possible, and about "set and forget" heat pump temperature while allowing for daily comfort adjustments. • The compressor must be clear of obstructions in order to operate at maximum efficiency. This means that if it is covered in snow, it should be cleared away. **Additional options:** • Educate consumers about control strategies that can be used to maximize heat pump performance in a house with an existing system.

Quality assurance

Quality assurance (QA) is the only measure recommended here that increases savings by boosting the operating efficiency (coefficient of performance, or COP) rather than by increasing run-hours. Roughly half of DHP installations are estimated to have either over- or under-charged refrigerant levels. Many more have other quality issues that affect COP. Programs may be reluctant to implement more stringent QA practices due to concerns about cost or beliefs that it is not possible or appropriate to "police" installers. However, many ways to improve installation outcomes do not involve sending inspectors for site visits. One promising option involves the use of smart thermostats to remotely detect installation and configuration faults.

BOX 5- Final Recommendation Preview for Quality Assurance
Practical recommendation: Record refrigerant charge levels for each DHP installed, and do not pay out incentives unless the refrigerant charge level is within manufacturer's parameters. If possible, use an electronic gauge such as those provided by Fieldpiece or iManifold. This can enable automated reporting and digital tracking **Additional options:** Additional QA/QC is warranted on DHPs, but savings estimates were not readily computable from available sources. These include: • Ensure that the height of the indoor head is at least 7 feet off the floor. • Preferably use a floor-mounted unit if there is room to deliver heat more effectively into the lower part of the space. If a wall unit is used, mount it several inches (6-8") below the ceiling (lower than minimum allowed clearance by 3-6" depending on manufacturer's minimum); or for a vaulted ceiling, mount with supply air outlet at approx. 6.5-7' from floor. • Ensure that the compressor unit is not so close to the ground that it can be covered by snow, and that it is not in a position to be rained on or covered in snow from the top. • Make thermostat data available to program managers for real-time QA/QC based on data after installation.

Changing the Program Paradigm

A common thread running through all of these recommended enhancement measures is the fact that DHPs, unlike an LED bulb, are not going to produce a consistent amount of savings simply by upgrading an inefficient unit to an efficient one. Programs can use them to save energy by ensuring that the right units are installed the right way in the right part of the right homes, then that they are operated and maintained correctly. This may seem a particularly daunting task when one considers its reliance on influencing numerous decisions by HVAC installers and consumers, and that no simple answers will be right for the endless combinations of building layouts, HVAC system configurations, and occupancy patterns. This problem cannot be solved by conditioning program participation with ever more rules and requirements aimed at fixing weaknesses identified in the latest evaluation.

Utilities could seek to drive performance-based implementation for DHPs. Many of the measures presented herein are viable due to the savings deficits caused by the deemed-savings model. Even the enhancement measures recommended in this report will be nothing more than band-aids if applied rigidly with the expectation of boosting savings by a fixed amount. In fact, they represent some of the pillars on which a true performance-based program should be built: Using data to match solutions to each consumer; working with manufacturers and installers to prioritize energy savings; and supporting consumers for the long run to ensure savings are achieved and maintained.

This shift from rebating products to investing in outcomes may seem challenging, and many will protest that the systems in which utility efficiency programs operate are not conducive to innovating new models. However, the outcomes demanded from programs are changing as the grid rapidly transitions to renewables and mandates evolve for resiliency planning, carbon reduction and other non-energy load priorities.

Future Recommendations

The authors recommend two specific further studies in these areas to investigate additional opportunities to enhance DHP savings:

- Field-testing new integrated controls technology, with an eye toward true integration between DHPs and the systems that they displace. This field testing is needed because the integrated controls market in this space is nascent and immature.
- Specific targeting using AMI or other granular data in order to find homes that could benefit from DHPs in meaningful ways, but that do not fall into the category of "uses more than 15,000 kWh per year." This is necessary because few studies exist that validate different targeting approaches based on the achieved level of savings.

1. Introduction

1.1. How to Read This Report

This report presents the context, knowledge, and potential ductless heat pump (DHP) program enhancement measures in three sections:

1. Meta Study: Key findings from third party research on DHP performance, case studies, and independent literature reviews
2. Market Study: Results from interviews and product research, including practical implications of specific products
3. Measure Study: Descriptions of five enhancement measures chosen and how their savings estimates were generated

Readers seeking a granular-level understanding of the specific measures suggested can skip to the Measure Study section. For background from the literature review, please read the Meta Study. For convenience, this report includes short explanations of the final results within the Meta Study, so that readers can read the background information with the context of where it leads. Please read the Market Study for specific product recommendations.

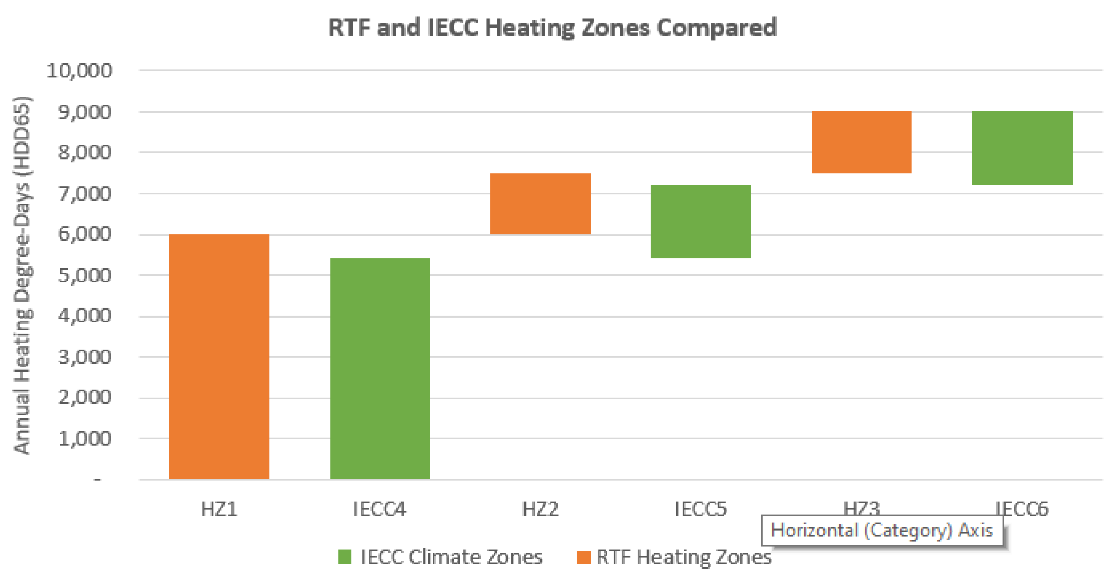
1.2. Origins

Ductless heat pumps have been actively sold in the Northwest since 2008. During the early years of market development for this new technology, the focus was on establishing the savings, developing best practices, training installers, and increasing awareness of the benefits of displacing electric resistance heating with the much higher efficiency offered by DHPs. The Northwest Energy Efficiency Alliance (NEEA) and the NW utilities have conducted numerous lab and field tests and market characterization studies. Early field tests revealed DHPs could displace more than 2,900-5,500 kWh per year in a typical zonal heated or forced air heated home, and the Regional Technical Forum (RTF) 2010 savings estimate was 3,500 kWh per year (Ecotope 2014, Baylon et al. 2012, Geraghty et al. 2009). Over the decade following this, the electric utilities of the Pacific Northwest ran incentive programs NEEA and its members have worked to accelerate market adoption of DHP by reducing their first cost, training installers, and increasing market awareness and availability of different makes and models of DHPs through existing distribution channels.

Recent program evaluations throughout the US have shown that DHPs are not delivering as much savings as field tests and product research indicate DHPs should produce. In recent evaluation cycles, NEEA identified DHP diminished savings as a problem that required further study. In late 2017 NEEA initiated a project to better understand this problem with the Pacific Northwest National Laboratory (PNNL) as the principal investigator and with funding support from Bonneville Power Administration, Silicon Valley Power and the American Public Power Association. The final results of this work were published in two reports (Metzger 2020 and Y. Chen 2020).

This study builds on the work of the PNNL study and learnings from similar studies, evaluations, and field tests from across the US and Canada. NEEA commissioned this report to pull together a comprehensive report on steps programs can take to enhance the savings from their DHP programs. The “enhancement measures” presented in this report are defined as incremental savings over current estimates provided by the Northwest Power Planning Council’s Regional Technical Forum (RTF) savings estimates for DHPs in both zonal and electric forced air heated homes. For simplicity’s sake, the savings estimates in this narrative are based on a weighted average heating load across climate zones in the Northwest. The RTF’s heating zones 1-3 are similar to International Energy Conservation Code’s climate zones 4-6, as shown in Figure 1 below.

Figure 1: RTF and IECC Heating Zones Compared



The research team that came together around this project is a coalition of experts with significant experience in DHP engineering, energy efficiency data analysis, building science, and scientific literature review. This research was supported with oversight and input from an advisory team of stakeholders from across the industry who have deep knowledge about DHPs.

1.3. Key Desired Outcomes

NEEA identified three desired key outcomes for this project:

- A reference document summarizing what is already known about DHP interactions with existing heating systems and best practices for maximizing mini-split performance in homes
- A list and description of currently available products and solutions (enhancement measures) that improve performance of DHPs as displacement heating solutions
- The savings, costs, and program implementation strategies of these enhancement measures in as much detail as possible

1.4. Process

The project was executed in four phases, punctuated by meetings with the advisory group to discuss findings, as follows:

1. The team started by reviewing 52 papers in order to evaluate the lay of the land in its meta study. Over the course of the study, the number of papers that the team would evaluate grew to 82 that are documented; quite a few others never made it to the list but were looked over and ultimately not included.
2. The team then conducted a market study that included interviews with a number of experts, and specification of products that could assist in the enhancement of DHP savings. The interviewees were asked a number of standardized questions which were used to inform the initial list of enhancement measures.
3. Next, the team developed a list of all potential enhancement measures either named or suggested in the studies and interviews. These enhancement measures were narrowed down based on pros and cons from expert opinions in the market study, and further based on whether they could be quantitatively defended given the evidence that had been gathered.
4. The team then developed this report. It includes a cost-benefit analysis for all enhancement measures that passed the high-level screening in the prior step. In addition, this report recommends enhancement measures to adopt now as well as future research needs to address knowledge gaps.

1.5. Core Assumptions

- Because programs in the Northwest are claiming electric savings only, and not fuel-switching savings, the study team's analysis assumes resistance heat as the baseline system. Many of the conclusions will apply equally to homes with thermostatically controlled fossil-fuel central heat such as natural gas, propane, or fuel oil, with a few noted exceptions.
- This study focused mainly on heating, but many of the conclusions should hold true for cooling savings as well. However, the Northwest is a heating-dominated climate, and many homes lack central air conditioning, so in this region, many homes that install DHPs may be adding new cooling load to some homes, even if they may also displace some less-efficient central air conditioning in others.
- This study focused on increasing savings opportunities for single-head DHP systems; multi-head systems were actively excluded from many of the team's calculations, though some of the general findings may be applicable.
- The enhancement measures presented herein constitute a refined and limited number of practical options for utility programs. They do not represent the full range of design, equipment selection, and installation options that improve performance.

1.6. Acknowledgments

- The authors would like to acknowledge the members of the advisory committee, who took many hours out of their busy schedules to give input and insight into the intricacies of DHPs and the programs that install them. The advisory committee consisted of Suzi Asmus, Debra Bristow, Matt Christie, Christopher Dymond, Tom Eckhart, Paul Hawkins, David Lis, Bruce Manclark, Rob McKenna, Cheryn Metzger, Andrew Shepard, Robert Weber, and Mark Wyman.
- Kudos to the interviewees: The researchers, manufacturers, and installers who participated in this work.

2. Meta Study

This meta study summarizes existing knowledge about ductless mini-split heat pumps' (DHP's) interactions with existing heating systems and best practices for maximizing mini-split performance in homes. The research team reviewed more than 50 reports, articles, presentations, and other documents for this meta study. While many of these documents measured the performance of DHPs, the vast majority are not focused on testing the incremental savings benefits of add-on technologies and strategies. However, even those studies that were not focused on "fixing" DHP performance often observed underperformance relative to expected or modeled savings, and the authors have cataloged those deficiencies in several broad categories.

Some of the reviewed studies did explore one or more potential means of improving DHP performance, and in some cases they estimated the savings of those improvements, either via a theoretical calculation or (less often) through some sort of real-world test. Within this report are lists and descriptions of currently available products and solutions (enhancement measures) that improve the performance of DHPs as displacement heating solutions. Where possible, savings, costs, and program implementation strategies of these enhancement measures are included in as much detail as possible.

This meta study is different from the one conducted previously by the Northeast Energy Efficiency Partnerships (Faesy et al. 2014). Rather than taking a broad survey of the state of DHPs and their market potential, barriers, and so forth, this report instead focuses on opportunities for enhancing the performance of DHPs in markets where they are already gaining traction. The 25 studies shown in the following table are the ones that most directly impacted the team's evaluation of measures and estimates of potential savings.

2.1. Relevant Studies Reviewed

Table 2. Summary of Research

Name of Source	Authors	Pub date	Key Learnings
UCONS Ductless Heat Pump Demonstration: Evaluation of Enhanced Controls and Operational Procedures for Tacoma Power (DRAFT)	Eckhart, Tom; Sullivan, Greg; Reichmuth, H.	2020	DHPs recover slowly, so eFAF carried morning load if DHP has nighttime setback; no low-cost integrated controls; two systems compete in winter, fight in summer (if eFAF not disabled); temperature loggers show simultaneous operation of DHP and eFAF in houses monitored
UCONS phase 2 Ductless Heat Pump Demonstration: Interim Evaluation of Phase 2 Enhanced Controls and Operational Procedures for Manufactured Homes at Franklin Pierce Estates Mobile Home Park	Eckhart, Tom; Sullivan, Greg; Reichmuth, H.	2020	Controls upgrade seems to reduce eFAF runtime, but space heaters might negate all the savings; no energy meters to verify whether this was the case in this particular study. Report contains inadequate post-install data to provide any real estimate of net savings.
J Hight: Promoting Efficiency and Electrification in Home Heating and Water Heating	Hight, Jim	2020	Co-ops assume that a dual-fuel solution is required. A significant economic incentive exists for alleviating the cost of propane as a co-op member. Importantly, HVAC installers in co-op regions don't think that heat pumps work well in cold climates. DHPs may be a key component of beneficial electrification, but education is needed.
Who's Leading: The Dance Between Mini-Splits and Existing HVAC Systems	Metzger, Cheryn; Ashley, Travis; Chen, Yan; Devaprasad, Karthikeya; Kolln, Jaime; Pang, Zhihong; Fenaughty, Karen; Martin, Eric; Parker, Danny; Dentz, Jordan; Dymond, Christopher; Lis, David; Sullivan, Greg	2020	1. Optimizing for comfort is paramount in energy savings. 2. If you leave it, they will use it, and if they use it, you better control it in concert with the DHP

Name of Source	**Authors**	**Pub date**	**Key Learnings**
Maximizing the Use of Ductless Mini-Splits in the PNNL Lab Homes	Ashley, Travis; Metzger, Cheryn; Kolln, Jaime; Sullivan, Greg	2020	Generally for central systems offset (with registers in DHP zone closed) did the best; for zonal, and central, complex schedule also did well.
Downstate Air Source Heat Pump Demonstration	Dentz, Jordan	2019	From study: • Comfort is a major motivator• Design details crucial (aesthetics of line sets) and impact costs• QA is important• Occupant education and expectations• Weatherization is underappreciated• Right sizing is possible, but small homes are challenging• Cooling and heating loads are similar in attached homes• If fossil fuel system left in place, good chance it will be used• Use of multiple systems will increase energy consumption From reading: Experimental design is also very important in this space. A number of confounding variables exist here (tech type, house type, full/partial replacement, quality assurance) that point to questionable results from this study. That being said, this study may be one of the best examples of how real-world replacements will go, because the building stock is varied in a way similar to the appearance of these confounding variables.
Integrated HVAC Control Methods for Mini-Split Heat Pumps in Existing Homes	Fenaughty, Karen; Martin, Eric	2019	Integrated controls are promising and can help solve the issue of competing heating and cooling between the DHP and the displaced system. A key challenge in this space is that there is some need for customized controls using IFTTT or other integration platform.
Heat Pump Best Practices Installation Guide for Existing Homes	ICF	2019	Recommends outdoor temperature lockout controls (details on p. 44), installing indoor units more than 30 cm below the ceiling (best practice 30-45 cm), for vaulted ceilings, discharge no higher than 2.5 m from floor.
CADMUS ETO 2019 Residential Ductless Heat Pump Study (single family and multifamily)	Jackson and Walczyk	2019	"Energy savings were... disappointing" From the report, they recommend the following measures: Indoor heads must be placed in the primary living space.• Additional indoor heads will not be recommended and we'll assume that installedsystems are 1-to-1 (additional indoor units are at the consumer's discretion, but they arenot expected to save additional energy and Energy Trust will not support them).• Develop a new measure for DHPs displacing wood heat which is cost-effective due tothe value of wood savings.• Incorporate cooling savings for homes that would have installed a less efficient coolingsystem in place of a DHP.• Quantify cooling comfort benefits for homes which add cooling.• Incorporate avoided electricity costs for the summer cooling season.

Name of Source	Authors	Pub date	Key Learnings
Impact Evaluation of Ductless HeatPumps andPrescriptive DuctSealing	Navigant; BPA	2018	From Study: Consumers use DHPs such that savings may be lower than current UES. This is the case if consumers:• Continue to use eFAF• Displace non-electric heating• Increase AC use• Switch from programmableto manual thermostatsSavings are 50% of UES if replacing eFAF, 84% if replacing zonal Savings for eFAF closer to UES if controls are well-managed and not displacing non-electric heat
Evaluating Cold Climate Heat Pumps: Understanding How and Where Cold Climate Heat Pumps Can Displace Less Efficient Heating Sources	Korn, David; Walczyk, John; Ari, Jackson	2017	Shows breakeven point visualization, field-tested cold-weather COPs
Cadmus Cold Climate ASHP Evaluation	Korn, David; Jackson, Ari	2017	From the report: " • Incentivize higher efficiency systems • Target homes heating with electric resistance or propane • Displace central air conditioners in new construction"
Integrated 2-stage thermostat mini-split mini-test preliminary control update	Fischer, Dana	2017	One table shows that integrated controls (and other strategies) cause the “annual production in gal of oil equity” to go up, but that seems to mean that the DHP is carrying more of the heating load. The table appears to measure savings in terms of oil production offset. IC appears to double the offset in this tiny sample size proof of concept test. Training is somewhat effective, and blocking furnace ducts does almost nothing.
ETO Existing Manufactured Homes Heat Pump Pilot Evaluation Final Report	Hardman, Trent; Chamberlain, Alex; Perussi, Matei; Kan, Ph.D., Cynthia; Horkitz, Karen	2017	From Report: "The subpilot found remote QA to be a valuable program tool. The subpilot demonstrated that the PMC could use Wi-Fi thermostats in multiple ways to conduct program QA: to validate the thermostat serial number; to confirm correct configuration and installation of thermostats; and to conduct long-term performance monitoring. The remote QA process allowed the PMC to detect and correct (or investigate) issues during each project stage. • Recommendation: Incorporate remote QA using Wi-Fi thermostats into future heat pump programs, where feasible. Ensure that program staff can access the data and that the thermostat vendor remains engaged and aligned with the program’s vision."

Name of Source	Authors	Pub date	Key Learnings
Ductless Mini-Split Heat Pump Impact Evaluation	Korn, Dave; Walczyk, John; Jackson, Ari; Machado, Andrew; Kongoletos, John; Pfann, Eric	2016	EFLH are much lower than TRM; field COPs are lower than published COPs; cost-effective switchover points vary by fuel.
Performance and Costs of Ductless Heat Pumps in Marine-Climate High-Performance Homes— Habitat for Humanity The Woods	Lubliner, Michael; Howard, Luke; Hales, David; Kunkle, Rick; Gordon, Andy; Spencer, Melinda	2016	Report measured and modeled performance and systemcost: DHP are cost-effective; more training is needed for installers; code should be updated in jurisdictions topromote effective use.
Ductless Mini-Split Heat Pump Systems: The Answers to Questions about Efficiency You Didn't Know You Had	Walczyk, John; Larson, Antonio	2016	SEER is not always accurate: sizing, location, and operations all factor into real-world performance
Northwest Ductless Heat Pump Initiative: Market Progress Evaluation Report #5	Conzemius, Sara; Kahl, Shannon	2016	Usage habits vary by displaced heating system: 97% of zonal users report DHP as primary heat source, compared to 85% of eFAF owners. This could have implications for consumer education
A Case Study of Residential New Construction Ductless Heat-Pump Performance and Cost Effectiveness	Lubliner, Michael; Kunkle, Rick; Carter, Bruce; Arneson, Rich; Stewart, Jeremy	2015	This study indicates that baseboard heat combined with DHP heat can result in significant savings. It should be noted that during the study, the schedules of the heating systems were controlled by the researchers. This study was also conducted for new construction homes, which are likely better insulated than other alternatives.
NEEP Ductless Heat Pump Meta Study	Faesy, Richard; Grevatt, Jim; McCowan, Brian; Champagne, Katie	2014	Multi head systems are relatively new to the market (as of 2015 study). As of 2015, manufacturers expected 10-50% growth over the next few years. Most consumers (70-80%) in the NE were looking to offset propane or oil costs. HSPF and SEER are potentially not applicable in cold climate zones as calculated.
Ductless Heat Pump Engineering Analysis: Single-Family and Manufactured Homes with Electric Forced-Air Furnaces	Baylon, David; Davis, Bob;	2012	

Name of Source	Authors	Pub date	Key Learnings
	Geraghty, Kevin; Gilman, Lucinda		
Residential Ductless Mini-Split Heat Pump Retrofit Monitoring	Geraghty, Kevin; Baylon, David; Davis, Bob	2009	Conducted PRISM billing analysis with post-installation submetering data; showed value of weather-adjusting consumption data. Exposed challenge of attributing 15% of DHP use to either heating or cooling, and thus recommends use of vapor line temp monitoring. Higher pre-installation consumption is correlated with higher savings, but larger home size is not. DHP installation does not seem to increase cooling energy consumption.

2.2. Research Findings: Yes, Ductless Heat Pumps (Can) Save Energy

The following section summarizes the key findings uncovered in the study team's meta study evaluation.

This study is concerned with investigating DHP savings during the heating season in homes previously heated primarily with electric resistance, either "zonal" baseboard units with independent thermostats in each room or electric forced air furnaces (eFAF) with a single low-voltage thermostat (as residential forced-air systems are rarely zoned). However, many of the recommendations also apply to fossil-fuel heating systems and cooling savings. DHPs save energy by delivering each unit of heat using less electric energy than resistance electric heat. This assumes the following:

1. The home uses electric energy for heating in the baseline condition
2. The DHP is displacing the baseline resistance heater for a significant portion of that load
3. The DHP has a coefficient of performance (COP) much higher than the baseline system's COP, which is at most 1.0

In the meta study, many documents provided insights into the degree to which each of these assumptions hold true in practice, and areas in which enhancement measures might hold the most promise.

While most studies of DHP performance show savings over other heating systems, those savings are often less than the amount predicted by engineering models (Navigant and BPA 2018). Causes of underperformance typically fall into one of three categories: Total heating load is smaller than expected, the portion of the load carried by the DHP is less than expected, or the COP of the DHP is lower than expected. This report will separately examine causes of underperformance and possible solutions in each of these three categories. For more discussion about interactions between underperformance in these categories, see section 5 on measure savings calculations.

The team found five general categories in which enhancement measures could take place:

- Targeting homes with significant electric heating loads
- Designing for displacement
- Integrated control of backup heating system
- Consumer education
- Quality assurance

Similar reasons for variations in DHP savings were found in the Northeast Energy Efficiency Partnerships' (NEEP's) Market Strategies report (Aldrich et al. 2017):

1. Wide variations in home thermal loads (size, plan, envelope performance, etc.)
2. Occupant understanding and operation of the heat pump
3. Control configuration (e.g., where thermostats are located, setpoints used)
4. Layout of home and zoning
5. Comfort (e.g., occupants may use more heat when they know it's more efficient)

This report will now explore each of these facets further in the meta study, market study, and measure study sections. Each of the five enhancement categories is discussed from eight aspects:

1. A results preview—for those action-oriented individuals
2. What is it all about?
3. Why does this produce savings?
4. How much (incremental) savings is possible?
5. Are there exceptions to this approach?
6. How can programs implement this approach?
7. What are the challenges to a successful implementation?

Are there any gaps in knowledge that could be addressed with future studies?

In addition to these aspects, the discussion of each of the five enhancement measures will commence with a preview of the recommendations about the most practical way to implement each measure.

2.3. Targeting: The More You Use, the More You Can Save

2.3.1. Results Preview

BOX 1 - Final recommendation preview for Targeting

Practical recommendation: Target homes with significant electric heating loads, based on an analysis of billing data.

Other options: Target homes with significant heating season load by performing weather regression analyses. By modeling heating load with data from monthly-read or AMI utility meters or smart thermostats, it is possible to include homes with less total annual energy use in the targeted group. Recommended analytical methods include:

- Utilize advanced metering infrastructure (AMI) data to determine how much heating energy the building uses based on regression models against outdoor temperature data. For this method, daily models are recommended over monthly models, but not required.
- If using monthly data, several options exist:
    - Good: Compute the average of three peak winter months of monthly data
    - Better: Compute the ratio of usage in winter to shoulder months
    - Best: Develop weather-regression models to disaggregate heating and cooling from base loads
    - Additional data can be used to increase the targeting method's utility. For example, real estate parcel data can be used to normalize heating and cooling loads by square foot of conditioned area.

2.3.2. What Is Targeting All About?

One factor that correlates with savings is the amount of energy used by participants in the pre-installation condition (BPA 2018). In short, if little or no electric energy is used to heat a home, then even if the installation of a DHP is able to efficiently offset the expected portion of that heating load, the absolute amount of electric savings will be small (Geraghty, Baylon, and Davis

2009). Multiple evaluations of DHPs and other enhancement measures have shown a wide distribution of savings among projects, so focusing marketing and incentive dollars on homes that have the best chance of achieving higher levels of savings will not only boost program cost effectiveness, it will also reduce the number of consumers who are encouraged to invest in a technology that will not reduce their energy consumption. In practice, this means using billing data to calculate a metric that can be used to either pre-select consumers for a marketing campaign (targeting) or as one of the criteria for participation in the program (qualification).

While the most effective metrics do require the generation of weather-based regression models, much simpler calculations can produce effective results as well. While some critics have raised concerns about the perception of "discriminating" against some consumers, efficiency programs already have numerous qualification criteria to ensure cost effectiveness. The study team's analysis indicates that targeting and screening has the most total potential to boost DHP savings, as well as being the most cost-effective enhancement measure.

2.3.3. Why does this produce savings?

While some electric savings will result from reducing the fan and pump energy when DHPs are installed in homes (or portions of homes) heated by fossil-fuel furnaces or hydronic systems, programs focused on claiming electric savings should target homes predominantly heated by electric resistance systems (Korn et al. 2016). Note that some jurisdictions are able to claim net energy (or CO_2) savings when "fuel switching" or displacing fossil-fuel heating with efficient electric heating, so in those cases the approach to targeting or pre-qualification would need to include consideration of the home's fossil fuel bills as well.

This might be due to the use of a secondary heating fuel, such as natural gas or propane, or to a highly efficient envelope or a very conservative thermostat setpoint. For example, this would be the case in vacation homes that spend large amounts of time in deep setback while unoccupied, and thus would produce less savings than average if retrofitted with a DHP.

2.3.4. How much savings is possible?

The study team's analysis of this enhancement measure found that 30% - 137% of additional savings is possible from targeting. The low-end estimate is based on a comparison of savings for homes with more than 15,000 kWh/year of total electricity use in the pre-treatment condition to the entire population, using the set of evaluation studies included in the Regional Technical Forum (RTF) measure workbook. While this is not the ideal way to segment and qualify consumers, it gives an estimate of the variation in savings between these sub-populations. A similar segmentation approach in the evaluation results of Energy Trust of Oregon's (ETO's) existing manufactured homes DHP program shows a potential savings increase of roughly 25% (Hardman et al. 2017). Another ETO evaluation of multifamily DHP savings found more than 75% additional savings for units that used in excess of 10,000 kWh/year versus the whole population (note that multifamily units are typically smaller and use less energy on average, so this may not actually represent a more lenient threshold, as it would have allowed only 35% of the past program population to qualify) (Rubado 2018).

Several methods can be easily used to target homes with large electric heating loads. The savings estimates generated in Table 1 are based on averaging the worst case (targeting a simple threshold of 15,000 kWh/yr or greater annual loads) and the best case (targeting a combination of multiple metrics from weather-regression models). Using only large load homes, however, limits the number of target homes and may miss those homes with smaller loads but proportionally large electric heating loads. Targeting is more effective when based on disaggregated heating loads derived from AMI data or monthly data, with some studies finding as much as 137% more savings from those well-targeted homes (Blunk, Golden, and Scheer 2020).

For monthly data, several options exist:

- Compute the average of three peak winter months of monthly data and use that to target houses based on the amount of usage as an absolute magnitude. This is a "good" option.
- A "better" option is computing the ratio of usage in winter to shoulder months, which is a stronger indication of the heating load above the base load in the building.
- The "best" option is to develop weather-regression models that disaggregate heating and cooling from base loads within the building, yielding a valid estimate of the heating load required for the building.

If AMI data are available, models can be built to determine how much heating energy the building uses based on regression models against outdoor temperature data. For this method, daily models are recommended over monthly models, but not required.

Targeting based on total annual energy use is easy to implement, but it is far from an ideal way to find the homes with the most savings potential. Some large homes with no electric heat may get selected, and small homes may fail to make the cutoff even if they have electric heat. Fortunately, better-discriminating metrics exist, and they also produce more savings. Sacramento Municipal Utility District (SMUD) used the CalTRACK methods to analyze the distribution of savings from its DHP program (Blunk, Golden, and Scheer 2020). Looking at the model parameters from only the baseline (pre-DHP installation) energy use, SMUD found that homes in the top 50% of not only annual kWh consumption, but also in the top 50% of the ratio of heating energy to total energy use, delivered more than double the annual energy savings of the average non-targeted project. This metric is produced by calculating a variable degree-day regression model of energy use (daily or monthly) versus outdoor temperature and then isolating the portion driven by cold weather, then expressing that as a proportion of the total annual energy use.

2.3.5. **Are there exceptions to this approach?**

While homes with smaller heating loads may have less savings potential (Rubado 2018), they may still be cost-effective applications for DHPs if they can be served with a smaller DHP unit and if they have a compact, open layout that allows the DHP to serve most of the heating load. However, since much of the installed cost for a single-head DHP does not directly scale with capacity (Navigant 2018), this segment of the population may still be hard to serve cost-effectively with DHPs in a retrofit scenario, although it may be easier in new construction and end-of-life replacement (market opportunity) conditions where no secondary electric resistance or fossil fuel system will be installed—a scenario that warrants further study. However, if the controls of the DHP and baseline systems are well-coordinated, the DHP may still be cost-effective (Lubliner et al. 2016).

A program may make exceptions to any usage-based qualification rule, though, since they are merely guidelines intended to identify houses most likely to yield cost-effective savings. Practitioners in Massachusetts, which has a usage-based qualification criterion of "900 kWh difference between sum of 3 winter-usage and 3 lowest-usage months" ("Mass Residential Electric Heating and Cooling Equipment Rebates" 2020), reported that they would consider paying the incentive for a home that failed to pass the test, provided that a site visit confirmed that the DHP was replacing resistance heat (Interview with Mass Save® staff, 2020).

2.3.6. How do you implement this approach?

Multiple aspects of baseline energy use may be used to predict savings. The fact that different baseline systems use various non-electric fuels complicates the measurement of savings, as well as the strategies for improving outcomes.

The simplest way to segment homes is by total annual energy consumption, but it's also the least specific. Savings resultant from DHP installation has been positively correlated to total electric use (Rubado 2018). In a recent 2013-2014 evaluation of multifamily DHP retrofits for the Energy Trust of Oregon (ETO), savings estimates from units that used more than 10,000 kWh per year were not only nearly three times the total savings as compared with units that used less than 10,000 kWh per year, but also a much higher percent savings relative to the baseline energy use.

The goal of targeting or pre-qualification is to identify homes that have electric resistance heat and use a lot of it, relative to the amount of conditioned space. Because resistance heat is such a large load, it often drives total consumption to above-average levels. However, it's more reliable to use a test that focuses on energy used for heating, which can be determined by creating a regression model with outside temperature. A simplified method to separate heating load from total load is to simply subtract three months of shoulder season bills (or the year's three lowest) from three months of heating-season bills, as Mass Save® (Massachusetts' statewide utility program) uses in its DHP qualification criteria. Normalizing the heating consumption by total annual load or conditioned floor space (if available) could make the metric even more reliable.

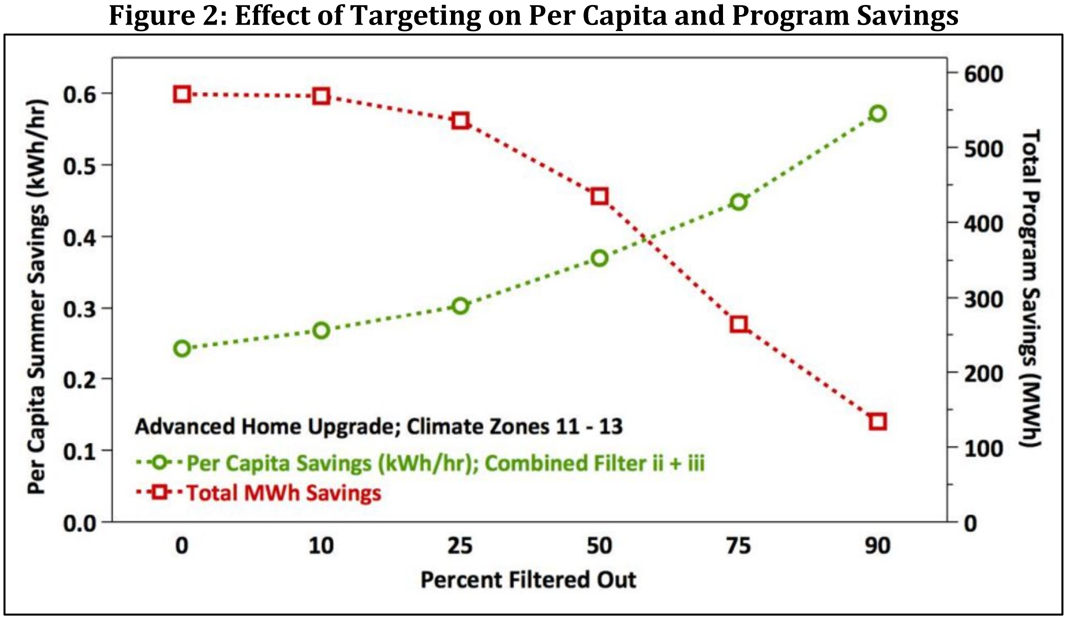
The team recognizes that performing a billing analysis before approving a DHP installation might represent a barrier that will delay or deter sales, beyond those to homes that did not qualify. Most of the examples from literature were simply post-hoc analyses of program results and did not actually implement the usage-based qualification criteria. Mass Save® is the notable exception; it reported that installers were usually able to gather the requisite bills from the consumer and do the simple addition and subtraction required to qualify the consumer. Since most DHP projects are initiated by an installer, and since confirming eligibility for the rebate is important in order to accurately quote the project, having a self-contained process that the installer and consumer can complete on their own may be the most robust approach.

Even this simple calculation can present challenges if the consumer can't find all their bills. And requiring the installer to perform the calculation definitely precludes any additional modeling sophistication. Having the utility perform the calculation would presumably streamline the installer's process, but it would add a secondary hurdle of obtaining consumer permission to share data (or calculations thereof) with the installer. In addition, most utilities do not have the IT capabilities to provide billing analysis tools to their call centers. From these limitations, the path of least resistance is for the utility to pre-calculate each home's "score" for whatever metric is chosen and then store the score or a pre-qualification flag in the consumer information system (CIS) annually, after the end of each heating season. Then the utility can put a note on each bill or send promotional mailings to qualified consumers or confirm the consumer's qualification status over the phone. This approach also allows the utility to update the qualification rules over time without needing to re-train installers.

2.3.7. What are the challenges to a successful implementation?

Although demand-side management (DSM) programs have traditionally been cautious about limiting access to incentives, both targeting and screening can be used to ensure cost effectiveness for both the program as a whole and for the individual consumers who are being encouraged to invest in DHPs in order to save money. Targeting may also reduce the number of projects in the program's DHP portfolio, even though it increases the savings per project. The planning analysis should include not only the change in expected savings per project for different levels of targeting thresholds, but also the change in total program savings by multiplying the per-project savings by the percent of projects that would be eligible under that threshold. **Error! Reference source not found.**2 illustrates an example from a whole-home upgrade program (Scheer, Borgeson, and Rosendo 2017), but the same logic applies to any program. Notice how trimming the bottom 25% of projects (using the targeting metric, not the post-installation metered savings) sacrifices almost none of the program savings, as those projects are saving very little energy. While the top 25% have much higher per-capita savings per project, the total program savings suffers from the deep cuts in project count. Note that if a program invested in aggressively marketing to the targeted homes, this effect could be mitigated.

Figure 2: Effect of Targeting on Per Capita and Program Savings



Note: From Scheer, Borgeson, and Rosendo, 2017

2.3.8. What are the knowledge gaps?

Implementing a targeting strategy based on hourly energy use data for homes within the Northwest, and studying the efficacy of the program, would be beneficial.

The industry should study new construction and end-of-life replacement (market opportunity) conditions to determine the level of potential economic opportunity.

2.4. Designing for Displacement: Put the right DHP where it will do the most good

2.4.1. Results preview

BOX 2 - Final recommendation preview for Design
Practical recommendation: Only pay incentives on DHPs installed in spaces designated as "living rooms." **Other options:** Designate high air-flow regions of each specific house, or a set of rules to place DHPs in areas that will guarantee optimal air dispersal. Do not pay any incentives for DHPs installed in previously unconditioned spaces.

2.4.2. What is Designing for Displacement all about?

Traditional HVAC system efficiency recommendations are fairly straightforward: install more efficient equipment (and install sealed ducts in conditioned spaces, as a side note). Installing DHP in existing homes to displace but not replace the existing HVAC equipment requires a more tailored approach. Decisions about the location and sizing of the DHP, as well as any modifications to the existing central HVAC system, will affect the project's energy savings. These projects typically have no dedicated HVAC "designer"; at best, a distributor may help the installer select DHP equipment. This is a broad topic area; no simple answers exist that work for every situation, and many strategies sound good but don't seem to work. The most reliable strategy seems to be simply limiting program incentives to DHPs installed in the living room, though that may be harder than it sounds.

2.4.3. Why does this produce savings?

The savings from a DHP are proportional to the amount of load that can be shifted from the baseline system to the DHP. Putting the DHP in a large, open room should allow the DHP to heat more of the home. Using mechanical fans to "distribute" the heat does not seem to solve this problem, though, as they use more energy than they distribute (and rarely actually deliver comfort). More nuanced strategies may exist that would show benefits from interventions that keep doors open more often, and for design strategies that factor in the movement of heat between floors or occupant behavior. However, if the goal is to specify a succinct set of conditions under which DHPs can, on average, produce cost-effective savings, limiting incentives to units installed in living rooms is currently the only safe recommendation.

Regarding the installed height of the indoor unit, placing it lower on the wall will place the return air intake into a cooler stratum of air. Typically, a layer of warm air by the ceiling is present that is 5–10°F warmer than the air lower in the room. The COP of the heat pump improves in proportion to the return air temperature, so heating-dominant applications may actually benefit from installing a heat pump even lower, perhaps two to three feet off the floor. The team found no field studies that tested this hypothesis directly, though one of the authors has installed two DHPs at three feet off the floor in their own home, and finds it very effective during the heating season with minimal compromise in cooling performance. Another option to deliver heat lower in a room or open space is to install "floor-mounted" or low-wall consoles, though these units are more expensive than conventional wall cassettes and furniture placement may preclude their use in many homes.

2.4.4. How much savings is possible?

Many system design strategies sound plausible but have not been shown to have a meaningful impact on energy savings. One example is right-sizing DHPs. Like many HVAC systems, DHPs are often over-sized by installers who are concerned about comfort complaints; however, if the design is focused on cooling rather than heating, this practice may result in under-sized systems if the house is in a heating-dominated climate such as the Northwest (Rosenbaum 2020 - personal communication). Conversely, if the DHP is sized to meet the whole building's maximum load on the design day, that may result in over-sizing, particularly if the existing central heating system is left in place and the house is not compact and open-plan enough to circulate heat from the DHP to all rooms (Eckhart 2020 - interview).

The authors' preferred strategy, which several interviewees agreed with, involves sizing the DHP for the room or portion of the house that it can reasonably serve. A 2016 Massachusetts evaluation found that most DHPs were actually sized correctly to meet those loads (Korn, Walczyk, and Ari 2017). Conventional wisdom around sizing air conditioning holds that over-sizing systems will lead to short-cycling and under-dehumidification (multiple personal communications between David Korn and associates), the evidence of the impact on energy consumption is mixed. A NIST meta study found mixed results from studies of over-sized heat pumps (Domanski, Henderson, and Payne 2014). While in another study of the field performance of cold-climate inverter-driven heat pumps, the authors observed that one site seemed to have an oversized unit; they cited cycling during mild outdoor temperatures as the likely cause of low measured COP (Williamson and Aldrich 2015).

Another set of system design strategies seeks to address the challenge of integrating the central HVAC distribution system with the DHP. Several variations on this approach exist for homes with forced-air-furnaces: Blocking off supply registers in spaces directly served by the DHP; running the central system in fan-only mode to move DHP-conditioned air to remote rooms; or adding powered "transfer grills" that move DHP-conditioned air to adjacent rooms. One study tested blocking supply registers across five homes with mixed results; on average, this strategy delivered only a minimal improvement, while integrated controls delivered much better results (Fischer 2017).

None of the other distribution system-reconfiguring approaches has been demonstrated to save energy, and they may actually increase energy use. For example, using a forced-air system in fan-only mode will do little to improve comfort in other spaces, as DHP-conditioned air in the return ducts will mix with return air from other rooms, and be delivered at or below the desired heating setpoint temperature in the best-case scenario. In more likely scenarios, the conditioned air will be lost through duct leaks or cooled by ducts running through unconditioned spaces. In any case, the benefit is unlikely to outweigh the energy used by the ventilation fan motor.

The most compelling strategy found in the literature was suggested by an evaluation report that broke out savings by the room in which the DHP was installed (Jackson and Walczyk 2019). It yielded some evidence that DHPs installed in the living room produced an additional 309 kWh/year—about 30% more savings than the population-wide average from that study. While consumers certainly have valid reasons to want a DHP in other rooms, if a program's goal is to promote cost-effective energy savings, applying incentives to those projects may not be justified. In addition, efficiency estimates for design simplification are not always informative; the seasonal energy efficiency ratio (SEER) is not accurate for all installations due to actual location, sizing, and operations (Walczyk 2016). While re-calculating SEER for a particular installation may or may not result in re-ordering of DHP installation options, it might change cost effectiveness. Operational improvements could yield benefits (steady temperature rather than manual setbacks).

Installing indoor units lower on walls constitutes the other potential for savings in the system design phase, since the primary intended load in the Northwest is heating. The Canadian Home Performance Stakeholder Council's *Heat Pump Best Practices Installation Guide for Existing Homes* (ICF Canada 2019) recommends installing indoor units 12 to 18 inches below the ceiling, unless the ceiling is more than eight feet high, in which case the indoor unit should be mounted so that discharge is no more than eight feet from the floor (ICF Canada 2019). This is lower than the manufacturer's minimum clearance, so it would take some training and quality assurance practices to produce this outcome; on the other hand, once this market transformation is accomplished and lower placement is the norm, the impact can persist and spread. The likely savings from this strategy is in the range of 2–8% additional savings per project, based on rough engineering estimates.

2.4.5. **Are there exceptions to this approach?**

Better ways undoubtedly exist for distinguishing which locations in a home will effectively allow the DHP to supply enough of the heating load than simply making the consumer or installer check a box that says "Was the DHP installed in a 'living room'?" Any program concerned with consumer satisfaction would likely have a mechanism for granting exceptions to this rule. If those exceptions were granted for installations in large, open, frequently occupied rooms, the savings improvement would likely still be achieved. In an ideal scenario, this savings enhancement strategy would be accomplished with holistic design techniques that considered not only the geometry of the home, but also the other sources of heating and cooling, the levels of insulation and solar gain, and occupancy patterns. In practice, the only program model that rewards such improvements without adding undue burden to implementers is pay-for-performance.

2.4.6. **How can programs implement this approach?**

The system should be installed in the most open space on the first floor of the house, typically the living room. Comfort is a top motivator for the installation of DHP systems, and thus the system must be installed in a location that is both efficient and provides for occupant comfort. In a recent evaluation report, The Cadmus Group identified comfort as the #3 reason that survey respondents wanted to install a DHP, with 62.2% of sites whose occupants were responding stating that this was a factor (Cadmus 2019).

In addition, the interplay between occupant comfort and the occupant's ability to control the legacy heating system is a key factor in whether DHP installations achieve their full offset potential. This dynamic is typically described as a situation in which comfort in bedrooms is not maintainable by a single DHP installation (Metzger 2020) but could, in theory, apply to any room where comfort is insufficient due to DHP heating capacity and rate. The solution to this comfort vs. control quandary has been explored by supplementing individual bedrooms with heaters and locking out additional controls (UCONS 2020). Other worthwhile avenues of investigation in this space include whether blankets or electric blankets can substitute for space heating in control lockout regimes. Anecdotal evidence points to blankets and behavior change as effective means of providing incentives to maintain thermostat setback in low-income situations (Heatsmart 2019) and the DOE website points to electric blankets as more efficient than space heaters,[1] yet the authors cannot find any study that evaluates electric blankets as a supplemental enhancement measure for energy savings.

Other factors in the design of a DHP system can also impact performance, for example the length of refrigerant pipes. If they are too short, they transmit noise, but if they are too long, efficiency is reduced (Talmage 2013).

2.4.7. **What are the challenges to a successful implementation?**

Numerous sources point to consumer desire for comfort and the ability to address localized heating and cooling problems as the primary drivers for purchasing DHPs, rather than energy savings. If the consumer is trying to address a cold bedroom over the garage, they are not going to install a DHP in the living room instead, no matter the incentive. If consumers or installers feel this unfairly limits the ability to take advantage of the incentive, they may be tempted to interpret the definition of "living room" liberally. Offering a low-tier incentive for all heat pumps and a much higher incentive for those installed in living rooms might be effective. The challenge is how to market the program so that most of the incentives are paid for installations in living rooms, which will likely require further studies.

2.4.8. **What are the knowledge gaps?**

Some previous studies, such as the 2019 ETO evaluation by Cadmus (Jackson and Walczyk 2019), may contain data that would be useful in further analysis. For example, if Cadmus can re-run the comparison between single- and multi-DHP homes with the supplemental-fuel data removed from both, that would help to refine the estimated increase in savings when only one DHP is installed. Otherwise, Energy Trust of Oregon could re-run the analysis on a fresh batch of program data; if it now has a larger batch of projects in its dataset, the statistical uncertainty for some of the room types might also improve.

In addition, any proposed techniques to shift incentives to projects in which the DHP is serving a large portion of the home's load could be tested in pilots with a rigorous experimental design,

[1] https://www.energy.gov/energysaver/articles/electric-blanket-delivers-ko-space-heater-during-energyfaceoff-round-three

even by simply adding a condition on the incentive form that requires the consumer and contract to attest to the installation location.

Researchers could also test the boost in DHP performance due to installed height which could likely take place in a lab home. Alternately, a large program could A/B test the requirement. However, training all installers on how to install units lower on walls, and then randomly assigning each home to the "right" or "wrong" approach would be difficult and impractical. A small study with participants willing to have a DHP installed, then moved after one winter, might yield a reliable measurement if the DHPs and other heating sources were sub-metered.

2.5. Integrated Control: Maximize DHP Runtime

2.5.1. Results preview

BOX 3 - Final recommendation preview for Integrated Controls
Practical recommendation: For eFAF houses: install connected or communicating thermostats on both the DHP and existing system, where at least one of them coordinates both systems like a two-staged heater. This requires the DHP to have some form of communication that can interface with the thermostat other than the standard DHP "remote" control (see section 3). **Other options:** A totally stand-alone controller that can be added to the existing HVAC system to prevent it from running when outside temperatures are mild enough that the DHP should be able to carry the whole load. Connected or communicating thermostats installed on both the DHP and the existing system, then integrated through a third-party service such as IFTTT, SmartThings, Hubitat, etc.

2.5.2. What are Integrated Controls all about?

As discussed previously, one major challenge to achieving the maximum technical potential savings from DHPs is shifting the heating load from the incumbent inefficient HVAC system to the efficient DHP (increasing heating load displacement). In the worst-case scenario, the DHP is used only to add cooling load, and is shut off completely during the heating season. In other cases, the DHP and existing HVAC thermostats are set to the same temperature, in which case the central heating system will likely come on first and satisfy heating requirements before the DHP has even run, or worse yet, might cause the DHP to switch to cooling mode so that the two systems are fighting with each other and using more energy than the baseline condition. Instead, the goal should be for the DHP, as the more efficient system, to carry as much of the heating load as possible.

The solution may appear to be simply removing or disabling the existing HVAC system so the DHP will carry the full heating load (Dentz 2019). The limitations to this objective are two-fold: First, the capacity of the DHP is not always adequate to meet the whole home's heating load; second, the heat from the DHP is delivered at a single point in the home and may not be effectively distributed to more distant rooms. Because the capacity of heat pumps decreases as outdoor temperature drops, just as the heating load increases, sizing a DHP for the "design day" (i.e., the lowest temperature expected for that location) would result in a unit that is vastly oversized for the majority of the heating season. Also, on colder days, remote rooms in a home are likely to lose heat faster than warm air from the DHP can passively circulate to heat them, particularly in bedrooms where the door might be closed. For these two reasons, using DHPs to meet 100% of a home's load is typically not practical, and most installers find it to be more cost-effective to ensure occupant comfort by leaving the existing HVAC system in place.

Controls can enable the automation of the DHP, the displaced system, or both together in concert. The last scenario, in which the systems are controlled together, is often referenced as "integrated controls," which may include hardware, software, and sensors. While the market for integrated controls is immature, intelligent use of one set of smart controls can achieve some level of coordination. In cases where the displaced system remains, the DHP should be utilized as much as possible, but should not be expected to meet the entire home design load. Relieving a DHP of the responsibility of meeting 100% of a home's design load requires implementation of some form of controls that limit the use of the displaced pre-existing system. In these cases, the controls system or systems are responsible for balancing comfort and efficiency. The study team found evidence of savings opportunities that involved the controls for the DHP alone, as well as for the existing baseline system alone; however, the biggest potential—as well as the biggest challenges—came from controls strategies that integrated both systems (Fenaughty 2019, Metzger 2020). Of note: While the users of any control system are important to a strategy's success, the authors are addressing the subset of control strategies that are purely behavioral in the "Consumer Education" section (2.6) that follows this one.

2.5.3. **Why does this produce savings?**

The goal of installing DHPs for efficiency programs (and, hopefully, for consumers) is to reduce energy consumption by shifting heating load from electric resistance (zonal or eFAF) to the higher-efficiency DHP. However, many systems are poorly controlled, resulting in underutilization of the DHP when the existing system continues to meet the heating or cooling load. While educating consumers about the right way to operate their DHP might address some of the worst issues, such as DHPs that are turned off all winter long, achieving the optimal balance of comfort and savings will be difficult with the current baseline control system: A manual or basic programmable thermostat on the central heating system and an IR remote control for the DHP. All of the controls solutions presented in this report are intended to provide a straightforward way for residents to maintain their homes at the desired temperature while using the DHP to deliver as much of that heat as possible. Over-using the DHP is unlikely because it rarely operates at a COP below 1.0, the same as the baseline heating system. However, energy use and operational costs could go up if some or all of a house is heated to a higher temperature than was typical prior to the DHP installation.

2.5.4. **How much savings is possible?**

For an individual home that installs integrated controls, the team found evidence in the literature of average savings potential ranging from a low of 21% to a high of 234% improvement over the amount of savings expected with standard controls (see Section 4.7 for more details). These savings are derived from academic studies, and thus come with some caveats. The studies from which these levels of savings were derived are not directly measuring the performance of installing integrated controls systems. Rather, they report the savings (or run-time in equivalent full-load hours) for both general population projects and separately for homes that fully removed the pre-existing systems, reported not using them any longer, or in one case compared typical population savings to savings in the top quartile of projects, theorizing that those were more representative of savings potential when the DHP is correctly controlled. For these savings calculations, the team estimated that controls could save an additional 95% for projects that installed the appropriate controls system for their application, then configured and operated it correctly. However, the team derated that savings level significantly because even if installed correctly, many intelligent controls will likely be used incorrectly.

2.5.5. Are there exceptions to this approach?

Zonal controls are harder than eFAF controls to integrate with DHPs. While some communicating thermostats are available for 240V resistance heaters, many more options exist for standard 24V thermostats that work with most furnaces and boilers. Zonal systems also typically have a separate thermostat in most rooms, so a home could easily need to install three or more communicating thermostats to upgrade a zonal system, making it cost-prohibitive. Alternatively, zonal heating systems can be controlled using communicating relays at the breaker panel or retrofitted to the baseboards themselves; however, that hardware may not be cheaper than 240V communicating thermostats. Finally, because each room typically has a separate thermostat, it is both far more expensive to install relays or controls for each zone, and much easier to simply set back any zonal thermostats in the room with the DHP (or disable those baseboard units entirely), allowing the zonal baseboard thermostats in more distant rooms to supplement the DHP heating as needed.

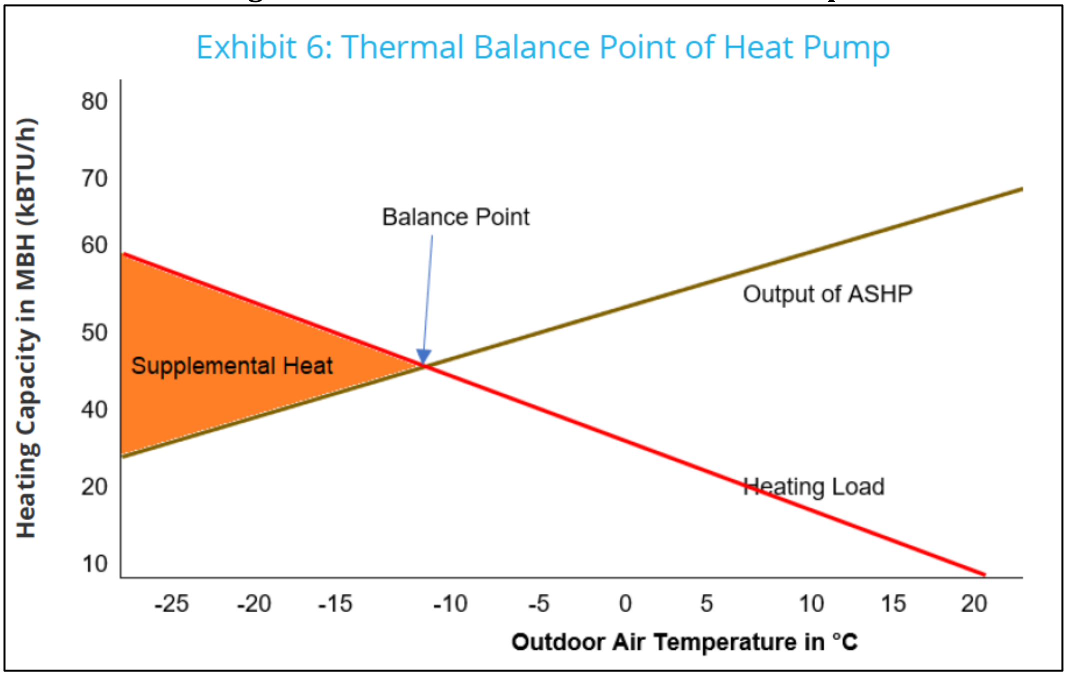
As a result, the controls recommendations in this section are primarily focused on furnaces, though to some extent they are also relevant to hydronic baseboard "radiators" with 24V thermostats controlling the whole house or large zones such as an entire floor.

In the case of eFAF existing equipment, some experts interviewed in the course of this work have argued that integrated controls are solving the wrong problem, and that the more elegant solution is to install a central heat pump in the existing distribution system, adding a heat exchanger while leaving the resistance heating element as a backup. The two systems can then be coordinated using a traditional two-stage controller or thermostat. This approach can also be used for fossil-fuel furnaces, though the controls should be configured to switch heat sources at the economic optimum temperature based on an outdoor sensor (Korn and Jackson 2017).

2.5.6. How can programs implement this approach?

Controls for the pre-existing system: One strategy echoed by several sources is to lock out the less-efficient baseline HVAC system above a specified outdoor air temperature, thus ensuring that the DHP is the only source of heat until the temperature drops below this point. One way to calculate the lockout temperature is to use the "thermal balance point" at which the DHP capacity is equal to the home's heating load (see **Error! Reference source not found.**3 below) (ICF Canada 2019).

Figure 3: Thermal Balance Point of Heat Pump



Note: From the Home Performance Stakeholder Council's *Heat Pump Installation Guide for Existing Homes* (ICF Canada 2019)

This thermal balance point is the minimum temperature that could be used for this strategy, as it does not account for any limitations of conditioned-air distribution. In addition, if implemented using an outdoor temperature sensor, its success depends on the accuracy of the home's heating load calculation (disregarding variations from wind-driven infiltration) and of the DHP's output curve. The general lack of accuracy and precision of both curves may introduce significant uncertainties into the estimation of the balance point, which would then likely be pushed higher to avoid comfort callbacks.

Even when installers make an effort to coordinate controls between DHP and baseline systems, they may make bad poor assumptions about the temperature where the DHP should no longer operate. Anecdotal evidence suggests that many installers believe that heat pumps should not operate below 30–40°F, so compressor lockouts have sometimes been configured to prevent them from running below that temperature. While this approach may have, at one time, been a reasonable way to prevent comfort complaints with central heat pumps, it is not an appropriate control strategy for modern DHPs that typically have high heating output down to low single-digit temperatures.

However, the other way of ascertaining the balance point of the DHP is to note when it runs continuously but fails to meet the setpoint. Viewed in this way, the DHP and backup system are operating like a two-stage HVAC system; when the first stage runs for a certain period of time without meeting setpoint or the setpoint is not maintained within a fixed deadband, it calls the second stage. Since most DHPs do not support 24V thermostats (at least without complex setups *and* compromise to their operating modes), standard two-stage thermostats would likely be an ineffective large-scale strategy for integrating DHP and eFAF controls.

Integrated controls for both the DHP and pre-existing system: The best solution for both energy savings and for consumer comfort and satisfaction is broadly recognized as having one system that integrates control of both the DHP and the pre-existing system. This could be accomplished by having a single HVAC control product that can connect to both systems and allow the consumer to specify a comfort temperature in one interface, then coordinate both systems to achieve that outcome in the optimal way (to the authors' awareness, none exists at this time). It could also be accomplished by two separate systems where one of them provides the primary consumer interface for programming temperatures and schedules, which then generates a control scheme based on operating conditions and sends commands to the other system. The most promising existing products that seem to straddle this line consist of separate, Wi-Fi-enabled controls made by a third-party manufacturer. The unit that controls the DHP simply emulates the infrared-control signals as if it were a handheld remote, and the two controls coordinate their response with their respective heating systems in the cloud, via their Wi-Fi connection. Management of the integration approach details are accomplished via user setup options in a mobile app.

Either of these approaches can theoretically deliver identical outcomes, but there are some implicit tradeoffs. A single control system that is purpose-built for controlling both DHPs and central heating systems should be easier to use and have the widest range of control capabilities, particularly if it is made by the DHP vendor (because DHPs typically have more complex controls than traditional central heating systems, and their controls are typically proprietary systems rather than conventional 24V contactors). A control system that can integrate with a consumer's existing thermostat should be cheaper to purchase and install, if the consumer already owns a compatible model. However, these are only broad generalizations, and specific control systems should be evaluated for compatibility, ease of use, effectiveness of controls, and installed cost, ideally through field testing.

Integrated control systems can operate the two systems like a two-stage system, as described above. They can also implement a "droop" control in which the less-efficient central system is always set 3–5°F below the DHP's setpoint (Metzger et al. 2020). This should ensure that the central system runs only when the DHP's capacity is less than the home's heating load.

One of the benefits of any integrated control system is the single interface for setting and changing the desired temperature and schedule, so that it is not only easier for the user to operate, it is also harder for them to accidentally override the savings strategy.

Remote temperature sensors can improve comfort: Since one of the objectives for coordinating controls between a DHP and central heating system is to ensure that no occupied rooms get too cold, the best way to achieve this outcome is to actually measure the temperature (and occupancy, if possible) of any rooms that are far from the DHP. Some controls systems offer wireless remote sensors for this purpose. If properly integrated in the control scheme, the central heating system can supplement the DHP when it is not meeting the heating load in any of the sensed locations, not just in the room where the DHP is located.

Control of the DHP: Whether an improved control system for the DHP alone could do much to increase the amount of load served by the DHP is unclear. However, even if control of the two systems is not explicitly integrated, installing a separate wall-mounted thermostat for the DHP can solve some sources of under-utilization. Because many DHPs try to maintain setpoint based on an internal temperature sensor in the return air duct of the indoor unit (the remote control typically does not contain a temperature sensor), and because DHPs are often installed very close to the ceiling, the DHP may sense a higher room temperature than is representative of the occupied space. Another factor is that DHP controls are inconsistent in their response to particular temperature settings; large discrepancies often exist between the setting and the room temperature, regardless of indoor unit location. Remote wall-mounted sensing controls generally seem to reduce this discrepancy.

Further, in a larger open space, particularly one that has some obstructions (for example, a kitchen/living/dining room space with large cased openings between the rooms), or in a sub-optimal location, the DHP may sense only the temperature in its immediate surroundings rather than the temperature of the entire space that it is fully capable of heating. Also, a DHP installed near a supply register from the central furnace may overestimate the actual temperature in the room and not run as often or turn down its capacity. Installing a true remote thermostat in a location out of the direct path of any furnace registers, and representing the temperature of the entire space the DHP is intended to serve, can allow the DHP to more effectively respond to the average temperature of the space and thus run more often to meet more of the heating load (Rosenbaum interview 2020). Many DHP manufacturers do offer factory-approved, wired and/or wireless wall-mounted thermostats designed to directly control their units; several third-party manufacturers also offer room-sensing remote units that emulate the infrared control signals of the factory handheld remote.

For DHPs augmenting central heating systems that use fossil-fuel central heating systems, an intelligent control system could lock out the DHP when the outside temperature is below the economic crossover point (Korn et al. 2017). This is the temperature at which the DHP's cost per unit of delivered heat surpasses the central system's cost per unit, due to the COP of the DHP decreasing with lower outdoor air temperatures. The costs of electricity and the heating fuel influence this calculation, as does the efficiency of the central heating system, so this crossover point will vary with time and location. However, for homes with electric resistance heat (either zonal or forced-air furnace), both the DHP and baseline systems are using the same fuel (electricity), so there is typically no economic balance point; the worst-case COP for the DHP is 1.0, which is the same as that for the resistance heat system.

Manual controls: While a resident can manually set up non-integrated, non-communicating controls for both a DHP and pre-existing system to implement the "droop" algorithm, or simply to turn down the central system's thermostat until it gets really cold outside, such an undertaking falls more under the category of "education" than controls. Programming any sort of setback schedule would be cumbersome, as both systems would need to be programmed manually (though maintaining the DHP at a constant temperature might actually be more efficient anyway). The same applies to setting the home's HVAC systems to "away" mode. Even for knowledgeable and committed consumers, this effect would persist only until someone unaware of the controls scheme adjusted one controller or another, so true integrated controls are far preferable (Aldrich et al. 2017). A small-scale study in Maine supports this conclusion, showing much greater savings from integrated controls than from education (Fischer 2017).

Setbacks can do more harm than good: While setbacks have long been promoted by efficiency advocates based on the logic that they reduce heat loss by reducing temperature difference between the building and outdoors, this savings is predicated on the use of conventional (single-capacity) combustion systems that have the same efficiency during recovery from setback as they would have if maintaining indoor temperature during the setback period. This assumption, however, does not hold for modern DHPs, which operate at reduced COP in order to increase capacity during recovery periods. Those periods are defined by a large delta difference between current indoor temperature and the desired setpoint temperature (Williamson and Aldrich 2015) In cases where setbacks occur overnight, the recovery period also corresponds closely to the lowest outdoor temperatures of the day, when COPs are lower. Consequently, many practitioners are now recommending a strategy of "set it and forget it," in which the DHP is set to the desired comfort temperature for the entire heating season and only adjusted as desired for comfort. (Rosenbaum interview, McCracken interview)

2.5.7. What are the challenges to a successful implementation?

Improving DHP controls is by far the most attractive enhancement measure encountered in this research. The research has demonstrated the potential for control algorithms that could deliver significant savings. While the cost and usability of home automation devices, including smart thermostats, have been rapidly improving in recent years, the main reason they are not included in every new DHP installation is that current solutions are not energy savings-focused, and most are expensive, complicated, or both. The value proposition for installers is low, and as long as the consumer is comfortable, they generally do not want to add an integrated control that may increase risk of callbacks and risk increasing the cost of a system such that they might lose a competitive bid.

The shortcomings are not all the fault of the controls manufacturers. Developing new products for a small market of early adopters is expensive, and manufacturers must educate homeowners and HVAC installers on the benefits of a feature—integrated HVAC controls—that most have never needed before. And while smart thermostats could mostly count on integrating with the standard 24V control wiring found on virtually every HVAC system (with the notable exception of the "common wire" that is missing from many older systems), DHPs typically use proprietary communications mechanisms that are not designed to integrate with third-party controls. Hopefully, the industry will converge on new communication standards that support the full functionality of DHPs, but for now installers are left to fend for themselves in the "wild west" of compatibility charts and online discussion boards.

In the face of such obstacles, efficiency programs might be tempted to wait on the sidelines until controls products emerge that consumers want, and HVAC technicians are able to support. If the goal of such programs is to effect market transformation and deliver energy savings above a baseline condition, this is likely to be counterproductive. Rather, now is an ideal time to hasten and guide the development of an emerging product class beyond consumer comfort and convenience and toward greater energy savings. Below are several challenges that programs could specifically address:

- Offering substantial incentives for connected/integrated controls, even if products are imperfect now, can encourage the market to meet this need. This is the approach taken by Mass Save®, which has seen growing interest from manufacturers to develop new integrated controls products that meet the (admittedly modest) program requirements. This may require a different perspective than the traditional cost/benefit analysis to view the incentives as an investment in developing the future market, rather than simply based on the savings that today's products can deliver. It may also require programs to identify alternate goals to use when developing a qualified product list (QPL) so that their market signals are communicated clearly.
- Supporting the development of new HVAC communication standards through participation in industry working groups and other collaborative activities can align industry efforts. Ultimately, the hardware manufacturers (for both the DHPs and the third-party controls) must create and adopt those standards; however, programs can coordinate through existing national and regional groups to develop and communicate their requirements for energy-saving features that could be included in the next generation of controls. Once again, manufacturers are most likely to respond to financial inducements, which could take the form of either criteria for future QPL or simply in a "race for a solution" with a cash bounty or guaranteed promotional rewards, similar to the L Prize™ that sped development of an affordable LED lightbulb ("EERE Success Story—L Prize™ Competition Drives LED Lighting Innovation, Energy Savings" 2016).
- Providing training and support services to HVAC contractors can aid the development of a qualified workforce. Many of the professionals who will be specifying and installing these integrated controls in place of traditional thermostats lack the necessary expertise in connected hardware and building automation systems. This is compounded by the fact that this product category is so new that the hardware landscape is constantly changing and there are almost no peers with enough experience to provide advice or support. Programs can help by developing trainings, support documents and hotlines, online product-selection tools, and other information resources to help contractors successfully navigate this market transition. In addition, programs could promote contractors who have invested in such training through certifications such as "Smart on Smart," recommended by the Home Performance Coalition (Rinaldi and Bunnen 2018).
- Educating consumers about the availability and benefits of integrated controls will build a lasting market. Consumers are more likely to trust advice from efficiency programs than from product manufacturers and HVAC installers, both of whom stand to gain financially from the sale of expensive optional equipment. Will installing an integrated controls system save more money than it costs? Programs can not only reduce the risk of these investments through incentives, they can also provide education and product selection guides to help consumers navigate a complicated choice and to weigh energy benefits as well as more readily-apparent features such as integration with other home automation systems and their decor.

  Beyond static advice on product selection, programs should also consider providing or supporting dynamic performance-monitoring services that could connect to the data from connected controls and alert residents if the controls (or possibly the HVAC system itself) were no longer working properly. This is particularly important for an efficient technology such as integrated controls, whose savings could be severely diminished if users inadvertently change the settings in the future, even if the product were specified, installed, and commissioned correctly.

2.5.8. What are the knowledge gaps?

The most obvious question for continued study is exactly which controls strategy will produce the most savings. The research that the Pacific Northwest National Laboratory (PNNL) and the Florida Solar Energy Center (FSEC) have been conducting with heavily-instrumented and laboratory homes has already provided insights into how different control schemes could work; further questions could doubtless be addressed in the same way, including the integration of multiple indoor air temperature sensors in each HVAC zone, and predictive controls to optimize tradeoffs between comfort and grid cost or CO_2 impacts. However, given the size of the gap between today's status quo and the potential for even simple control strategies, such an undertaking may not be in the critical path to delivering more savings for programs.

2.6. Consumer Education: Let People Know How DHPs Work Best

2.6.1. Results Preview

BOX 4- Final recommendation preview for Consumer Education
Practical recommendation: Educate consumers on basic facts about their new DHP, such as: DHPs can heat as well as cool. A small but significant number of consumers do not recognize that their DHP is a heater. Maintaining heat pump use for heating as much as possible, and about "set and forget" heat pump temperature while allowing for daily comfort adjustments. The compressor must be clear of obstructions in order to operate at maximum efficiency. This means that if it is covered in snow, it should be cleared away. **Additional options:** User should be educated about control strategies that can be used to maximize heat pump performance in a house with an existing system.

2.6.2. What is Consumer Education all about?

Various interviewees mentioned pervasive consumer misunderstandings about how to use heat pumps. This includes the hard-to-kill belief that heat pumps don't work at low temperatures, even though many of the new "cold climate" DHPs continue to provide efficient heat at outside temperatures well below 0°F. Another pervasive misconception is that DHPs only provide cooling, so many consumers turn them off during the winter. More subtle misunderstandings persist about the most efficient and effective ways to operate the controls. These misunderstandings may cause consumers to use their DHPs less than is economically optimal, or to use them in ways that produce less-efficient operation. For example, if the DHP setpoint is lower than the central heating thermostat is set, the DHP will probably never come on during the winter; furthermore, if it is set to "auto," it might even try to cool the space at the same time as the other system is trying to heat the space.

The interviews also indicated that some installers might also have inaccurate or outdated information about how to specify, install, and configure DHPs and their controls. While these problems may require installer education to correct, the authors have examined these issues in other sections. Estimating savings from installer education is outside the scope of this chapter, and any attempt to do so would be highly uncertain. However, experienced heat pump installers with whom the team spoke during the market research emphasized the importance of training staff on designing and installing systems (Mark Stephenson, Vermont Energy, personal communication 6/8/2020).

Among the things consumers need to know about heat pumps, these are among the most important:

1. Leave DPHs on—they heat even when it is cold outside.
2. Set the DHP and HVAC to heat or cool, not both—this circumvents the DHP battling with incumbent HVAC.
3. Use a small setback—DHPs are more efficient when running slowly and continuously than when coming back from a big setback.
4. Minimize the use of the backup HVAC—turn it off or set it a few degrees lower so that it serves only as backup, since it is much more expensive to operate.

2.6.3. Why does this produce savings?

The savings calculation for consumer education assumes that a portion of correctly installed DHPs are not carrying as much of the heating load as they could be, due to operator error. Since the savings for DHPs is proportional to the amount of load shifted from baseline HVAC equipment to the DHP, DHPs that are under-utilized or used only for cooling will produce no savings or will actually increase electric load. Explaining to consumers how to use their DHP most effectively can help at least some of those underperforming projects to achieve their full savings potential. As the vast majority of projects do not seem to experience this issue, most projects will benefit only a little or not at all from this kind of education. Even some homes that are under-utilizing the DHP cannot or will not respond to education. However, even if only a small percentage of projects are improved by education, those consumers should see a huge improvement in savings. Not only does this help overall program performance rates, it will reduce the number of consumers who install DHPs in hopes of saving energy and money but do not see their bills decline.

2.6.4. How much savings is possible?

The gap between engineering models of expected DHP savings and the evaluation results of achieved savings indicates that roughly 50% of potential savings are not materializing. Several reasons exist for these lost savings, and improperly operated DHPs due to misinformed consumers may affect only a small percentage of projects. However, in those homes where the DHP is used only for cooling and displaces no electric heat, the lost savings is effectively 100% for that project (and the added cooling may even increase the electric load in the summer). A 2018 BPA evaluation found that in the 18% of homes where the DHP was not used to displace eFAF heat, either due to disuse or displacement of fossil fuel heat instead of electric heat, kWh use increased by 450 kWh/year, while those that displaced some or all eFAF heating saved 2,190 kWh/year or 4,009 kWh/year, respectively (Navigant and BPA 2018).

These misunderstandings may affect only a modest portion of the total DHP; a 2016 NEEA consumer survey reported that almost all consumers claimed to use the DHP for at least some heating, and 85% of homes with eFAF said they used the DHP as their primary heat source (Conzemius and Kahl 2016). However, consumer education can be accomplished at an almost-negligible marginal cost through a brochure left behind by the installer or mailed to the consumer once their incentive is processed. A series of ongoing emails could even remind consumers about maintenance and offer additional efficiency products and services.

To maximize cost effectiveness, many programs could make use of regionally or nationally developed high-quality materials that can then be rebranded and used by each program to educate their customers. In addition, this communications strategy would ideally address the best timing (e.g., at time of installation, one month afterward, at the beginning of the next heating system) and channel (e.g., mailed brochure, bill stuffer, email) for maximum understanding and engagement.

One example of an effort similar to NEEA's GoingDuctless.com website and resources is Minnesota's is the ASHP Collaborative, led by the Center for Energy and Environment. It has produced a website to promote these materials that will include design and installation guides, online trainings, and information about utility rebate programs. Efforts such as this should not be evaluated for cost effectiveness like an add-on measure, but instead be considered as part of a holistic strategy to ensure that the program achieves the full savings potential of the installed DHP projects.

If consumer education is part of a program that includes integrated controls, it could boost savings from that measure as well. Because integrated controls systems only produce savings if they are configured and used correctly, the authors' savings estimate for the controls enhancement assumes that only a fraction of those control system installations will actually deliver their full savings potential. An education campaign that improves the rate of successful operation could increase the percentage of controls projects that operate effectively, thus boosting the realization rate. While it might not be necessary to calculate and attribute savings separately to "integrated controls" and "education about how to use integrated controls," including an education component in an integrated controls program has the potential to significantly improve realization rates.

2.6.5. **Are there exceptions to this approach?**

Leaving aside the possibility that a future program could end up serving a population that is already very knowledgeable about how to operate DHPs for maximum effect, consumer behavior would be unlikely to impact DHP performance in a couple of situations. If DHPs are being installed in homes with no other heat source (either as new construction or where the policy is to remove the baseline system), there is no chance that the consumer would use the DHP for anything less than 100% of the heating load. Also, if some sort of controls system is installed that automatically optimizes the load between the DHP and the central system, and the consumer can simply use a single thermostat to specify a desired comfort temperature, then it would be necessary to educate them about how to operate the two systems correctly.

Note that while an ideal controls system is a replacement for education, the reverse is not true. Education is only expected to prevent the worst-case outcome where the DHP produces no savings or increases energy use. The authors do not recommend attempting to educate consumers about how to manually implement some sort of economic optimization controls scheme. Any recommendations to consumers about how to configure the DHP and baseline system to share the load must be optimized not for maximum overall efficiency, but for the maximum that can be achieved with an acceptable level of cognitive burden on the home's occupants. This likely limits advice to simple generalizations such as "Set the DHP to your desired temperature and the old thermostat a few degrees lower" and "Turn up the DHP first if you are cold."

2.6.6. **How can programs implement this approach?**

Two factors merit consideration in implementation of consumer education: *what* to tell consumers about how to use their new DHP, and *how* to tell them. A few recurring themes appeared in multiple guides and expert interviews regarding the operational strategies to share with consumers:

- Use the DHP for heating—it's not just an air conditioner!
- Use it as your primary heating system and only run the other(s) when you are uncomfortable.
- Set the old thermostat a few degrees lower than the DHP setting.
- Don't use deep setbacks or turn the temperature up and down frequently.
- Follow the manufacturer's recommended maintenance guidance regarding cleaning and servicing of both indoor and outdoor units.

Some good examples already exist such as the NW Ductless Heat Pump Project's *Homeowner Guide* (https://goingductless.com/assets/documents/uploads/DHP_Homeowners-Guide_REF.pdf), and the Canadian Home Performance Stakeholder Council's *Heat Pump Installation Guide for Existing Homes* (ICF Canada 2019) have a sections for homeowners, and Efficiency Vermont provides guidance in the form of anti-patterns (Efficiency Vermont n.d.). Numerous other studies and reports provide recommendations on better and worse ways to operate DHPs, though most are not written for end-users.

The more important question—and the harder one to answer—is how and when to deliver this information so that it has the desired effect. To the extent that our industry has considered consumer messaging, it has mostly been focused on selling DHPs to consumers; for an example, consider the 2015 NEEA consumer messaging study (van de Grift and Billingsley 2015). Addressing this question will require additional consumer studies, though it can build on messaging research from other industries.

2.6.7. **What are the challenges to a successful implementation?**

The primary challenge is that most utility energy efficiency programs focus on incentives for equipment purchases not on the full range of design, installation, operation and maintenance that are crucial for maximizing mini-split heat pump performance. Addressing this challenge will require installers to adequately train the consumers and users of the systems that they install. This is perhaps a reflection of a broader pattern in the current state of energy efficiency programs, which equates the installation of each unit of efficient equipment with a fixed amount of savings, and does not consider how, where, or when it is used. Perhaps this is still a backlash from the early "conservation" movement of the 1970s that admonished people to put on a sweater and make do with less energy consumption. Or perhaps the industry is still trying to replicate the success of lighting programs that blithely assume the ability to replace a single piece of equipment with an alternative that does the exact same job while using less energy, thus allowing calculation of the energy savings for each unit without regard for how that equipment interacts with the rest of the building and its occupants.

Heat pumps, like many of the emerging technologies that will be needed to make the transformation to a decarbonized and electrified energy system, are not simply a drop-in replacement that will deliver their full savings potential once consumers decide to purchase and install them. Their success depends on delivering the right one to the right home in the right way, and then on operating it correctly over its entire lifetime. This supports the reasons targeting and system design are important; consumer education is one more example of how the full savings potential of this product category is only achievable with consideration of the full context of its use. In this sense, when the authors recommend "consumer education" as a valuable component of a successful DHP program, it is part of a broader shift to achieving energy impacts through a long-term relationship with consumers, and not just marketing a set of "qualified products" to them.

From this perspective, an ideal education strategy might pick up where targeting and system design and quality assurance leave off: Supporting consumers through the use phase of the DHP's life cycle. This would include multiple distinct messaging opportunities, starting with an introduction to heat pump operation at the time of installation, following up a few days or weeks later with tips for getting the most out of your new DHP, then sending periodic reminders at seasonal changeovers and maintenance anniversaries. Such support would also ideally include some customization based on electric meter or DHP device data analysis, flagging early warning signs that the controls are configured sub-optimally or that a performance issue might require repair.

It is not clear whether this sort of service would be best provided by an efficiency program, an HVAC installer, a DHP or integrated controls manufacturer, or by some entirely new kind of energy service provider. However, if one looks to the digital transformations of shopping, banking, and transportation (to name a few) from static product-oriented industries that are now being disrupted by consumer-centric services, rebate programs could similarly be eclipsed by new models that not only deliver more savings, they could also provide better value and consumer satisfaction. Consider, for example, the way Sealed is bundling heat pumps with smart thermostats, insulation, and other products, while providing up-front financing and a savings guarantee (https://sealed.com/climate-control/).

2.6.8. Are there any gaps in knowledge that could be addressed with future studies?

While the optimal recommended strategies to consumers might be further refined, that gap is not the most critical one to address at this time. Rather, the key question to address is how to deliver these messages in a manner that will be compelling and will cause consumers to act on them. In addition, efficiency programs need to understand the tradeoffs of cost and reliability of using different channels through which to provide messaging. Installers might be able to provide the most nuanced advice, but "training the trainers" would require too much effort. Email might be cheaper, while a mailing addressed with "Or current resident" is more reliable even after the original consumer moves out of the house. Some of these questions might require field trials, but others could be addressed through design exercises with behavioral experts.

2.7. Quality Assurance: Making Sure the DHP Operates Efficiently

2.7.1. Results preview

BOX 5- Final recommendation preview for Quality Assurance
Practical recommendation: Record refrigerant charge levels for each DHP installed, and do not pay out incentives unless the refrigerant charge level is within manufacturer's parameters. If possible, use an electronic gauge and capture automated reporting and digital tracking data. **Additional options:** Additional QA/QC is warranted on DHPs, but savings estimates were not readily computable from available sources. These include: • Ensure that the height of the indoor head is at least 7 feet off the floor. • Preferably use a floor-mounted unit if there is room to deliver heat more effectively into the lower part of the space. If a wall unit is used, mount it several inches (6-8") below the ceiling (lower than minimum allowed clearance by 3-6" depending on manufacturer's minimum); or for a vaulted ceiling, mount with supply air outlet at approx. 6.5-7' from floor. • Ensure that the compressor unit is not so close to the ground that it can be covered by snow, and that it is not in a position to be rained on or covered in snow from the top. Make thermostat data available to program managers for real-time QA/QC based on data after installation.

2.7.2. What is quality assurance and COP maximization all about?

The estimated savings from DHPs is based on an assumption that they operate at roughly the rated coefficient of performance (COP) claimed by the manufacturer. However, this rating is only relevant insofar as the DHP is installed and operated according to the manufacturer's specifications. In practice, faulty installation practices can result in performance degradation that will erode savings. The most significant among these are refrigerant undercharge and (to a lesser extent) refrigerant overcharge. Numerous other installation problems have been documented, including mounting of the outdoor unit, routing of condensate lines, and maintaining the thermal integrity of refrigerant lines (Dentz 2019), but the frequency and savings potential of these issues has not been adequately quantified.

The practical process for minimizing these installation faults is to implement a regimen of quality assurance (QA). Specific QA techniques that can be applied to DHPs have been implemented in the northwest since the launch of utility programs, and are still being investigated by organizations such Minnesota's Center for Energy and Environment (CEE n.d.) One unique approach for this particular technology is to use data from smart thermostats for remotely detecting operational and configuration faults (Hardman et al. 2017).

2.7.3. Why does this produce savings?

At a high level, the answer is simple: Increasing the COP results engenders more savings by reducing the amount of energy to deliver heat to the home. Of course, the strategy of implementing a quality installation and quality assurance practice encompasses a number of specific tactics around various components of the DHP equipment. A full discussion of the physics behind the reasons a properly-installed and -configured DHP uses less energy per unit of heat delivered is outside the scope of this report. However, the bottom line is that errors in installation happen frequently,[2] and those errors almost never improve the performance of the DHP. Without a process in place to correct the errors, they will continue undetected, since very few of them are serious enough to impact consumer comfort, even if they significantly increase energy use.

2.7.4. How much savings is possible?

While a 2018 DOE literature review of HVAC installation issues confirmed the overwhelming evidence of installation faults—particularly in refrigerant-based systems such as DHPs—it conceded that the exact savings potential was hard to pin down (Department of Energy 2018). That report pointed back to a seminal 2014 National Institute of Standards and Technology (NIST) study that found that faults in ducted heat pumps could result in energy losses of 30% (Domanski, Henderson, and Payne 2014); note that only issues of refrigerant undercharge and overcharge apply to DHPs, while duct leakage and duct sizing do not. A recent NREL report revisited this question and concluded that improper refrigerant charge and indoor airflow rates are the most significant impacts (Winkler et al. 2020). Only 50% of installations in their meta study were properly charged, while 25% were undercharged and 25% were overcharged. Undercharge faults could result in an energy use increase of more than 20% and overcharge faults in an increase of more than 10% (ibid).

While data is insufficient to determine savings potential from the one remote QA monitoring study uncovered during this research (Hardman 2017), the results seem promising in terms of the number of problems it was able to diagnose. Among the 19 homes in which thermostats were installed and connected to the internet, the authors found:

- 6 thermostats not configured with the proper settings (max savings)
- 2 incorrectly installed heat pumps
- 3 sites with high aux heat ratios, which revealed problems with low airflow, deep setbacks, and an incorrectly configured thermostat that was locking out the compressor below 35°F

2.7.5. Are there exceptions to this approach?

In this case, the answer is simply "No." While many efficiency programs may consider managing a QA process too expensive, or requiring too much administrative burden for staff, installers or customers, the authors firmly believe this is a false economy.

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[2] Author's note: In this case, "frequently" means much more frequently than would be expected. The rate of defect in HVAC installation is appalling. While it is outside the scope of this report, this topic is of special interest to at least one author, who has studied it extensively.

2.7.6. How can programs implement this approach?

If a program's approach to QA consists of sampling 5–10% of projects in the standard naïve fashion, this is probably inadequate for anything other than catching the worst-offending installers who blatantly need more training. Programs should either be looking for ways to achieve 100% QA by building it into the installer close-out procedure, begin utilizing more robust statistical sampling based on known techniques for finding defects based on manufacturing science, or implement automated or remote methods. This final option holds the most promise, as it can provide automated fault detection and diagnostics (FDD) throughout the life of the equipment, which will detect additional problems and thus deliver additional savings.

2.7.7. What are the challenges to a successful implementation?

It is generally understood that QA doesn't result in long term change unless it is coupled with QC activities that work to resolve barriers to compliance. While the literature is thin on challenges to QA approaches, the interviews consistently indicated that QA is viewed as a cost center that can never be used to enforce installer compliance. The key contributing factors are defeatism, deemed savings-centric mindsets, policies and incentive structures, and a lack of basic knowledge about quality science and statistics. In details:

- <u>Defeatism</u>: In the interviews, and in the previous experience of the authors, this mindset has been cited many times is the perception that very little above and beyond what they have prescribed can change the behavior of installers or their tendency to avoid the rules.
- <u>Deemed savings-centric mindsets and policies</u>: At the core of the lack of motivation to fix the problem is the deemed savings model. Because in deemed savings programs, the installation of a unit is proof enough that it is producing savings, there is very little incentive for the implementer to improve performance of the measure from an economic standpoint.
- <u>Lack of basic knowledge about quality science and statistics</u>: QA/QC is viewed as an all or nothing tool that must be enforced in a labor-intensive, 100% sampling framework by many program implementers and policy makers. Despite more than 100 years of quality science existing since Walter Shewhart first started using control charts to improve factory operations, the authors know of only a single case in which this statistical approach is being used in quality inspections for installers, and it is a program for which one of them is responsible. The lack of these basic quality frameworks within the industry's programs is a reprehensible defect in thinking that subjects all parties—consumers, utilities, and installers—to additional costs and sub-par effectiveness of programs, enhancement measures, and work.

2.7.8. Are there any gaps in knowledge that could be addressed with future studies?

Two specific study areas present themselves:

1. No studies exist regarding how performance improves when a statistically valid QA/QC program, informed by quality science, is put into place.
2. A more extensive study of automated QA would likely bear fruit, as only preliminary studies have been conducted on this approach. A significant pilot along these lines

would be beneficial and could produce excellent data from which to suggest formal program design changes.

3. Market Study

The research team conducted a study of experts in research, contracting, manufacturing, and other roles in the DHP market. Each of these interviews used a standardized series of questions to determine an understanding of the state of the space. The important interview takeaways are included in the Meta Study above and in the Measure study below.

In addition to the interviews, the team researched products in the market, which largely consisted of researching integrated controls and determining how best to utilize them to garner enhanced DHP savings. At the time of this writing (March–October 2020), the DHP control market is still developing, and many products on the market could evolve from simplistic states into the more advanced state that the market needs.

3.1. Interviews conducted

Interviews were conducted with the following experts:

Table 3. List of Interviewees

Name	Organization	Category
Matt Christie	TRC	Researcher
Abi Daken	EPA ENERGY STAR	Researcher
Jordan Dentz	NYSERDA	Researcher
Eric Dubin	Mitsubishi	Manufacturer
Mike Duclos	NESEA	Contractor
Tom Eckhart	UCONS	Researcher
Richard Faesey	Energy Futures Group	Researcher
Steve Girard	Girard Heating and Cooling	Manufacturer
Dave Holland	Resideo	Manufacturer
Scott Libby	Royal River Heat Pumps	Installer
Tony Larson	National Grid	Researcher
Dave Lis	NEEP	Researcher
Bruce Manclark	CLEAResult	Researcher
Jake Marin	VEIC	Researcher
Eric Martin	NYSERDA	Researcher
Charles McCracken	CLEAResult	Program tech support
Alan Meier	LBNL	Researcher
Cheryn Metzger	PNNL	Researcher
Dan Meyers	Flair	Manufacturer
Jonathan Moscatello		Consultant/contractor
Danny Parker	FSEC	Researcher
Marc Rosenbaum	South Mountain Co	Researcher
Dan Rubado	Energy Trust of Oregon	Researcher
Adam Scheer	Recurve	Researcher
Ben Schoenbauer	MN CEE	Researcher
Mark Stephenson	Vermont Energy	Contractor
Kyle Svendsen	Eversource	Researcher
Mark Wyman	Energy Trust of Oregon	Researcher

3.2. Interview Questions

The following questions were asked of each category of interviewee. As per agreement with the interviewees, major takeaways are included in this report but individual quotes are not.

3.2.1. Researcher

- What do you see as the biggest drivers for underperformance of DHPs installed today?
- Do you know of recent studies that measured performance of DHPs in the field?
- What techniques or technologies exist to improve the field performance of DHPs?
- Do you know of any studies that have tested those techniques and technologies independently?

- Do you believe (or have evidence) that DHPs are not being operated so that they can handle the economically optimal portion of the heating load?
- What technologies exist to improve coordination of controls between the DHP and the baseline/backup system?
- Do you believe (or have evidence) that DHP savings estimates might be systematically over-predicting savings?
- How might we improve project analysis to better estimate (and/or target) potential DHP savings when selling/proposing/screening projects?

3.2.2. **Manufacturer**

- What do you see as the biggest drivers for underperformance of DHPs installed today?
- Do you know of recent studies that measured performance of DHPs in the field?
- Do you know of any studies that have tested those techniques and technologies independently?
- Do you believe (or have evidence) that DHPs are not being operated so that they can handle the economically optimal portion of the heating load?
- What technologies exist to improve coordination of controls between the DHP and the baseline/backup system?
- Do you believe (or have evidence) that DHP savings estimates might be systematically over-predicting savings?
- How might we improve project analysis to better estimate (and/or target) potential DHP savings when selling//proposing/screening projects?
- Are you planning to release integrated controls for HPs?

3.2.3. **Installer**

- What do you see as the biggest reasons for underperformance of DHPs installed today?
- On the other hand, how do you think that we can increase the savings of DHPs?
- Are there technologies that can improve the field performance of DHPs?
- Do you believe (or have evidence) that DHPs are not being used for the economically optimal portion of the heating load, that is heating when most heating hours occur?
- What technologies exist to help controls of the DHP and the baseline/backup system work together?
- How might we improve project analysis to better estimate (and/or target) potential DHP savings when selling/proposing/screening projects?

3.3. Integrated Controls Product Search

Three main categories of controls can be used to enhance the savings from DHPs:

1. Lockout: A totally stand-alone controller that can be added to the existing HVAC system to prevent it from running when outside temperatures are mild enough that the DHP should be able to carry the whole load
2. Cloud Integrated: Connected or communicating thermostats installed on both the DHP and existing system, then integrated through a third-party service such as IFTTT, SmartThings, Hubitat, etc.
3. Native Control: Connected or communicating thermostats installed on both the DHP and the existing system (currently limited to eFAF), where at least one of them includes a

native interface to provide the user's desired heating schedule by coordinating both systems. This might be achieved by a single-manufacturer solution, or a smart thermostat that can control compatible third-party thermostats on the other system.

Aside from manufacturer-specific systems for which the DHP must match the control system, two aftermarket solutions meet the criteria for category 3 above: Flair Puck and Resideo (described in detail in Section 3.3.3). The authors recommend either one of these two solutions, or any of the manufacturer-specific ones.

3.3.1. Lockout - Outdoor Lock-out Controls for Central HVAC

The controls solutions for category 1 are fairly simplistic, consisting simply of an outdoor temperature thermostat that prohibits the existing HVAC system from operating until temperatures are too cold for the DHP to effectively heat the house. This is a common control strategy for "locking out" aux heat in a central heat pump above a given outdoor temperature. Numerous options should be available at any HVAC distributor for approximately $25–$75; examples include:

- Goodman OT18-60A
- Johnson Controls A421ABC-02C

The team's conversations with experts uncovered conflicting views about this lockout strategy. Some recommended it, citing the low cost, ease of installation, and broad compatibility with any HVAC system that uses a 24V DC thermostat control loop. Control units rated to handle the 240V AC line voltage for zonal systems are available, and can be installed to control either all baseboards or just a subset of the circuits in the home. On the other hand, this type of control is not integrated in any way with the DHP, so residents would need to be educated about using the DHP for heat. If it is not in heating mode or fails to heat the house adequately for any reason, the central HVAC system will not provide backup heat until the outside temperature drops below the lockout setpoint. Also, it will not prevent the DHP from operating concurrently with the central HVAC, which could be good or bad depending on the home's layout.

Due to the risk of comfort issues and the possibility of callbacks, HVAC technicians will likely want to set the lockout temperature much higher than the optimal minimum temperature for DHP-only heating, which will reduce the savings potential for this strategy. While this strategy probably represents the most cost-effective option if done right, it's unlikely that programs, installers, and consumers will all be aligned to implement it successfully. Typically, when a conflict like this arises, energy savings get sacrificed in favor of comfort, convenience, and consumer satisfaction.

A similar solution includes "dry-contact" adaptors that many DHP manufacturers provide; these allow the DHP to connect to and be controlled by a conventional 2-stage heat pump thermostat operating on 24V. While the user interface and setup is much simpler, in these cases the use of the "dry-contact" adaptor typically compromises the variable-speed algorithms in the DHP as well as limiting or eliminating user control of other important features (such as indoor fan modes, vane position, dry-mode cooling, etc.). Because of the potentially serious impact on the

DHP's functioning, including efficiency, the authors likewise consider them not viable for large-scale promotion by programs.

3.3.2. Cloud Integrated - Connected Controls Systems

Many controls solutions in category 2 have been tried in recent years, due to the emergence of both internet-connected thermostats and Internet of Things (IoT) integration scripting platforms such as IFTTT, SmartThings, and Hubitat. These systems should be able to coordinate the heating load between the existing HVAC system and the DHP, depending on outdoor air temperature and other factors. They require the consumer or installer to configure a Wi-Fi thermostat such as an ecobee, Honeywell, or Nest on the existing HVAC system (or, for zonal systems with line-voltage thermostats, a Stelpro Ki, Tado°, or Sinopé on each zone) and a second Wi-Fi thermostat on the DHP. Although some DHP manufacturers are beginning to offer native Wi-Fi thermostats, for many DHPs the only option is to use a third-party Wi-Fi controller such as Flair Puck, Sensibo, Ambi Climate, Ceilo, or the Honeywell D6 Ductless Controller.

While in theory this solution provides all the functionality needed to achieve comfort, control, and savings, achieving those outcomes can be convoluted and fragile. Scripting the IoT integration platforms is a cumbersome process; the detailed instructions for setting up a simple "permanent hold" schedule for one DHP and one central HVAC system at a single outdoor temperature crossover point can take as many as 51 steps ("Panasonic MASS Rebate Mini-Split System Changeover Procedure" 2020). Also, because the integration scripting is running outside of both thermostats, it typically does not respond gracefully if occupants manually adjust the thermostat interface (either using built-in controls or through the mobile/web app) to change the desired setpoint.

Further, these systems are all still undergoing rapid development in both their technology and business models, and a solution that relies on the interactions of three distinct pieces of technology is prone to fail when any one of them makes a change to its application programming interface (API) in the future. For example, some time after Nest was acquired by Google, the API was slated to transition from the "Works with Nest" platform to the "Google Home" platform, which would have broken all IFTTT integrations. Fortunately, the outcry from users has apparently resulted in a solution to keep that integration working for now. However, an efficiency program counting on 10–20 years of energy savings from the investment in this measure should consider not only the possibility that one of the technology providers will make a breaking change to the system, but also the possibility that the current residents will move out or lose interest in maintaining the cloud scripting services.

While home automation enthusiasts may enjoy using these services to customize the functionality of their HVAC systems, investing in this type of technology is not a reliable way for efficiency programs to procure long-term energy savings.

Unfortunately, for zonal systems, this is currently the only option of which the authors are aware. Because the need for integrating eFAF and DHP controls is largely due to the limitations of heating more distant rooms with the DHP, some experts interviewed suggested that integrated controls for zonal systems are likely not worth the significant expense (around $100 per zone) when similar results could be achieved by setting back the zone thermostat in the same room as the DHP to a "safety" temperature several degrees below the DHP comfort setpoint and educating residents about using the DHP as primary heat.

3.3.3. Natively Control Integrated Connected Controls Systems

The best-case options for coordinating the operation of the DHP and existing HVAC system are native controls (typically third-party to the DHP) where the interface for one or both of the systems' thermostats includes that functionality. This provides occupants with a single, unified interface that can also be reflected in the physical thermostat(s). This option offers the best opportunity for optimization across comfort, convenience, and savings. However, the only connected thermostats with this capability (so far) are 24V models that will not work with electric resistance zonal systems[3].

Two options can currently provide an integrated controls solution across a wide range of DHP models: 1) Flair Puck and 2) the Honeywell Home Resideo Ductless Integration. Because these two options allow programs to support consumers and installers with a mass-market integrated controls solution, they are described in greater detail here.

Table 4. Control Technologies Comparison

	Flair Puck	**Honeywell Home/Resideo**
Connection to the DHP	Gateway Puck in IR range of the DHP ($120)	D6 Ductless Controller in IR range of the DHP ($125)
Connection to the eFAF or other central HVAC	Ecobee, Honeywell (Lyric or TCC), or Nest* connected thermostat ($80-$250)	Honeywell Home T6 Pro Smart or T10 Pro Smart connected thermostat ($150-$250)
Additional room sensors?	Yes: add Sensor Pucks or ecobee room sensors	Yes: add RedLink™ Room Sensors
Other features	"Smart vent" to add zoning to FAF supply registers is available	Wired indoor/outdoor sensor available
User Interface	More complex, and more flexible, setup and operation; multiple login accounts required	Relatively simple; single manufacturer account

* *Note:* Nest integration is currently in flux due to the API transition discussed above.

Some of these solutions are available from DHP manufacturers as a proprietary ecosystem that includes the DHP, DHP thermostat, central HVAC thermostat, and a web/mobile app. In some cases, the proprietary communications even extend to the central HVAC equipment, offering even more control options. These solutions should be viable for consumers who have the right set of compatible equipment or are willing to upgrade other system components to match. While this is more likely to appeal to new-construction projects or high-end retrofits, if the existing

[3] While it is possible to install a 24V thermostat in place of a 240V (or "line voltage") thermostat with the addition of a 240V relay and 24V transformer, that would add more expense and complexity than most programs are willing to consider.

systems and DHP are both compatible this may be a viable option. Mass Save® maintains a list of qualified integrated controls products that includes options for most popular DHP brands.

3.3 When a DHP is the Wrong Solution

The authors believe that in some circumstances, a DHP may not be always be the right type way to reduce use of low efficiency heating/cooling systems. The team found other solutions that may serve the house better than a DHP solution.

If a heat pump can be provided to a space with the right capacity, and matched to the space such that the legacy system shutting off does not rob other spaces of heating and cooling, the heat pump can definitely fully displace ducted legacy systems. The primary difficulty is in matching the heat pump to the space in a way that doesn't cause problems for more distant spaces also served by the legacy system. Three solutions discussed in this section are inverter-driven heat pumps that either use or replace the legacy air handler. These solutions make no changes to the zoning provided by the legacy system; their advantage is that 100% of the legacy system is displaced where and when capacity is sufficient. The only disadvantage, outside of cost, is the loss of partial cooling compared with a ductless unit that can heat just one area or zone while occupied.

3.3.4 Air Handler Replacements

These solutions completely replace the air handler in a ducted system and include a cabinet, air handling fan, heating and cooling coil, and are matched to an outdoor condensing/evaporating unit. They are essentially drop-in replacements for smaller ducted systems and can add cooling to a heat-only furnace. Because the capacities for heating top out at about 50,000 BTUh, they are candidates for homes with more than one (albeit smaller) air handlers, or for smaller homes with relatively low heat loss. Another limitation of the units is that some are rated for somewhat limited static pressure, so depending on the unit and the existing duct system, ducts may require modifications for the heat pump to work well. The units do, however, provide an important opportunity for greatly increasing the efficiency of eFAFs and for displacing fossil fuel. Table 5 shows the current offerings of two manufacturers. The product lines are constantly expanding and may be available in somewhat larger sizes in the future.

Table 5. Examples of Inverter-Driven Ducted Air Handler Units

Makers	Heating Capacities kBTU (T)	Cooling Capacities kBTU (T)	Air Flow (cfm)	Heating COP (HSPF)	SEER
Mitsubishi SVZ-KPxx, PVA-AxxAA7	13.5k (1)–46k (4)	12k (1)–42k (3.5)	910	(9.5–13.6)	16–21.4
LG LVxxxHV	56k (4.5)	58k (4)	480–1000	3.22–3.52 (9.5–11)	16.5–19.2

3.3.5 Coil Replacements/Additions

Manufacturers have been discussing coil-only replacements that would insert into an existing air handler much like conventional air conditioner and heat pump "A coils" do in conventional units. Daiken offers a VRV Life product that combines its gas furnace with a cased A-coil that can operate independently or at the same time as the gas furnace. It is not marketed as a drop-in coil replacement, apparently requiring a Daiken communicating gas furnace, but its presence shows that a drop-in coil replacement is in theory possible.

Table 6. Example of Inverter-Driven Coil Replacements

Maker	Heating Capacities kBTU (T)	Cooling Capacities kBTU (T)	Air Flow (cfm)	Heating COP (HSPF)	SEER
Daiken CXTQxxTASBLU	27k–66k (5.5)	24k (2) –60k (5)	NA – based on equipment match	NA – based on equipment match	NA – based on equipment match

3.3.6 Compact-Ducted Systems

These systems are typically inverter-driven heat pumps matched to cassettes that serve new low-pressure-drop so-called compact-ducted (sometimes called “mini-duct”) systems. They are essentially a new ducted system and are not discussed in depth here. However, they may be far more efficient than multi-zone heat pumps (which are currently popular outside the single-zone DHP programs) to deliver heat and cooling to multiple small rooms and thus complete a full conversion to heat pump technology, regardless of the pre-existing system type.

4 Measure Study

4.3 Overview

This section provides a detailed analysis of the five suggested individual enhancement measures, as well as the justification for the additional savings projected. The goal of this section is to enable the reader to reproduce the study team's results, and simultaneously to invite them to build on and revise the hypotheses, assumptions, and methods. All of the analyses in this document are built upon assumptions around the technology, consumer use of the technology, and uptake of solutions if there were to be a change in the market. The authors have taken steps to proceed conservatively in the estimation of savings potential for each enhancement, and believe that if perfectly implemented, the savings potential could be above and beyond what is portrayed in these calculations.

The team chose five "enhancement measures" based on both suggestions of experts and team members' abilities to estimate savings from the enhancement measures. Other enhancement measures were suggested and considered, but most were discarded due to the lack of citable sources for savings estimates, or because early indications suggested that they could not be effectively implemented or would fail cost/benefit screening. The authors believe that this set of enhancement measures is at the intersection of practical, effective, and defensible, and note that given additional information, some other more practical or effective enhancement measures should be just as defensible.

A complete list of the enhancement measures the study team considered can be found here. In general, the enhancement measures fall into five categories: Targeting, Design, Integrated Controls, Consumer Education, and Quality Assurance. For this exercise, the team chose the most practical and defensible enhancement measure in each category, as follows:

1. Targeting: Target houses with significant electric heating loads
2. Design for Displacement: Only install DHPs in living rooms (until better studies provide finer distinctions)
3. Integrated Control: Proper use of Integrated Controls
4. Consumer Education: Make sure consumers know how to use their DHPs
5. Quality Assurance: Correct refrigerant charge levels

The results presented in this study are Northwest regional estimates. For any particular climate or market place the estimated savings will likely differ and therefore should be considered separately. The intent of the savings calculations here is to provide a starting point for more detailed consideration of climate and local market effects or if the DHPs are being used to displace something other than electric resistance heating.

The enhancement measures suggested within this document are intended to be defensible based on the literature and implementable based on the knowledge and experience of the authors. The authors attempted to be quite exhaustive in the early planning stage and constructed a list of every potential option they could identify. (available upon request from NEEA).

The authors trimmed the list using simple rules: If the savings can't be reasonably cited and/or justified from the technical literature, then the enhancement is not an option. If the approach would require a significant amount of ongoing involvement from the building occupant, it was discarded or downgraded. This approach is reflected in each of the enhancement measures suggested below.

4.4 Savings Baseline

The savings from these five measures is incremental over a baseline developed by the NW Power Planning Council's Regional Technical Forum (RTF) and approved in October of 2019.

The advisory committee for the project suggested that all the baselines associated with this project should relate back to the measure assessment workbooks for eFAF replacement and displacement of zonal resistance heating. For quick reference, these are the workbooks used as baselines:

- Residential DHP for Zonal Homes v5.1
- Residential Ductless Heat Pump on Forced Air Furnace v2.1

The 2018 BPA evaluation was an influential document for the workbooks with its well-summarized, granular information about how savings related to reported heat pump usage and coincident displacement of the central or zonal system in the retrofitted home (Navigant and BPA 2018). The team made a core assumption that to achieve the top level of savings in the BPA evaluation, the system must be well-controlled.

The baselines from the workbooks are divided into zones (NEEA Zones 2 and 3 are grouped together). The evaluated first-year savings are:

- For an eFAF replacement:
  - HZ 1: 2,550 kWh
  - HZ 2 : 12,570 kWh
  - Blended average of HZ1 and HZ2: 2,560 kWh [4]
- For a zonal electric heating systems:
  - HZ 1: 1,780 kWh
  - HZ 2 & 3: 965 kWh
  - Blended average: 1,709 kWh.

IECC and RTF heating zones are fairly similar. Figure 1 (p.8) provides a graphical comparison of the heating degree day ranges of the RTF HZ1, HZ2, HZ3 to IECC climate zones.

Baseline savings are derived from the RTF workbooks for eFAF and zonal replacements with DHPs. These workbooks can be found here:

[4] HZ3 sample size was only 8 sites where savings were inexplicably low and therefore not used by the RTF the average.

- eFAF: https://nwcouncil.box.com/v/ResDHPonFAFv2-1
- Zonal: https://nwcouncil.app.box.com/v/ResDHPforZonal-v5-1

4.5 Enhancement Measure 1: Targeting Homes with Significant Electric Heating Loads

4.5.4 Description of Measure

Targeting will involve some analysis of whether the home is a viable energy-saver. This is typically determined from pre-existing data on energy usage, behavior patterns, or other characteristics of the home. Three ways to conduct this analysis are:

1. Target the home based on total usage (e.g., overall number of kWh used per year)
2. Target the home based on the ratio of usage in winter to shoulder months as a metric to determine which homes will save
3. Develop weather-regression models to disaggregate heating and cooling from base loads in order to provide an accurate prediction

For this measure, the authors recommend targeting houses based on not only total energy use, but on some measure of heating energy. This could be a simple swing-season calculation or a full energy regression model. If homes with large heating loads are targeted, this measure is expected to create average savings improvements of 2,169 kWh/year for eFAF homes and 1,449 kWh/yeah for zonal homes.

The minimum-effort approach for targeting involves focusing on homes that consume more than 15,000 kWh per year in electricity. This more minimal measure is expected to enhance DHP savings by 840 kWh per year for houses where an eFAF system is being offset, and 562 kWh per year for houses where a zonal system is being offset. The measure can be utilized based on targeting against overall bills and is designed to enable targeting of houses without significant computational overhead. Upgrades on this measure include targeting with advanced metering infrastructure (AMI) data, thermostat data, or both.

4.5.5 Supporting Evidence from Literature Review and Interviews

Several of the interviewees discussed their work in evaluation of energy efficiency upgrades and indicated that they found larger houses more capable of savings. Two key hypotheses presented are that 1) in two-story houses a DHP on the first floor can offset heating needs on the second floor because warm air rising to heat bedrooms in upper floors and 2) given that larger houses use more energy, including distribution energy, proportional offsets equate to larger energy use reductions. The literature review supports these hypotheses. As discussed above, multiple studies demonstrate that these savings opportunities exist in larger houses.

The interviews also provided supporting evidence that in addition to simple targeting, the targeting can be accomplished effectively using AMI data from individual houses, or even monthly billing data.

4.5.6 Savings Calculation Approach

For the best-case scenario of targeting based on weather-modeled heating load ratios, the team used the SMUD study (Blunk, Golden, and Scheer 2020) to calculate the ratio of targeted to un-targeted savings. Since targeting improved savings from 1,300 kWh/year to 3,100 kWh/year, that represents a 137% improvement in savings per project. Applying that ratio to the baseline savings of 2,560 kWh/year and 1,709 kWh/year for eFAF and zonal system, respectively, indicates a maximum savings potential of 3,498 kWh/year for eFAF projects and 2,335 kWh/year for zonal projects.

Starting with the zonal workbook, one can reproduce the authors' calculations as follows:

1. For both of the calculations for HZ1 and HZ2&3, perform the following:
    - Sum the total number of samples across each evaluation, binning by load size (indicated in column B).
    - Compute a weighted average estimated savings for each load bin category.
    - For each bin, compute the incremental benefit by subtracting the weighted average of savings from the savings for all DHPs (the first row in the weighted average savings column).
2. If done correctly, the results should be as follows:

Table 7. Targeting Worksheet for Heating Zone 1

Heating Zone 1: VBDD R^2 < 0.8 OR Has Supplemental Heating Fuels			
Total samples	**Weighted Average (at or above annual kWh)**	**Incremental Benefit**	**TMY Total Elec. Consumption, Pre-DHP Install (kWh)**
976	2614	0	[0–10,000]
2356	2831	217	[10,001–15,000]
2406	3194	580	[15,001–20,000]
2403	3877	1263	[> 20,000]

Table 8. Targeting Worksheet for Heating Zones 2 & 3

Heating Zones 2 & 3 (Combined): VBDD R^2 < 0.8 OR Has Supplemental Heating Fuels			
Total samples	**Weighted Average (at or above annual kWh)**	**Incremental Benefit**	**TMY Total Elec. Consumption, Pre-DHP Install (kWh)**
49	1474	0	[0–10,000]
147	1619	145	[10,001–15,000]
235	1923	449	[15,001–20,000]
524	1856	382	[> 20,000]

Calculating using the same targeting for eFAF is not possible, so the team made an assumption that the zonal savings could be extrapolated to the eFAF savings using the ratio of baseline savings for the two system types. The baseline savings figures primarily reflect the amount of electric resistance heat that is displaced by more-efficient DHP heating, where eFAF systems produce more savings as they are less efficient overall due to fan energy and duct losses. The improvement due to targeting will increase participants' baseline energy use in both groups equally, assuming a similar distribution of home sizes, insulation and air-sealing, and non-electric heating system use in both groups. Since eFAF displacements are evaluated to save 1.45 as much as zonal displacements (BPA Eval 2018), the incremental savings for each group was multiplied by this number to yield the following:

Table 9. Targeting Worksheet 2 for HZ 1

Heating Zone 1: VBDD R^2 < 0.8 OR Has Supplemental Heating Fuels	
TMY Total Elec. Consumption, Pre-DHP Install (kWh)	**eFAF Incremental Benefit**
[0–10,000]	0
[10,001–15,000]	325
[15,001–20,000]	869
[> 20,000]	1892

Table 10. Targeting Worksheet 2 for HZ 2 & 3

Heating Zones 2 & 3 (Combined): VBDD R^2 < 0.8 OR Has Supplemental Heating Fuels	
TMY Total Elec. Consumption, Pre-DHP Install (kWh)	**eFAF Incremental Benefit**
[0–10,000]	0
[10,001–15,000]	218
[15,001–20,000]	673
[> 20,000]	573

The team assumed that targeting would not be used to remove more than half the available homes. The benefit from targeting therefore was based on the average of the best case savings and worst case savings. The best-case is so strict that it eliminates 75% of projects, and the worst-case will incorrectly categorize many candidates The way this would be accomplished is to some sort of modeled heating-energy metric, that enables targeting homes with high electric resistance heating loads.

Table 11. Targeting Results

eFAF	**Annual kWh**

Baseline savings	2,560
Increased savings from best-case targeting	3,498
Increased savings from worst-case targeting	840
Average of best- and worst-case	2,169
Zonal	
Baseline savings	1,709
Increased savings from best-case scenario	2,335
Increased savings from worst-case scenario	562
Average of best- and worst-case	1,449

4.5.7 Knowledge Gaps and Uncertainty

These estimates were computed from the RTF's measure assessment workbook on zonal displacement for DHPs, which has some methodological challenges. For instance, in the workbook, systems with no additional heat sources are automatically lumped in with systems that have good correlation of energy savings from existing heat sources.

The RTF workbook for eFAF displacement is also quite different from the one constructed for zonal displacement. This introduces uncertainty around how much more savings can be garnered by displacing eFAF systems at various prior load use cases.

Even more critically, the specific distribution of savings potential across the homes in a particular efficiency program's territory will determine how the targeting parameters will affect savings and participation rates. A pre-program analysis of targeting potential should be conducted using that program's existing billing data. If no DHP program data exist, program staff can conduct a preliminary analysis with billing data, but should also conduct a follow-up analysis with actual program participants to ensure that the targeting metric is properly selected to maximize savings.

4.5.8 Further Study Suggestions

Several further study opportunities would be immediately beneficial:

- Evaluate eFAF savings grouped by similar bins to the zonal displacement savings.
- Study other targeting methods, including swing analysis, monthly bill regression, or the use of AMI data to more accurately determine how a focus on heating consumption, and specifically load shape, can facilitate targeted savings opportunities. This would likely allow houses with less than 15,000 kWh per year usage to be targeted.
- Analyze billing data from across the Northwest to establish default targeting criteria.
- Develop open-source code and implementation guides for programs.

4.6 Enhancement Measure 2: Designing for Displacement (only install DHPs in living rooms)

4.6.4 Description of Measure

The installation of systems in inappropriate or previously unconditioned spaces is a key source of underperformance in system design. A reason for this underperformance is that the air distribution throughout a house varies from room to room, and DHPs do not utilize ducts to distribute conditioned air to the house. To counter this source of loss, this measure advocates that heat pumps be installed only in living rooms, which are open areas central in the house. Another formulation of this measure would see DHPs installed only in spaces in the house with good air distribution, as measured by how open they are to other parts of the house.

4.6.5 Supporting Evidence from Literature Review and Interviews

Multiple interviewees suggested that a key source of underperformance is lack of air distribution in the house, and the inability of DHPs to make all rooms comfortable. One interviewee took this suggestion so far as to point out that single-bedroom homes may be better-suited for DHPs because the occupants are more likely to leave the bedroom door open at night, and may even be convinced to utilize hinges that automatically open the door unless it is latched.

In addition to anecdotal evidence, the literature review shows evidence that installing DHPs only in living rooms can increase savings. Cadmus conducted a study for the Energy Trust of Oregon in 2019 (Jackson and Walczyk 2019) in which a weighted average of DHP savings showed 809 kWh in annual savings, while those installed in living rooms showed 1,118 kWh per year, an improvement of 38%.

4.6.6 Savings Calculation Approach

DHP savings and count per room from the Cadmus study are replicated here:

Table 12. Designing for Displacement Worksheet

Room Type	Site Count	DHP Count	TMY Pre-Usage [kWh/Site]	Low Savings (90 % lower)	Savings [kWh/DHP]	High Savings (90% CI Upper)	Savings %	Cost [$/DHP]	Cost Confidence Interval at 90%
Living Room	415	449	13218	770.00	1,118.00	1,465.00	9.10%	5796	omitted
Bedroom	203	233	14187	147.00	621.00	1,096.00	5.00%	7037	omitted
Other	31	36	14643	-294.00	826.00	1,945.00	6.50%	6309	omitted
Kitchen	29	33	13805	-930.00	206.00	1,342.00	1.70%	6151	omitted
Dining Room	26	32	14562	-922.00	201.00	1,393.00	1.70%	6310	omitted
Office	16	18	14987	-2,345.00	-509.00	1,327.00	-3.80%	8245	omitted
Basement	16	19	17568	-1,995.00	-191.00	1,573.00	-1.30%	8343	omitted
Sunroom	6	11	16538	-4,883.00	-952.00	2,908.00	-10.50%	3330	omitted

Hallway	4	4	14290	-1,801.00	384.00	2,569.00	2.70%	7870	omitted
Loft	3	4	12405	-1,141.00	333.00	1,807.00	3.60%	5399	omitted
Bathroom	2	3	9947	-919.00	2,181.00	5,281.00	32.90%	2969	omitted
Garage	2	2	20580	1,224.00	3,668.00	6,112.00	17.80%	3500	omitted
Total	**736**	**820**	**Weighted average**	**279**	**809**	**1373**			

Using the difference between the weighted average of all savings and the savings of only installing in living rooms allows computation of the expected savings. Note that room types with fewer than 10 samples were omitted from the analysis; those rows are greyed-out in Table 13.

Table 13. Designing for Displacement Results

Input	**Low**	**Mean**	**High**
Savings improvement if installed in living room	176%	38%	7%
Average savings (kWh/year)	279	809	1373
Savings improvement (kWh/year)	491	309	92

4.6.7 Knowledge gaps and uncertainty

This category fairly clearly illustrates the benefit of placing DHPs in spaces that are open and where air can circulate. Does this 38% mean be extrapolated to all programs? How does this apply to programs that already have some level of contractor training or program requirement for heating the "main living area"? In addition, How does house geometry affect the savings that can be garnered by installing a DHP? While on average, installing in living rooms is clearly preferable, this is due to the average living room being in the center of the house, rather than specific to the geometry. Studies of house geometry would help close the knowledge gap in this area.

4.6.8 Further Study Suggestions

Specific evaluations focused on determining savings from DHPs as a function of location in the house have been cited in this report, but more could be done. The team recommends this type of analysis for inclusion as a feature of all future evaluations, and that this topic be considered for a stand-alone study.

4.7 Enhancement Measure 3: Integrated Controls

4.7.4 Description of Measure

Integrated controls are a cornerstone of effective savings opportunities in residential DHP installations. These controls can come in three flavors:

1. Automated and intelligent control of the displaced heating system
2. Automated and intelligent control of the DHP after installation

3. Automated, intelligent, and coordinated control of the DHP and the displaced system

While option (3) has the potential to yield more savings than (1) and (2), even when they are both implemented in a single house, this option currently exists only in a prototype form that requires significant setup and represents a fragile system, often utilizing an IFTTT integration. The authors believe that significant savings from integrated controls will not be certain until a stable and scalable implementation of option (3) exists.

To this end, the authors' recommendation is to implement (1) and (2) in a coordinated manner, and not to touch controls outside of the heating season. The specific control strategy that works for this method is a setback technique in which the DHP is set to a comfortable temperature and the central system is set back 2–4 degrees. While an outdoor temperature lockout would be even more effective than this methodology, it may not be friendly to installer operations.

4.7.5 Supporting Evidence from Literature Review and Interviews

Several papers in the literature review evaluated the effect of integrated controls, including:

- Metzger 2017
- Korn 2016
- Dentz 2018
- Navigant 2018
- Fenaughty 2019
- UCONS 2020

Some notes from selected papers are replicated in the following table:

Table 14. Integrated Controls Studies and Their Savings

Year	N	Improvement	Study Name	Notes
2020	N/A	35%	Metzger, Cheryn, Travis Ashley, Yan Chen, Karthikeya Devaprasad, Jaime Kolln, Zhihong Pang, Karen Fenaughty, et al. 2020. "Who's Leading: The Dance Between Mini-Splits and Existing HVAC Systems."	Based on modeled results of eFAF offset vs. baseline 3.
2017	7	91%	Fischer, Dana. 2017. "Integrated 2-Stage Thermostat Mini-Split Mini-Test Preliminary Control Update." Presented at the NEEP ASHP Workshop, June 27.	Based on test #3 "Integrated controls" and considering the increased percent use of the heat pump (called "production" here) as the percent increased savings.
2016	152	234%	Korn et. al. 2016. "Ductless Mini-Split Heat Pump Impact Evaluation."	"Substantially more savings could be achieved (i.e., the top 25% of savings) if newly installed DMSHPs are operated more regularly and continuously by better matching and integrating them zonally with primary heating systems, through better configuration design and installation, and installer and consumer education and training." (p. 24)
2018	15	21%	Dentz 2019. "Downstate Air Source Heat Pump Demonstration."	"If you leave it, they will use it" suggests that homes with existing systems left in place only displaced about 60% of consumption on average, so only ~2/3 of savings potential was achieved. While it's possible to achieve 50% more savings by removing the baseline central system, it's not clear how much IC would be able to achieve in practice.
2018	2332	99%	Navigant and BPA. 2018. "Impact Evaluation of Ductless Heat Pumps and Prescriptive Duct Sealing."	"However, for DHP replacing eFAF, the team found that evaluated savings were higher and close to current UES for program participants who did not continue to use eFAF as their primary heating and for participants who did not use DHP to displace non-electric heating, such as wood heat." (p. 17) As this evaluation has a realization rate of 50.3%, this suggests a potential for almost 100% improvement from controls.

Generally, implementing integrated controls improves outcomes significantly in most studies that evaluated their effectiveness.

4.7.6 Savings Calculation Approach

The approach to savings calculations for integrated controls is to assume that systems with partial displacement (as listed in the current evaluated savings) are not using proper integrated controls. The authors then evaluated the bounds of achievable improvements from the research papers in the range of evaluated savings shown above. The potential percentage savings is multiplied by the savings evaluated for systems with partial displacement of the existing system, yielding a maximum potential improvement. A derating factor of this maximum improvement is then applied to reflect the likelihood that the controls strategy would be effectively achieved. This derate factor ranged from 10-30-50% and was based on the experience of the team in dealing with individuals programming thermostats. The team felt that a 30% derate factor would provide a conservative and believable estimate of effective integrated controls implementation.

Table 15. Integrated Controls Worksheet and Results

eFAF				
Input	**Low**	**Mean**	**High**	**Units**
Current evaluated savings	1,939	2,560	2,811	kWh/year
Savings improvement from ICs	21%	86%	234%	percent increase in savings
Max savings improvement	407	2,202	1917	kWh/year
Percent of ICs that are used correctly	10%	30%	50%	
Likely savings	41	660	959	kWh/year
Zonal				
Input	**Low**	**Mean**	**High**	**Units**
Current evaluated savings	1,509	1,709	1,909	kWh/year
Savings improvement from ICs	21%	86%	234%	percent increase in savings
Max savings improvement	317	1,470	4467	kWh/year
Percent of ICs that are used correctly	10%	30%	50%	
Likely savings	32	441	2234	kWh/year

4.7.7 Knowledge Gaps and Uncertainty

While the evidence that integrated controls can lead to savings is compelling, two key caveats need to be addressed:

1. All of the true integrated controls as described in option (3) above exist only in prototype state.
2. All of the evidence that is given as derived from the evaluations and measure assessment workbooks relies on an assumption that improved integrated controls will increase displacement, which is supported but not certain.
3. The assumed derate factor can only be estimated prior to program implementation and is fairly uncertain, hence the conservative estimate that only 30% of the potential savings would be realized on average.

4.7.8 Further Study Suggestions

Two studies should be undertaken in the near future:

1. A large-scale pilot of the most effective disjoint (options 1 and 2) integrated controls strategy, along with an evaluation of the savings thereof
2. A survey of the incentives that would most encourage hardware manufacturers to implement true integrated controls, as suggested in option (3)

4.8 Enhancement Measure 4: Consumer Education

4.8.4 Description of Measure

Consumers typically do not understand what a DHP is or how it works. At the extreme end of the spectrum of low-information consumers, there exists a group that doesn't associate the DHP with a heating product, thus using it only for air conditioning. This results in systems having little to no displacement of heating systems. In order to combat this situation, the team recommends sharing the following key points with the consumer:

- Use the DHP for heating; it's not just an air conditioner!
- Use it as your primary heating system and only run the other(s) when you are uncomfortable.
- Set the old thermostat a few degrees lower than the DHP setting.
- Don't use deep setbacks or turn the temperature up and down frequently.
- Follow the manufacturer's recommended maintenance guidance regarding cleaning and servicing of both indoor and outdoor units.

4.8.5 Supporting Evidence from Literature Review and Interviews

The bulk of the evidence for this measure comes from interviews with experts and observations of the project team. In several interviews, experts provided anecdotal evidence of evaluations they had done in which DHP users were not aware that the product could heat. On the project team, Bruce Harley presented more anecdotal evidence, stating that he had also done an evaluation where this was the case.

In order to compute savings, the team assumed that the vast majority of systems with little to no displacement could be affected by a consumer education campaign. This is in line with the hypothesis that the majority of losses in this category are from consumer misuse of the product.

4.8.6 Savings Calculation Approach

The "Little to no eFAF displacement" evaluated savings from Tables 4–6 of the 2018 BPA evaluation report document represents 18% of users that displaced little or no electric savings, either because they did not use the DHP for their primary heat or because they did not use electric heat before installing the DHP. and consequently saved almost no energy (or even increased electric consumption). Because this particular measure has more uncertainty than others, the authors chose conservative estimates for savings calculations:

- The maximum percentage of homes not using a DHP for heat is set at 11% for eFAF replacing systems.
- This percentage is decreased for zonal systems at 5%, likely because these users are already accustomed to per-room heating systems.
- The team chose 0 kWh per year as the baseline for systems that aren't being used for heating, instead of -450 kWh, in order to take the conservative approach.

To calculate savings, the team assumed that the system will move from "little to no displacement" to "partial displacement." The calculations are shown in Table 16 below.

Table 16. Consumer Education Worksheet and Results

eFAF				
Input	**Low**	**Mean**	**High**	**Units**
Percent of homes not using DHP for heat	5%	11%	18%	
Percent of those homes that will be educated	0%	50%	100%	
Potential savings if DHP is used for heat	1318	2190	3062	kWh/year
Improved savings per home	0	125	547	kWh/year
Zonal				
Input	**Low**	**Mean**	**High**	**Units**
Percent of homes not using DHP for heat	1%	3%	5%	
Percent of those homes that will be educated	0%	50%	100%	
Potential savings if DHP is used for heat	880	1462	2044	kWh/year
Improved savings per home	0	22	102	kWh/year

4.8.7 Knowledge gaps and uncertainty

- The actual percentage of users who don't know that a DHP can be used for heat is not well-studied.
- Some portion of zero to little displacement homes likely had DHPs installed in unconditioned spaces, and the breakout of that percentage is unclear.

4.8.8 Further Study Suggestions

Two further study suggestions are pertinent:

- An evaluation that asks consumers the specific question "Are you aware that a DHP can be used to heat your home?" may be the best way to remove the uncertainty from this estimate.
- A study should be conducted on the methods and timing of education interventions. In one particularly notable interview, the research team heard that even professionals in the consumer education space do not know which methods will work specifically for heat pumps.

4.9 Enhancement Measure 5: Quality Assurance

4.9.4 Description of Measure

Despite best intentions of installers who install DHPs, significant quality issues are to be expected. Quality install programs are a central component of HVAC incentives, yet are frequently discounted in terms of savings that can be garnered. Quality assurance on an installation should cover many aspects, including:

- Is the compressor located in an area where it could be easily covered by snow?
- Do the refrigerant lines have leaks?
- Is the system's refrigerant level in line with manufacturer recommendations?
- Are all wall penetrations properly sealed?
- Is the condenser ground clearance appropriate?

To include a quantifiable measure for quality assurance, the team chose correct refrigerant charge levels. This measure has been shown in the literature to reduce the efficiency of installation of HVAC equipment, and has been studied well enough to estimate the effect of corrective enhancement measures.

Supporting Evidence from Literature Review and Interviews

Both the literature and interviews showed awareness of this issue and examples how poor QA had reduced the performance of heat pumps, though in some cases the examples were based on other types of heat pumps besides ductless units.

- Dentz 2019: 20 sites, 6 had notable QA issues, 4 of those were refrigerant-related
- DOE 2018
- BPA 2018
- HVAC Save - the state of Iowa instituted a comprehensive program for QI/QC
- NREL 2020

Savings Calculation Approach

Estimates of refrigerant charge issues in residential HVAC were derived from the June 2018 DOE report, which stated that refrigerant overcharge occurs in 4–50% of units, undercharge occurs in 29–78%, and that each of these issues creates a loss between 2 and 20 percent. Assuming that the evaluated results are based on the reduced savings from mis-charged DHPs, we take the inverse percentage as the savings potential. Multiplying the sum of likelihoods by the percent savings potential from fixing an under/overcharge error together with the evaluated savings from the measure assessment workbook results in an expected mean loss of 255 and 170 kWh per year for eFAF and Zonal units, respectively, as shown in Table 17.

Table 17. Quality Assurance Worksheet and Results

Input	Low	Mean	High	Units
Refrigerant Overcharge	4%	27%	50%	Likelihood
Refrigerant Undercharge	29%	54%	78%	Likelihood
Loss of savings from refrigerant problems	2%	11%	20%	Savings reduction
Increase in savings if repaired	2%	12%	25%	Percent
Average savings without errors - eFAF	1280	2560	3840	kWh/year
Potential savings from QA - eFAF	127	255	382	kWh/year
Average savings without errors - Zonal	854.5	1709	2563.5	kWh/year
Potential savings from QA - Zonal	85	170	255	kWh/year

4.9.5 Knowledge Gaps and Uncertainty in Savings Estimates

The authors do not know exactly how many DHP systems are installed with incorrect refrigerant charge levels. Assuming they suffer deficiencies at the same rate as normal residential HVAC systems is a decent assumption, but some programs may require more accuracy.

4.9.6 Further Study Suggestions

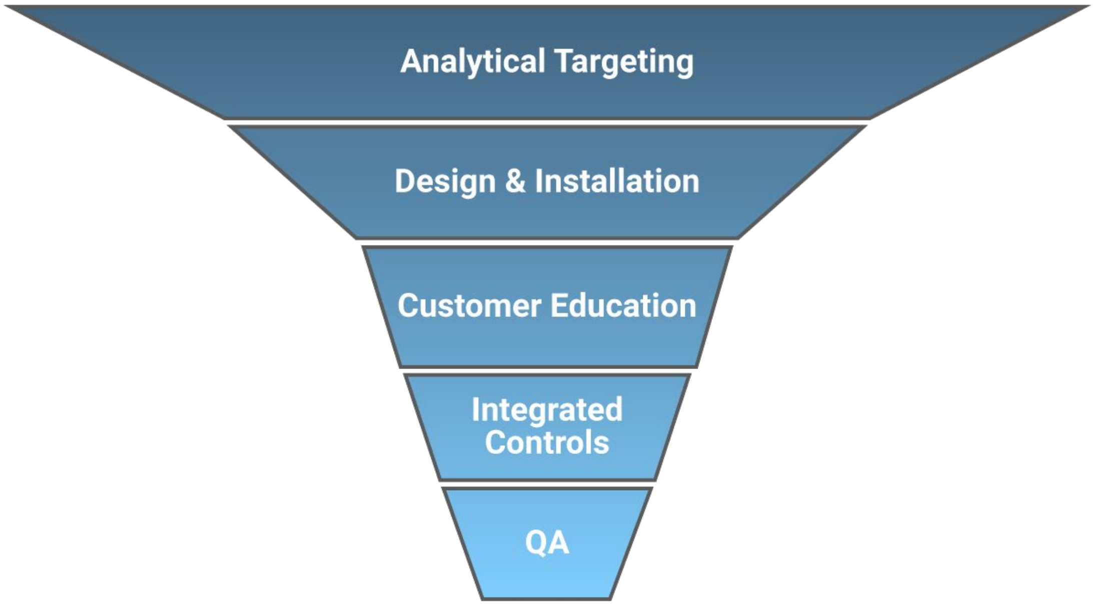
Generally, quality is substantially overlooked as a part of program implementation, even though it is commonly acknowledged that it affects the outcomes of programs. The authors do not know the root cause of this phenomenon, but suggest that it be studied at the same time that actual effects of quality on DHP performance are studied.

5 Conclusions and Future Work

Substantial additional program savings are possible. It is likely that savings could be doubled over current RTF UES values if all enhancement measures were used. This suggests that there are likely several hundred thousand homes in the Northwest where DHPs are cost effective energy efficiency measures for displacing electric resistance heating. The challenge however is that achieving these savings will require utility programs to operate more like weatherization programs than like energy efficiency "widget" programs where care is taken to identify the pre-existing condition and the way in which the weatherization is completed. The potential enhancement measures described herein and the meta study can provide substantial guidance on how to develop more home specific DHP program measures and contractor guidelines.

While it is clear that DHPs are delivering less savings than engineering estimates would predict, there is no single cause and therefore no singular or simple fix. If there were a single, easy-to-install hardware device that would fix all problems with DHP performance, the authors would recommend incenting it. However, no such device or technology exists, or likely could. DHPs are not lightbulbs–the measures implemented to improve them must be dynamic and responsive to the varying sources of underperformance. The sources of underperformance fall into the five categories the authors have highlighted: Poor (or no) targeting of homes that are most viable for DHPs, placement of DHPs in zones that do not distribute heat well, poor integration of baseline and DHP controls, less than optimal use of the DHP due to lack of consumer education, and improper installation leading to reduced COP. Solutions to these issues are also not universal. Targeting strategies vary by data availability and analytics capabilities; system design and controls strategies vary by home size and system type; and creating feedback mechanisms to ensure quality installation and proper use requires constant vigilance, and is frequently ignored by program implementers as a source of underperformance, despite years of overwhelming evidence.

Though each one of the five strategies described in this report can improve outcomes by itself, the maximum savings can be achieved by combining all of them into a holistic optimization approach. Most importantly, each strategy applies to a particular phase of a project, and the remaining opportunity diminishes once that phase has passed. The specific order the authors advocate is: 1) targeting, 2) proper design and installation, 3) proper use of integrated controls, 4) consumer training and education, and 5) proper quality assurance.



Following this framework can increase the value to both installers and consumers of energy efficiency and savings resulting from DHP installations.

Finally, during the course of this work, a number of additional questions arose that could not be answered within the available scope of work. The team has shown to a reasonable degree of certainty that the savings exist to justify changing program dynamics to incorporate these new measures, and are fairly confident that given additional study, even more detailed savings estimates could be achieved. The authors' recommendations follow.

5.3 Future Work

The authors see several areas in which future work makes sense within the context of this report. Here are the largest ones:

- Field-testing new integrated controls technology, with an eye toward true integration between DHPs and the systems that they displace. This field testing is needed because the integrated controls market in this space is nascent and immature. The specific piece that seems to be missing from most integrated controls is that they do not link up seamlessly to both the DHP and the existing system, and that user setup and operation is not simple and intuitive.
- Specific targeting using AMI or other granular data in order to find homes that could benefit from DHPs in meaningful ways, but that do not fall into the category of "uses more than 15,000 kWh per year." This is necessary because data on savings as it relates to very granular energy use data are sparse. A calculator that uses regional HDD and CDD, DHP cost, combined with time-series data about home energy use, should be created in order to evaluate targeting metrics for homes that are more specific than those given in this report. This will help smaller homes (e.g., those that use less than 15,000 kWh per year) to be viable targets for DHP installation.

Appendix A – Calculation Spreadsheet

Calculation spreadsheet available upon request (cdymond@neea.org)

Screen capture below.

	A	B	C	D	E	F	G
1	**eFAF**	*Evauated baseline savings*	*2560*	https://nwcouncil.box.com/v/ResDHPonFAFv2-1			
2	Enhancement Measure	Expected Savings Improvement (kWh/year)	Percent of baseline	Percent of savings	Cost (Low)	Cost (high)	Utility Value
3	Target houses based on billing data	2,169	85%	51%	$10.00	$50.00	$542
4	Only install DHPs in living rooms	976	38%	23%	$10.00	$100.00	$244
5	Proper use of Integrated Controls	660	26%	16%	$100.00	$500.00	$165
6	customers understand that DHPs can	165	6%	4%	$1.00	$5.00	$41
7	QA - Correct refrigerant charge levels	255	10%	6%	$20.00	$100.00	$64
9	Total Enhancement Improvements	4,226	165%	100%			
14	**Zonal**	*Evauated baseline savings*	*1709*	https://nwcouncil.box.com/v/ResDHPforZonal-v5-1			
15	Enhancement Measure	Expected Savings Improvement (kWh/year)	Percent of baseline	Percent of savings	Cost (Low)	Cost (high)	Utility Value
16	Target houses based on billing data	1,449	85%	53%	$10.00	$50.00	$362
17	Only install DHPs in living rooms	652	38%	24%	$10.00	$100.00	$163
18	Proper use of Integrated Controls	441	26%	16%	$100.00	$500.00	$110
19	customers understand that DHPs can	26	2%	1%	$1.00	$5.00	$7
20	QA - Correct refrigerant charge levels	170	10%	6%	$20.00	$100.00	$43
22	Total Enhancement Improvements	2,738	160%	100%			
25	**Assumptions**						
26	Utility value of 1 kWh per year	$0.25	savings over				
29	**Color Code**						
30	Primary Result						
31	User Input						

Dashboard | Savings by HZ | Baseline Savings | Targeting | System Design | Integrated Controls | Customer Education | QA and Performance Payments

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