DRAFT

R113 Ductless Heat Pump Evaluation

Connecticut Energy Efficiency Board (EEB)

Prepared by DNV GL under subcontract to NMR Group, Inc.

March 13, 2016

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1 EXECUTIVE SUMMARY

This study was undertaken to identify the lower than expected realization rate for ductless heat pumps (DHPs) reported in the R16 Impact Evaluation of the 2011 program year, "Impact Evaluation: Home Energy Services—Income Eligible and Home Energy Services Programs (R16)," (herein described as the R16 Impact Evaluation). A secondary objective of the study was to provide forward looking information to assist the utilities and EEB in getting the most impacts from DHPs.

The findings presented here describe the households that installed DHPs in single and multifamily residences in Connecticut through the Connecticut Energy Efficiency Fund (CEEF) programs and describes the HVAC equipment and participants before and after installing DHPs in 2011 (included in the R16 Impact Evaluation) as well as customers who participated in the DHP rebate program between 2013–2014 through the first quarter of 2015.

In 2014, the EEB published the final report for the R16 Impact Evaluation, a comprehensive evaluation that estimated the program impacts for multiple measures installed through the HES and HES-IE programs.[1] The evaluation found mixed results for the realized energy savings form the DHP measure, which yielded a 46% realization rate.

The R16 Impact Evaluation identified several potential reasons as possible culprits of the low realization rate:

- Differences in participant types between those that were used in the study that informed the PSD and the R16 study.
- Other factors that may be attributed to customer behavior, for example, "takeback effects" occurring due to an increase in room temperature or operating hours in anticipation of lower operating costs, or changes in equipment operations resulting in the switch to a handheld remote control from a traditional thermostat

Comment [GR1]: First incidence of acronym. Please spell out.

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[1] Connecticut Energy Efficiency Fund, Final Report, Impact Evaluation: Home Energy Services—Income-Eligible and Home Energy Services Programs (R16), December 2014. http://www.energizect.com/your-town/hes-and-hes-ie-impact-evaluation-r16-final-report-12-31-14, p. 7.

Program Description

Figure 1. The Butter Brook Hill Apartments.

DHP rebates are available to all Eversource and UI residential customers via whole house retrofit and HVAC rebate programs. DHPs are eligible measures in Energize Connecticut's Home Energy Solution (HES) and Home Energy Solutions-Income Eligible (HES-IE) programs. They can also be rebated independent of these direct install initiatives when installed by a contractor certified by the manufacturer of the product and that has attended an EnergizeCT training seminar. Customers with income at or below 60% of state median income that have not participated in weatherization services in the previous 18 months are eligible for the HES-IE Program and may qualify to receive a DHP at no cost to them. As an example, the Butter Brook Hill Apartments in New Milford, pictured in Figure 1, provides seniors with independent living options and was one of many multifamily properties to receive DHPs with funding from the HES-IE Program in 2011.

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Comment [GR2]: Check with Companies: While HES/HES-IE do have significant DI components, DHPs are not one of them. Better to use "whole house retrofit"?

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Comment [GR3]: Though were these largely ARRA funded? Has the Company done many no-cost HES-IE DHPs using only ratepayer funds?

Study Methods

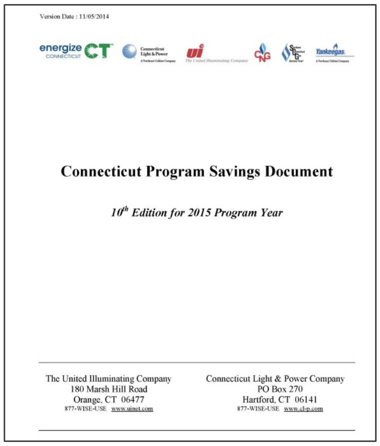
The study employed a variety of quantitative and qualitative methods. Given the study objectives, it was necessary to collect data from both 2011 participants evaluated in the R16 Impact Evaluation and recent participants from the 2013–2014 and first quarter of the 2015 program years.

One hundred and twenty four computer-aided telephone surveys were completed. DNV GL conducted the telephone surveys during the fourth quarter of 2015 with residential customers of Eversource and UI who had participated in the Connecticut HES program and had installed DHPs with program support.

A subset of 20 telephone survey respondents were recruited to participate in an on-site survey. The inclusion of on-site surveys provided more detailed and granular data than could be collected over the phone.

DNV GL conducted in-depth vendor interviews. Although this effort produced limited interviews, those completed gained vendor perspectives on their program experience, education and instruction, the customer's decision making process, methods for system sizing and the influence of ARRA funding.

Comment [GR4]: First incidence of this acronym. Please spell out.



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Connecticut Program Savings Document

10th Edition for 2015 Program Year

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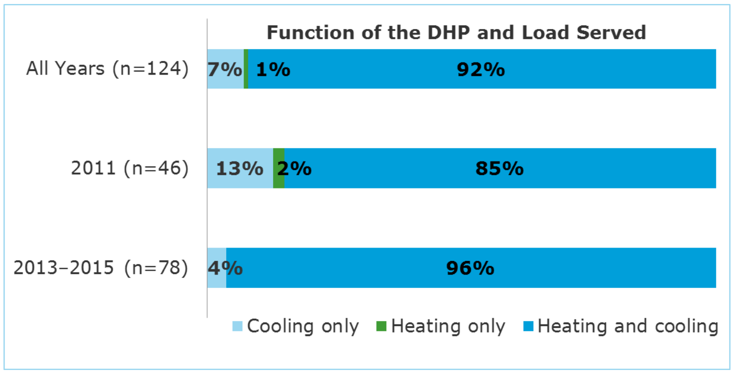
The study reviewed the 2012 Connecticut PSD used in the R16 impact study as well as the current (2015) PSD. The PSD reviews assessed the pre and post installation heating and cooling assumptions that informed the PSD savings factors and provided a high-level comparison of the DHP PSD calculations for with ex-ante calculations from other cold climate states such as Massachusetts, New York, New Jersey and the Mid-Atlantic Technical Reference Manual. Finally, this report contains **a billing analysis case study** and a brief literature review. The case study offers recommendations on possible ways to improve precision of the savings estimates. The literature review includes results from several DHP evaluations and other published technical reports.

Findings

This study found evidence to support a number of likely reasons why DHP realization rates did not meet program expectations. However, we also note that rebated DHPs met and and often exceeded customer expectations. Virtually all customers are very satisfied with the the equipment, it's cooling capacity and the associated improvement in comfort levels. The perponderance of duel fuel households and customer operating strategies may be hindering program savings, and are described below, but the customers believe they are getting good value from their investment and have very positive feelings about the program.

As seen in Figure 2, **92% of all respondents (2011 and 2013–2015) reported using their DHPs for both heating and cooling.** The more the DHP is used, the more savings it should generate, and customers are using their units during all four seasons, albeit not always for all 12 months.

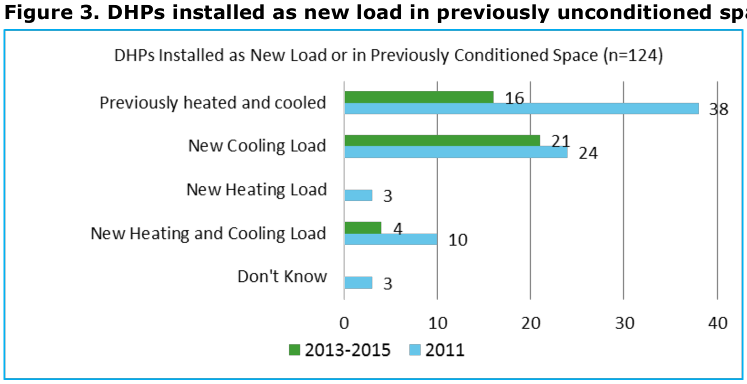
Figure 2. Function of the DHP and load served.



The highest savings rates are realized when DHPs replace electric resistance heating or a less efficient cooling source. **Whereas 100% of the 2011 group transitioned to the DHP from electric resistance heat, only three in ten respondents (28%) from the 2013-2015 program years transitioned from electric.** The remainder increased their electric load by integrating a DHP with a pre-existing fossil fuel heating system.

Evaluated savings are negatively impacted when DHPs serve spaces that were not previously conditioned. **Thirty Six percent of respondents reported that they installed the DHP in a space that was previously only heated and added a cooling load where none previously existed. An additional 11% percent**

Figure 3. DHPs installed as new load in previously unconditioned space.



installed the DHP in an unconditioned space or in new space, thus adding new heating and cooling loads (Figure 3**).**

The majority of pre-existing cooling systems that were replaced by DHPs are no longer in use. Most participants used the DHP to serve all of their their cooling needs. Seventy two percent reported that they removed and disposed of their old system, 20% are still using their pre-existing system and 9% reported that the systems remained installed but were not being used.

Survey respondents frequently mentioned that the DHP cannot provide adequate heat in colder weather? Although the savings rate of a DHP is influenced by the pre-existing HVAC system and fuel type, it is also influenced by how the pre-existing systems are integrated with the DHPs.

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Nearly 17% of 2011 and 22% of 2013–2015 phone respondents reported that either they do not use the DHP during the coldest months of the winter, or that it is used as a back up to the pre-existing heating system (Figure 4). Sixty three percent of respondents operate their DHP as the primary heating system and use the pre-existing system as supplemental heat. Another 7% reported operating the pre-existing system in tandem with the DHP. Ten percent of respondents have transitioned to the DHP for 100% of their heating needs.

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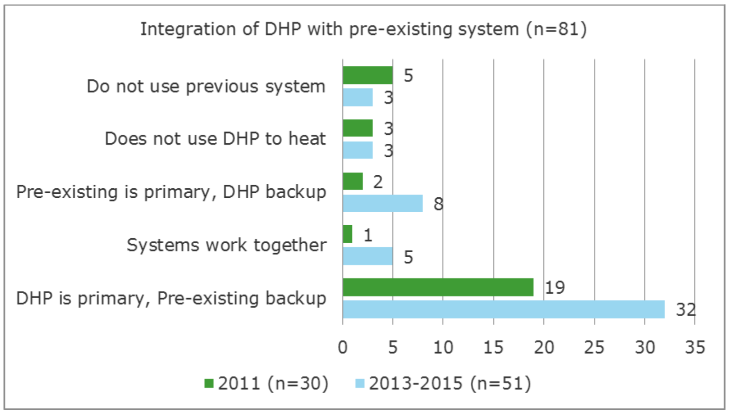
The on-site results revealed that 3 out of 20 participants reverted to oil as their sole heat source because fuel prices were so low. While the phone survey results hinted at the issue, the on-site survey provided an opportunity to understand the interplay between fuel prices and DHP use. With the current delivered residential price of electricity around $0.19/kWh and average #2 fuel oil prices at $2.16/gallon, it is currently less expensive to use fossil fuels than the DHP.[2] The price point at which the DHP becomes a better choice than oil varies depending on the efficiency of the DHP.

[2] 2016 Summary of Connecticut Electric Rates. 1 January 2016, https://www.eversource.com/Content/docs/default-source/rates-tariffs/2016-ct-electric-rates.pdf; Turmelle, L. Connecticut regulators approve higher electricity rates, *New Haven Register,* 15 February 2016, http://www.nhregister.com/article/NH/20151116/NEWS/151119613. Weekly Connecticut No. 2 Heating Oil Residential Price. 2016, February 10. U.S. Energy Information Administration, https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=W_EPD2F_PRS_SCT_DPG&f=W

Figure 4. Integration of DHP and the pre-existing heating system



In Figure 4, one can see the number of ways that customers integrate their pre-existing systems with their DHP. Operational patterns and how the DHP is integrated is well documented as having a direct effect on operating efficiency and realized savings. However, control strategies for the DHP alone, much less operating two systems together, are unique to DHPs, and must be learned.

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Based on respondent descriptions of how they operated their DHPs, and despite a sense that they understood the equipment, many were adopting operational strategies that lowers equipment efficiency and erodes the full potential of the DHP to save energy. Aside from reading the operating manual cover to cover, education is likely to be the only channel for customers to become familiar with information that describes the unique operating characteristics of the DHP and the operating strategies required to yield savings. Sixty-eight percent or survey respondents reported receiving an average of 36 minutes of education and training, with the 2013–2015 group tending to cite longer training periods. **It is clear that the programs rebating DHPs take customer education very seriously.**

Regardless of the time devoted to education, 94% percent believed that they received enough education and understood how to operate the DHP although several said they were still confused about the controls. However, during the on-site surveys, participants described their training and education in more detail and a different picture emerged. One-half of the 20 on-site particpants reported receiving sufficient instruction, three indicated that they were not given any instructions at all and three were asked to refer to the manual for instructions.

Takeback Effects

An objective of this study is to identify evidence of takeback effects from increased interior temperatures in anticipation of lower operating costs. "If I can save money with the DHP, maybe I can turn up the heat without increasing my bill." This attitude and a subsequent increase in indoor temperature settings were suggested as contributing to the low realization rate noted in the R16 study. After collecting information on customer's thermostat practices, interior set points before and after the DHP was installed, and customer attitudes, there was not enough evidence to conclude that temperature takeback was a factor in the low realization rate. There are several reasons why this is the case. Most important, it is difficult to make a one-for-one comparison between thermostatic behavior before and after installation of the DHP for three reasons:

- Participants report that the DHP thermostat must be set 2-5 ^{o}F higher than the pre-existing system just to maintain the same interior temperature.
- It is typical for the pre-existing system and the DHP to operate concurrently during colder months.
- Thermostat settings for pre-existing equipment usually included a setback strategy but automated setback strategies are not used with the DHPs.

Comment [GR5]: The text in the report's main body says that "several" respondents report doing this. Is this issue overstated here?

PSD Review

The approach taken to calculate DHP savings in the 2015 Connecticut PSD is in many ways the most advanced savings approach reviewed among neighboring states and the mid-Atlantic TRM. All of the savings formulas in the New York, New Jersey, Massachusetts, and the mid-Atlantic TRM adhere to the same core approach as the Connecticut PSD. However, the CT PSD also incorporates a savings factor that inherently includes operating efficiency and a realization rate that reflects evaluations performed since the study that produces those savings factors. All approaches reviewed used heating seasonal performance factor (HSPF) as the standard measure of heat pump heating efficiency, and seasonal energy efficiency ratio (SEER) as the cooling equivalent. Use of these values is consistent with industry practice. However, we note that HSPF does not include testing at temperatures below 17 degrees, which introduces uncertainty around its relevance for the DHP technology. A NEEP study also points out that DHP SEER rating may not be 100% representative of actual equipment performance in Connecticut because DHPs are tested under less extreme design temperatures.[3]

Comment [GR6]: Though would this affect EER ratings more than SEER ratings?

[3] NEEP, Ductless Heat Pump Meta Study, November 13, 2014, p 8,9

Billing Analysis

Multiple billing analyses were reviewed in this study. Many had similar savings rates to the R16 Impact Evaluation and almost all had similar sampllng errors. The biling analysis methods and results are consistent with other studies in many regards.

Billing analysis converts utility billing data into useful estimates of normalized (weather adjusted) annual consumption (NAC). Energy savings are estimated by observing changes in NAC between the pre and post installation or treatment periods. It is a common technique in impact evaluation because it presents a cost effective method for estimating the interactive savings of multiple measures and it uses readily available billing, program tracking, and weather data as primary inputs. Many participants in the R16 Impact Evaluation had multiple measures installed at the same time, as will most participants going forward. In these cases, a whole house approach is necessary to account for the interactive effects of each measure.

One complicating factor for the DHP program is that most customers are running two heating systems. They may turn off their heat pump in colder weather, or have it be secondary to the pre-existing non-electric heat. Billing analysis is a powerful tool given that it can make statistically valid savings estimates with 12 months of data. However, in order to produce reliable estimates, HVAC equipment must operate consistently relative to outdoor temperature for all 12 months. Based on the results presented here, these conditions are unlikely to be true for many DHP installations.

1.1 Summary Conclusions

The following conclusions and recommendations rest upon the findings from this study.

The good news

Program participants from all years surveyed and visited in this study are overwhelmingly satisfied and happy with the DHP installed through the program. It is clear that the DHPs are meeting participant expectations.

Cause of low realization rate in R16

The first objective of this study is to understand the primary drivers of the realization rate of 45%. This study identified three primary drivers of the realization rate in the R16 Impact Evaluation.

1. The PSD cooling saving factor is based on program operations and installation conditions that differ from that observed among 2011 participants (the reference year of the R16 impact study).

2. Participants in the R16 study had a moderate number of installations that added to heating loads, which was not accommodated for in the PSD calculation used at the time.
3. There is evidence that many customers are adopting control strategies that reduce the overall efficiency of their DHPs.

Each of these is discussed in more detail below.

1. PSD Cooling Assumptions

The PSD kWh cooling savings factor is 3.1 kWh per MBTU for Hartford and 3.2 kWh per MBTU for Bridgeport. These values are sourced from a 2009 study of the ductless pilot program. These values are based upon an assumed baseline RAC of 9.0 EER and included 22.5% of sites where the DHP represented an increase in cooling capacity over baseline (participants that had no pre-existing cooling system). In this study, nearly 61% of 2011 sites did not have cooling serving the space before the DHP was installed, which would have a significant effect on the realization rate in the R16 report.

We do note that the 2014 PSD was updated for the 2015 Program Year. The 2015 version still uses the same cooling savings factors from the 2009 pilot study but includes the realization rate from the R16 Impact Evaluation to inform the final ductless savings estimate. Because the R16 Impact Evaluation is more representative of current HES and HES-IE participants, all things being equal, the updated PSD calculation, with additional modifications, should result in more representative realization rates.

2. Added Heating Loads

The PSD in place at the time of developing the tracking savings for 2011 participants had an assumption that installed DHPs replaced electric heat and had no supplemental non-electric heat serving the space. In our study, roughly 9% of 2011 participants surveyed reported that the DHP was installed in a space that was either not previously heated or was an addition. In a billing analysis, these sites would have negative savings and have a disproportionate impact on the realization rate.

Comment [GR7]: And were many of the displaced existing heating systems non-electric?

3. Heating Use and Control Strategies

In the northeast, where second heating systems are often necessary, how those systems are operated in conjunction with the DHP can greatly influence savings. In our study, nearly 17% of 2011 participants reported that they are either not using their DHP in the winter or they are using it as a back up to the pre-existing system. These behaviors will negatively affect the ability of the DHP to produce savings.

Evaluation risks in future years

In many ways, we believe the 2013–2015 participant groups are at increased risk of low electric savings realization rates than the 2011 group evaluated in the R16 study. There are several reasons why electric savings among this group of participants are likely to be lower than those estimated from the PSD, even with the use of the R16 realization rate.

- As noted earlier, electric heating and cooling loads are added when DHPs do not replace existing electric equipment serving the same space. In the 2013–2015 participant groups, we estimate that 44% of DHP installations were in spaces that were previously not air conditioned and 17% in spaces that were not previously heated.
- In addition to new loads due to DHP installation in locations not previously conditioned, we also note that non-electric fuels heated many spaces where a DHP was installed. We estimate that in those areas heated before the DHP was installed, 72% were heated by non-electric fuels. This condition will increase the electric heating load and result in an erosion of evaluated savings.
- Many DHPs are not primary heating systems, but function as a backup or are supplemented by electric resistance baseboard and non-electric fossil systems. In our review of industry evaluations, many of them note that that some portion of DHP participants realize low or negative electric savings because electric resistance is not the pre-existing heating system.
- As oil prices continue to decline, it becomes increasingly less expensive for customers to use fossil fuels as their heat source compared to electricity (their DHP). This would result in DHPs being shut down, reducing electric savings rates of installed systems.
- Low oil prices are also likely to slow program growth among participants who might normally enter the program specifically to mitigate the high price of fossil fuels. It may not be possible for program marketing efforts to overcome the cost/benefit of operating a DHP during periods of depressed fossil fuel prices.

Takeback Effects

There are few emperical studies on temperature takeback, though there is consensus that takeback exists to some degree, particularly for HVAC measures. To the extent we were able to identify the conventional behaviors associated with thermostatic take back, it appears to be an isolated phenomena. In our estimation, there are many other operational patterns identified in this study that are likely to have a much greater influence on energy savings than takeback.

Education

How the customer controls the DHP has a direct effect on its operating efficiency. First, the remote control device is new and the operational patterns that optimize DHP efficiency do not align with the conventional wisdom surrounding more traditional HVAC equipment such as dramatic setback strategies or frequently turning the DHP on and off.

In the Northeast, it is necessary to have a backup heating system to supplement the DHP in colder weather. Under these circumstances, where the customer also needs to integrate DHP use with a second system, education about integrating the pre-existing system with the DHP becomes an even more critical factor for the DHP to achieve anticipated levels of savings.

Comment [GR8]: Not always. In some cases a properly sized cold climate heat pump can meet the full heating load, particularly in a well weatherized home. That said, most DHP installations only cover some portion of a dwelling's conditioned floor area.

Other Conclusions

- The characteristics of operational patterns of DHP users indicate that this measure is a good candidate for a two-stage, variable degree-day billing analysis approach. The telephone survey and on-site audits revealed that customers adopt different strategies for integrating their DHP and their pre-existing heating systems that result in large swings of heating reference temperatures. A two-stage model (or PRISM-like analyses) calculates a unique reference temperature for each household and is the recommended approach. It is unknown whether adopting a variable degree-day model will increase or decrease the evaluated savings rate, but it should reduce statistical error and increase the reliability in the results.
- The savings factors from the 2009 study of the ductless pilot program are most accurate when the pre and post conditions of the DHP sites inherent in the savings factors are similar to those being evaluated. The 2009 study had particular criteria around eligibility for DHP installation. The conditions around those installations resulted in a specific set of pre-existing system scenarios and customer use behaviors from which savings were calculated. Those conditions and the various ways in which the results were presented and available from the report makes their application reasonable for PSD purposes, although their accuracy is dependent upon the similarity of program design and operations at the time of the study and those that the study results are being applied to.

Comment [GR9]: Yes. But should more/better participant data be collected and should the PSD be expanded to more fully capture the different heating and cooling scenarios encountered in the field?

1.2 Summary Recommendations

Comment [GR10]: Anything to be said about contractor installation and sizing practices?

Anything more explicit to say about the use of different/better control hardware to integrate DHPs with the existing heating systems?

The following recommendations are intended to help improve the accuracy of tracking savings estimates, mitigate future evaluation risks, and maximize electric savings from DHP installations.

<u>Recommendation 1: Update the current PSD:</u> The current PSD formula should be updated to better reflect the conditions in which DHPs are being installed and used. The PSD does provide a realization rate to revise savings based upon the R16 study. However, the majority of particpants in R16 were from a unique customer base (multifamily under relatively controlled circumstances) which is not representative of subsequent participants. These revisions should account for instances of load added when the unit is installed in a previously unconditioned space or when it displaces non-electric heating sources (i.e., fossil fuel or wood).

Comment [GR11]: Good! Did DNV GL review the current DHP rebate application? How can it be improved to help support this greater PSD granularity?

<u>Recommendation 2: Perform a billing analysis using a more representative sample of program particpants:</u> An alternative to the above recommendation would be to perform a billing analysis that better captures the DHP installation pre and post conditions on more recent participants. This result could be used to displace the current realization rate in the PSD as a factor to adjust the savings derived from the DHP formula. Recommendation 6 below provides a recommendation on the form such a billing analysis might take if such an effort is undertaken.

Comment [GR12]: While possibly difficult and expensive to do, would this approach be even better if billing analyses were done of different sub-populations: no previous heating, displace cooling, etc. and then applied to the more granular PSD approach in Recommendation 1?

<u>Recommendation 3: As an alternative 1 and 2 above, perform an on-site engineering analysis:</u> An alternative to the previous two recommendations would be to perform a study on more recent participants where a sample of sites is metered and analyzed, akin to the KEMA study performed on the pilot program. Albeit a more expensive option than those covered in the previous two recommendations, such a study would provide new cooling and heating savings factors for the PSD based upon current DHP installation pre and post conditions and could also provide non-electric savings impacts for purposes of understanding greenhouse gas emission reductions associated with DHPs.

Comment [GR13]: What about leveraging ongoing metering efforts in MA and RI?

<u>Recommendation 4: Educate customers on DHP operation strategies that generate the highest savings rates:</u> Although it is clear the program takes customer education seriously, the impact of customer behavior on realized electric savings warrants continued attention. This study suggests that customer education and knowledge of how to integrate the DHPir system with their pre-existing system diminishes over time. Some ideas to help maintain high levels of desirable DHP opeartion includes providing additional information on the EnergizeCT web site on control, maintenance and operations strategies to supplement the functional information already provided on the site (e.g. "How a Heat Pump Works" and Heat pump FAQs).[4] Such a new section might be called "How to Maximize your DHP Savings." Additional delivery channels coud be explored.

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<u>Recommendation 5:</u> Increase program engagement with the electric resistance heating customers who have the highest savings potential.

[4] http://www.energizect.com/your-home/solutions-list/ductless-split-heat-pump-rebates

Based on our review of the study that forms the basis of the PSD, the R16 impact study and the data gathered from 2013-2015 participants, we believe that the mass market conditions in which DHPs are being installed is going to reduce electric savings further than observed in the R16 study. One way to mitigate this would be a target-marketing campaign directed to those electric resistance customers with the highest savings potential (where the DHP is displacing electric resistance heat, there is pre-existing room air conditioning that is removed from service and customer education focuses on how to integrate the use of DHP with the pre-existing heating system). There is also an opportunity to increase marketing efforts to customers with relatively high cooling loads. These high potential savers can be identified through signatures in existing consumption data.

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__Recommendation 6:__ **Use a two-stage, variable degree-day approach for all future billing analyses to estimates DHP savings.** In order to improve the reliability of any future DHP evaluations performed with a billing analysis, we recommend the use of a two-stage variable degree-day billing analysis approach. We also recommend that the study maximize the sample size available for the analysis as attrition limited the sample that was available in the R16 Impact Evaluation. Further, to reduce the high attrition rate that occurred in the R16 Impact Evaluation, the PA's should favor using 12 months pre- and post-installation period over a shorter evaluation timeline. An option to the billing analysis might include better understanding customer control strategies for duel fuel heating customers by employing a 24–36 months sliding billing analysis to determine if customer usage patterns change over time.

Comment [GR14]: Should anything be done to model back-up fossil fuel consumption, understanding that getting oil usage data can be a challenge?

2 INTRODUCTION

This report summarizes the findings of ductless heat pumps (DHP) installed in single and multifamily residences in Connecticut through Connecticut Energy Efficiency Fund (CEEF) programs. This study, assigned the number R113, was scoped iteratively with the Energy Efficiency Board (EEB) consultants and culminated in a final approved scope of work dated August 3, 2015.

DHPs are eligible measures in Energize Connecticut's Home Energy Solution (HES) and Home Energy Solutions-Income Eligible (HES-IE) programs, and they are also independently rebated. Under a variety of installation and operating scenarios, DHPs have been recognized as a cost-effective, energy efficient and demand reducing strategy in cold climates such as Connecticut. DHPs are an integral part of Connecticut's energy efficiency program offerings for multiple reasons. They promote passive demand reduction over both the heating and cooling season, they have the potential to play a meaningful role in fulfilling Connecticut's greenhouse gas reduction targets[5], they are increasingly functional in colder weather and installation is simpler and less expensive than alternate HVAC systems.

Comment [GR15]: Only if displacing resistance space heat and only if operating at a system COP greater than 1.0 at the time of winter peak. In many instances DHPs negatively impact system peak when displacing fossil fuels.

A recent impact evaluation in Connecticut found mixed results regarding the energy and savings actually realized by DHP installations which yielded a 46% realization rate. In 2014 the EEB published the final report for "Impact Evaluation: Home Energy Services—Income Eligible and Home Energy Services Programs (R16)," a comprehensive evaluation of the program year 2011 which estimated the program impacts for multiple measures installed through the HES and HES-IE programs.[6] This study will herein be described as the "R16 Impact Evaluation." DHPs served as one important measure assessed in the R16 Impact Evaluation.

The R16 Impact Evaluation identified baseline assumptions and takeback effects as possible culprits of the low realization rate. The R16 Impact Evaluation used a billing analysis approach to estimate DHP program impacts. The study calculated a DHP realization rate of 46%, with a precision of +/-35% at the 90% confidence interval. The core impetus for the research presented here was to identify factors contributing to the realization rate in the R16 Impact Evaluation. The authors of the 2014 Evaluation suggested several factors that may have

[5] The Connecticut Department of Energy and Environmental Protection. 2013 Comprehensive Energy Strategy for Connecticut. 2013 p. iv,

[6] Connecticut Energy Efficiency Fund, Final Report, Impact Evaluation: Home Energy Services—Income-Eligible and Home Energy Services Programs (R16), December 2014. http://www.energizect.com/your-town/hes-and-hes-ie-impact-evaluation-r16-final-report-12-31-14, p. 7.

influenced the DHP realization rate for the 2011 HES and HES-IE programs. Two of the core factors suggested in the report excerpted below include differences in baseline assumptions between the Connecticut Program Savings Documentation (PSD) and the impact study and factors attributed to customer behavior (i.e., takeback effects):[7]

> *"measure-level and whole-house findings, ex ante savings estimates for ductless heat pumps overestimated actual savings and did not account for scaled-down savings, which could relate to take- back effects or the accuracy of baseline assumptions (e.g., some level of continued baseboard heating or increased cooling loads)."*
>
> *"….given the prevalence of ductless heat pumps for multifamily participants and the associated lower realization rate, there is a need to review the ex ante assumptions used in the savings calculation for this measure."* [8]

Other studies have speculated on high levels of takeback. A recent study of DHP retrofits in multifamily buildings identified high levels of takeback caused by an increase in average temperature settings during the heating season.[9] Takeback takes many forms beyond increases in average indoor temperatures. It may be introduced because DHP's supplement, not replace, electric or non-electric systems in greater proportions than originally believed. Our analysis of the prevalence of supplemental heating systems and a review of results from several additional studies released since the R16 Impact Evaluation lend insight into this issue.[10]

Comment [GR16]: Provide URLs in footnotes whenever possible.

Concerns regarding small sample sizes may have biased the R16 Impact Evaluation results. We note that evaluating the 2011 program year may have netted different evaluated savings for the DHP due to its small sample size. In fact, the R16 Impact Evaluation cites that "it is very possible that another study with similarly small sample sizes or, preferably, larger ones would produce different conclusions about savings from measures with high sampling errors." Supplementing the R16 Impact Evaluation results with additional research, as done here, provides insight into the interaction between the DHPs and their potential to

[7] Connecticut Program Savings Documentation for the 2012 Program Year

[8] Final Report, Impact Evaluation: Home Energy Services—Income-Eligible and Home Energy Services Programs (R16), 2014

[9] NEEP Glossary of Terms, Version 2.1, July 2011. Rebound Effect, takeback effect, snap back: A change in energy-using behavior that yields an increased level of service that is accompanied by an increase in energy use and occurs as a result of taking an energy efficiency action.

[10] For example, The Massachusetts Energy Efficiency Advisory Council. EEAC EM&V BRIEFING, September 2014, p. 12; The Electric and Gas Program Administrators of Massachusetts, Ductless Mini-Split Heat Pump Customer Survey Results. September 2014. The Maine Low-Income Weatherization Study, January 2016

generate program savings and can provide useful information for program designs going forward.

2.1 Objectives

The primary objective of this study is to understand the drivers of the measure level realization rate in the R16 Impact Evaluation. The following factors were identified in the R16 Impact Evaluation as possible drivers of the realization rate:

- Differences in baseline assumptions between the PSD and the R16 Impact Evaluation
- Factors attributed to customer behavior, for example, "takeback effects" occurring due to an increase in room temperature or operating hours in anticipation of lower operating costs, or changes due to the adoption of a handheld control from a thermostat

Another study objective is to gather and synthesize information to provide forward-looking information for programming planning purposes. Given the importance of DHPs to program and utility savings goals described earlier, this objective seeks to provide insight into the primary drivers of the realization rate more generally for DHPs and to provide recommendations on how the various program channels that promote DHPs can realize as much energy savings impact as possible.

The current study explores these objectives using a variety of quantitative and qualitative methods. Given these study objectives, it was necessary to perform data gathering of both 2011 program participants and more recent (2013–2015) participants. The final scope also included a review of the PSD, a brief review of recent studies of DHPs, a billing analysis case study, 124 telephone surveys with participants controlled to represent both single and multifamily customers, interviews with program vendors and 20 on-site surveys. These methods are described in more detail in the following section.

Comment [GR17]: The program rebate form should be reviewed.

2.2 Program Description

DHP rebates are available to all Eversource and UI residential customers via direct install and rebate programs. DHPs are eligible measures in Energize Connecticut's Home Energy Solution (HES) and Home Energy Solutions-Income Eligible (HES-IE) programs. They can also be rebated independent of these direct install initiatives when installed by a contractor certified by the manufacturer of the product and that has attended an EnergizeCT training seminar. Customers with income at or below 60% of state median income that have not participated in weatherization services in the previous 18 months are eligible for the HES-IE Program and could qualify to receive a DHP at no cost to them. The DHPs installed in the multifamily participants in this study received their DHP with a significant funding support from the American Recovery and Reinvestment Act of 2009

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(ARRA).[11] The customer characteristics of the 2011 multifamily participants and those of potential future multifamily participants will be similar. Despite the fact that ARRA funds are no longer available, the 2011 group was studied to help identify reasons for the low realization rate from R16 and provide insights for future program planning regarding DHP in multifamily units.

Comment [GR18]: Should there be more discussion of the 2011 sample which was heavily weighted to MF installations vs. current program activity which is probably more directed to SF installations?

The HES and HES-IE programs are the flagship residential program offerings with a purpose to identify comprehensive cost effective energy conservation opportunities, educate, and communicate these opportunities to the homeowner. The programs offer energy-saving measures offered at the time of the assessment, but most importantly for this evaluation, they also involve identifying additional measures that households could install to increase their energy savings. Currently DHP are among the measures that could be recommended to participants.

The table below reflects the current efficiency level and rebate available per home. Rebated DHP systems must be ENERGY STAR® certified with matched assemblies in which both the condenser unit and the evaporator coil are installed simultaneously. A key element of receiving a rebated DHP unit is required training on its use for tenants or property owners where installed and a utility post installation inspection.

Table 1. Minimum Efficiency Levels / Rebate Schedules (2015)

Eligible Equipment Type	Minimum Efficiency for Rebate	Rebate Per Home
AHRI rated ductless heating and cooling system of matched assembly of single indoor units	20 SEER 10 HSPF	$300
AHRI rated ductless heating and cooling system of matched assembly of multiple indoor units	18 SEER 9 HSPF	$300
A $1,000 rebate is available for homes with existing electric resistance heating with a Home Energy Assessment prior to installation. HES Technician will provide the $1,000 rebate form		

[11] American Recovery and Reinvestment Act of 2009 is commonly referred to as the stimulus package and enacted into Congress in February 2009.

3 STUDY METHODS

This part of the report provides detailed information on the activities and data collection methods undertaken in this study. We begin with a discussion of the PSD review followed by the methods used across a series of data collection activities that include participant telephone surveys, on-sites, and vendor surveys. We conclude this section by describing our approach to performing a billing analysis case study. The primary data collection activities (surveys, on-sites) were performed to improve the understanding of underlying customer characteristics and behaviors relevant to usage patterns of DHP. Data collection instruments are provided as appendices to this report.

3.1 Telephone Survey (CATI)

One hundred and twenty four telephone surveys were completed. DNV GL conducted telephone surveys during the fourth quarter of 2015 with residential customers of Eversource and UI who had participated in the Connecticut HES and had installed DHPs with program support. The surveys were designed to collect information from program participants and to identify households that were willing to schedule an onsite visit to obtain additional detailed equipment information.

The surveys were administered as a computer-aided telephone interview (CATI) with program participants. In order to reduce non-response bias, DNV GL instructed the survey firm to make up to five attempts to contact each customer, including calling at different times of day and different days of the week. The interviewers were trained to read questions verbatim, and offered response options only when instructed.

Survey Instrument

DNV GL developed the participant survey to address six key objectives:

- Takeback effects such as the participant changing temperature settings in anticipation of cost savings resulting from the new unit
- Differences in assumptions between the PSD and the recent R16 Impact Evaluation
- Installations that involve adding new equipment, rather than replacing (i.e., heating/cooling a space where no equipment previously existed)
- Occupant learning/behavior
- Changes in occupants/occupancy

Additional information was collected to cover participant demographics such as level of education and annual household income. The survey concluded with an invitation to have an engineer visit their home to collect information about the equipment. Upon agreement, the participant was placed on the list of households to schedule for the onsite visit. The final survey instrument is provided in0 Appendix B: On-site Form.

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Sample Design

The sample frame for the participant surveys was developed from program participation files provided by Eversource and UI. Participants were assigned to a program year group (2011 or 2013–2015) and were further stratified by specific year and utility. The sample included all participants with an associated phone number and included original participants from the R16 Impact Evaluation. The second source was the 2013–2015 database of DHP rebate participants. The reason behind having these two groups was to provide the opportunity to examine possible causes of the realization rate in the R16 impact study while also exploring recent participants to provide forward looking conclusions and recommendations. Table 2 presents the sample design, the designated targets of completed surveys and the final disposition of completed surveys by year and utility.

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Table 2. Sample and targets allocated by year and utility

Year Group	Utility	Population	Proportion	Target Number of Completed Surveys	Disposition
2011	Eversource	377	31%	47	36
2011	UI	162	13%	23	10
2013–2015	Eversource	649	53%	63	70
2014*	UI	41	3%	7	8
Total		1,229	100	140	124

*There were no UI participants included in the 2013 or 2015 sample

Final Survey Disposition

Despite the age of the sample for the 2011 participants, the telephone survey substantially reached its targeted number of responses. Survey targets were representative of each utility for the program year groups (2011 and 2013–2015) according to the original population of 1229 participants. There were challenges in response rates for the 2011 sample because it was so old. This resulted in slight differences between the 2011 targets and the 2011 responses. This also means the study did not achieve an exact proportional balance between UI and Eversource participants (15% of completes versus 18% of population).

Comment [GR19]: Are these the UI %?

Attempts to contact all UI program participants available were made until the survey effort was completed, the maximum of five attempts at reaching the participant had been made or the respondent was found to be ineligible or refused.

Comment [GR20]: Does this explain why there were "no UI participants in the 2013 or 2015 sample"?

Thirty seven percent of the completed surveys were from the 2011 program year and 63% were from the 2013–2015 program year. The length of the survey averaged ten minutes in length.

Table 3 summarizes the overall response rate for the telephone survey of program participants. The response rate calculation approach (formula and final disposition categories) mirrors the American Association for Public Opinion Research (AAPOR) calculator.[12] The overall response rate (AAPOR RR3) was 27.0%. Response Rate 3 (RR3) provides an estimate of what proportion of sample points of unknown eligibility are actually eligible. HES-IE participants from the 2011 program year comprised 53% of the total sample. Although not shown, we experienced a 17% completion rate from participants in the 2011 program year. We consider this proportion of respondents to be highly successful given that the original HES-IE sample was drawn over five years ago.

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Table 3. Overall survey response rate

Sample Description	Description	Number	Percent
Starting Sample	Phone numbers available	1,229	
Never Called	No attempts to contact were made	539	
Sample Used	Attempted to contact at least once	690	
Known Not Eligible	No eligible respondent, non-residential or terminated at screener questions	97	
Estimated additional not eligible	=(1-Percent Eligible)*(Not complete, unknown eligibility)	127	
Sample-Valid	=Sample Used – Known Not Eligible – Estimated additional not eligible	466	
Complete	=Phone interviews completed ÷ Sample Valid	124	27%
Refused	=Declined to participate in phone interview ÷ Sample Valid	51	11%
Not Completed - Eligible	=In queue to call back to complete interview with eligible respondent ÷ Sample Valid	27	6%
Not Completed - Est. Eligible	=Not completed, unknown eligibility * Percent eligible	264	57%

Each respondent surveyed was living at his or her current address at the time of the DHP installation. One customer had moved to a similar unit containing a DHP within the same multifamily complex.

[12] The American Association for Public Opinion Research. 2011. Standard Definitions: Final Dispositions of Case Codes and Outcome Rates for Surveys. 7th edition. AAPOR. AAPOR Response Rate Calculator Overview http://www.aapor.org/Response_Rates_An_Overview1.htm

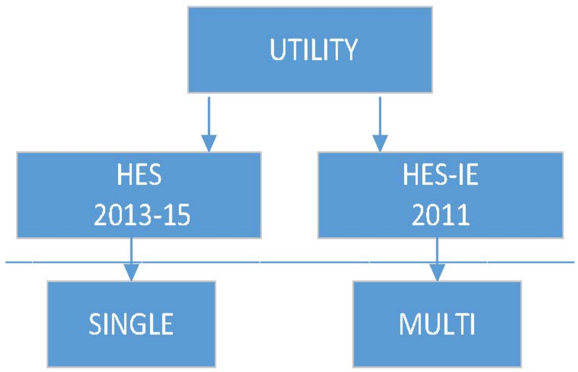
The distribution of the sample and number of respondents was parallel within dwelling types, programs and years and is shown in Figure 5. All single-family dwellings (with up to four dwellings per address) were HES participants who received their rebates between 2013 and 2015. All of the 2011 respondents were exclusively multifamily HES-IE participants. There were 42 HES participants in the 2011 sample but they did (not?) respond to the survey. One-hundred percent of HES (2013 to 2015) and 7% of HES-IE (2011) respondents owned their homes.

Comment [GR21]: So does the MF vs. SF focus of the two samples have any relevance to the savings results and RRs?

Comment [GR22]: Were only HES-IE MF DHP participants included in R16?

Comment [GR23]: Many/most of whom were SF?

Figure 5. Composition of sample and respondents



3.2 On-sites

A subset of 20 telephone survey respondents were recruited to participate in an on-site survey. The inclusion of on-sites in the study design supports the phone survey as it allows more detailed and granular data to be gathered than over the phone. All respondents of the telephone survey were offered a $100 incentive if they participated in an on-site survey. The table below provides a summary of respondents that showed an interest in participating in an on-site survey and number of on-site completions by year category and utility

From 53 of the 2011 telephone survey respondents, 27 expressed an interest in an on-site and 6 were completed. Among the 2013–2015 respondents, 41 expressed an interest in an on-site survey and 17 were completed (Table 4). Overall, 15% of the completed on-sites were UI customers and 85% were from Eversource, matching the telephone survey completion rates.

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Table 4. Final on-site sample

Utility	Size of Original Sample from CATI	No. of participants recruited for on-site Surveys	No. of on-sites completed
2011[a]			
Eversource	42	26	5
UI	11	1	1
Total	53	27	6
2013–2015[b]			
Eversource	64	15	12
UI	7	2	2
Total	71	17	14
All Years			
Eversource	106	41	17
UI	18	3	3
Total	124	44	20

a. All sites are HES-IE multifamily buildings

b. All sites are 2013–2015 single family

Table 5 presents the final disposition of the recruitment calls made for the 20 on-site visits. Recall this recruitment effort was based upon respondents who agreed to have a visit performed; hence, the high rate of cooperation. Overall, the response rate was 45% with a 2% refusal rate.

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Table 5. Final On-site Recruitment Disposition

Disposition Description	Participants
Completion	20
Refusal	1
No answer	14
Unable to schedule	9
Total customers called	44
Response rate[a]	45%
Refusal rate[b]	2%
Cooperation rate[c]	95%

a. Response rate is the number of completions by total customers called.
b. Refusal rate is the number of refusals divided by total customers called.
c. Cooperation rate is total completes divided by refusals and completes.

On-site Data Collection

The on-site data collection focused on heating and cooling systems, gathering both baseline information and information about equipment operations. The on-site data collection form is provided in Appendix B: On-site Form. Field staff obtained detailed technical information and observations that cannot be reliably collected during the telephone survey such as:

- Manufacturer and model number
- Heating and cooling capacity (Btu) and efficiency (HSPF, SEER)
- Configuration (quantity, size and location of zones)
- Quality of installation
- Schedule of operation and temperature settings
- Pre-existing heating and cooling system and fuel type, operational patterns, and interaction between DHP and existing systems
- Building envelope characteristics
- Patterns of HVAC equipment operation
- Customers understanding of the technology and how to operate it efficiently

Comment [GR24]: Was control hardware characterized?

3.3 Vendor Surveys

DNV GL conducted in-depth interviews (IDIs) to gain vendor perspectives on the following topics:

- Background and vendor program experience

- DHP system baseline/previously existing condition
- Education and instruction
- Customer's decision making process
- Methods for system sizing
- The influence of ARRA funding

The list of vendors was drawn from the 2011 tracking data. NMR provided the DNV GL team with the list eligible vendors for the R113 vendor survey. A key element of vendor eligibility for the interview was whether they had been surveyed for other evaluation efforts.[13] NMR screened the list of vendors, which resulted in a final sample of eight vendors. Four of the vendors were private companies. The other four were community action agencies (CAAs) who managed DHP installations in 2009-2010 with a shared funding from Eversource, UI, State Agencies and the American Recovery and Reinvestment Act of 2009 (ARRA).[14]

The DNV GL team attempted to contact all vendors in the sample. After calls had commenced, the DNV GL team revisited the Cadmus data and identified three additional contacts. In addition, NMR contacted each vendor that had been included in other studies and asked if they would be willing to participate in a second survey. One of those vendors had left the program. Two additional vendors were suggested from one vendor who installed DHP's in the small business program only. Despite the effort to maximize vendor interview completions, only two interviews were completed; one vendor and one CAA. Table 6 summarizes vendor the final vendor interview outcomes by type.

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Table 6. Vendor Survey Disposition

Survey Disposition	CAA	Vendor	Comments
Interview Complete	1	1	
Partial Interview	0	1	Vendor needed to suspend interview and we were unable to complete the rest of the survey
Non-working number	0	1	Internet and HES website as source
Ineligible	0	2	Installations restricted to small businesses
Non-contact	3	4	Unable to reach contact
Total	4	9	–

[13] Including R4 HES and HES-IE Process Evaluation, R151 Air Sealing, Duct Sealing, and Insulation Evaluation, and R157 Multifamily Process Evaluation.

[14] Community action agencies (CAAs) are social service agencies serving income eligible clients.

3.4 PSD Review

Many of the assumptions for the PSD calculations originated from a 2009 impact analysis of a DHP pilot, which directly metered DHP performance at 40 sites, 22 of which were in Connecticut (the remainder in Massachusetts). All the Connecticut DHPs in the prior study had a nominal capacity of 24,000 BTU (2 tons), were primarily installed in condominiums, and did not meet the entire heating or cooling load of the home. Baseline heating information was collected at the majority of the sites, but was not available for cooling.

Comment [GR25]: And all displaced resistance space heat, yes?

As part of this study, it was important to review the PSD DHP savings calculation method in use in the 2011 program year (the year evaluated in the R16 impact study) as well as the current PSD. More specifically, the PSD review effort included:

- A review of the pre and post installation heating and cooling assumptions that informed the PSD savings factors in place for the program year evaluated (2011)
- A review of differences between TMY2 temperature data used to inform the PSD DHP savings factors and the TMY3 data used in the R16 Impact Evaluation
- A high-level comparison of the PSD calculation for DHPs with ex-ante calculations from other cold climate states such as Massachusetts, New York, New Jersey and the Mid-Atlantic Technical Reference Manual

4 RESULTS

The following section describes the results of the telephone and on-site surveys. It begins with a description of the space conditioning function of the DHPs and their current usage relative to the pre-existing heating systems. It also presents pre-existing fuel types for heating and pre-existing technologies for cooling. Also included is an analysis of how the pre-existing condition and current usage patterns influence program savings.

This study analyzed survey responses by year, program, dwelling type and primary fuel. It presents most results by program year because dwelling type and program can be inferred from the program year. The 2013–2015 group is 100% HES single-family participants, and the 2011 group are HES-IE multifamily participants. Recall, the purpose of the 2011 sample was to gather data on causes of the realization rate in the 2014 R16 Impact Evaluation.

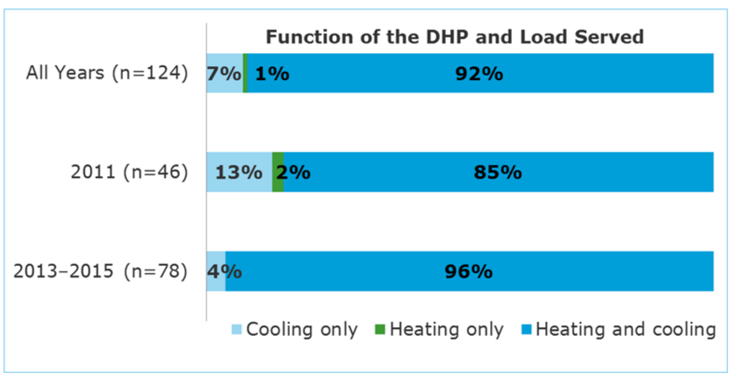
Comment [GR26]: Again, were all 2011 DHP participants HES-IE MF?

4.1 DHP Function and Operating Conditions

Most installed DHPs are being used for both heating and cooling. In aggregate (across both sets of program years), 96% (n=124) of telephone survey respondents reported using their DHPs for both heating and cooling (Figure 6). This proportion of DHP use for heating and cooling is higher than that found in a recent web based survey of 430 customers who installed DHPs through COOL SMART in Massachusetts in where the portion of installations serving both heating and cooling was 75%.

Thirteen percent of 2011 survey respondents and 4% of 2013–2015 survey respondents reported that they use the DHP for cooling only. Reasons for not using

Figure 6. Function of the DHP and load served



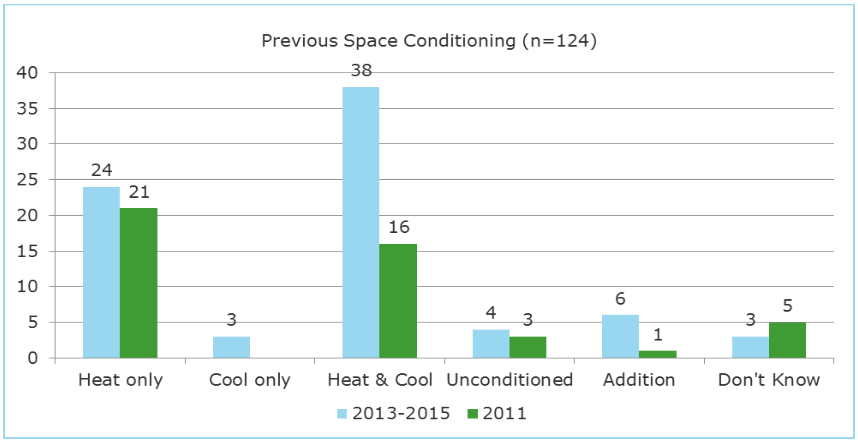
the DHP for heating fell evenly into three categories: the DHP could not meet the heating load, it was too expensive, or the space is unconditioned in the winter. One person reported using their DHP only for heating, citing financial reasons.

4.1.1 Heating and Cooling Pre-Existing Fuel Usage

Fifty four respondents reported that the space served by the DHP was heated and cooled (Figure 3) while another 45 respondents reported the space was only heated and 3 reported it was only cooled. Evaluated savings are negatively impacted when DHPs serve spaces that were not previously electrically conditioned. Across years, seven DHPs were installed in spaces that were reported to be additions, and seven other respondents reported that their DHP was installed in a space that was previously unconditioned.

Comment [GR27]: If all of 2011 sample was HES-IE MF then surprised to see any installations in previously unconditioned space. Or in an addition.

Figure 7. Pre-existing space conditioning



Nearly 9 out of every 10 phone survey respondents (88%) reported that their DHP was installed as a retrofit, with the balance reporting installation in a new space (e.g., an addition). As one might expect, when the DHP system is installed to displace pre-existing electric heating, electric savings can occur during the entire heating season.

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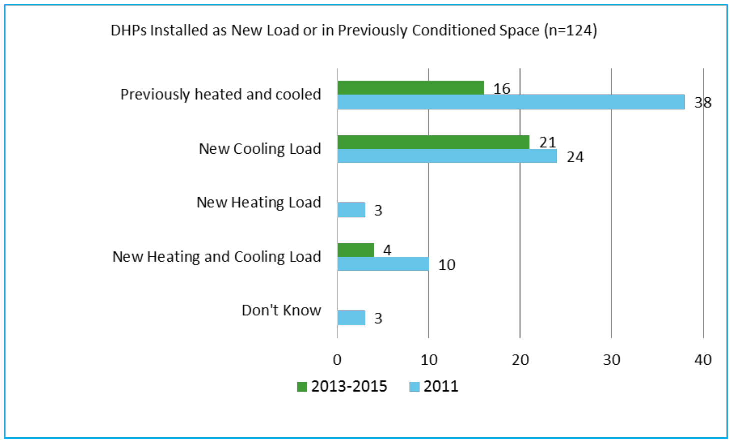
Figure 4 presents the number of each program year group that are adding electric load for heating, cooling or both with their DHP. This includes 45 respondents across years that added cooling load and 14 that added both cooling and heating load. The additive loads noted for the 2011 program year likely depressed the realization rate in the R16 Impact Evaluation because they are not accounted for in the tracking estimates for heating specified in the Connecticut PSD and are only accounted for in part in the cooling. A description of these issues is presented in Section 5, The PSD and Savings Factors Review.

Fifty six percent of 2013–2015 telephone respondents increased their electric heating load because fossil fuel heating systems previously heated the space served by the DHP (Figure 8). Nearly three in ten respondents (28%) from the 2013–2015 program years reported they transitioned to their DHP from electric heat. All respondents in the 2011 group were part of the ARRA program serving income-eligible electric customers residing in multifamily buildings and used electric resistance heat before their DHP system.

Figure 8. DHPs installed in previously conditioned and unconditioned space



When space was previously cooled, room air conditioners were found to be the typical baseline, which is the same basis for the Connecticut PSD algorithm savings factor (**Error! Reference source not found.**). Nearly two-thirds of respondents reported their previously cooled space was served by room air conditioners (RAC) and 11% were reported to be central air conditioners (CAC). This rate of displacing room air conditioners versus central air systems is largely to be expected given the appeal of a system that does not rely on adding ductwork where none previously existed. In fact, the PSD savings algorithm uses a RAC with nine EER as its baseline.

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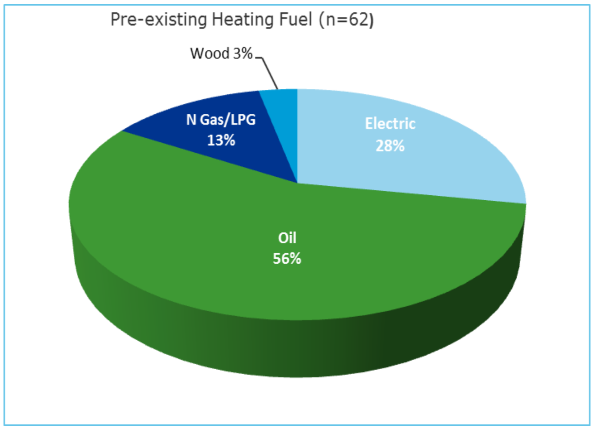
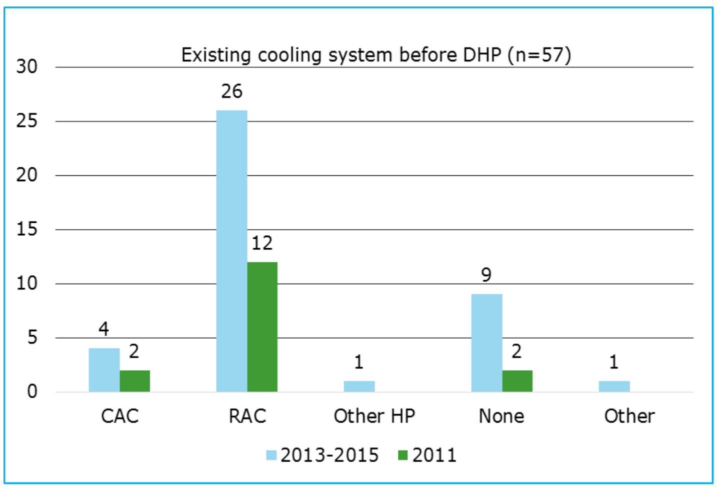
Figure 9. Pre-existing heating fuel type 2013–2015



Most participants are only using the DHP to serve their cooling needs as the majority reported that they removed their previous system after installing the DHP or are otherwise not using them. Among phone respondents, 72% reported they had removed their pre-existing cooling system, 20% reported still using their

Figure 10. Pre-existing cooling system type



Base is respondents that were previously cooled previous system and 9% reported that the systems remained installed but were not being used.

Table 7 compares the heating and cooling configuration before (columns) and after (rows) the DHP installation and reports whether the DHP was installed in new or existing space. The results in Table 7 are similar to the 2014 Ductless Mini-Split Heat Pump Customer Survey Results in Massachusetts[15] with one exception; the Connecticut results show an increased percentage of customers who purchased a DHP to supplement a pre-existing heating system. This reported increase (43% compared to 25% in MA) is likely due to the high representation of Connecticut's income-eligible multifamily participants with electric baseboard heating respresented in the survey sample.

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The color-coding in the table shows the what combinations of pre- and post-DHP HVAC status result in an added load or savings event. **There are many scenarios where the intersection of pre and post conditions in either heating or cooling modes produces added electric loads.** Blue represents scenarios where there is added cooling or heating electric load. These scenarios will negatively affect evaluated electric savings, although we note that these circumstances may reduce fossil fuel consumption and lower greenhouse gas emissions. Green represents pre/post scenarios that produce savings as long as the previous heating system was electric, which was the case in 28% of 2013–2015 participants in the survey.

[15] Cadmus Energy Services Division, http://ma-eeac.org/wordpress/wp-content/uploads/Ductless-Min-Split-Heat-Pump-Customer-Survey-Results1.pdf, Table 3, p. 9

Table 7. Space conditioning pre and post DHP installation

Space Conditioning Post DHP Installation	Space Conditioning Pre DHP Installation						
	Existing Heated Only	Existing Cooled Only	Existing Heated and Cooled Only	Existing Not Heated or Cooled	New Space	Don't Know	Total
DHP used only for heating	0.8%*	-	-	-	-	-	0.8%
DHP used only for cooling	2.4%	0.8%	0.8%	0.8%	0.8%	1.6%	7.3%
DHP used for both heating and cooling	33.1%	1.6%	42.8%*	4.9%	4.9%	4.8%	91.9%
Total	36.3%	2.4%	43.6%	5.7%	5.7%	6.4%	100.0%

*savings dependent on previous heating source being electric

Blue = added cooling or heating load   Green = savings

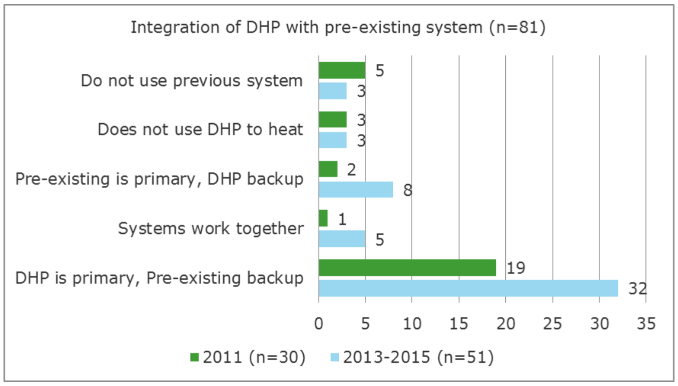
4.1.2 Customer Behavior

As summarized in the table above, electric savings from a DHP are dependent on the manner in which the space was previously conditioned in terms of fuel type and technology. However, it is also dependent on the way in which previously existing systems that have not been removed are used in conjunction with the DHP. As noted earlier, participants infrequently use previously existing air conditioning systems after their DHP has been installed. However, telephone survey respondents frequently mentioned that the DHP cannot provide adequate heat in colder weather.

Comment [GR28]: So does this value account for the low 2014-2015 electric resistance baseline saturation?

Nearly 17% of 2011 and 22% of 2013-2015 phone respondents reported that their DHP is either not used in the winter or is used as a back up to the pre-existing system (Figure 11). Sixty three percent of respondents operate

Figure 11. Integration of DHP with the pre-existing heating system



their DHP as the primary heating system and use the pre-existing system to supplement. Another 7% reported operating the pre-existing system in tandem with the DHP. We do note there is evidence from a recent study that suggests participants are more apt to rely on their DHP as their primary heating system as they experienced its ability to effectively heat their spaces[16]. Ten percent of respondents have transitioned to the DHP for 100% of their heating needs.

Comment [GR29]: Is there any information on the hardware, i.e., thermostats, used to effect this integration?

To illustrate the impact on savings from the integration of the DHP with pre-existing systems, we consider recent evaluations of multifamily DHP installations.

In January of 2016, a Maine Low-Income Weatherization Evaluation reported that tenants that used a DHP only (without any backup heating source), achieved savings of 989 kWh.[17] This is consistent with the Mini-Split Heat Pumps Multifamily

16 http://www.neep.org/sites/default/files/resources/NEEP%20DHP%20Report%20Final%205-28-14%20and%20Appendices_0.pdf

17 Efficiency Maine Low-Income Multifamily Weatherization Evaluation Report, FINAL, January 14, 2016

Retrofit Feasibility Study from the Office of Energy Efficiency and Renewable Energy (EERE). [18]

The EERE study analyzed three cold-climate multifamily DHP retrofit projects: the HES-IE DHP program evaluated in the R16 Impact Evaluation, Maine's Low Income Weatherization Program (evaluated in 2014) and a small multifamily project in Centralia, Illinois. EERE concluded that DHPs had higher savings rates when they displaced electric resistance heating.

Modeled savings from this same EERE study showed similar results. In the New York City climate, converting from electric resistance to DHPs saved approximately 30% of annual kWh consumption. Converting from oil saved about 4%; converting from natural gas returned the lowest level of savings. Despite the fact that savings were modeled under ideal conditions, the results illustrate the potential and value of DHP as an energy efficiency measure.

Because thermostat settings affect achieved energy savings, during the telephone survey, respondents were asked, "do you use the same, higher or lower heating temperature settings on your older heating system since you installed the DHP?" From Figure 12, 36% of respondents reported lowering their thermostats or using less heat from their pre-existing system. Fifty-one percent reported that their thermostat settings remained the same.

From the on-site surveys, we learned that telephone survey responses regarding temperature setting have multiple meanings, each with different implications on savings. Keeping the pre-existing system thermostat settings the *same* after installing a DHP could suggest that the DHP was put into service with no associated operational changes to the pre-existing system. However, it appears to be more complex than that. The combined results of the telephone and on-site survey show that participants commonly practice two distinct operating strategies.

Comment [GR30]: Total or just heating?

Comment [GR31]: $ or kWh? Why would there be any kWh savings?

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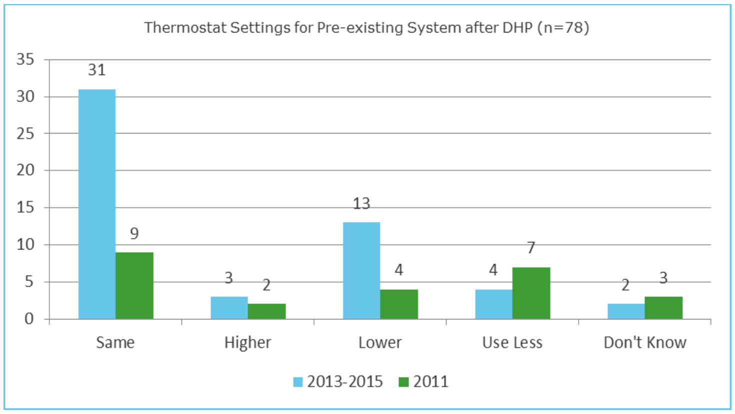
[18] EERE, Mini-Split Heat Pumps Multifamily Retrofit Feasibility Study, May 2014, p. ix, NREL, Field Monitoring Protocol: Mini-Split Heat Pumps, March, 2011; Building Energy Optimization software (BEopt)modeling, https://beopt.nrel.gov/

In the first scenario, the DHP serves the heating load until the outdoor temperature drops to a level defined by the customer (heating reference temperature).[19] At that heating reference temperature, the pre-existing system is placed into service, and the interior temperature is maintained at historical levels (the same). When the pre-existing system is turned on, the DHP is removed from service until the outdoor temperature exceeds the heating reference temperature. Both systems are primary at different times of the year. If the DHP is less efficient at these colder temperatures, the customer has optimized the efficiency of both systems. Customers engage in this strategy to improve equipment efficiency and save money. This strategy is preferred; that the DHP comes first. We estimate that roughly 63% of customers are using this strategy.

Figure 12. Thermostat settings for pre-existing system after DHP



The second scenario is similar to the first, except the DHP remains on and in service during the heating season and acts as a supplement to the pre-existing system. Participants who are motivated by comfort appear to adopt this strategy. We estimate that roughly 12% of participants use this strategy. One might regard this as a type of takeback. In this case, the customer is not raising the temperature setting to increase comfort at the expense of savings. They are turning on a second system to increase the temperature.

[19] Publically reported degree-days are calculated at heating reference temperatures of 60 or 65 degrees. However, each home has a unique or variable heating (and cooling) reference temperature. Most billing analysis models find the variable reference temperature in order to reduce the error of the evaluated savings estimates.

4.2 Influence of Fuel Prices on DHP Usage

While the phone survey results hinted at the issue, the on-site survey provided an opportunity to understand the interplay between fuel prices and DHP use. In these visits, 3 out of 20 participants mentioned that because oil prices were so low, they were reverting to their existing oil burners as their sole heat source.

Whether a DHP costs less to operate than a fossil fuel-based system depends on the relative cost of producing heat with each system, on average, over the heating season. With the current delivered residential price of electricity around $0.19/kWh and average #2 fuel oil prices at $2.168/gallon, it is currently more economical to use fossil fuels as the only heat source. DHPs that condition previously unheated spaces in colder months will not be impacted by this price differential.[20]

Figure 13 demonstrates the average cost over a heating season to produce 100,000 BTUs using an oil boiler, a DHP with an HSPF of 9, and a cold-climate DHP with an HSPF of 13.5.[21] In order to account for climatic effects on nameplate heat pump efficiency, we used the following model, developed by the Florida Solar Energy Center, to estimate the percent decrease or increase in nameplate HSPF based on the 99% winter design temperature. For Hartford, the design temperature is 8 °F:[22]

$$\%\ Decrease\ in\ HSPF = a + b \times Temperature + c \times Temperature^2 + d \times HSPF$$

a = .1041	*b* = -.008862	*c* = -.0001153	d = .02817	R-Squared = .9648

Based on the model results shown in Figure 13, it will cost, on average, $2.92 to produce 100,000 BTUs over the course of the heating season using the DHP, while it will cost only $1.96 to produce 100,000 BTUSs using the existing oil boiler. If

Comment [GR32]: Of what system efficiency?

Comment [GR33]: So what is the % decrease for Hartford?

And did FSEC consider the improved cold climate performance of ccHPs?

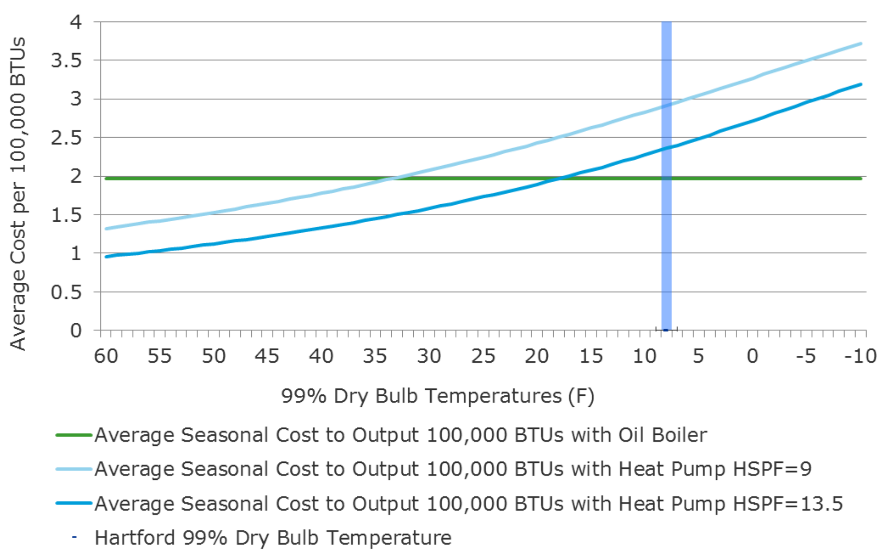
[20] 2016 Summary of Connecticut Electric Rates. 1 January 2016; Connecticut regulators approve higher electricity rates, New Haven Register, 15 February 2016; Weekly Connecticut No. 2 Heating Oil Residential Price.

[21] Assumptions: DHP has a HSPF=9, Oil = $2.168/gal. and Electricity = $0.$.19/kWh

[22] ASHRAE Handbook: Fundamentals, I-P Edition, Ch. 14; Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps.

electricity prices remained constant, oil prices would have to increase to $3.22/gallon for a DHP with a nameplate HSPF of 9 to be cost effective over oil.

Figure 13. Seasonal cost of producing 100k BTUs with oil boiler and DHPs



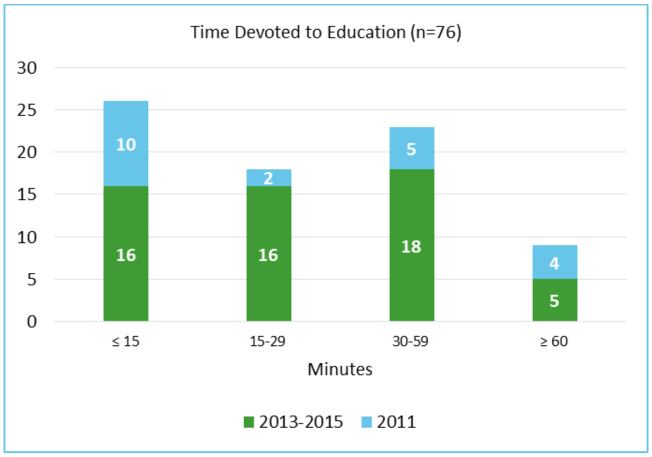
Using a cold-climate DHP with an HSPF of 13.5, it will cost on average $2.36 to produce 100,000 BTUs over the course of the heating season using the DHP, compared to $1.96 for the oil boiler. A higher efficiency cold-climate DHP is cost effective when oil prices reach $2.61/gallon (and electricity prices remain constant).

The economic effect of high fuel prices may have impact on both program growth and evaluated savings. Program growth may slow for potential participants who enter the program specifically to mitigate the high price of fossil fuels. Evaluated savings are often driven by how the DHP is operated, which is influenced by fluctuating fuel prices.

4.3 Customer Education

How the customer controls the DHP has been well documented as having a direct

Figure 14. Time devoted to customer education



effect on its operating efficiency and realized savings.[23] For example, the NEEP meta study noted:

> *"The lack of controls that are understood by customers, and especially controls that integrate with the existing central heating system, remains an issue that undermines full achievement of the savings potential."*

Many of the operational patterns that optimize efficiency can be counterintuitive for some customers; for example, according to one vendor, even though they spend time educating the customer onsite and leave manuals, "some [customers] still think it's better to turn off the DHP."

The DHP program recognizes the need for customer education and requires that it be provided during installation. Vendors become aware of this during their required training to become approved installers. As intended, the vast majority of phone survey respondents (90%) across years reported receiving education from their

[23] Emera Maine-Heat-Pump Pilot Program-Final-Report, Revised November 17, 2014; NEEA and the Bonneville Power Administration, Addendum No. 1 to the Ductless Heat Pump Impact and Process Evaluation: Field Metering Report Ductless Heat Pump Cold Climate Performance Evaluation, March 29, 2013. P. 38; NEEP, Ductless Heat Pump Meta Study, November 13, 2014, p. 8,9

installers, building managers or a CAA representative (**Error! Reference source not found.**).

Deleted: Figure 15

In addition, 68% of respondents were able to report the length of education received, which averaged 36 minutes for both the 2013–2015 and 2011 groups

Figure 15. Number of customers who reported receiving education

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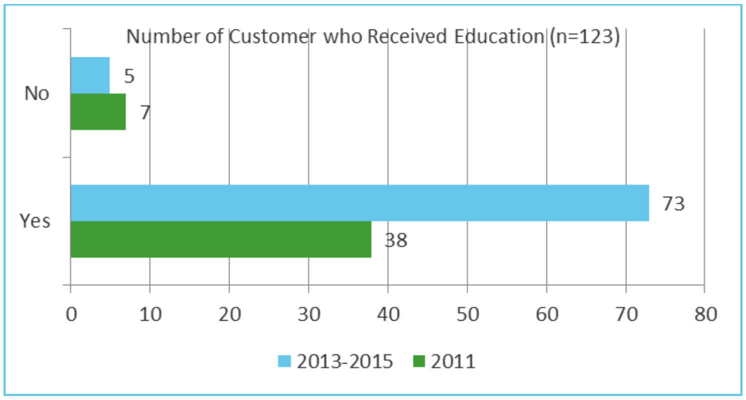

(**Error! Reference source not found.**). This level of commitment to education is noteworthy. More recent participants tend to cite longer training durations although the recollection of participants in 2011 might be suspect since so much time has passed since the education occurred. Regardless of the time devoted, 94% percent believed that they received a sufficient amount of education and understood how to operate the DHP. Although not shown, across both the 2011 and 2013–2015 program years, 80% of respondents reported the installer demonstrated the controls and all but two thought it was easy to operate the equipment.

Deleted: Figure 14

The 20 on-sites were designed to gather more in depth information that can be difficult to gather over the phone, such as the type and amount of instruction received at installation and any problems or issues experienced during the initial operating period. These results suggest some issues that were not revealed in the phone survey.

- Ten on-site participants (one-half) received sufficient instruction and had no problems after the installer left.
- Three indicated that they were not given any instructions on how to control the temperature and fan settings and this created some difficulty.
- Three on-site customers reported receiving generally insufficient instructions; two customers were told to "read the manual."
- Two on-site customers recalled the contractor installed wall mounted controls to get the functionality of a programmable thermostat.
- The remaining two on-site participants were HVAC contractors and self-installed the DHPs.

Comment [GR34]: So somewhat contrary to the characterization in the ES: **It is clear that the programs rebating DHPs take customer education very seriously.**
There seems to be room for significant improvement in this area.

As stated earlier, teaching customers how to integrate the DHP with existing equipment and how to operate it efficiently is an important part of a program promoting a new technology such as the DHP. The Emera Maine DHP evaluation concluded, "Customer education was essential to maximizing savings" in order to teach customers how to balance DHP use with pre-existing electrical heating systems.[24]

Figure 16. Factory supplied remote control

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For example, turning the DHP on and off on a frequent basis and thermostat setback strategies that create large differential interior temperatures lowers the average efficiency of a DHP. How much of an impact these behaviors have on performance, efficiency and savings is a function of several variables including outdoor temperature and the frequency of these behaviours. If a space remains unoccupied for long periods, it may make sense to shut off the DHP. However, frequent temperature adjustments and setback strategies are not recommended in northern climates during cold conditions. Indeed, this is why DHP supplied remote controls tend to not have set back functionality.

[24] Emera Maine-Heat-Pump Pilot Program-Final-Report, Revised November 17, 2014

Most on-line education materials describe DHP technology and "how it works."[25] Operational strategies that optimize DHP efficiency and performance are conspicuously absent. One source we were able to find on-line is a NEEA/BPA sponsored flyer, "Getting the Most out of Your Ductless Heat Pump". This document provides a brief instruction guide that describes how to operate the DHP efficiently.[26]

As noted earlier, some studies observed that DHP's purchased for only cooling or as a supplemental heat source, may increase in use over time beyond the original intent.[27] Due to this, savings may be delayed as customers move through a learning curve and develop energy saving strategies over time. As occupants become more familiar with DHP technology, customer behavior may favor increased efficiencies.

4.3.1 Takeback effects

An objective of this study is to identify evidence of takeback effects from increased interior temperatures in anticipation of lower operating costs. There are virtually no empirical studies on DHP takeback, but after decades experience with energy efficiency programs, there is consensus that takeback exists to some degree, particularly for HVAC measures. Estimates of takeback, as a percent of savings, fall within a commonly accepted range of 10 to 30%.[28] Although takeback is rarely measured empirically, takeback is implicitly accounted for in billing analyses that use comparison groups. The SEEAction evaluation guide acknowledges the dearth of research on takeback effects. It states that "there is no correct answer to whether or not takeback should be evaluated, particularly given that the magnitude of the takeback effect is not known; however, the evaluation planning efforts and the reported results should indicate whether takeback is addressed or not."[29]

In this study, it was difficult to make a one-for-one comparison between thermostatic behavior of the pre-existing heating HVAC systems and the DHP for three reasons:

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[25] DOE, Ductless Min-split Heat Pumps, http://energy.gov/energysaver/ductless-mini-split-heat-pumps, Mitsubishi Electric, http://www.mitsubishicomfort.com/benefits, Energize CT, "How is the System Controlled" and "Are Ductless Heat Pumps Efficient," http://www.energizect.com/your-home/solutions-list/ductless-split-heat-pump-rebates yes. Mass Save, http://masssave.com/en/residential/csvideos,

[26] goingductless.com, "Getting the Most out of Your Ductless Heat Pump," http://missoulaelectric.com/fileaccess/getfile/1021.pdf

[27] Ductless Mini-Split Heat Pump (DMSHP) Baseline Determination Memo, 2015.

[28] U. Irfan, How Bad Is the Rebound from Energy Efficiency Efforts? Scientific American, May 21, 2013

[29] Energy Efficiency Program Impact Evaluation Guide Evaluation, Measurement, and Verification Working Group December 2012, DOE/EE-0829, p. 7–7

- Several participants reported that they set the DHP 2-5 °F higher than the pre-existing system to maintain the same comfort level (i.e., the same interior temperature).
- It is typical for the pre-existing system and the DHP to operate concurrently during colder months.
- Reported thermostat settings for pre-existing equipment usually included a setback strategy, with separate temperatures for day and night. Although most respondents report that they use the "same" amount of heat at night as they are during the day, the majority are not applying setback strategies with their DHPs.

We collected detailed information about thermostat settings before and after installing the DHP during the on-site surveys. Of the 20 on-sites:

One-half reported that their thermostat settings for heating and cooling are the same as before installing the DHP and seven reported raising their temperature 2–5 F to maintain the same comfort level. Two respondents reported completely shutting down their DHPs and reverting back to their oil system for 100% of their heating needs to take advantage of current low oil prices. The reported temperature settings for each of the on-site surveys are reported in Table 8.

We did not collect data on thermostat settings during the telephone survey, but probed more generally about how they used the thermostat, whether they used more or less heat, and if they changed the thermostat settings.

Many telephone respondents reported routinely adjusting DHP thermostats according to the outdoor temperature, which suggests that the DHP is not adjusting its output to the satisfaction of the participants. Several others reported frequent on/off operations based on occupancy. From 31 comments, only two directly addressed thermostatic temperature.

> *"I can keep it warmer in the house by using less money."*
>
> *"I used to put the old heat up to 80 to get nice heat. I might have even put it higher. This system I never put past 74 or 76. If I do put it up that high, I have to lower it during the day or during the evening. Once it gets too hot you can't stand it."*

The first appears to be turning up the thermostat, thereby exhibiting takeback; the other is clearly turning the thermostat down compared to before, which would increase savings.

Based on the data collected here, we find the results to be inconclusive on whether takeback is eroding energy savings due to several confounding effects:

- The need to increase the DHP thermostat a few degrees higher in order to maintain historical comfort levels.

Comment [GR35]: This is noted (overstated?) in the ES. How large a % is "several"?

Comment [GR36]: This possibly implies that data was collected prior to installation. This was not the case as these values were self-reported.

Comment [GR37]: Also provide %. But why? Is this a shortcoming of the DHP? Of the customer control strategy?

Deleted: Table 8

Comment [GR38]: But why does a participant "need" to set higher temperatures to maintain similar comfort levels?

- The fact that in many households, two HVAC systems are operating at the same time.
- Setback strategies cannot be compared between the DHP and traditional pre-existing HVAC systems.

To the extent we were able to identify the conventional behaviors associated with thermostatic takeback, it appears to be isolated. Other operational patterns identified in this study and added electric loads are likely to have a much greater influence on energy savings.

Table 8. Thermostat settings from on-site surveys

Pre-existing Fuel	Pre DHP Heating Set Points (°F)	Pre DHP Cooling Set Points (°F)	Thermostat settings of DHP	Notes
Electric	70/60	65/55	Settings required at ±5 degrees on to reach same interior temp	
Electric/Propane	68	70	Settings did not change	
Electric	70	65	Settings did not change	
Electric	60	60	Uses heat from common areas	DHP runs at 90 °F for 30 minutes before sleep
Electric	70	70	Settings required at ±5 degrees on to reach same interior temp	
Electric	65/70	68/70	Settings did not change	
Electric	65/70	70/75	Settings did not change	Installed wall mounted controls
Electric	70/65	68/75	Settings did not change	Manually controls 5 units. Installed a wall tstat in one room
Electric	70	70	Settings required at ±5 degrees on to reach same interior temp	
Electric	65/70	68/70	Settings did not change	
Electric	68/72	72/75	DHP tstat setting does not match interior temperature	
Oil				Will use oil because it's less expensive
Oil	70/65	70/75	Settings did not change	
Oil		85	Settings did not change	Turns off below 20 °F
Oil	72	80	72 °F to maintain room at 70 °F	Will use oil because it's less expensive

Pre-existing Fuel	Pre DHP Heating Set Points (°F)	Pre DHP Cooling Set Points (°F)	Thermostat settings of DHP	Notes
Oil	65/70	75/70		Will use oil because it's less expensive
Oil	70/65	70/75	Settings did not change	
Oil	70/65	70/75	Must set higher (winter) and lower (summer) to reach same interior temp	DHP turned off in cold weather
Gas	70/65	70/75	Settings did not change	
Gas	70/65	70/75	Settings required at ±5 degrees on to reach same interior temp	

4.4 Customer Satisfaction

Customers contacted in this study who purchased their DHPs through the EnergizeCT initiatives reported very high levels of satisfaction. Despite the myriad of issues that might hinder the ability of DHPs to produce savings, customers are happy with their units.

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This was very apparent when we asked about their satisfaction with the DHP. On a scale from 1 to 7, with 1 being dissatisfied and 7 being very satisfied, the average satisfaction rating over 118 telephone respondents was six, with 37% of respondents reporting a satisfaction of seven. Only nine respondents rated their satisfaction below four, citing comfort challenges and the high cost of heating and cooling with the DHP.

We further note that in response to a broad question soliciting comments about the DHP program, participants generally provided very positive feedback. Among the 49 telephone respondents who provided comments, very high levels of satisfaction with the cooling capacity and performance improvements compared to RAC's was mentioned frequently. Forty participants expressed great enthusiasm about the ability to deliver high quality space conditioning. For example, one respondent said, "it cools better and it is quieter." Another said "It's awesome, I am so glad I have it, it's the best investment I ever made." Several promoted economic and health benefits.

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Only three respondents expressed frustration; one described a messy contractor and two others described difficulties navigating the rebate process. Some are surprised that the DHP cannot meet their heating needs in the colder months; however, they are very happy with its cooling features. One person said, "It's not perfect, but I like it."

5 CT PSD AND SAVINGS FACTORS REVIEW

The PSD in place for the estimation of DHP energy savings evaluated in the R16 Impact Evaluation was based largely upon a KEMA study performed in 2009.[30] This study analyzed the savings of DHP units installed in a pilot implemented in Massachusetts and Connecticut. This study directly metered DHP performance at 40 sites, 22 of which were in Connecticut. All of the Connecticut DHPs had a nominal capacity of 24,000 BTU (2 tons), were primarily installed in condominiums, and did not meet the entire heating or cooling load of the home. In the KEMA study, baseline heating information was collected at the majority of the sites, but was not always available for cooling. The 2009 report notes that the pilot systems evaluated "were installed primarily in homes with electric strip or radiant heat and AC."

The PSD energy savings calculation from 2011 (the program year evaluated in the R16 Impact Evaluation) is provided below for cooling and heating[31]. The denominator of the calculation to determine the realization rate would be based on the application of this calculation to the DHP units installed.

$$Annual\ heating\ kWH\ savings = H_{Cap}\ \text{x}\left(\frac{1}{HSPF_b} - \frac{1}{HSPF_I}\right)\text{x}\frac{1}{A}\ \text{x kWh}_{SavingsH}$$

$$Annual\ cooling\ kWH\ savings = C_{Cap}\ \text{x}\left(\frac{1}{SEER_b} - \frac{1}{SEER_I}\right)\text{x}\frac{1}{B}\ \text{x kWh}_{SavingsC}$$

where,

$H_{Cap} = Heating\ Capacity\ in\ MBTU$
$C_{Cap} = Cooling\ Capacity\ in\ MBTU$
$HSPF_b Baseline\ Heating\ Seasonal\ Performance\ Factor\ (3.413\ for\ homes\ with\ existing\ eletric\ resistance\ heat\ and\ 7.7\ for\ all\ others)$
$HSPF_I = Installed\ heating\ Seasonal\ Performance\ Factor$
$SEER_I = Installed\ Seasonal\ Energy\ Efficiency\ Ratio$
$SEER_b = Baseline\ Seasonal\ Energy\ Efficiency\ Ratio\ (10.1\ for\ homes\ with\ existing\ electric\ resistance\ heat\ and\ 13.0\ for\ all\ other\ homes\ (code)$
$KWH_{SavingH} = Heating\ savings\ from\ 2009\ study(\frac{130\ kWh}{MBTU}\ for\ Hartford, \frac{140\ kWh}{MBTU} for\ Bridgeport)$
$KWH_{SavingC} = Cooling\ savings\ from\ 2009\ study\ (\frac{3.1\ kWH}{MBTU} for\ Hartford, \frac{3.2\ kWh}{MBTU} for\ Bridgeport)$
A=0.171, Efficiency conversion factor for heating to convert savings from heat pumps studied to the actual installed equipment.

[30] KEMA, Ductless Mini Pilot Study, Final Report, June, 2009

[31] Note that the PSD also allows custom calculations in the determination of DHP savings, however, we believe the formula provided above is predominant.

Comment [GR39]:

Comment [GR40R39]: And was it all resistance heat? Oh, just "primarily"?

Comment [GR41]: The below estimates the savings from efficiency improvements over either displaced resistance heat or an less efficient HP.

B=0.037, Efficiency conversion factor for cooling to convert savings from heat pumps studied to the actual installed equipment.

This PSD formula relies on direct inputs on the capacity and efficiency of the unit installed. The final key assumed value in the formula is that of $KWH_{SavingH}$ and $KWH_{SavingC}$. These values originate from the KEMA study in 2009 and effectively drive the remainder of the calculation and ensuing savings estimate. Given the importance of these values to the calculated tracking savings, we examined the report to find these values and to better understand the assumptions that are implied in their PSD use.

The kWh heating savings per MBTU in the PSD is 130 kWh and 140 kWh for Hartford and Bridgeport, respectively. These values are reflected in the KEMA report (Table 23) as normalized annual heating savings estimates savings based on a whole premise regression of units that did not include non-electric supplemental heat. These results are referred to as the "No Supplemental Heat" results as the KEMA analysis only includes customers that did not have supplemental non-electric heat available to heat the space served by the DSHP. There were 22 such customers in this analysis. The "No Supplemental Heat" result was provided in the report to show the potential for additional savings that could be achieved if the customer selection criteria were changed so that only customers who heated with electricity would be considered for participation.

The kWh cooling savings per MBTU in the 2011 PY PSD used in the impact study realization rate is 3.1 kWh and 3.2 kWh for Hartford and Bridgeport, respectively. These values come from page vi of the report as the cooling savings based on the "Fully Adjusted" analysis using a baseline RAC of 9.0 EER. The "Fully Adjusted" analysis is based on a sample of 38 installations. These include those sites that did not have baseline AC units cooling the space served by the pilot installed DHPs (22.5%) and those DHP installations that represented an increase in cooling capacity over baseline.

The algorithm for calculating savings in the current PSD has the same core approach as that presented above (i.e., that in place for the year evaluated in the R16 study) and is also founded upon the same KEMA study.[32] The estimates of kWh savings per MBTU for Hartford and Bridgeport cooling and heating savings are the same. One change between 2011 and 2015 is that the formula has evolved to include the number of zones (or heads) that have been installed. The 2015 current PSD approach is discussed in more detail in the next section.

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[32] Connecticut Program Savings Document, 10th Edition for 2015 Program Year

5.1 Review and Comparison of PSD/TRM Calculations

Ductless and air source heat pumps are offered throughout the Northeast and Mid-Atlantic states as an efficiency measure. Many of the jurisdictions that offer these technologies have approved methods for calculating electric ex ante annual savings. These methods are often captured in state or regional technical manuals. For purposes of this study, we performed a high level comparison of the current Connecticut PSD approach and inputs to calculating DHP savings with the documented approaches from New York, New Jersey, Massachusetts, and the mid-Atlantic TRM. To perform this, we used the most recent TRM or PSD document available from each jurisdiction. These results are summarized in Table 9 and Table 10 below.

Deleted: Table 9

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Although we do not provide the actual formulas for each jurisdiction, we do provide the key inputs to the formulas that are input from either program paperwork or as assumed in the documents reviewed. All of the savings formulas reviewed adhered to the same core approach with elements of capacity, change in efficiency and hours of use reflected in some fashion. In addition, all approaches used Heating Seasonal Performance Factor (HSPF) as the standard measure of heat pump heating efficiency, and Seasonal Energy Efficiency Ratio (SEER) as the cooling equivalent. Use of these values is consistent with industry practice. However, as noted in the NEEP Meta study, HSPF does not include testing at temperatures below 17 degrees, which introduces uncertainty around its relevance for the DHP technology. The NEEP study also points out that DHP SEER rating may not be as accurate as desired for DHPs as they are based upon standardized testing requirements[33].

The Massachusetts, New Jersey, and New York heating and cooling electric annual savings calculations are largely the same in structure and use manufacturer rated capacities and efficiencies with heating and cooling equivalent full-load hours (EFLH) to calculate savings. All three jurisdictions have baseline efficiencies to calculate lost opportunity (i.e., replace on burnout) savings with only New York providing an option to calculate early replacement savings. There were no realization rates provided in the documents reviewed to refine these savings beyond their initial calculated value.

The Mid-Atlantic TRM approach differed slightly in that it uses estimates of the actual cooling and heating loads that the DHP is expected to provide. While the TRM approach does not explicitly indicate the source of this input, it does suggest that Manual J or a similar modeling approach can be used. Given the latitude implied, it is possible that rules of thumb or other rough calculations might be employed to fill this input. Despite this exposure to inconsistent methods of load calculation, the

[33] NEEP, Ductless Heat Pump Meta Study, November 13, 2014, p 8,9

use of a location specific calculation can be expected to improve the accuracy of the savings estimates produced. In addition, the Mid-Atlantic TRM approach includes a factor to account for elimination of duct loss (15%) when displacing/replacing gas heat.

The approach taken to calculate DHP savings in the 2015 PSD is in many ways the most advanced savings approach reviewed. The CT PSD approach uses kWh per MBTU savings values based on the 2009 study. These values incorporate the actual operating efficiencies and customer use of the DHP units into their estimate. This is an improvement over savings approaches that use nominal efficiencies and assumed EFLH. However, it is important to note that the appropriateness of these values is dependent on similar program conditions occurring in the years in which the PSD is applied as that present at the time of the study informing the inputs. The CT PSD also contains the only DHP calculation that has a documented realization rate available to adjust the gross energy savings estimate (63% for single family and 52% for multifamily). In other words, the CT PSD uses the initial 2009 study to inform the algorithm that calculates the tracking savings estimate then uses the 2014 Cadmus study to refine that estimate.

Table 9. Heating Ex Ante Savings Calculation Comparison

Jurisdiction	Inputs from Application	Key Assumptions
Connecticut[34]	• No. of Units • Capacity of Units • Installed HSPF[a]	• Heating Factor (kWh/MBTU) =130 (Hartford), 140 (Bridgeport) • Early Replacement Baseline HSPF= 3.4 • Replace on Failure Baseline HSPF = 8.2
New York Air Source Heat Pump[35]	• No. of Units • Capacity of Units • Installed HSPF	• SF Detached EFLH = 970b • MF Low Rise EFLH = 1,085[c] • Early Replacement Baseline HSPF= 6.8 • Replace on Failure Baseline HSPF = 8.1
New Jersey Air Source Heat Pump[36]	• Capacity of Unit • Installed HSPF	• EFLH = 965 • Baseline HSPF= 7.7
Massachusetts[37]	• Capacity of Unit • Installed HSPF	• EFLH = 1,200 • Baseline HSPF= 8.2
Mid-Atlantic[38]	• Installed HSPF	• DHP Heating Load = Calculated[d] • Early Replacement Baseline HSPF= Known or 5.96 • Replace on Failure Baseline HSPF = 8.2

[a] Heating Seasonal Performance Factor

[b] Mean of all average Single Family detached heating EFLHs

[c] Mean of all Multifamily Low Rise 1979-2006 vintage heating EFLHs

Comment [GR42]: Only for resistance baseline?

Comment [GR43]: In comparison, this would appear to be a HP baseline.

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34 Connecticut Program Savings Document, 2015.

35 New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi-Family, and Commercial/Industrial Measures, Version 3, Issue Date - June 1, 2015

36 New Jersey Board of Public Utilities, New Jersey Clean Energy Program, Protocols to Measure Resource Savings, Revisions to August 2012 Protocols Release Date March 17, 2014

37 Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures, 2013–2015 Program Years – Plan Version, October 2012

38 Mid-Atlantic Technical Reference Manual Version 4.0, A Project of the Regional Evaluation, Measurement and Verification Forum, Prepared by Shelter Analytics, Facilitated and Managed by Northeast Energy Efficiency Partnerships

[d] Calculated from Manual J or similar

Table 10. Cooling Ex Ante Savings Calculation Comparison

Jurisdiction	Inputs from Application	Key Assumptions
Connecticut	• No. of Units • Capacity of Units • Installed SEER	• Cooling Factor (kWh/MBTU) =3.1 (Hartford), 3.2 (Bridgeport) • Early Replacement Baseline SEER= 10.1 • Replace on Failure Baseline SEER = 13.0
New York Air Source Heat Pump[39]	• No. of Units • Capacity of Units • Installed SEER	• SF Detached EFLH = 354[a] • MF Low Rise EFLH = 325[b] • Early Replacement Baseline SEER= 10.0 • Replace on Failure Baseline SEER = 13.0
New Jersey Air Source Heat Pump[40]	• Capacity of Unit • Installed SEER	• EFLH = 600 hours • Baseline SEER= 13.0
Massachusetts[41]	• Capacity of Unit • Installed SEER	• EFLH = 360 hours • Baseline SEER= 14.0
Mid-Atlantic	• Installed HSPF	• DHP Cooling Load = Calculated • Early Replacement Baseline SEER= Known, 10.0 if CAC or 8.5 if RAC • Replace on Failure Baseline SEER = 14

[a] Mean of all average Single Family detached cooling EFLHs

[b] Mean of all Multifamily Low Rise 1979-2006 vintage cooling EFLHs

[39] New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential, Multi-Family, and Commercial/Industrial Measures, Version 3, Issue Date - June 1, 2015

[40] New Jersey Board of Public Utilities, New Jersey Clean Energy Program, Protocols to Measure Resource Savings, Revisions to August 2012 Protocols Release Date March 17, 2014

[41] Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures, 2013–2015 Program Years – Plan Version, October 2012

5.2 TMY Comparison and Review

Typical meteorological year (TMY) data contains "hourly values of solar radiation and meteorological elements" representing typical meteorological conditions over long periods. TMY data is used by designers to model renewable energy conversion systems. The heating degree-days (HDD) and cooling degree-days (CDD) calculated from TMY data are used to build temperature normalization files for billing analyses as a substitute for normalization files built from historical average daily temperatures. Although TMY values do not reflect meteorological extremes, TMY data represent typical climatic conditions for specific locations.[42] This study was tasked to compare the heating degree-days (HDD) and cooling degree-days (CDD) of TMY2 and TMY3, and if differences exist, determine if they had the potential to influence the realization rate reported in the R16 Impact Evaluation.

TMY2 was the standard in 2007–2008 and was built from average daily temperature between 1976 and 2005. TMY2 was updated to TMY3 in 2008 and was built from temperature data from 1991 through 2005. HDD and CDD values in the TMY3 update are, on average, 6% lower than TMY2, and in the case of Bridgeport's CDD values, decreased by 10%. The percent change in HDD and CDD between TMY2 and TMY3 for Hartford and Bridgeport is shown in Table 11. The PSD requires that TMY data must use TMY values from either Hartford or Bridgeport, whichever is "the closest location on heating degree-day (HDD)" basis because Hartford's HDD values are 10% greater than Bridgeport's and CDD values are 25% greater (see Table 11). This difference highlights the importance of using location specific degree-days, which has a direct influence on the PSD savings estimates.

Deleted: Table 11

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Estimated savings estimates in the KEMA 2009 Ductless Mini Pilot Study informed the PSD DHP savings calculation. The KEMA study was conducted before TMY3 was released and used TMY2 data to normalize weather conditions. Updates to TMY2 were available prior to the 2014 R16 Impact Evaluation and TMY3 formed the basis for its normalization file.

The differences in HDD and CDD values between the studies' normalization periods would cause savings to decrease in the R16 study billing analysis if all other study factors remain the same. Put another way, in a side-by-side comparison on a large population of homes, savings will be higher when normalized with a greater number of HDD and CDD such as found in TMY2.[43] The influence of the change in the TMY2 and TMY3 data in the DHP savings estimates between the R16 and 2009 KEMA study is difficult to assess because the errors of the estimates were high in each (due in

[42] National Renewable Energy Laboratory, National Solar Radiation Data Base, 1991- 2005 Update: Typical Meteorological Year 3, http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

[43] M. F. Fels, K. Kissock, M.A. Marean, and C. Reynolds, PRISM® Advanced Version 1.0 Users' Guide (Center for Energy and Environmental Studies, Princeton, New Jersey, January 1995; Ductless Mini Pilot Study, 2009, p. iii

part to small sample sizes). However, the use of TMY3 in the R16 study undoubtedly put downward pressure on the realization rate.

Comment [GR44]: Was this noted/discussed in the ES?

Table 11. Percent difference between TMY2 and TMY3 for Hartford and Bridgeport

	HDD (base 60 °F)			CDD (base 70 °F)		
City	TMY2	TMY3	TMY3 HDD Change	TMY2	TMY3	TMY3 CDD Change
Hartford	5,122	4,843	-5%	530	500	-6%
Bridgeport	4,480	4,357	-3%	417	374	-10%
% Difference	13%	10%		21%	25%	

6 BILLING ANALYSIS CASE STUDY

The billing analysis case study provides a brief review of billing analysis approaches for DHP evaluations, recommendations for the HES and HES-IE Program going forward, and a summary of recent billing analyses produced for DHP evaluations. A broader overview of billing analysis methods and their application to Connecticut's energy efficiency programs is included in the "Review of Impact Evaluation Best Practices (R91)" published in 2015.[44]

6.1 Billing Analysis

Billing analysis converts utility billing (consumption) data into useful estimates of normalized (weather adjusted) annual consumption (NAC). Savings are estimated by observing changes in NAC between the pre and post installation or treatment periods.

Using statistical regression techniques, billing analysis correlates metered consumption data to localized temperature data. The method produces robust estimates of NAC when fuel consumption is highly correlated to outdoor temperature. Billing analysis is performed in a single stage, or as the first stage of a subsequent of two-stage analysis.

It is a common technique in impact evaluation because it presents a cost effective method for estimating the interactive savings of multiple measures and it uses readily available billing, program tracking, and weather data as primary inputs. Many participants in the R16 Impact Evaluation had multiple measures installed at the same time, as will most participants going forward. In these cases, a whole house approach is necessary in to account for the interactive effects of each measure.

6.1.1 Billing Analysis Models for Ductless Heat Pumps

One complicating factor for the DHP program is that most customers are running two heating systems. They may turn off their heat pump in colder weather, or have it take a back seat to the pre-existing non-electric heat. Billing analysis is a powerful tool given that it can make statistically valid savings estimates with 12 months of data. However, in order to produce reliable estimates, HVAC equipment must operate consistently relative to outdoor temperature for all 12 months. Based on the results presented here, these conditions are unlikely to be true for many DHP installations.

Single Stage versus Two Stage Approaches

Comment [GR45]: To assess GHG impacts, estimates of fossil fuel use will also need to be estimated. As well as to populate a full TRC assessment that includes fuel switching/displacement. Should this be addressed here? If so, then how to handle the challenge of oil billing data?

There are two common billing analysis approaches; single stage and two stage methods. The first stage of the two-stage billing analysis approach closely follows the model specifications of PRISM® (Princeton Scorekeeping Method), a common billing analysis reference technique.[45] NAC is estimated separately for each site in the pre-

[44] Connecticut Energy Efficiency Board, Review of Impact Evaluation Best Practices (R91), December 22, 2015;

[45] M. Fels, ed. Measuring Energy Savings: The Scorekeeping Approach, Special PRISM Issue of Energy and Buildings. (1986): 9 (1–2) [sixteen papers describing background on PRISM and sample applications; primary background reference for PRISM users]

and post-periods. After each site has been weather normalized, a second stage analysis uses whole house NAC to estimate measure level savings.

Instead of determining NAC on individual sites, the fixed effects model measures the average consumption across all sites. Because only a subset of sites are transitioning from the pre- to post-program period at any given time, there are many sites to inform an estimate of non-program changes for each month.

A two-stage, variable degree-day approach is recommended for calculating DHP savings because of the wide range of degree-day bases in dual fuel households.

The weather normalization methods of the single versus the two-stage approach are very different. The assumption of the fixed effects model is that a single reference temperature or degree-day base can appropriately summarize a group of sites. In contrast, the first stage of the two-stage model calculates the degree-day base and NAC for each site before determining measure level savings estimates.

Because the outdoor temperature at which households turn on and off the DHP varies over an unusually wide range, households with DHPs should have the temperature set point be determined at the site level.

6.1.2 Data quality and attrition

Efforts to reduce data attrition will immediately translate to increased sample sizes and greater reliability of the savings estimates. If data attrition rates had been lower for R16, the savings estimates would have produced lower sampling errors, likely modified savings estimates and produced a different realization rate.[46] Whether savings would have been higher or lower is unknown.

Data quality and data attrition is endemic to billing analysis evaluations and not anj issue specific to R16. Attrition lowers sample size and may increase bias if it is not random.[47] According to the authors of the R16 Impact Evaluation, the greatest contributor to data attrition was an insufficient number of billing intervals, and outlier removal, which in itself is labor intensive and not typically automated.

The R16 Impact Evaluation goes on to say that the largest source of attrition in the gas data was an incomplete matching of customer billing and tracking data due to

46 The R16 DHP savings estimates produced a sampling error of ±35%. R16 notes correctly, "the reader, however, should recognize results with a sampling error greater than ±10%–20% do not adhere to standard statistical conventions for acceptable levels of precision. In short, it is very possible that another study with similarly small sample sizes or, preferably, larger ones would produce different conclusions about savings from measures with high sampling errors." CADMUS and NMR Group, Final Report, Impact Evaluation: Home Energy Services—Income-Eligible and Home Energy Services Programs (R16), p. 73.

47 Data quality and attrition are the results of: an insufficient number of intervals (i.e., less than 12 months of pre and post data), missing intervals, duplicate records, an inability to match tracking and billing data, and match premises to buildings in a multifamily setting.

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ther lack of a key, or unique identifier, that links customers, consumption and measures across fuels.

The 2011 particpant and comparison groups in R16 experienced data attrition rates of of 42 and 29% respectively.[48] The Maine 2016 Low-Income Multifamily evaluation experienced even higher attrition rates.[49]

Several strategies for mitigating attrition and improving evaluation data management are described in "R33 Observations & Recommendations from CT Residential Program Database Interviews."[50] Where attrition is a result of an insufficient number of billing periods, Program Administrators must make the trade-off between waiting 12 months to measure consumption in the post period or living with decreased levels of reliability.

6.2 DHP Billing Analyses Savings Estimates

Table 12 provides an overview of the savings estimates for several cold climate DHP evaluations. Despite the fact that they are not reported over a common set of metrics, it is clear that the R16 Impact Evaluation reported savings are similar to other cold-climate DHP programs. An overview of DHP evaluations and research reports, including findings and recommendations, is included as Appendix A: Overview of DHP Evaluations and Research Reports.

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[48] Final Report, Impact Evaluation (R16), pp. 134–135

[49] Efficiency Maine, Efficiency Maine Low-Income Multifamily Weatherization Evaluation Report, FINAL, January 14, 2016, http://www.efficiencymaine.com/docs/Low-Income-Multifamily-Final-Evaluation-Report-2016.pdf

[50] Connecticut Energy Efficiency Board, R33 Observations & Recommendations from CT Residential Program Database Interviews, FINAL (1/26/2016), NMR Group, Inc.

Table 12. Billing analysis case study, evaluated savings and realization rates

Study (n)	Estimated Savings[a]							Realization Rate (%)
	Whole House (kWh/year/house)	Total % Savings	Heating (kWh)	Baseload (kWh)	Cooling (kWh)	Demand (KW)	Non-electric (unit, savings)	
R16 Impact Evaluation (n=59), single family, **unknown pre-existing fuel and current fuel mix**	–	-	1,331 (±35%)	-	-	-	-	46%
R16 Impact Evaluation (n=815), multifamily, **DHP and electric resistance**	–	-	803 (±32%)	-	-	-	-	46%
Efficiency Maine LI Multifamily Weatherization, 2016[c] **DHP Only**	1,401 (±166)	15.6%	989 (±5)	383 (±43%)	28 (±64%)	-	3,085 ccf 13.7%	50% (±6)
Efficiency Maine LI Multifamily Weatherization, 2016 **DHP and electric resistance**	–	-4%	-	-	-	-	-	-13%
Emera Maine-Heat-Pump Pilot Program-Final-Report, 2014." (n=51) **DHP and oil**	-2,948[d]	-	-2,387	-163[e]	-398	-.14 summer -.35 winter	239 gal. oil	-
BPA, DHP & Process Evaluation: Billing Analysis Report, 2013, (n=2295) **DHP only**	–	-	2,786	-	-	-	-	-

Comment [GR46]: Did DHP capacities vary much by study?

Comment [GR47]: What is this?

BPA, DHP & Process Evaluation: Billing Analysis Report, 2013, (n=889), **DHP and unspecified supplemental fuel**,	–	-	1,126	-	-	-	-	-

a Blank cells represent unreported values, Ohio Electric Partnership Program Impact Evaluation Results for April 2004- March 2005 not included due to age of technology

b Multifamily

c Weatherization and DHP savings were similar to DHP only due to interactive (whole-house) effects

d. Despite negative savings, Emera placed a high value on reductions in oil consumption and greenhouse gas emissions

e. n=38 for baseload only

Table 13. Billing analysis case study methods

Title	Measures (n)	Billing Analysis Method	Comparison Group
Efficiency Maine, "Efficiency Maine Low-Income Multifamily Weatherization Evaluation Report, FINAL, January 14, 2016, http://www.efficiencymaine.com/docs/Low-Income-Multifamily-Final-Evaluation-Report-2016.pdf	(n=13 properties) (n=222 units)	Low-income, multifamily, weatherization and DHP program The Efficiency Maine study used whole-building methods specified in the Uniform Methods Project[51] and a site-specific variable DD method similar to PRISM®.	Yes
Connecticut Energy Efficiency Fund, CADMUS and NMR Group, R16 Impact Evaluation, http://www.energizect.com/your-town/hes-and-hes-ie-impact-evaluation-r16-final-report-12-31-14	(n=59)	R16 Impact Evaluation of the CT HES and HES-IE (multi-measure) program The R16 Impact Evaluation used a fixed-effects model. The available sample size and attrition rate, although common, contributed to the high level of uncertainty (+-35).	Yes

[51] NREL, The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures, Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol. p. 8-14, http://www1.eere.energy.gov/wip/pdfs/53827-8.pdf

Title	Measures (n)	Billing Analysis Method	Comparison Group
Emera Maine, EMI Consulting, 2014.09.30 "Emera Maine-Heat-Pump Pilot Program-Final-Report, September 30, 2014, Revised November 17, 2014." http://www.emiconsulting.com/assets/Emera-Maine-Heat-Pump-Final-Report-2014.09.30.pdf	(n=64)	Heat Pump Pilot Program The analysis reviewed "correlations and covariations to identify variables with the highest statistically significant impacts on the energy and fuel use data such as house size. Using results from in-depth interviews, savings were correlated to operational patterns."[52] Billing analysis methodology was not provided.	None
Ductless Heat Pump Impact & Process Evaluation: Billing Analysis Report, #13262, August 2013 https://neea.org/docs/default-source/reports/ductless-heat-pump-impact-process-evaluation--billing-analysis-report.pdf?sfvrsn=6 NEEA/BPA, Final Summary Report for the Ductless Heat Pump Impact and Process Evaluation, #E14-274, February 2014	(n=3,621)	Three state DHP and supplemental fuel analysis The pre and post -installation period each used ~18 to 30 months of billing data and PRISM®. This report provides a detailed description of a well-designed billing analysis using a variable degree-day method using strict PRISM® protocols over a large sample. This study presents a comprehensive and clear example of best practices for billing analysis approaches.	None

[52] Emera Maine-Heat-Pump Pilot Program-Final-Report, 2014, p. 10

7 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations rest upon the findings from this study.

7.1 Conclusions

We begin this section with a brief review of customer satisfaction with their DHP. We then discuss one of the primary objectives of this study, which was to examine the primary drivers of the R16 Impact Evaluation. This is followed by an examination of other factors that can influence DHP savings and information to assist the utilities in getting the most impacts out of DHPs in the future.

The good news

We would like to begin this section with the finding that program participants from all years surveyed and visited in this study are overwhelmingly satisfied and happy with the DHP installed through the program. We feel this is very important because while this report presents causes of low realization rates and examines conditions that might lead to lower electric savings, it is clear that the DHPs are meeting participant expectations. Part of the reason why we believe people are happy is because while the DHP might not be producing expected levels of electric savings from a program point of view, they are likely reducing energy costs for customers.

Cause of low realization rate in R16

Comment [GR48]: Numbering below needs to be corrected.

Comment [GR49]: Should/could these be summarized in a table? With some indication of the direction and magnitude of their impact on the R16 RRs?

The first objective of this study is to understand the primary drivers of the realization rate of 45%. Based on our research, we believe there are three primary drivers of the realization rate in the R16 Impact Evaluation.

4. The PSD cooling saving factor is based on program operations and installation conditions that differ from that observed among 2011 participants (the reference year of the R16 impact study).
5. Participants in the R16 study had a moderate number of installations that added to heating loads, which was not accommodated for in the PSD calculation used at the time.
6. There is evidence that many customers are adopting control strategies that reduce the overall efficiency of their DHPs.

Each of these is discussed in more detail below.

4. <u>PSD Cooling Assumptions</u>

The PSD kWh cooling savings factor is 3.1 kWh per MBTU for Hartford and 3.2 kWh per MBTU for Bridgeport. These values are sourced from a 2009 study of the ductless pilot program. These values are based upon an assumed baseline RAC of 9.0 EER and included 22.5% of sites where the DHP represented an increase in cooling capacity over baseline (participants that had no pre-existing cooling system). In this study, nearly 61% of 2011 sites did not have cooling serving the space before the DHP was installed. This change in pre-existing conditions between that assumed in the tracking estimate and that present in the evaluated estimate would have a significant effect on the realization rate in the R16 report.

We do note that the 2014 PSD was updated for the 2015 Program Year. The 2015 version still uses the same cooling savings factors from the 2009 pilot study but includes the realization rate from the R16 Impact Evaluation to inform the final ductless savings estimate. Because the R16 Impact Evaluation is more representative of current HES and HES-IE participants, all things being equal, the updated PSD calculation, with additional modifications, should result in more representative realization rates.

5. Added Heating Loads

The PSD in place at the time of developing the tracking savings for 2011 participants had an assumption that installed DHPs replaced electric heat and had no supplemental non-electric heat serving the space. In our study, roughly 9% of 2011 participants surveyed reported that the DHP was installed in a space that was either not previously heated or was an addition. In a billing analysis, these sites would have negative savings and have a disproportionate impact on the realization rate.

6. Heating Use and Control Strategies

In the northeast, where second heating systems are often necessary, how those systems are operated in conjunction with the DHP can greatly influence savings. In our study, nearly 17% of 2011 participants reported that they are either not using their DHP in the winter or they are using it as a back up to the pre-existing system. These behaviors will negatively affect the ability of the DHP to produce savings.

Evaluation risks in future years

The previous section reviewed the drivers of the low realization rate in the 2014 study of 2011 participants. In many ways, however, we believe the 2013–2015 participant groups are at increased risk of low electric savings realization rates than the 2011 group evaluated in the R16 study.. There are several reasons why electric savings among this group of participants are likely to be lower than those estimated from the PSD, even with the use of the R16 realization rate.

- As noted earlier, electric heating and cooling loads are added when DHPs do not replace existing electric equipment serving the same space. In the 2013–2015 participant groups, we estimate that 44% of DHP installations were in spaces that were previously not air conditioned and 17% in spaces that were not previously heated.

- In addition to new loads due to DHP installation in locations not previously conditioned, we also note that non-electric fuels heated many spaces where a DHP was installed. We estimate that in those areas heated before the DHP was installed, 72% were heated by non-electric fuels. This condition will increase the electric heating load and result in an erosion of evaluated savings.
- Many DHPs are not primary heating systems, but function as a backup or are supplemented by electric resistance baseboard and non-electric fossil systems. In our review of industry evaluations, many of them note that that some portion of DHP participants realize low or negative electric savings because electric resistance is not the pre-existing heating system.
- If oil prices continue to decline, it will become increasingly less expensive for customers to use fossil fuels as their heat source compared to electricity (their DHP). This would result in DHPs being shut down, reducing electric savings rates of installed systems.
- Low oil prices are also likely to slow program growth among participants who might normally enter the program specifically to mitigate the high price of fossil fuels. It may not be possible for program marketing efforts to overcome the cost/benefit of operating a DHP during periods of depressed fossil fuel prices. Customers will continues to purchase DHP for cooling only, but survey results show that most customers heat and cool with the DHP. It is not clear whether the motivation to improve or add cooling will overcome the influence of low fossil fuel prices on participation.

Comment [GR50]: In the R16 sample or in the 2013-2015 sample?

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Takeback Effects

An objective of this study is to identify evidence of takeback effects from increased interior temperatures in anticipation of lower operating costs. There are few emperical studies on temperature takeback, though there is consensus that takeback exists to some degree, particularly for HVAC measures.

In this study, it was difficult to make a one-for-one comparison between thermostatic behavior of the pre-existing HVAC systems and the DHP for three reasons:

- The need to increase the DHP thermostat a few degrees higher in order to maintain previous comfort levels
- The fact that in many households, two HVAC systems are operating at the same time
- Setback strategies cannot be compared between the DHP and traditional pre-existing HVAC systems

Comment [GR51]: See previous comments on this statement/finding.

Based on the data collected, in the midst of the shortcomings bulleted above, our findings are largely inconclusive on this matter. To the extent we were able to identify the conventional behaviors associated with thermostatic take back, it appears to be an isolated phenomena. In our estimation, there are many other operational patterns identified in this study that are likely to have a much greater influence on energy savings than takeback.

Education

How the customer controls the DHP has a direct effect on its operating efficiency. First, the remote control device is new and the operational patterns that optimize DHP efficiency do not align with the conventional wisdom surrounding more traditional HVAC equipment such as dramatic setback strategies or frequently turning the DHP on and off.

In the Northeast, it is necessary to have a backup heating system to supplement the DHP in colder weather. Under these circumstances, where the customer also needs to integrate DHP use with a second system, education about integrating the pre-existing system with the DHP becomes an even more critical factor for the DHP to achieve anticipated levels of savings.

It is clear that the program takes customer education very seriously and that it is an integral part of the DHP offering. Across both the 2011 and 2013–2015 program years, 80% of respondents reported the installer demonstrated the controls. However, we do note that several expressed confusion about the controls after the installer left. At the on-sites, where we gathered more detailed information on the amount and type of education received, respondents reported receiving a lower and more generalized level of instructions with gaps in education about control strategies.

Other Conclusions

Comment [GR52]: See previous comments about possible needs to estimate changes in fossil fuel use. How would that consideration influence this discussion?

- The characteristics of operational patterns of DHP users indicate that this measure is a good candidate for a two-stage, variable degree-day billing analysis approach. The R16 billing analysis used a fixed effects model to estimate the savings from the DHP measure and produced precision estimates on the order of ± 30%. From a methodology standpoint, the fixed effects model calculates a single reference temperature (thermostat setpoint) across all households. The telephone survey and on-site audits revealed that customers adopt different strategies for integrating their DHP and their pre-existing heating systems that result in large swings of heating reference temperatures between households. Under the best of circumstances, such wide ranges of reference temperatures pose modeling challenges for any billing analysis. However, a two-stage model (or PRISM-like analyses) calculates a unique reference temperature for each household, instead of averaging across all households in the sample and is the recommended approach. It is unknown whether adopting a variable degree-day model will increase or decrease the savings rate, but it should reduce statistical error and increase the reliability in the results.

- Data attrition produced high sampling errors in the reported savings. Reducing data attrition by waiting to collect 12 months of pre and post installation data will reduce errors in the estimates and increase precision.
- The PSD DHP savings algorithm compares favorably against DHP savings algorithms from other jurisdictions reviewed in this study. The DHP PSD approach incorporates actual DHP performance by virtue of its use of the 2009 KEMA study. In the 2015 PSD, it also uses realization rates to adjust these savings with a realization rate from the R16 study.
- The savings factors from the 2009 study of the ductless pilot program are most accurate when the pre and post conditions of the DHP sites inherent in the savings factors are similar to those being evaluated. The 2009 study had particular criteria around eligibility for DHP installation. The conditions around those installations resulted in a specific set of pre-existing system scenarios and customer use behaviors from which savings were calculated. Those conditions and the various ways in which the results were presented and available from the report makes their application reasonable for PSD purposes, although their accuracy is dependent upon the similarity of program design and operations at the time of the study and those that the study results are being applied to.

7.2 Recommendations

Comment [GR53]: See comments in ES.

The following recommendations are intended to help improve the accuracy of tracking savings estimates, mitigate future evaluation risks, and maximize electric savings from DHP installations.

Recommendation 1: Update the current PSD: The current PSD formula should be updated to better reflect the conditions in which DHPs are being installed and used. The PSD does provide a realization rate to revise savings based upon the R16 study. However, the majority of particpants in R16 were from a unique customer base (multifamily under relatively controlled circumstances) which is not representative of subsequent participants. These revisions should account for instances of load added when the unit is installed in a previously unconditioned space or when it displaces non-electric heating sources (i.e., fossil fuel or wood).

Recommendation 2: Perform a billing analysis using a more representative sample of program particpants: An alternative to the above recommendation would be to perform a billing analysis that better captures the DHP installation pre and post conditions on more recent participants. This result could be used to displace the current realization rate in the PSD as a factor to adjust the savings derived from the DHP formula. Recommendation 6 below provides a recommendation on the form such a billing analysis might take if such an effort is undertaken.

Recommendation 3: As an alternative 1 and 2 above, perform an on-site engineering analysis: An alternative to the previous two recommendations would be to perform a study on more recent participants where a sample of sites is metered and analyzed, akin to the KEMA study performed on the pilot program. Albeit a more expensive option than those covered in the previous two recommendations, such a study would provide new cooling and heating savings factors for the PSD based upon current DHP installation pre and post conditions and could also provide non-electric savings impacts for purposes of understanding greenhouse gas emission reductions associated with DHPs.

Recommendation 4: Educate customers on DHP operation strategies that generate the highest savings rates: Although it is clear the program takes customer education seriously, the impact of customer behavior on realized electric savings warrants continued attention. This study suggests that customer education and knowledge of how to integrate the DHPir system with their pre-existing system diminishes over time. Some ideas to help maintain high levels of desirable DHP opeartion includes providing additional information on the EnergizeCt web site on control, maintenance and operations strategies to supplement the functional information already provided on the site (e.g. "How a Heat Pump Works" and Heat pump FAQs).[53] Such a new section might be called "How to Maximize your DHP Savings." Additional delivery channels coud be explored.

Recommendation 5: Increase program engagement with the electric resistance heating customers who have the highest savings potential. Based on our review of the study that forms the basis of the PSD, the R16 impact study and the data gathered from 2013-2015 participants, we believe that the mass market conditions in which DHPs are being installed is going to erode electric savings further than observed in the R16 study. One way to mitigate this would be a target-marketing campaign directed to those electric resistance customers with the highest savings potential. There is also an opportunity to increase marketing efforts to customers with relatively high cooling loads. These high potential savers can be identified through signatures in existing consumption data.

Recommendation 6: Use a two-stage, variable degree-day approach for all future billing analyses to estimates DHP savings. In order to improve the reliability of any future DHP evaluations performed with a billing analysis, we recommend the use of a two-stage variable degree-day billing analysis approach. We also recommend that the study maximize the sample size available for the analysis as attrition limited the sample that was available in the R16 Impact Evaluation.

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[53] http://www.energizect.com/your-home/solutions-list/ductless-split-heat-pump-rebates

APPENDIX A: OVERVIEW OF DHP EVALUATIONS AND RESEARCH REPORTS

Author, Title, Date, Web link, Location	Objectives, Study Sample, Method	Conclusions	Recommendations
Efficiency Maine, "Efficiency Maine Low-Income Multifamily Weatherization Evaluation Report, FINAL, January 14, 2016 http://www.efficiencymaine.com/docs/Low-Income-Multifamily-Final-Evaluation-Report-2016.pdf	The objective was to assess the effectiveness of the Low-Income Multifamily Weatherization Program in achieving its savings goals Low-income Home Energy Assistance Program eligible multifamily homes in Maine In-depth interviews, telephone surveys, billing analysis	The Maine study showed positive heating savings and negligible cooling savings due to a very low cooling load. Multifamily properties that received only heat pumps were the only group that had statistically significantly baseload savings. The reasons for this were unexplained as weatherization measures typically produce baseload savings. Most tenants that use their DHP as the primary heating system realized positive savings. Customers who used both electric baseboard and DHPs realized negative savings. Training regarding DHP operations was insufficient. Most tenants were satisfied with the DHPs ease of use and how well it heated their apartments. There was some uncertainty whether owners/managers would have installed DHP without the 100% subsidization. Persistence of training is unclear in the income eligible multifamily sector due to potentially high turnover of managers and tenants and in cases where tenants do not pay their own electric bills.	Increased minimum annual electricity usage for DHP projects Offered training to property managers Provided stickers for tenant's ER thermostats, "Expensive Heat – Use Heat Pump First". Identify methods, such as training, to increase reliance of DHP as primary heat source Consider revisiting the assumptions of expected energy savings for low-income multifamily programs. Consider assigning a smaller percent of the heating load due to occupant's reliance on existing heating system. Define incentives for future income-eligible multifamily programs based on overall objectives.
Emera Maine, EMI Consulting, Emera Maine-Heat-Pump Pilot Program-Final-Report, 2014.09.30	The objectives of the evaluation were to estimate program impacts on energy consumption, greenhouse gas	Increase in summer and winter peak KW demand of .14KW and .35KW respectively. DHPs increased annual electricity consumption across all seasons by 2,947	Train contractors and educate customers on effective placement of heat pumps.

1, September 30, 2014, Rev. November 17, 2014 http://www.emiconsulting.com/assets/Emera-Maine-Heat-Pump-Final-Report-2014.09.30.pdf. Emera service territory encompasses 9,350 square miles in eastern coastal and central Maine	emissions, energy costs, non-energy benefits and program's processes. The evaluation studied residential and small commercial Emera Maine customers who used oil, propane, ER, or kerosene as a primary heat source, and spent $1,400 or more on heat annually. These customers were eligible to receive $600 rebates, on-bill financing and referral credits for DHP's. Qualitative research, Telephone survey, Web survey, in-home meters, On-site surveys, In-depth interviews and billing analysis	kWh with a relative increase of 27% winter and 16% summer peak impacts. Savings ranged from a low of based on operation patterns from a low of 300kWh/month for on/off operations to a high of over 900 kWh for automatic settings coupled with an associated reduction in pre-existing fuel sources. DHP's are a viable heating technology for cold weather climates. Customer education regarding strategic use of their heat pumps is key to maximizing cost savings. Single zone heat pumps have difficulty replacing a multi-zone system. Participants in the program are experiencing increased comfort and better air quality in their home. Some low heat pump users kept household thermostats set between 64 and 66 degrees. High usage was often driven by thermostat settings between the heat pump and the pre-existing systems.	Educate participants regarding heating strategies with existing systems. Continue to coordinate with heat pump distributors regarding advancements in multi-zone cold weather units.
NEEA/BPA, Final Summary Report for the Ductless Heat Pump Impact and Process Evaluation, #E14-274, February 2014 The Northwest Energy Efficiency Alliance and the Bonneville Power Administration, Addendum No. 1 to the Ductless Heat Pump	The study was conducted in Montana, Eastern Idaho and, Puget Sound The DHP studied DHP technical performance, market acceptance, market progress, lab testing, field monitoring, billing analysis, and cost-effectiveness.	The use of supplemental fuels leads to substantial reduction in savings, up to 30 to 40%. Failure to screen for supplemental fuels will reduce the overall savings effect of the DHP technology. Increased indoor temperature results in lower savings. The effect is small (less than 10% of measured savings) but there is evidence that the occupants are using slightly higher temperatures once the DHP is installed.	

Impact and Process Evaluation: Field Metering Report Ductless Heat Pump Cold Climate Performance Evaluation, March 29, 2013. http://neea.org/docs/default-source/reports/e14-274-dhp-final-summary-report-(final).pdf?sfvrsn=8	The objectives were to describe the energy use DHP, determine the cooling use, establish the offset to space heating, cost-savings impacts, incremental cooling, climate and occupancy parameters that explain the observed savings and summarize the non–space-heating energy uses. Savings were calculated from metered net heat output of the DHP. The DHP program displaced existing electric heating systems. Detailed field monitoring was necessary to distinguish performance impacts related to occupant actions from efficiency and performance	The second indoor air handler (head) allows another zone to be conditioned. In colder regions, the effect is to offset the load and reduce operating time. The impact of DHP efficiency ratings on overall performance or savings was small. The equipment had a wide variation in efficiency ratings, but the savings were highly correlated to the system operation and occupant control. In no climate did the cooling from the DHP exceed or even approach the levels of heating savings. DHP heating savings in multifamily buildings were less than expected (n=12) The study found "takeback"—significant increases in heat output after the installation of the DHP. In addition, the DHPs were not fully utilized because ER was estimated to account for 25% to 57% of input heating energy. The degree of conversion to DHP usage was strongly associated with the degree of savings.	

APPENDIX B: ON-SITE FORM

R113 DHP Evaluation On-Site Survey

The residential on-site survey will collect equipment and operations data on installed DHPs (DHP's), pre-existing heating and cooling systems, customer education, building characteristics occupancy, information and information about equipment operations. Field staff will obtain detailed technical information during the on-site visit that is not easy to collect or confirm during a telephone survey such as:

- Manufacturer and model number, heating and cooling capacity (Btu) and efficiency (HSPF, SEER)
- Configuration (quantity, size and location of zones)
- Quality of installation
- Schedule of Operation
- Pre-existing and supplemental heating and cooling system and fuel type
- Building type and envelope characteristics

1	**DNVGL ID**	**From CATI Excel File**
2	**Site ID#**	
3	**Date**	
4	**Customer**	
5	**Phone**	
6	**Address**	
7	**City**	
8	**EMAIL**	
9	**Type of Building (Circle)**	**Single Family attached**
		Single Family Detached
		Multifamily Unit (2-4)
		Multifamily Unit (5+)
		Other
10	**Building Envelope & condition**	

11	Size sq. ft.	
12	#occupants	
13	Has #occupants changed since installation of DHP?	

DATA COLLECTION: CURRENT DHP SYSTEM

Can you show me the interior units installed?

 # 14: Evaporator Unit

Unit #	Manufacturer	Model #	Size Btuh	HSPF SEER	Room Types served	Prev. H or C	Quality good, fair poor
1						H C	G F P
2						H C	G F P
3						H C	G F P
4						H C	G F P
5						H C	G F P

ENTER EXTERIOR UNIT INFORMATION IN BOX BELOW; CROSS-REFERENCE INTERIOR UNITS IN FINAL COLUMN.

Can you show me the exterior condenser units?

#15: Condenser Unit

Con #	Evp #	Manufacturer	Model #	Size Btuh	# of Units served	HSPF SEER	Quality good, fair poor
							G F P
							G F P
							G F P
							G F P
							G F P

CUSTOMER LEARNING AND KNOWLEDGE

I know you answered questions about education you received about how to operate the unit in the phone survey. I just have a few questions

16. After the installers left and you operated the system for a while, was there anything else you wanted to know that was not covered by the installer?
17. Do you have any questions now? (answer if possible, otherwise say we will follow up)
18. What is the most difficult part of operating the system
19. Does the customer know how to operate the system now?
YES **NO** **Explain:**

AFTER YOU START THE FOLLOWING QUESTIONS, IF THE CUSTOMER INDICATES THAT THEY HAVE ALREADY ANSWERED THESE QUESTIONS IN THE CATI THEN SKIP THIS SECTION

20. Do you use the auto setback functions for temperature control	**Winter**	**YES**	**NO**
	Summer	**YES**	**NO**
IF CUSTOMER DOES NOT USE SETBACK, **21. Is there a reason you don't use the setback function?**			
22. Do you control the DHP with the remote or using the controls on the DHP?	**Thermostat** **At DHP Unit** **Both**		
23. Is the comfort level the same as the pre-existing system? **(PROMPT FOR HOTTER, COOLER, RUN FOR LONGER TIMES, SET HIGHER TEMPERATURES)**			

24. Is the same true in very cold weather?
25. Is the same true in very hot weather?
26. Is there anything you want to say about the comfort?

27. DHP temperature settings

VERIFY BASED ON ACTUAL SETTINGS.

For Unit 1 Temperature Settings	Temperature
Unit Location (area served):	
Programmed or manual?	
Settings for summer and winter periods.	**Summer: Months: __________ to ________** **Period 1: ___:___ to ___:___ _____° F** **Period 2: ___:___ to ___:___ _____° F** **Period 3: ___:___ to ___:___ _____° F** **Period 4: ___:___ to ___:___ _____° F**
	Winter: Months: __________ to ___________ **Period 1: ___:___ to ___:___ _____ F** **Period 2: ___:___ to ___:___ _____°F** **Period 3: ___:___ to ___:___ _____°** **Period 4: ___:___ to ___:___ _____°**

For Unit 2 Temperature Settings	
Unit Location (area served):	
Programmed or manual?	

For Unit 2 Temperature Settings	
Settings for Summer and Winter periods.	**Summer: Months: _________to ___________** **Period 1: __:__ to __:__ _____° F** **Period 2: __:__ to __:__ _____° F** **Period 3: __:__ to __:__ _____° F** **Period 4: __:__ to __:__ _____° F**
	Winter: Months: _________ to ___________ **Period 1: __:__ to __:__ _____° F** **Period 2: __:__ to __:__ _____° F** **Period 3: __:__ to __:__ _____° F** **Period 4: __:__ to __:__ _____° F**

BASELINE DATA COLLECTION: HEATING SYSTEMS

THE FOLLOWING INFORMATION IS FOR ALL PRE-EXISTING PRIMARY HEATING SYSTEMS. PROMPT CUSTOMER TO EXPLAIN REASONS.

28. Pre-existing heating systems

Primary heating system	DHP Unit #	In Use ?	Why is it turned on? Use last row if needed.	When is it turned on?	Same as before the DHP?
Elec. Res BB.(type)		Y N		______ Early, Mid, Late	______ Early, Mid, Late
Gas boiler or forced air		Y N		______ Early, Mid, Late	______ Early, Mid, Late
Oil		Y N		______ Early, Mid, Late	______ Early, Mid, Late
Other: ______		Y N		______ Early, Mid, Late	______ Early, Mid, Late
A previous DHP		Y N		______ Early, Mid, Late	______ Early, Mid, Late

COLLECT DATA ON THE PRE-EXISTING HEATING SYSTEM AND CUSTOMER USE.
CONFIRM THE SYSTEM TYPE AS PART OF THE ON-SITE OBSERVATION, IF POSSIBLE.

Unit #	Is/was the pre-existing heating system controlled by pre programmed auto temperatures or set to a constant temperature at all times?	At ~ what outside temperature did the customer start to use the previous system?	IF UNIT STILL IN USE: ~ what outside temperature does the customer start to use the pre-existing system
1	(pre programmed) Y N		
2	(pre programmed) Y N		
3	(pre programmed) Y N		

Unit #	In general, do the heating temperature settings you used with the DHP differ the settings with the previous system? If so, describe.	If settings have changed, why have they changed?
1		
2		
3		

29. Why did you keep the existing heating system?

BASELINE DATA COLLECTION: COOLING SYSTEMS

SURVEY PRE-EXISITNG AIR CONDITIONING IN THE SPACE NOW COOLED BY THE DHP.
CONFIRM THE SYSTEM TYPE AS PART OF THE ON-SITE OBSERVATION, IF POSSIBLE.

IF NO PRE-EXISITNG AIR CONDITIONING IS STILL IN OPERATIONS, COMPLETE VISIT.

30. Pre-existing cooling systems

	# Prior to DHP installation	# Currently in operation
Central Air Conditioning (CAC)		
Room Air Conditioning (RAC)		

Unit #	Is/was the pre-existing cooling system controlled by pre programmed auto temperatures or set to a constant temperature?	At approximately what outside temperature did the customer start to use the previous system?	IF UNIT STILL IN USE: approximately what outside temperature does the customer start to use the pre-existing system now?
1	**(pre programmed) Y N**		
2	**(pre programmed) Y N**		
3	**(pre programmed) Y N**		

Unit #	RAC or CAC (from above)	Is the system still in use?	What month was the system used before the DHP	If still in use What month is the system turned on	Temperature settings
		Y N	**______ Early, Mid, Late**	**______ Early, Mid, Late**	
		Y N	**______ Early, Mid, Late**	**______ Early, Mid, Late**	
		Y N	**______ Early, Mid, Late**	**______ Early, Mid, Late**	

IF PRE EXISITNG SYSTEM IS STILL USED, NOTE THE TEMPERATURE SETTINGS.

What temperature settings did the customer use for the system(s) before the DHP was installed (this may be difficult to collect)?

Baseline cooling system	Time Start	Time Finish	Degrees F
Period 1			

Baseline cooling system	Time Start	Time Finish	Degrees F
Period 2			
Period 3			
Period 4			
Period 5			

Unit #	In general, do the temperature settings you use with the DHP differ from the settings you used with the previous system? If so, describe	If settings have changed, why have they changed?
1		
2		
3		

31. Why did you keep the existing cooling system?

THANK YOU FOR ALL OF YOUR TIME TODAY. WE APPRECIATE YOUR WILLINGNESS TO LET US INTO YOUR HOME TO GATHER THIS INFORMATION.

HAVE INCENTIVE FORM COMPLETED, PROVIDE INCENTIVE, LEAVE BUSINESS CARD

R113 Incentive Confirmation Form

Verification of receipt of $100 incentive payment

Name:

Address:

My signature below verifies that I received the $100 gift card

Signature **Date**

Provided by: DNV GL Employee Name

Incentive card number:

27.1. DHP temperature settings

VERIFY BASED ON ACTUAL SETTINGS, IF POSSIBLE.

For Unit 1 Temperature Settings	Temperature
Unit Location (area served):	
Programmed or manual?	
Settings for summer and winter periods.	**Summer: Months: _________ to _______** **Period 1: __:__ to __:__ _____° F** **Period 2: __:__ to __:__ _____° F** **Period 3: __:__ to __:__ _____° F** **Period 4: __:__ to __:__ _____° F**
	Winter: Months: _________ to __________ **Period 1: __:__ to __:__ _____ F** **Period 2: __:__ to __:__ _____°F** **Period 3: __:__ to __:__ _____°** **Period 4: __:__ to __:__ _____°**

For Unit 2 Temperature Settings	
Unit Location (area served):	
Programmed or manual?	
Settings for Summer and Winter periods.	**Summer: Months: _________to __________** **Period 1: __:__ to __:__ _____° F** **Period 2: __:__ to __:__ _____° F** **Period 3: __:__ to __:__ _____° F** **Period 4: __:__ to __:__ _____° F**
	Winter: Months: _________ to __________ **Period 1: __:__ to __:__ _____° F** **Period 2: __:__ to __:__ _____° F** **Period 3: __:__ to __:__ _____° F** **Period 4: __:__ to __:__ _____° F**

27.2 DHP temperature settings

VERIFY BASED ON ACTUAL SETTINGS, IF POSSIBLE.

For Unit 1 Temperature Settings	Temperature
Unit Location (area served):	
Programmed or manual?	
Settings for summer and winter periods.	**Summer: Months: _________ to _______** **Period 1: __:__ to __:__ _____° F** **Period 2: __:__ to __:__ _____° F** **Period 3: __:__ to __:__ _____° F** **Period 4: __:__ to __:__ _____° F**
	Winter: Months: _________ to __________ **Period 1: __:__ to __:__ _____ F** **Period 2: __:__ to __:__ _____°F** **Period 3: __:__ to __:__ _____°** **Period 4: __:__ to __:__ _____°**

For Unit 2 Temperature Settings	
Unit Location (area served):	
Programmed or manual?	
Settings for Summer and Winter periods.	**Summer: Months: _________to __________** **Period 1: __:__ to __:__ _____° F** **Period 2: __:__ to __:__ _____° F** **Period 3: __:__ to __:__ _____° F** **Period 4: __:__ to __:__ _____° F**
	Winter: Months: _________ to __________ **Period 1: __:__ to __:__ _____° F** **Period 2: __:__ to __:__ _____° F** **Period 3: __:__ to __:__ _____° F** **Period 4: __:__ to __:__ _____° F**

APPENDIX C: TELEPHONE SURVEY

INTRODUCTION/SCREENING

DIALSCR My name is [**interviewer name**], and I am calling on behalf of <**UTILITY**> from **[CATI]**. This is not a sales call. <**UTILITY**> provided your contact information based on locations where a DHP was installed as part of the Connecticut Home Energy Solutions Program. We're contacting customers regarding their satisfaction with the heat pump and how they operate it in their homes. Is this <**CONTACT_NAME**>?

1	Yes	SCR1
2	No	SCR1
97	[Don't know]	SCR1
98	[Refused]	END

[If < **CONTACT_NAME** > not available, read intro below then ask for "head of household"]

[IF NECESSARY]

- SURVEY LENGTH: the survey should take around 10 minutes.
- CALLING FROM: I work for [CATI]. We are an independent research firm who has been contracted to conduct this study on behalf of <**UTILITY**>.
- REASON FOR STUDY: We are conducting a study to learn more about The Connecticut Home Energy Solutions Program, Energize Connecticut and your DHP. Connecticut does these studies periodically to evaluate how to make their programs work better.
- IF RESPONDENT IS CONFUSED ABOUT WHAT A DHP IS: The DHP is the heating and air-conditioning unit that was installed through the wall. There is likely to be more than one wall unit. It has an outdoor compressor or box.
- IF RESPONDENT EXPRESSES CONCERN: I am not selling anything, and your responses will be kept confidential. If you would like to talk with someone from the <utility> about this study, please contact < **UTILITY_CONTACT** > <**UTILITY_PHONE** >.]

SCR1. Our records show that a DHP was installed at <ADDRESS> in <YEAR>. Were you living at this address when the heat pump was installed?

1	Yes	SCR1b
2	No	SCR1a
97	[Don't know]	END
98	[Refused]	END

SCR1a. Were you the landlord for <ADDRESS> in <YEAR>, when the heat pump was installed?

1	Yes	SCR2
2	No	SCR1b
97	[Don't know]	END
98	[Refused]	END

SCR1b. Are you currently living at <ADDRESS>?

1	Yes	SCR2
2	No	END
97	[Don't know]	END
98	[Refused]	END

SCR2. Are you familiar with the decision to purchase the DHP?

1	Yes	INTRO1
2	No	SCR3
97	[Don't know]	SCR3
98	[Refused]	END

SCR3. Who is familiar with that process?

1	[RECORD FIRST and LAST NAME as SCR3NAME]	SCR3a
97	[Don't know]	Intro1
98	[Refused]	Intro1

SCR3a. Could I speak with <SCR3NAME> now?

1	[Yes]	[Skip back to SCR1]
2	[No]	SCR4
97	[Don't know]	SCR4
98	[Refused]	SCR4

SCR4. When is a good time I could call back to reach <SCR3NAME>?

[RECORD DAY and TIME]	[End - Call back later – note name <SCR3NAME>]
97 [Don't know]	[End - Call back later]
98 [Refused]	[End - Call back later]

[If SCR1a does not equal 1, i.e. not a landlord, THEN ASK INTRO1,
If SCR1a=1, i.e. a landlord, GO TO INTRO3:]

INTRO1. Do you own or rent this residence?

1	Own
2	Rent
77	OTHER, SPECIFY
97	[Don't Know]

98	[Refused]

INTRO 2. Of the 52 weeks in a year, how many weeks do you spend in this residence per year?

1	[Number response 0-52] weeks/year
98	[Refused]

INTRO3 How many DHPs are currently installed inside the residence at <**ADDRESS**>?

1	One	D1
2	Two	D1
3	Three	D1
4	Four or More	D1
97	[Don’t Know]	END
98	[Refused]	END

DECISIONS:

[IF SCR3=97-98 SKIP TO F1]

D1. What were your reasons for purchasing a DHP? [DO NOT READ, ACCEPT MULTIPLE]

1	The utility Rebate	D2
2	Comfort	
3	Space not previously cooled and heated	
4	Space not previously cooled	
5	Space not previously heated	
6	Space not cooled and heated adequately	
7	Space not cooled adequately	
8	Space not heated adequately	
9	Save money on my energy bill	
10	More efficient heating and cooling	
11	More efficient cooling	
12	More efficient heating	
13	It was less expensive than other cooling/heating options	
14	Wanted “zoned” heating and cooling	
15	Wanted “zoned” heating	
16	Wanted “zoned” cooling	
17	It was given to me	
77	OTHER, SPECIFY	
97	[Don’t know]	D3

98	[Refused]	D3

D2. From the reasons you just provided, what was your **main** reason for purchasing a DHP?

1	The utility Rebate
2	Comfort
3	Space not previously cooled and heated
4	Space not previously cooled
5	Space not previously heated
6	Space not cooled and heated adequately
7	Space not cooled adequately
8	Space not heated adequately
9	Save money on my energy bill
10	More efficient heating and cooling
11	More efficient cooling
12	More efficient heating
13	It was less expensive than other cooling/heating options
14	Wanted "zoned" heating and cooling
15	Wanted "zoned" heating
16	Wanted "zoned" cooling
17	It was given to me
77	OTHER, SPECIFY
97	[Don't know]

98	[Refused]

D3. How did you determine which specific make and model of DHP to install? [DO NOT READ. ACCEPT MULTIPLE]

7	Recommended by auditor/person who did energy assessment
1	Recommended by contractor
2	Recommended by Store/ distributor~~/store~~
3	Recommended by friend
4	Shopped for best priced unit
5	Recommended on Web
6	Performance: compared manufacturers specifications
77	OTHER, SPECIFY
97	[Don't know]
98	[Refused]

FUNCTION

F1. What space in your residence does/do your DHP system serve? [ACCEPT MULTIPLE, READ OPTIONS]

9	All of home [If this selected, do not read rest of list]
1	Master Bedroom
2	Other Bedrooms
3	Living Room, Family Room or Den
4	Whole residence
5	Kitchen
6	Office

7	Sunroom or three-season space
8	Auxiliary spaces, such as basements, lofts, attics. .
77	Other, please specify
97	Don't know
98	Refused

F2. Are you using your DHP for cooling only, heating only, or both heating and cooling?

1	Cooling only	F4
2	Heating only	F3
3	Both heating and cooling	F3
97	Don't Know	F5
98	Refused	F5

F3. During the very cold conditions that we experienced in Connecticut last winter how did you use your DHP to **heat** the designated space? [READ RESPONSES and ACCEPT ONE]

1	Did not use at all.	F3a
2	Used it along with existing heating system	F4, or F5 if F2=2
3	It was the only system to heat this space	F4, or F5 if F2=2
77	Other [please specify]	F4, or F5 if F2=2
97	[Don't Know]	F4, or F5 if F2=2
98	[Refused]	F4, or F5 if F2=2

F3a. What is the reason that you do not rely on the heat pump for heating? [READ RESPONSES and ACCEPT ONE]

1	The heat pump could not meet the	F4, or F5 if F2=2

	heating requirements of the space	
2	The heat pump costs too much to operate	F4, or F5 if F2=2
3	I closed up that space and was not heating it at all	F4, or F5 if F2=2
77	Other [please specify]	F4, or F5 if F2=2
97	[Don't know]	F4, or F5 if F2=2
98	[Refused]	F4, or F5 if F2=2

F4. [DO NOT ASK if F2=2] During very hot summer conditions above 90, how did you use your DHP to **cool** the designated space? [READ RESPONSES and ACCEPT ONE]

1	Did not use at all.
2	Used it along with existing cooling system
3	It was the only system to cool this space
77	Other, please specify
97	Don’t Know
98	Refused

F5. On a scale of 1 to 7, where one is very dissatisfied and 7 is very satisfied, how satisfied have you been with the energy **cost** of your heating and/or cooling using the DHP?

1	1 Not at all Satisfied to 7, Very satisfied
97	Don't Know
98	Refused

[IF F5< 4, THEN ASK F5a. OTHERWISE SKIP to B1]

F5a. Why did you give the rating that you did on the previous question? [ACCEPT MULTIPLE]

1	Comfort challenges
2	Energy bill too high during heating
3	Energy bill too high during cooling
77	[Other, please specify]
97	[Don't know]
98	[Refused]

BASELINE

B1. We would like you to think about the DHP installed in <YEAR>. Was this DHP system installed in a building addition, a previously unheated or uncooled space, or an existing heated and cooled space [READ RESPONSES and ACCEPT ONE]

1	It was heated only	B2
2	It was cooled only	B4
3	It was heated and cooled	B2
4	It was neither heated nor cooled	E1
5	It is a brand new space, i.e. installed in building addition	E1

77	Other, please specify	E1
97	Don't know	E1
98	Refused	E1

HEATING

B2. [ASK only if B1=1 or 3] What was the primary fuel that heated the residence before the DHP was installed? [READ 1-5]

1	Electric baseboard [Electric]	
2	Oil furnace	
3	Natural Gas	
4	Propane/LPG	
5	None	Skip to B3
6	Would have only installed a new cooling system	
77	Other, please specify	
97	Don't know	
98	Refused	

B2a. When the DHP was installed was the previous heating system serving the residence removed or is it still installed?

1	Removed	B3
2	Still installed	B2c
3	Don't use	B3
77	Other, SPECIFY	B3
97	Don't know	B3

98	Refused	B3

B2c. How does the previous heating system function today in the residence with the DHP? [READ RESPONSES and ACCEPT ONE]

5	Do not use previous heating system	B3
1	The previous system functions as a back-up or supplemental system to the DHP	B3
2	The previous system and the new DHP run together at all times.	B3
3	The previous system still runs as the primary system. The DHP is used as a back-up system only when needed.	B3
4	The previous system is still the the primary system. The DHP is only used for cooling.	B3
77	Other	B3
97	Don't Know	B3
98	Refused	B3

B3. If you had not installed a DHP in your residence, what type of heating fuel would you have most likely installed, if any? [READ 1-6]

1	Would have kept existing heating system	For all responses: If B1=1, go to E1, If B1=2 or 3, go to B4
2	Electric baseboard [Electric]	
3	Oil furnace	
4	Natural Gas	
5	Propane/LPG	
6	Would have only installed a new cooling system	
77	Other, please specify	

97	Don't know	
98	Refused	

COOLING

B4. [ASK only if B1=2 or 3] What type of primary system cooled the residence before the DHP was installed? [READ 1-5]

1	Central air conditioning	B4a
2	Room or window air conditioning	B4a
3	Central heat pump	B4a
4	Other DHP system	B4a
5	None	B5
77	Other, please specify	B4a
97	Don't Know	B5
98	Refused	B5

B4a. When the DHP was installed was the previous cooling system serving the residence removed or is it still installed?

1	Removed	B5
2	Still installed	B4b
3	Don't use	B5
77	Other, SPECIFY	B5
97	Don't know	B5
98	Refused	B5

B4b. How does the previous cooling system function today in the residence with the DHP? [READ RESPONSES and ACCEPT ONE]

5	Don't use the previous cooling system	B5
1	The previous system functions as a back-up or supplemental system to the DHP	B5
2	The previous system and the new DHP run together at all times.	B5
3	The previous system still runs as the primary system. The DHP is used as a supplemental system only when needed.	B5
4	The previous system still runs as the primary system. The DHP is only used for heating.	B5
77	Other	B5
97	Don't Know	B5
98	Refused	B5

B5. If you had not installed a DHP in the residence what type of cooling system would you have most likely installed, if any?

1	Would have kept existing cooling system
7	None/Didn't have cooling before
2	Central air conditioning
3	Room or window air conditioning
4	Central heat pump
5	The installed DHP was all that was considered
6	Would have only installed a new heating system
77	Other, please specify
97	Don't know
89	Refused

EDUCATION FROM CONTRACTOR:

E1. Did the contractor give instructions on how to operate the heat pump to someone in the residence?

1	Yes	E2
2	No	Tb1
97	Don’t Know	Tb1
98	Refused	Tb1

E2. Who did the contractor give the instructions to?

2	Me
3	Husband/Wife/Partner/Housemate
1	[OPEN ENDED]

97	Don't Know
98	Refused

E3. How much time did they spend giving instructions?

1	[OPEN ENDED]
97	Don't Know
98	Refused

E4. Did you feel that they gave you enough instructions?

1	Yes
2	No
97	Don't Know
98	Refused

E5. Did they review the owner's manual with you?

1	Yes
2	No
97	Don't Know
98	Refused

E6. Were you shown how to set the temperatures on the heat pump so it turns on and off automatically?

1	Yes
2	No
97	Don't Know

98	Refused

E7. Did they leave you information on how to contact them?

1	Yes
2	No
97	Don't Know
98	Refused

E8. Is it easy or difficult to operate the DHP system?

1	Easy
2	Difficult
97	Don't Know
98	Refused

TAKEBACK EFFECTS –HEATING

TB1. [ASK ONLY IF B1= 1 or 3; SKIP if (B2a=1 removed or don't use) or (B2c=don't use)] Do you use the same, higher or lower heating temperature settings on your older heating system since you installed the DHP?

1	Same	TB1a
2	Higher	TB1a
3	Lower	TB1a
4	Use Less	TB1a
5	Use More	TB1a
97	Don't Know	TB1a
98	Refused	TB1a

TB1a. [ASK ONLY IF F2=2 or 3] Since the DHP was installed, have you changed your heating temperature settings on the DHP?

1	Yes	TB1b
2	No	TB2
97	Don't know	TB2
98	Refused	TB2

TB1b. Why? –[OPEN ENDED]

COOLING

TB2. [ASK ONLY IF B1= 2 or 3, DO NOT ASK if (B4=5 None] or (B4a=1 Removed or don't use] or (B4b = Don't Use)] Do you use the same, cooler or warmer temperature settings on your older cooling system since you installed the DHP?

1	Same	Tb2a
2	Cooler	Tb2a
3	Warmer	Tb2a
4	Use Less	Tb2a
5	Use More	Tb2a
97	Don't Know	Tb2a
98	Refused	Tb2a

TB2a. [ASK ONLY IF F2=1 or 3] Since the DHP was installed, have you changed your cooling temperature settings on the DHP?

1	Yes	TB2b
2	No	Q1
97	Don't know	Q1

98	Refused	Q1

TB2b. Why?

[OPEN ENDED]

DEMOGRAPHIC/CONCLUSION:

Q1. Is there anything else about the rebated DHP that you would like to share?

[OPEN ENDED]

Q2. What is the highest level of education you have completed? [DO NOT READ]

1	No schooling
2	Less than high school
3	Some high school
4	High school graduate or equivalent e.g., GED
5	Trade or technical school
6	Some college
7	College degree
8	Some graduate school
9	Graduate degree
77	Other [Specify_______]
97	[Don't know]
98	[Refused]

Q3. What was your annual household income from all sources in 2014, before taxes? Please stop me when I reach the category that best describes your household's income. [READ LIST]

1	Less than $20,000 per year,
2	$20,000-49,999,
3	$50,000-74,999,
4	$75,000-99,999
5	$100,000-149,999,
6	$150,000-199,999, or
7	$200,000 or more?
97	[Don't know]
98	[Refused]

Q4. We would like to offer you an Amazon gift card of $100 to have an engineer visit your home to collect equipment information and understand how the DHP system is functioning in your residence. Are you interested?

IF NEEDED: Yes, they will need to come into your home to look at the make and model of your DHP.

1	Yes	Q5

2	No	END
98	Refused	END

Q5. An engineer ~~from DNV GL~~ will be calling you to schedule an appointment. Is this the best number to call?

1	Yes
2	No [RECORD PHONE NUMBER]
98	Refused

END

That's all the questions we have prepared for you today. Thank you for your participation in this survey

IF NEEDED: If you have any questions about this survey or how your responses to this survey will be used please contact Michelle Marean, 207-773-0110 EXT 45109.

Q7. RECORD GENDER [DO NOT ASK.]

1	Male	Terminate Call
2	Female	Terminate Call
97	[Don't know]	Terminate Call

APPENDIX D: VENDOR SURVEY

R113 DHP Evaluation
Participating Vendor Interview Guide
Created November 2015

The objectives of the vendor interviews are to collect information on the criteria that they use when recommending DHPs, the baseline conditions that are considered when sizing DHPs, and the extent to which they educate customers on the operations and maintenance of the DHP systems for both single and MF dwellings. The vendor interview guide will include the following types of questions

- Assess differences in participant types between those that were used in the study that informed the PSD and the current study (such as multifamily versus single family)
- Examine the propensity of takeback effects such as the participant changing temperature settings in anticipation of cost savings resulting from the new unit.

Version History

Date of Change	Action
11/19/15	Draft for submission

R113 Overall Objectives

Question #	R113 Vendor IDI Objectives
1–13	Background and vendor or CAA program experience Are different make and models installed outside of program
14–20	Identify baseline conditions that vendors use to identify good candidates for a DHP Under what conditions are DHPs not recommended
21–33	Describe the type and length of operations and maintenance education/instruction provided to customers. How often do customers call with questions? What types of questions do they ask?
34–46	Information about the customers decision making process What methods are used to size a system?

47–54	Information about decisions to maintain or remove supplemental heating and/or cooling Solicit observations about DHP's and customer equipment operation
55–58	How ARRA funding influenced the market and installations of DHPs.

Sample: The work plan outlined a plan to complete 10 interviews from a random selection of vendors. The final sample includes five community action programs and three private vendors. As a result, we will attempt to reach all vendors in the sample.

Note to Interviewers

This interview guide is intended to direct the discussion with vendors who installed DHPs (DHP) for the Energize Connecticut Home Energy Solutions and Home Energy Solutions-Income Eligible program years 2011 and 2013–2015.

Five of eight vendors in our sample are community action agencies (CAA) which are social service agencies serving income eligible clients. The remaining three are private companies that participate in the program.

2011: The CAAs represent approximately 95% of the 2011 sample. CAAs offer a range of social services, which include weatherization services and a low income heating assistance program (LIHEAP). According to 2010 CT legislative and media documents, DHPs installed in 2011 were partially funded with federal money under the American Recovery and Reinvestment Act of 2009 (ARRA, say each letter) and partially with State and utility funds at State financed housing units.

2013–2015 HOME ENERGY SOLUTIONS Program: Initiated by the customer, a utility certified technician conducts an energy audit at a customer cost of $99. The audit technician provides written recommendations for deeper energy-saving measures such as insulation, high-efficiency heating and cooling, water heating, windows and appliances. All customers in this sample installed a DHP and received a rebate. This survey is targeted to the vendors who installed the DHPs.

This vendor IDI is a flexible approach to elicit details regarding several key topic areas. Follow the script as closely as possible. If a particular response needs additional clarification or a follow up line of questioning, please pursue even though the follow-up questions are not explicitly on the interview guide.

Introduction

Private Vendor Script

Hello, my name is <ANALYST NAME>. I'm calling from DNV GL on behalf of Energize Connecticut. Our records indicate that you've installed DHPs (DHPs) through the Home Energy Solution (HOME ENERGY SOLUTIONS) and the Home Energy Solution-Income Eligible (HOME ENERGY SOLUTIONS-Income Eligible) programs. Energize Connecticut wants to ask your company a few questions that will allow them to understand your experience with the program and your observations about installations of residential DHPs in order to improve the program. Are you familiar with the DHP rebate program?

Do you have some time to go over some questions relating to your process recommending and installing DHPs through the Home Energy Solutions and Home Energy Solutions-Income Eligible programs?

[IF THEY'RE NOT FAMILIAR WITH THIS PROGRAM, ASK FOR ANOTHER COMPANY CONTACT THAT MIGHT BE MORE KNOWLEDGEABLE]

[IF THEY ASK HOW LONG THE INTERVIEW WILL TAKE, TELL THEM ROUGHLY 15–20 MINUTES]

[IF VENDOR SAYS THEY DO NOT HAVE TIME TO GO OVER QUESTIONS, ASK IF THERE IS A BETTER TIME TO CALLBACK AND SCHEDULE A TIME TO SPEAK.

The information you share with us is confidential and will only be shared in aggregate. The purpose of our call is to collect information from participating vendors to inform future utility programs. The questions we're asking today relate to your experience with the Home Energy Solutions and HOME ENERGY SOLUTIONS-Income Eligible programs. Let's move onto our first question.

[IF THEY HAVE QUESTIONS ABOUT OUR LEGITIMACY, THEY CAN CONTACT ENERGIZE CONNECTICUT AT 1-877-WISE-USE]

CAA Script

Hello, my name is <ANALYST NAME>. I'm calling from DNV GL on behalf of Energize Connecticut.

According to our records, your organization installed or supervised the installation of DHP (IN 2010) (BETWEEN 2013 AND 2015) for income eligible customers. Energize Connecticut wants to ask your organization a few questions that will allow them to understand your experience with the program and your observations about installations of residential DHPs in the income eligible multifamily sector. Mai I speak with the weatherization manager.

[IF THEY DO NOT KNOW THE RIGHT CONTACT, ASK TO SPEAK TO THE EXECUTIVE DIRECTOR AND REPEAT THE SCRIPT ABOVE]

Do you have some time to go over some questions relating to your process recommending and installing DHPs through AARA and Home Energy Solutions-Income Eligible programs?

[IF THEY ASK HOW LONG THE INTERVIW WILL TAKE, TELL THEM ROUGHLY 15-20 MINUTES]

[IF VENDOR SAYS THEY DO NOT HAVE TIME TO GO OVER QUESTIONS, ASK IF

THERE IS A BETTER TIME TO CALLBACK AND SCHEDULE A TIME TO SPEAK.

[IF THEY HAVE QUESTIONS ABOUT OUR LEGITIMACY, THEY CAN CONTACT ENERGIZE CONNECTICUT AT 1-877-WISE-USE]