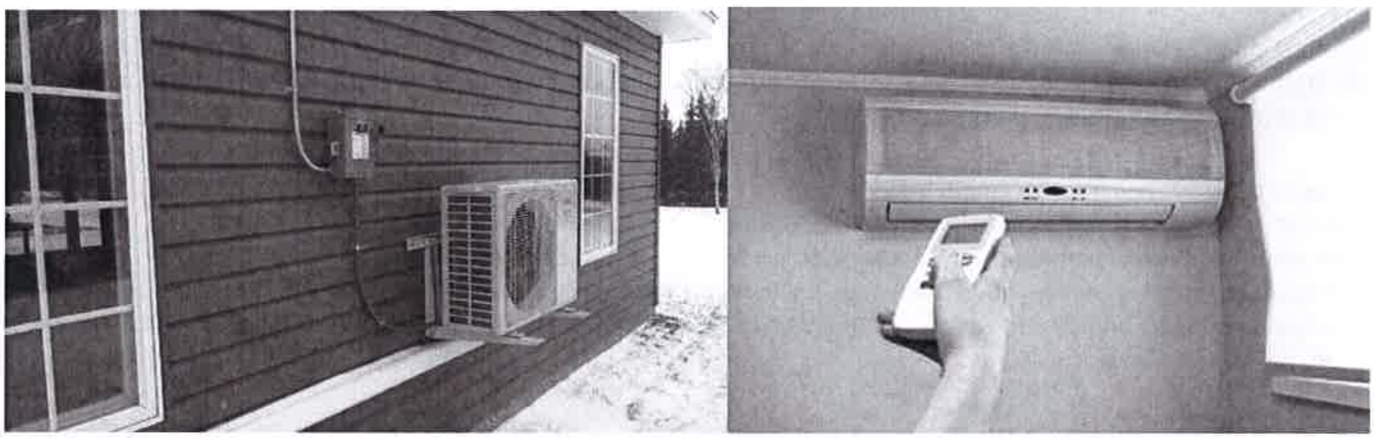
Northeast Energy Efficiency Partnerships



EM&V Forum: Primary Research – Ductless Heat Pumps

April 2014

Executive Summary and Table of Contents

About NEEP & the Regional EM&V Forum

REGIONAL EVALUATION,
MEASUREMENT & VERIFICATION FORUM

NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate energy efficiency in the building sector through public policy, program strategies and education. Our vision is that the region will fully embrace energy efficiency as a cornerstone of sustainable energy policy to help achieve a cleaner environment and a more reliable and affordable energy system.

The Regional Evaluation, Measurement and Verification Forum (EM&V Forum or Forum) is a project facilitated by Northeast Energy Efficiency Partnerships, Inc. (NEEP). The Forum's purpose is to provide a framework for the development and use of common and/or consistent protocols to measure, verify, track, and report energy efficiency and other demand resource savings, costs, and emission impacts to support the role and credibility of these resources in current and emerging energy and environmental policies and markets in the Northeast, New York, and the Mid-Atlantic region.

Energy & Resource Solutions (ERS)

energy & resource solutions ers

ERS was founded in 1995 to provide energy efficiency services and over the past 19 years has developed an exclusive consulting practice focused on energy efficiency and emerging technologies. With offices in Massachusetts, Maine, New York, Texas, California, and Oregon, our staff of more than eighty professionals includes professional engineers, certified energy managers, and LEED-accredited professionals. ERS is involved in many diverse activities, including engineering analysis and modeling of energy efficiency measures; all levels of program evaluation including process and program assessments, impact analysis, and program planning and delivery.

Emerging Technology Program Primary Research – Ductless Heat Pumps

prepared for

Regional Evaluation, Measurement& Verification Forum; Northeast Energy Efficiency Partnerships

ers

energy & resource solutions

120 Water St., Suite 350
North Andover, MA 01845
(978) 521-2550
Fax: (978) 521-4588
www.ers-inc.com

May 2014

Contents

ACKNOWLEDGMENTS

Brian McCowan of ERS managed the project, and was the primary researcher and author of this report. He was assisted by ERS Senior Engineer Frank Arena, ERS Engineers Cameron Kinney and Michael Wacker, and ERS Editor Lisa Markowski. For the overall Emerging Technology project, additional ERS contributing staff included Todd Winner, Richard Doughty, Sarah Eckstein, and Jill Rogers. Additional research was conducted by Dunsky Energy Consulting, Livingston Energy Innovations, and Opinion Dynamics.

Elizabeth Titus of the EM&V Forum coordinated the project with management and technical assistance from Chris Neme of Energy Futures Group.

The primary research portion of this project would not have been possible without the cooperation and assistance of Carol Woods and Chris Johnson of New Hampshire Electric Cooperative (NHEC), and the NHEC customers who agreed to participate in the study. The project team thanks them for their efforts.

The project team also wishes to acknowledge the EM&V Forum project subcommittee, which provided valuable input during the development of this project.

EM&V Forum: Primary Research
Ductless Heat Pumps

1 EXECUTIVE SUMMARY

This report presents the results of primary research conducted to better determine the potential for energy savings and efficiency program support for ductless mini-split heat pumps (DHPs) in the residential sector, particularly in heating-dominant climates, and to determine appropriate methodologies for assessing the savings. The primary research conducted is part of a continuing effort to assess several emerging technologies and innovative program approaches by the Regional Evaluation, Monitoring and Verification Forum (EM&V Forum or Forum) managed by the Northeast Energy Efficiency Partnerships (NEEP). It also is informed by and builds on the Northeast/Mid-Atlantic Air Source Heat Pump Market Strategies Report prepared for NEEP (December 2013).

Prior to this primary research, secondary research was conducted for several emerging technologies, one of which was DHPs for residential applications[1]. The goals of the secondary research were to provide performance and savings guidelines allowing the Forum members to develop measures and programs that realize measurable savings, and to identify knowledge gaps that require further study to close.

With the cooperation of the New Hampshire Electric Cooperative (NHEC) and their customers, nine residential DHP installations were monitored. The weather station closest to the monitored installations is in Laconia, NH. According to National Weather Service data, the average annual heating degree days for Laconia for the last 10 years is 7,109, based on a 65°F balance point. Eight of the DHPs monitored are considered to be "cold-climate" systems, capable of delivering 100% of rated capacity at 5°F. [2] One larger DHP was monitored that is capable of delivering 100% of rated capacity at 17°F. Table 1.1 provides summary information regarding the participant homes and DHPs installed. Further details regarding the monitored systems are presented in Section 3, including summary tables 3.1 – 3.4. A tenth site was withdrawn when the homeowner decided against moving forward with the monitoring process. The monitoring

[1] Other technologies investigated include: advanced power strips, heat pump (hybrid) water heaters, set-top boxes for home entertainment, LED lighting, and biomass pellet heating systems. Primary research was also completed on commercial applications for advanced power strips. See http://www.neep.org/emv-forum/forum-products-and-guidelines/index for reports from these efforts.

[2] DOE ENERGY STAR program references NEEP and Vermont efficiency programs in defining cold-climate DHPs as those capable of delivering 100% of rated capacity at 5°F. https://www.energystar.gov/products/specs/sites/products/files/NEEP%20Supplementary%20Comments%202.pdf

period ran from February 2013 to early September 2013, including 4 months of the heating season, the spring shoulder season, and a full cooling season.

The monitoring of the NHEC sites demonstrated that the systems performed very well for both heating and cooling, in most cases, exceeding the expectations of the homeowners. Performance during cold weather periods, including well below 0°F, and energy savings are both impressive, with most homeowners relying on the DHPs as their primary heating and cooling systems.

In addition, ERS is teamed with Navigant Consulting in evaluating DHP installations in the New York City service territory of Consolidated Edison (Con Edison), as part of a multi-program impact evaluation. The twenty-five units monitored as part of this separate evaluation were not cold-climate models, and the conclusion based on the metered data, as well as participant interviews, is that they are used primarily for cooling. The impact evaluation has been completed, but as of the completion of this report, it is under final review by Con Edison. While the results have not been released, some high-level findings noted in this report were made available to compare with the NH metered findings. The final results of the Con Edison research will be included as an appendix to this report when available.

Table 1-1. Participant Site Summary

Site #	Location	Year Built	Total Building Area (ft^2)	Total # DHPs Installed	Monitored DHP	DHP Size (Tons)	Space Served	Room Area (ft^2)	Heating Displaced	Cooling Replaced/Displaced*
1	Plymouth	1950	1,500	1	Fujitsu 30RLX	3	Living room	280	Kerosene & propane space heaters, wood stove	Window A/C
2	Gilmanton	1995	2,000	2	Mitsubishi FE09NA	0.75	Living room	320	2 propane fireplaces	Window A/C (5)
3	Meredith	1995	Apt. 1,500 Total 6,500	2	Mitsubishi FE12NA	1	In-law apt. living room	168	Oil-fired boiler	Window A/C
4	Northfield	2004	1,875	3	Mitsubishi FE12NA	1	Living room	270	pellet stove, propane fireplace, 3 kerosene heaters	Window A/C (2)
5	Tuftonboro	1990s	2,000	2	Mitsubishi FE12NA	1	Kitchen	540	Propane-fired boiler, pellet stove	Window A/C (2); plannedrepair central
6	Alton	2005	2,400	1	Mitsubishi FE18NA	1.5	Kitchen/ great room	1250	Oil-fired boiler	No existing A/C; planned central A/C
7	Holderness	1996	1,600	2	Mitsubishi FE18NA	1.5	Great room	600	Oil-fired boiler	No existing A/C; planned central A/C
8	Sanbornville	1986	2,200	2	Mitsubishi FE18NA	1.5	Living room	800	Oil-fired boiler	Window A/C
9	Campton	1995	4,000	1	Mitsubishi FE12NA	1	Sunroom	600	Oil-fired boiler	No existing A/C; no planned A/C

1.1 Project Goals

The focus of this primary research is to assist in closing the knowledge gaps associated with DHPs that were identified during the first phase of this project, and to further refine the recommendations for establishing savings calculation methodologies. The goals are summarized as:

- **Energy performance** – Estimate system energy performance through the monitoring of electrical demand and usage, as well as indoor and outdoor temperatures. An additional goal was to estimate coefficient of performance (COP) levels at various climate conditions.

- **Cold weather performance** – The recent and current DHPs designed for residential heating demonstrate great promise for heating in cold climates. This study proposed to determine if the systems are efficiently delivering adequate heat during periods of low outside air temperatures (OATs) and meeting homeowner expectations for cold-weather heating.
- **Potential cooling season load building** – There is a concern that in heating-dominant climates, DHPs purchased for heating will also be used to cool spaces that were not previously cooled, and for which there were no plans for cooling, thereby building summer peak loads. By determining purchase motivators and cooling performance, we sought to identify the potential for cooling season load building, and/or savings.
- **Load shape** – For the peak hours (1:00–5:00 p.m. during non-holiday weekdays June – August) identified by the New England Independent System Operator (NE-ISO), the study sought to determine the average load shape of the monitored systems.
- **Identify user operational procedures** – Unlike central heating and cooling systems which are typically controlled by automatic thermostats, DHPs offer the user the ability to control the units with a handheld remote control that offers many different operational modes and adjustments. A study goal is to determine typical usage of this feature and how this usage interacts with other space conditioning systems installed.
- **Understand purchasing decisions** – Program administrators have a particular interest in learning the motivations associated with the purchase of energy efficient equipment. In the case of DHPs, whether purchases/installations are driven by a desire to heat, cool, or both is important, as is the decision to replace conventional systems or displace a portion of the heating/cooling they contribute to the home.
- **Replacement and displacement of conventional systems** – Directly related to the above is the actual replacement and/or displacement of conventional systems/fuels after initial operation of the DHP; i.e., is the DHP operated as originally intended, or do operators make adjustments following their initial experience with the systems.
- **Comfort levels** – Fan-forced heating is known to introduce discomfort for occupants if temperate air is directed onto skin. Because the DHPs we monitored deliver air from a single fan unit at a variety of airflow rates and temperatures, we sought to learn if the study participants had experienced such discomforts, and/or had made adjustments to the systems or their operation for comfort reasons.
- **EM&V methodologies** – Phase 1 of this project proposed algorithms and methodologies for calculating energy savings associated with DHPs. The data collected during this phase was intended to enhance those recommendations.

1.2 Conclusions

All of the stated goals of this project were addressed, with some limitations associated with the difficulty of monitoring DHP performance in occupied homes. Estimated savings associated with multiple baselines (i.e., electric baseboard, oil-fired boiler, gas furnace, and minimum standard DHP heating sources) were calculated using normalized weather data. We were able to identify the ability of the systems to provide heat during periods of extremely cold OATs. In addition, the project has identified a great deal of information regarding decision making related to both purchasing and operating DHPs in heating-dominant climates. Of particular interest is the observation that participant operational usage of the systems evolved following their initial experiences with the systems, as most owners who initially considered their DHPs as supplemental heating systems began to rely on their systems as primary heat sources.

The results detailed in this report are summarized in the three sections that follow.

1.2.1 Significant Heating Savings Are Achieved Compared with Electric and Fuel Oil Baselines

The monitoring of heating performance for 4 months of the heating season, and extrapolating weather-normalized performance for an entire heating season demonstrates that the systems are capable of delivering significant energy and cost savings in the New England climate, as shown in the tables below. The estimated savings for the eight cold-climate DHPs, average approximately $832 per heating season compared with an electric resistance heat baseline, and approximately $398 compared with a standard efficiency air-source heat pump (ASHP). Savings associated with an oil heat baseline, which is the actual baseline for a majority of the participant sites, are also significant at an average of $613 per heating season (September 15 – May 31).

Tables 1-2 through 1-4 present the weather-normalized estimated heating season energy usage and savings compared with the three baselines:

- Electric resistance baseboard heat
- An ASHP that meets minimum federal efficiency standards
- An oil-fired boiler with an average system efficiency (includes distribution losses) of 78%

A weighted average savings is also calculated for each baseline at 1 ton of heating (12,000 Btu) to allow for the simple calculation of average savings for different size DHPs.

Potential savings associated with a natural gas baseline were also estimated. Due to the current price of natural gas, the savings are small. The estimated natural gas savings are presented in Section 4.3.5.

For all savings calculations presented, the baseline usage is the amount of fuel (electricity, oil, or natural gas) that would be required to produce the same amount of heat produced by the metered DHP.

Table 1-2. Monitored DHP Normalized Heating Season (Sept 15 – May 31) Usage & Savings Compared with Electric Resistance Baseline

Site #	1*	2	3	4	5	6	7	8	9	Average* (Sites 2-9)
System mfg.	Fujitsu	Mitsubishi	Mitsubishi	Mitsubishi	Mitsubishi	Mitsubishi	Mitsubishi	Mitsubishi	Mitsubishi	N/A
Model	30RLX	FE09NA	FE12NA	FE12NA	FE12NA	FE18NA	FE18NA	FE18NA	FE12NA	N/A
Heat cap. (Btu/h)	37,500	10,900	13,600	13,600	13,600	21,600	21,600	21,600	13,600	16,263
Rated HSPF	9.5	10.0	10.6	10.6	10.6	10.3	10.3	10.3	10.6	10.4
Adjusted HSPF**	8.55	9.00	9.54	9.54	9.54	9.27	9.27	9.27	9.54	9.4
Avg heating COP	2.51	2.64	2.8	2.8	2.8	2.72	2.72	2.72	2.8	2.8
Baseline electric resistance usage (kWh)	9,226	10,054	7,030	5,531	5,416	10,164	10,630	14,460	11,605	9,361
DHP energy usage (kWh)	3,682	3,812	2,514	1,978	1,937	3,741	3,913	5,323	4,151	3,421
DHP savings (kWh)	5,544	6,242	4,515	3,552	3,478	6,423	6,717	9,137	7,454	5,940
Savings @ $0.14/kWh	$776	$874	$632	$497	$487	$899	$940	$1,279	$1,044	$832
Sites 2-9 weighted average savings per ton (12,000 Btu) of heating (kWh)										**4,502**
Sites 2-9 weighted average savings per ton (12,000 Btu) of heating										**$630**

* Site #1 is not included in the average calculations, as it is not a cold-climate model.

** The HSPF is adjusted by a factor of 0.9 to account for climate conditions for central New Hampshire.

Table 1-3. Monitored DHP Normalized Heating Season (Sept 15 – May 31) Savings Compared with Standard Air-Source Heat Pump Baseline

Site #	1*	2	3	4	5	6	7	8	9	Average*
Baseline ASHP energy usage (kWh)	6,173	6,727	4,703	3,700	3,623	6,801	7,113	9,675	7,765	6,263
DHP energy usage (kWh)	3,682	3,812	2,514	1,978	1,937	3,741	3,913	5,323	4,151	3,421
DHP energy savings (kWh)	2,491	2,915	2,189	1,722	1,686	3,059	3,199	4,352	3,614	2,842
Savings @ $0.14/kWh	$349	$408	$306	$241	$236	$428	$448	$609	$506	$398
Sites 2-9 weighted average savings per ton (12,000 Btu) of heating										**2,154**
Sites 2-9 weighted average savings per ton (12,000 Btu) of heating										**$302**

* Site #1 is not included in the average calculations, as it is not a cold-climate model.

Table 1-4. Monitored DHP Normalized Heating Season (Sept 15 – May 31) Savings Compared with Fuel Oil Baseline

Site #	1*	2	3	4	5	6	7	8	9	Average*
Baseline #2 fuel oil displaced (gallons)	291	317	222	174	171	321	335	456	366	295
Baseline #2 fuel oil cost @ $3.70	$1,077	$1,173	$820	$645	$632	$1,186	$1,241	$1,687	$1,354	$1,092
DHP energy usage (kWh)	3,682	3,812	2,514	1,978	1,937	3,741	3,913	5,323	4,151	3,421
DHP energy usage cost @ $0.14/kWh	$516	$534	$352	$277	$271	$524	$548	$745	$581	$479
Net savings	$561	$640	$468	$368	$361	$662	$693	$942	$773	$613
Weighted average savings per ton (12,000 Btu) of heating										**$465**

* Site #1 is not included in the average calculations as it is not a cold-climate model.

1.2.2 The Systems Perform Well at Extremely Cold Temperatures

All of the systems monitored performed well at cold temperatures, with all but one of the systems producing effective heat well below 0°F. Eight of the nine systems continued producing heat down to their lowest minimum outdoor temperature limit of -18°F, although full output is not maintained when outdoor temperatures are below 5°F. The remaining system is a larger (30,000 Btu/h) DHP (Site #1) that continued to deliver heat down to its minimum operational limit of 0°F.

1.2.3 Additional Conclusions

In addition to potential savings and cold-climate performance, we were able to formulate several other conclusions regarding the performance of DHPs, as follows:

- **Cold weather performance is critical for heating in the study-area climate zone**. Both customer satisfaction and monitored performance were substantially lower for the DHP installed at site #1, which was not among the "cold-climate" systems, but rather a system with a 17°F full output low temperature rating and a 0°F operational limit. The participant recently added electric baseboard to the same area.
- **Published HSPF and COP ratings can be misleading**. Because of the modulating nature of DHPs and variations in climate conditions, the standard rating methods are not necessarily good predictors of field performance. However, applying adjustment factors to the ratings improves the ability to use the ratings for predicting savings. For this study, a factor of 0.9 (10% reduction in the rating) was applied to the published HSPF rating for the monitored DHPs. In contrast, the adjustment factor used by the DOE calculator HeatCalc for standard ASHPs for the same climate region is approximately 0.66 (34% reduction in the rating). Published HSPF ratings are typically based on the climate conditions in "AHRI Zone IV," which extends as far north as coastal southern New England. Details of heat pump rating systems and their adjustment factors are found in Section 4.
- **DHPs typically displaced conventional heating**. No heating systems were uninstalled due to the installation of the DHPs. However, all systems fully or partially displaced heating produced by non-heat pump sources. The fuels and systems displaced included central oil boilers, vented kerosene and propane space heaters, unvented propane space heaters, and biomass pellet stoves. Table 3-3 provides details of displaced heating.
- **DHPs installed for supplemental heating often become a primary heating system with owner experience over time**. The participants progressively tended to rely on the installed DHPs as the primary heating system, as they learned the benefits through experience. Most participants reported an initial intent to utilize the systems to supplement the heat from installed central systems, but after positive experiences they began to rely on the systems as the primary heat source, especially when multiple DHPs had been installed.
- **For cooling, DHPs both replaced and displaced less-efficient air conditioning systems.** Six of the participants replaced standard window-installed air conditioners

(A/Cs). One of those six was also considering the repair of an unused central A/C system prior to installing the DHPs. In addition, two participants had contacted an HVAC dealer requesting a quotation for installing central A/C. The same dealer proposed and installed the DHPs as a heating and cooling alternative to the A/C only central system. One participant installed the DHP for heating and cooling, where there were no existing or proposed cooling systems. Table 3-4 provides details of replaced and displaced cooling systems.

- **Cooling season load-building was not a significant factor for the monitored installations.** In all but one case, the DHPs installed replaced window A/C units, or DHPs were purchased instead of installing central A/C. With the increased efficiency of DHPs it can be concluded that summer peak load-building was not significant, and that even in the central NH climate, some cooling savings were achieved.
- **Average summer load shape is coincident with New England ISO targeted peak periods**. Although the cooling loads in Central New Hampshire are relatively small, the peak demand and the peak savings associated with cooling are coincident with the 1 p.m. to 5 p.m. weekday time periods identified as peak demand periods by the New England ISO. Section 5.2 provides cooling load shape charts and details.
- **Purchase decisions varied, but they were often associated with A/C**. The project participants decided to install DHPs for a variety of reasons, including: replacing fossil fuel space heaters, replacing window A/Cs, supplementing central heating systems, dehumidification, and even experimenting to assess the savings potential. Eight of the nine participants either replaced existing cooling systems or purchased the DHPs as an alternative to a standard cooling system.
- **Participants preferred simple remote control operation.** All participants control their DHPs with handheld remote controls. None have installed the optional wall-mount thermostats. Most users select a heating or cooling setpoint, depending on the season, and select "auto" for the fan speed. No participants reported utilizing automatic set-back features, and if any set-back/set-forward settings are selected it is done manually for specific individual time periods. None of the participants have utilized any of the special heating or cooling settings, such as "economy," available with the remote control, typically expressing that they had not yet seen a need to do so. Some of the participants reported selecting a fan speed rather than utilizing the "auto" setting at certain times, due mostly to sound levels. Dehumidification modes are sometimes selected during cooling season.
- **Comfort levels are high.** With the exception of site #1, participants were universally enthusiastic about the comfort levels achieved. None reported experiencing any negative comfort effects from conditioned air being blown directly on them. This can be attributed at least partly to proper placement and installation of the fan-coil units.
- **Typical usage varies by climate zone and fuel availability**. The monitoring in NH and the New York City area demonstrates that DHPs may be used very differently depending on the climate zone, as well as other factors. The preliminary findings of the Con Edison

impact evaluation include a conclusion that 80% of the savings in the territory are attributable to cooling. This is in direct contrast with the findings of this study, which determined that the great majority of the savings are associated with heating. In addition to climatic differences, the Con Edison program places a promotional emphasis on cooling, and both natural gas and district steam heat are prevalent.

1.3 Recommendations

The following recommendations for evaluation methodologies, program implementation strategies, and further study to close knowledge gaps are in addition to the recommendations made in Phase 1 of this study.

- **EM&V methodologies** – Phase 1 of this project proposed algorithms and methodologies for calculating energy savings associated with DHPs. The report also cautioned about the difficulty of assigning simple deemed values for systems that have highly variable usage and performance patterns based on climate conditions and occupant intervention. The data collected during this phase further reinforces those concerns and informs the following recommendations:
  - **Utilize standard ratings, recognizing the limitations.** SEER and HSPF, the ratings utilized for cooling and heating seasonal performance, respectively, are based on strict operational parameters, under several steady-state laboratory conditions. The AHRI methodology for calculating HSPF includes coefficients for six heating zones, which are differentiated from the climate zones utilized for energy codes. However, the HSPF ratings are typically published only for zone IV, which includes coastal southern New England, New Jersey, Virginia, Kentucky, Kansas, etc. (a map of the zones is presented in Section 4, Figure 4-1). The outside air temperature (OAT) covered by the rating is 17°F –47°F, which is appropriate for that climate zone. When performance for regions north and south of zone IV is predicted, heating performance will be inaccurate.
  - **An accurate savings tool for DHPs is needed**. HeatCalc, a DOE-supported downloadable spreadsheet tool, includes a calculator to adjust published HSPF ratings for the local climate.[3] However, the adjustment factors were formulated prior to the introduction of cold-weather performing heat pumps and these factors assume that electric resistance coils contribute part or all of the heating at colder temperatures. Updating the tool to be consistent with the cold-weather performance of cold-climate DHPs would provide program administrators, as well as market actors, a simple tool for estimating DHP savings.
  - **Utilize performance monitoring and billing analysis to assist in predicting savings**. Standards organizations, as well as the heat pump industry, recognize the limitations of COP, SEER, and HSPF for calculating the performance of continuously

[3] www.eia.gov/neic/experts/heatcalc.xls.

modulating DHPs. Field studies and impact evaluation efforts that include monitoring and/or billing analysis should be used to further inform and adjust savings calculations for DHPs. Impact evaluation sponsors should allocate enough elapsed time for DHPs to be evaluated over a minimum of three seasons. An added benefit of evaluating performance over three or more seasons, or for multiple years, is that it allows for the capture of changes in usage that typically take place as the users gain experience with the systems.

- **Program implementation strategies**. The following recommendations are related to promoting DHPs as components of efficiency program portfolios.
  - **Stay current with DHP advances**. Program administrators should work to stay current with this advancing technology. As this is being written, at least one manufacturer is in the process of introducing yet another increase in efficiency for DHPs, as well as larger and multi-head units that perform at the low temperatures currently reached only by single-head units.
  - **Promote DHPs appropriate for the climate zone.** For heating-dominant climates, program administrators should consider restricting program participation to the installation of systems that will operate at near full-load conditions at the design temperature for the region. Customer disappointment and savings snap-back are likely if support is given to DHPs that perform marginally in the lower ranges of the regional OATs.
  - **Consider DHPs for fuel switching.** In jurisdictions where incentives are allowed, DHPs are excellent candidates for fuel switching from oil heat. Where it is not allowed, DHP performance on a direct fuel cost basis is attractive compared to oil heat. When climate change is considered, replacing fossil fuel systems with DHPs becomes even more attractive. Most climate change studies suggest that replacing fossil fuel systems with efficient electric systems powered by clean generation and/or renewable energy sources is a necessary component of meeting long-term climate goals. A recent European study concluded that "achieving an 80% greenhouse gas (GHG) reduction across the economy will likely require massive electrification of space heating, water heating, and personal transportation while simultaneously de-carbonizing the power sector" (i.e., 95%–100% reliance on renewable, nuclear, and/or fossil fuels with carbon capture and storage).[4] A study of GHG emission reduction options for the state of California reached similar conclusions.[5] However, even before the grid is decarbonized, an efficient DHP would result in fewer carbon emissions than an efficient gas furnace or boiler under many scenarios. For example, consider a DHP

[4] European Climate Foundation, *Roadmap 2050: Practical Guide to a Prosperous, Low-Carbon Europe*, Volume 1, April 2010, p. 6. See www.roadmap2050.eu .

[5] Price, Snuller, Energy and Environmental Economics, "Meeting California's Long-Term Greenhouse Gas Reduction Goals", prepared for Hydrogen Energy International, November 2009.

with a seasonal average COP of 2.7 that receives its power from a 45%-efficient natural gas power plant and a grid with marginal line losses of 10%. The delivered efficiency of the heat – from power plant to home heat – is 110% (0.45 × 0.9 × 2.7). In contrast, even a very efficient gas home heating system (condensing furnace or boiler, coupled with an efficient distribution system) will typically not be more than about 90% efficient. Since both are ultimately using gas, the DHP will produce approximately 20% less carbon emissions.[6]

- **Closing knowledge gaps** – It is hard to close all the knowledge gaps on rapidly advancing technologies. But if efficiency programs are to meet goals, knowledge of products, applications, and usage patterns is critical. Key points include:
  - **Information sharing** – A lot of work is being performed right now on DHP performance. This study focused attention on user operational experiences and equipment performance, but only for one part of the country. The planned EM&V Forum meta-study of DHP research, combined with other efforts, is intended to further increase access to more comprehensive assessment of DHP under various baseline scenarios.
  - **Control options** – Control options for DHPs include both programmable wall-mounted thermostats and hand-held remote controls. As noted, all of the DHPs monitored for this study were controlled by hand-held remote controls. The hand-held remote controls utilize a thermistor (an electrical resistor that varies with temperature) inside the DHP return air stream to monitor room temperature while the remote wall-mounted unit bypasses the built-in thermistor, sensing temperature at the thermostat location. Although it was not analyzed as part of this study, the fact that these control options operate differently poses the question of how performance might be impacted. Comparative studies of DHP performance with the two control types would inform decision-making for program administrators, market actors, and homeowners.
  - **Controls integration** – This study revealed that from nine participants came nine different methodologies for controlling their DHPs in relation to other heating systems. The methods can best be described as "work-arounds." Especially with the advancement of "smart" controls, and Web-accessible thermostats, program implementers and evaluators should work with the industry to identify advantageous methodologies for controlling multiple systems, in order to encourage optimized control of the systems.
  - **Commercial markets** – To date, most of the focus on promoting DHPs, especially recently introduced high efficiency/low temperature models, has been on the residential market. The time is right to increase the penetration of high efficiency DHPs in the small/medium commercial market. In addition to the ability to perform

[6] Neme, Energy Futures Group, correspondence, March 2014.

at high efficiency levels, DHPs are able to: solve difficult heat/cooling zone issues; avoid simultaneous heating and cooling; isolate ventilation and conditioning systems; condition specialty areas such as server rooms; provide variable control for areas of variable occupancy such as conference rooms, etc.

- **Performance ratings** – Replacements for SEER and HSPF may not be available soon. A reasonable goal would be for manufacturers to supply the SEER and HSPF ratings appropriate for the efficiency program territories. Although it is understandable that the industry desires to publish one set of numbers, efficiency programs need performance metrics for the local climate in order to accurately predict savings, and market actors would benefit from improved performance predictors for sizing systems. Although the DOE-supported tool HeatCalc includes a calculator to adjust published HSPF and SEER ratings for the local climate, it too is inaccurate for predicting the heating performance of cold-climate DHPs.