The Humpty Dumpty of Heating: Piecing Together an Understanding of Ductless Mini-Split Heat Pump Usage in the Northeast

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ABSTRACT

The Massachusetts' COOL SMART program offers incentives to participants for the installation of qualifying, high-efficiency Ductless Mini-Split Heat Pumps (DMSHPs). In 2014, a team composed of individuals from Cadmus and Navigant (the evaluation team) began an evaluation of this program. DMSHP technology is one of the most versatile new technologies in the residential HVAC market and as such is still not well understood in terms of energy savings and participant usage behavior. This paper presents the findings from the first phase of this evaluation effort, including an online survey and an on-site interview during logger installation. The research findings indicate a participant population where the majority of installations are completed in retrofit applications and a substantially higher number of participants use the DMSHP for cooling rather than heating. The evaluation team also worked to identify the correct baseline assumptions for the participant population. The baseline question is significant because an incorrect assignment of a standard efficiency DMSHP instead of a pre-existing technology in a retrofit situation could result in a significant negative impact to the program energy savings. The evaluation team was able to explore participant purchase intentions and participant DMSHP use to determine that a blended baseline, composed of a standard efficiency DMSHP (Cadmus 2015) and a variety of existing and alternative systems was the correct baseline for the COOL SMART DMSHP program.

Introduction

Ductless Mini-Split Heat Pumps (DMSHPs)[1] are one of the most versatile new technologies in the residential HVAC market. DMSHPs offer a range of efficient heating and cooling options, without ductwork, providing solutions to address thermal comfort in individual rooms or whole homes as well as offering an opportunity for fossil fuel replacement. DMSHP usage can also vary significantly based on whether users plan to use the system to provide heating only, cooling only, or both heating and cooling and whether it will provide all or only part of their space conditioning. Program implementers and evaluators face significant challenges in understanding this technology. Presently, it is difficult to define an appropriate baseline or to understand whether existing savings estimates are even "in the ballpark" (NEEP 2014)

In 2014, a team comprised of individuals from Cadmus and Navigant (the evaluation team) began a study of participants in Massachusetts's COOL SMART program who installed DMSHPs. This study combined a large online survey (Vitoff et al. 2014) with a nested set of detailed one-on-one participant

[1] Within this paper ductless mini-split heat pump (DMSHP) should be equated with the group of technologies known as ductless heat pumps (DHPs). Others may differentiate the group of DHPs between mini-split heat pumps with one indoor head and multi-split heat pumps with multiple indoor heads. (Spencer, Decker & Vitoff 2015).

site interviews. These activities were designed to explore the motivations and perceived issues surrounding the use of DMSHP technology in participant homes, including answering the following questions:

- Do DMSHPs replace full heating systems or just displace a portion of existing heating?
- Do participants use DMSHPs to add new cooling capacity to their homes?
- How do participants make the choice as to what DMSHP system to install, e.g. cold-climate or not and single or multiple outdoor condenser units?
- Does the installation of a cold-climate DMSHP influence participant satisfaction with heating performance?
- What is the baseline against which DMSHPs should be evaluated?

Program Background and Objectives

The Massachusetts COOL SMART program offers rebates to customers who install qualified air conditioning equipment, including central air conditioners and air-source heat pumps. This paper is based on a study which focused on DMSHPs installed through the COOL SMART program.

The Massachusetts electric program administrators (PAs) implement the COOL SMART program via a network of contractors/trade allies that advise their customers about available rebates. A third party administers the program. The incentives available for DMSHPs through the COOL SMART program range from $150 to $500, depending upon the specifications of the installed unit or units. The efficiency parameters required to achieve each of the incentive levels in program year 2013 are listed in Table 1. The planning assumption used in estimating the existing deemed savings values for this program assumes a standard efficiency DMSHP[2] baseline.

Table 1. DMSHP Incentives through the Massachusetts' COOL SMART Program, 2013

	SEER	EER	HSPF	Incentive
DMSHPs Eligible for Incentives through the Massachusetts COOL SMART program	≥ 16	≥ 12	≥ 8.2	$150
	≥ 19	≥ 12.5	≥ 10	$300
	≥ 20	≥ 13	≥ 10	$500

Methodology

The findings presented in this paper are based on an ongoing evaluation of Massachusetts' COOL SMART program. To date, an online survey and in-person site interviews have been completed with a sample of participants who installed DMSHPs through the COOL SMART program. These activities were undertaken to investigate the motivations of participants who install DMSHPs through the COOL SMART program, and to identify the baseline for energy savings calculations. Ongoing work includes a full-year data logging study of a nested sample of the survey participants. This data logging study is aimed to determine actual energy performance and define savings attributable to the DMSHP systems relative to the aforementioned baseline.

Online Survey Methodology

The first task completed by the evaluation team was the online survey effort. The purpose of the

[2] A standardefficiency DMSHP is defined as a code-minimum, SEER 13 rated DMSHP.

online survey effort was to better understand the purchase motivations and current usage practices of the program participants. The population frame for this survey effort included 3,289 DMSHP participants, including 2,511 participants from program year 2013 and 778 participants from program year 2012. An invitation to a web-based survey was distributed to a sample of 1,628 participants. Of this group, bounce-back emails were received from 26 percent of the email addresses. Of the remaining 1,205 participants (74%) who received a working link to the online survey, 430 participants completed the survey and received a $10 incentive for providing their input. The overall response rate for participants with valid emails was 36 percent.

Segments of the population frame were oversampled in order to ensure an adequate number of responses from specific segments of interest. These population segments included participants who installed cold-climate DMSHPs and participants who installed multiple outdoor condenser units. Because of this oversampling, the final survey results are weighted based upon distribution in the overall population to ensure that the results are representative of the population as a whole. Results provided in this paper are weighted by individual participant rather than individual outdoor condenser unit installed. The basis of weighting is particularly significant for this population, as almost one-in-three program participants received incentives for installing more than one outdoor condenser unit.

It is important to note that all of the questions asked in the online survey about how participants used their DMSHP were asked in reference to a particular space in their home. Participants were asked to indicate which rooms the DMSHP served, and the survey tool then randomly selected one of the reported spaces about which to deliver a battery of questions concerning usage practices in that space. The survey was designed in this way to help to eliminate conflicting answers. As an example, the survey asked about previously installed HVAC systems. A DMSHP might have been installed to serve a living room and three-season porch. The living room may have previously had a window AC unit while the three-season porch had no previous cooling system. The expectation was that asking participants to limit their answers to a specific space (e.g., the living room or the three-season porch) would allow for the collection of the best data about DMSHP use.

On-Site Interview Methodology

During the web survey, participants were asked about their willingness to participate in a data logging study; a total of 307 participants indicated their willingness to participate. The evaluation team selected 135 of these sites at which to complete full-year data logging. The population subset chosen for full-year data-logging was selected to ensure adequate representation across a variety of variables, including whether the participant installed a cold-climate DMSHP unit and whether the participant installed multiple outdoor condenser units. During the meter installation site visit, an interview was completed by each household. This on-site interview allowed the evaluation team to collect valuable data related to baseline characteristics in all of the spaces that the DMSHP served, not just the singular space that was addressed through the online survey.

The evaluation team investigated the baseline question in more detail when on-site. Field staff asked the participants what options were considered for both heating and cooling in place of the DMSHP. The specific focus of this series of questions was to understand what the participant would likely have installed if they had not purchased the high-efficiency DMSHP. These answers informed the analysis of the participant's motives as well as contributed to identifying the baseline technology. The logic of this determination will be discussed in more detail in the results portion of this paper.

Findings

The online survey provided the first glimpse into the composition of the COOL SMART program DMSHP participant population. The online survey results showed a population where the majority of program participants own their home (98%), installed the DMSHP in their primary residence (88%), and reported that the DMSHP was installed in a single family home (89%). Additionally, most of the units were installed as a retrofit measure, with only two percent of participants indicating that the DMSHP was installed in a brand new space or a brand new home (Vitoff et al. 2014).

The survey results also identified an important corollary to this relatively large group of participants with similar home characteristics, a relatively small group of what can be considered outlier participants. The significance of this outlier group is deepened since several of the less common participant characteristics were higher than expected. For example, ten percent of participants reported that the DMSHP was installed in a vacation/secondary home.

DMSHP Usage Characterization

The online survey data showed that program participants were primarily using their DMSHPs for both heating and cooling (74%). A very small number of participants reported using their DMSHP only for heating (1%), while a relatively large percentage of participants (25%) reported using their DMSHP only for cooling. The respondents who only use their DMSHP for cooling are an interesting group, as they chose not to use the DMSHP for heating even though a DMSHP can provide less expensive heating than almost all other system options except natural gas (which is used as a heating fuel for only half of the participants in this group).

The majority of program participants reported that the DMSHP was installed in a space that was previously heated; Figure 1 illustrates that these spaces were either "only heated" (58%) or "heated and cooled" (31%). It is also interesting to note that while only two percent of the DMSHPs were installed to serve a new space, a larger percentage of units (7%) were installed in spaces that were not previously conditioned.

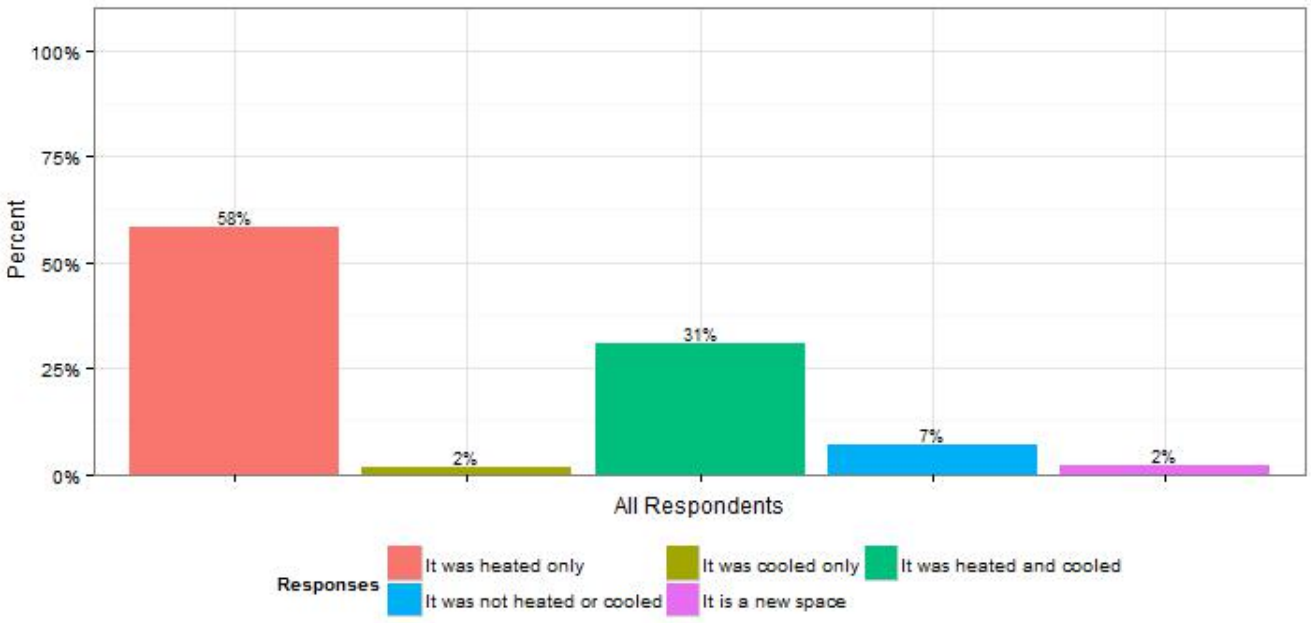

Figure 1. How the Space was Conditioned before the DMSHP was Installed

The survey results indicated that program participants added cooling to their existing spaces through the installation of DMSHPs, as indicated in
Table 2. Of the 58 percent of participants that previously only heated their space, 67 percent reported that their new DMSHP was used for both heating and cooling and 31 percent reported that their new DMSHP was used for cooling only. Participants also reported supplementing or replacing their existing heating and cooling systems with the DMSHP. Of the 31 percent of participants that previously had both heating and cooling in their existing space, 80 percent report that the new DMSHP is also used for both heating and cooling.

Table 2. Space Conditioning Before and After DMSHP

		ROOM CONDITIONING BEFORE DMSHP INSTALLATION					
		Existing Space Heated Only	**Existing Space Cooled Only**	**Existing Space Heated & Cooled**	**Existing Space Not Heated or Cooled**	**The Space is New**	**TOTAL**
DMSHP USAGE AFTER INSTALL	**DMSHP used only for heating**	0.95%	0.00%	0.13%	0.14%	0.00%	1.22%
	DMSHP used only for cooling	18.05%	0.34%	5.92%	0.53%	0.00%	24.84%
	DMSHP used for both heating and cooling	39.36%	1.28%	24.61%	6.41%	2.29%	73.95%
	TOTAL	58.36%	1.62%	30.66%	7.08%	2.29%	100.0%

The majority of survey respondents (89%) reported that the space served by the new DMSHP was heated before the installation of the DMSHP. The participants who reported heating their space before the installation of the DMSHP were asked what type of heating equipment was previously installed. The results of this question are illustrated in Figure 2. Of this group of participants, the largest sub-group (45%) reported having oil heat, followed by 27 percent who reported having natural gas heating.

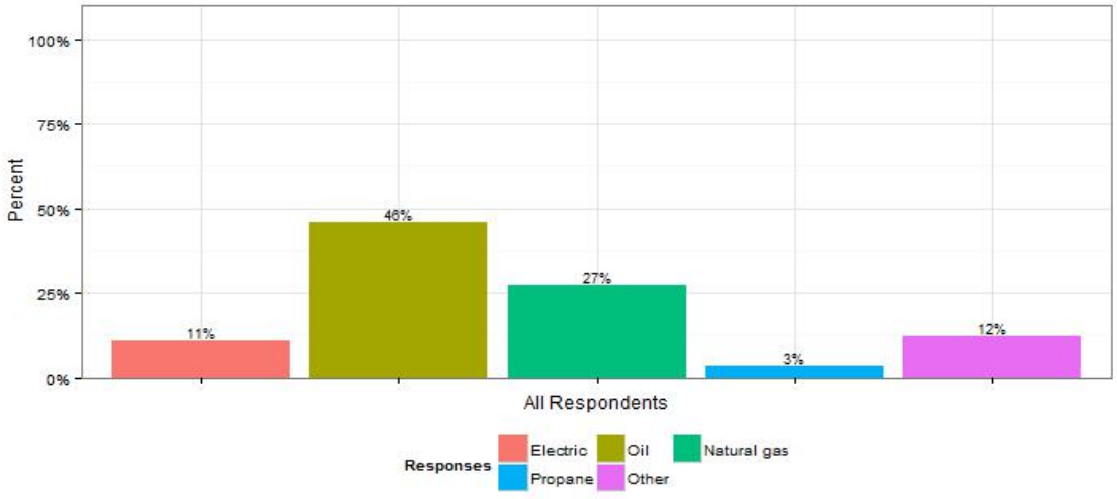

Figure 2. Primary Heating System Fuel Before DMSHP Installation, for Spaces where Heating was Present Before the Installation of the DMSHP

Of those participants who reported that their space was heated before the installation of the DMSHP, the majority (95%) indicated that the pre-existing system was still in place after the installation of the DMSHP. Only five percent reported that they removed the pre-existing heating system; these respondents noted that the system was removed because it either did not function well or their goal was to install a more efficient system.

For those survey respondents who indicated that they both had a pre-existing heating system and that the system was still installed, the majority reported that the two systems work together to meet the heating needs of their space. Most participants reported that the previous system functions as the primary system with the DMSHP providing backup heating (41%), followed by 29 percent of participants who reported that the DMSHP now functions as the primary system.

Thirty-two percent of the survey respondents indicated that the space of interest was cooled before the installation of the DMSHP. These participants were asked what type of cooling equipment was previously installed, and 85 percent indicated that the previous cooling equipment was a room or window air conditioner (AC). Of this group, a significant majority (88%) indicated that the existing cooling system was removed when the DMSHP system was installed.

The online survey findings provided valuable insight into the actions of the COOL SMART participants who received an incentive for the installation of a DMSHP, but they did not provide a strong understanding of the program baseline. The evaluation team determined that the results of the online survey did not provide enough information to accurately recommend a new baseline methodology for the COOL SMART program. To aid in this baseline determination, the team leveraged a metering study of participant sites which was already underway to complete an additional participant interview while on-site.

Baseline Technology Definition

The purpose of exploring the baseline question through this study was to determine if a standard efficiency DMSHP was the correct baseline for the COOL SMART DMSHP program, and if significant energy savings were being "missed" by not considering other baselines. To address the baseline question, the evaluation team used the results of the online survey and the on-site interviews to determine participants' purchase intents and likely alternative actions if they had not purchased a high-efficiency DMSHP. It is important to note that a DMSHP is different from other competing residential HVAC technologies because other systems do not offer the same amenities as the DMSHP, meaning that there are restrictions on when an alternative system can be considered the correct baseline technology for a DMSHP.

The baseline technology determination for a DMSHP must consider heating and cooling functions separately for each space since DMSHPs can provide both heating and cooling amenities, and pre-existing conditions could have been very different for the two space conditioning options. In some cases, a standard efficiency DMSHP is the correct baseline for both the heating and cooling amenity, and in some situations the baseline for heating and cooling may be very different. The following section details the logic used by the evaluation team to identify the correct heating and cooling baseline for each participant.

Participants Who Purchased the DMSHP for the Cooling Amenity Only. Participants who had bought the DMSHP primarily for the cooling amenity were motivated by the added benefit of central cooling in their house and the additional amenities associated with a DMSHP (quiet central cooling without expensive duct retrofits).[3] Participants who had bought the DMSHP for the cooling amenity had no other comparable options to achieve the same goal. Their purchase of a DMSHP was substantially more expensive than purchasing individual room air conditioners, and installing ducts where none exist for a traditional central air conditioner would have been substantially more invasive, leaving no other options but to install a DMSHP.

For this group, all participants have the same baseline regardless of their alternative actions because the DMSHP is the only equipment on the market with the added functionality that participants desire (such as a quiet system that can be retrofitted into a house without ducts). The consumer experience of owning a DMSHP is much different than that of owning room air conditioners and so the two cannot be properly compared.[4] Of the 32 percent of the participants who previously had cooling in the space served by their DMSHP, 89 percent stated that the previous equipment had been removed from the space. Therefore, the most reasonable baseline for all participants in this group is a **standard efficiency DMSHP for both heating and cooling**.[5]

Participants Who Purchased the DMSHP for the Heating Amenity Only. Participants who had bought the DMSHP primarily for the heating amenity were motivated by a desire to either save money on heating fuel with a more efficient system, or to add heating to a previously unheated or under-heated space. In order to determine a baseline for these participants, the evaluation team considered the participants' stated alternative action to achieve the same heating amenity. None of the participants with this characterization stated an alternative action for the cooling amenity because they confirmed that they had not bought the unit for cooling. This participant characterization is divided among the following subgroups:

- Participants who stated that they would have "left the space unconditioned" fit into a new construction application. They are adding heat to a previously unheated or under-heated space, and they would have still installed a heating system without the rebate. The program incented them to install a more efficient unit in this case. The most reasonable baseline for participants in this group is **a standard efficiency DMSHP for both heating and cooling.**
- Participants who stated that they would have "left their other heating system installed" fit into a retrofit application. Of the participants who had previous heating in the space served by their DMSHP, 95 percent stated that their previous heating system was still installed in the space. The most reasonable baseline for the participants in this group is the **existing equipment that previously served the space (which is currently served by the DMSHP for both heating and cooling).**
- Participants who stated that they "would have installed an alternative heating technology" fit into a replace-upon-failure application, with the nuance that they stated an alternative measure

[3]While DMSHPs do not provide true central heating and cooling, the effect of a DMSHP is similar to a central system in that it provides the conditioning amenity without having to remove it seasonally, the heating and cooling is more evenly distributed throughout a room, and a zonal effect is easily achievable with multi-head systems.

[4] Room air conditioners are not a sufficient baseline for central air conditioners because of the difference in amenities offered and the difference in consumer experience. In the same way, room air conditioners are not a reasonable baseline for DMSHPs.

[5] This study did not investigate alternate efficiency levels or collect market data to identify the current DMSHP market. Therefore, the evaluation team recommends using a standard efficiency DMSHP (rather than a higher efficiency, but still non-qualifying DMSHP) for cases in which the DMSHP is the most reasonable baseline).

that they would have implemented. Because these participants offered that they had bought the unit for heating and stated an alternative technology that they would have adopted in the absence of the program, **the heating baseline is the stated alternative heating technology. The cooling baseline is the existing equipment (if any existed). If no cooling equipment previously existed, this is reflected in the proposed baseline,** and results in increased energy consumption during the cooling season with the increase equal to the measured DMSHP consumption for these participants.[6]

Participants Who Purchased the DMSHP for Both Heating and Cooling Amenities. Participants who had bought the DMSHP for both heating and cooling amenities had mixed motivations. These participants were more nuanced in their purchase decisions, and therefore, require a more detailed look at their stated alternative actions.

The evaluation team determined that participants who bought the DMSHP for both the heating and cooling amenities and would have alternatively left the space unconditioned for either heating or cooling effectively represent a new construction-type application. This group of participants was assigned **a standard efficiency DMSHP as the baseline for both heating and cooling** because the sheer cost of a baseline unit – at least $3,000 – dwarfs the incremental costs of a high-efficiency unit of approximately $600. In the opinion of the evaluation team, the Cool Smart DMSHP incentive of $150-$500 did not motivate customers to install a DMSHP as opposed to leaving the space unconditioned in the alternative. In these instances, the team believes that the customer did not understand or appreciate the distinction of DMSHPs by efficiency level, thus responding that they otherwise would have done nothing despite saying they had been motivated to condition the space. It is possible that these customers are freeriders, but such a determination is not within the scope of the current research into baselines and gross energy savings.[7]

Alternatively, the team considered whether to characterize these baselines separately as a partial-new construction, partial-retrofit scenario. However, this option complicates the characterization, and it does not adequately indicate that the participant was able to add new functionality for both heating and cooling with the purchase of a DMSHP -- functionality that they had been looking to attain with or without the program's influence.

Proposed Baseline Technology

Using the logic detailed above, the evaluation team developed a flow chart that fits together all of the available sources of data and the baseline determinations to explain the decision making process for assigning baseline technologies. This logic chart is presented in **Error! Reference source not found.**. Specific counts within each box indicate how the population of data logging participants fit into this schema. The boxes in the figure with darker shading represent responses that were given most frequently.

Simplifying the results of the logic chart presented in **Error! Reference source not found.**, summarizes the percentage of participants who are assigned to each baseline for both heating and cooling. Following the logic outlined in this section, this table illustrates that nearly half of participants are assigned a standard efficiency DMSHP baseline for both heating and cooling.

[6] The scenario is not expected to significantly affect the impacts for DMSHPs, unless the households purchasing the equipment for heating decide to ultimately make use of cooling.

[7] It is possible that these customers are freeriders, but such a determination was not within the research scope which included determining the baseline and gross energy savings.

Table 3. Proposed Baseline for Metering Participants

Cooling Baseline Scenario Breakdown		**Heating Baseline Scenario Breakdown**	
Standard Efficiency DMSHP	47.3%	***Standard Efficiency DMSHP***	47.3%
Existing or Stated Alternative Tech.	52.6%	***Existing or Stated Alternative Tech.***	52.6%
New Room AC	8.9%	New Gas	2.7%
New Central AC	2.7%	New Electric Resistance	2.7%
Existing Room AC	27.6%	Extend Existing System (unstated)	1.8%
Existing Central AC	7.5%	Existing Gas	14.0%
Extend Existing System (unstated)	0.9%	Existing Oil	28.0%
No Previous Cooling	5.0%	Existing Electric Resistance	1.7%
		Existing Wood, Pellet or Fireplace	1.7%
TOTAL	99.9%	TOTAL	99.9%

Based on the results of this analysis, the evaluation team recommended that the COOL SMART program use a blended baseline for DMSHPs. This blended baseline recommendation consists of 47% standard efficiency DMSHP and 53% with a variety of existing and alternative systems for the remaining systems.

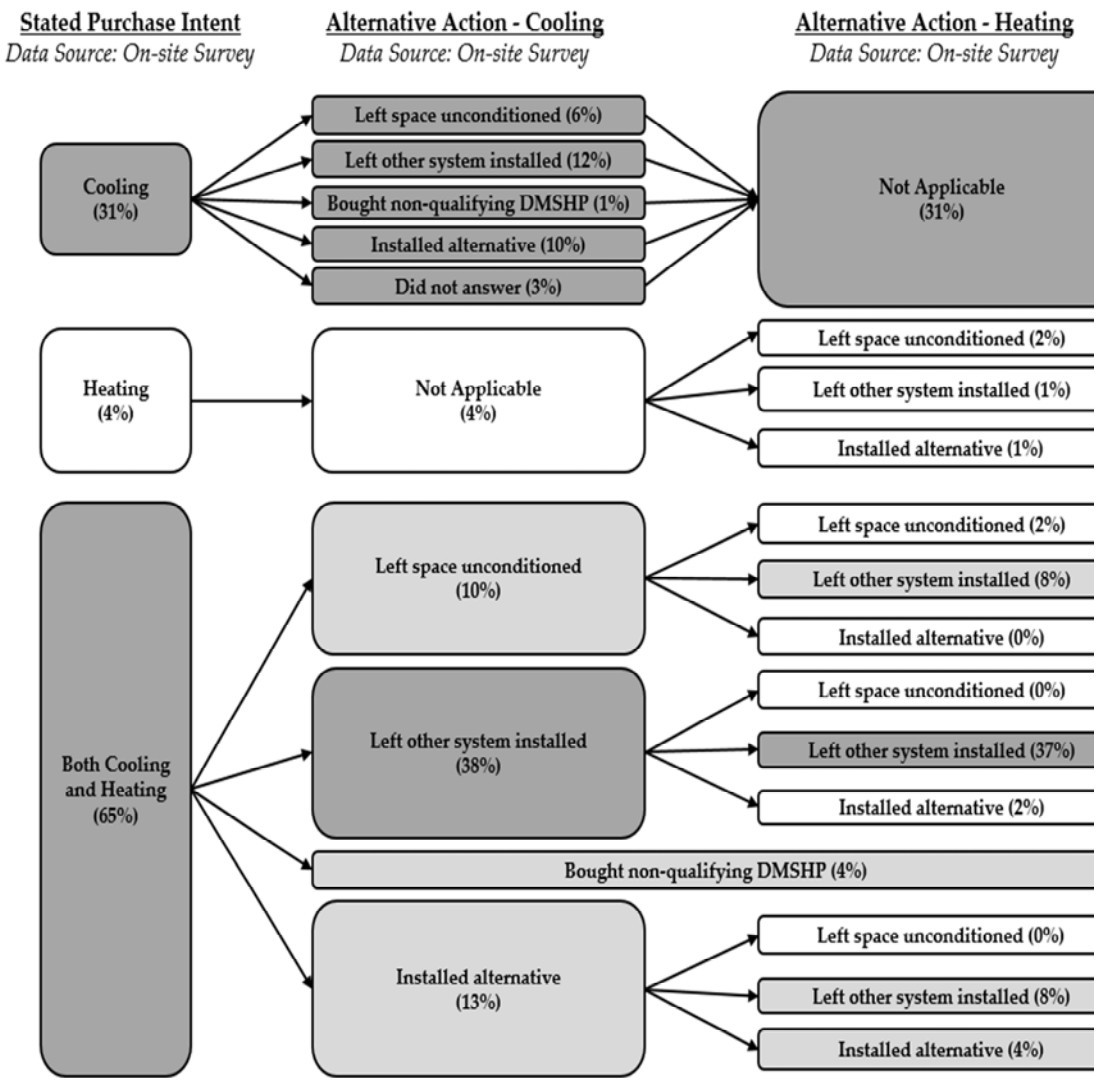

Figure 3. Logic Flow Chart to Determine Baseline, with Response Percentages (n = 116)

Conclusions

Prior to the completion of the online survey and the on-site interview, the DMSHP measure was one of the least understood measures in the Massachusetts' COOL SMART program. The results from these two evaluation efforts provide a much better understanding of this measure, specifically in relation to participant motivation and system usage practices. While the full metering study is still on-going, the evaluation efforts completed to date provide a valuable insight into the world of DMSHP technology.

DMSHPs are Installed for their Added Amenities. The survey results indicate rather clearly that DMSHPs are installed in situations where they are either replacing or supplementing existing equipment. DMSHPs incented through the COOL SMART program are rarely installed in new construction or major renovation situations. Approximately two-thirds of participants reported that they installed the DMSHP for reasons related to improving comfort, while the other one-third indicated that they were generally looking to save money on their energy bill.

DMSHPs are Primarily used for Heating and Cooling. Almost three-quarters (74%) of participants indicated that they use their DMSHP for both heating and cooling. When participants reported using their DMSHP for only one function, the majority indicated that it was used for cooling only. There are very few participants (1%) who only use their DMSHP for heating.

DMSHPs are Replacing Existing Cooling Systems. Thirty-two percent of participants reported that their space was cooled before the installation of the DMSHP. Of this group of participants, 85 percent indicated that the previous cooling system was a room or window AC. Additionally, of this group of participants who had pre-existing cooling, 88 percent indicated that the existing cooling system was removed when the DMSHP was installed. This finding points to rational decision making on the part of the consumer as DMSHPs provide more efficient and more cost effective cooling that room or window AC systems.

DMSHPs are Supplementing, Rather than Replacing, Heating Systems. Eighty-nine percent of participants reported that their space was heated before the installation of the DMSHP. Of this group, the majority (95%) reported that the pre-existing heating system was still in place after the installation of the DMSHP. For those participants where the pre-existing system is still installed, most participants reported that the two systems work together to meet the heating needs of the space. Forty-one percent reported that the pre-existing system functions as the primary system with the DMSHP providing backup heating, while 29 percent reported that the DMSHP now functions as the primary system. Regardless of which system is primary, the vast majority of participants using the DMSHP for heating are supplementing their existing systems rather than fully replacing their legacy heating equipment.

A Blended Baseline is Most Accurate for High-Efficiency DMSHPs. Roughly half (47%) of the participants interviewed were characterized such that a standard efficiency DMSHP baseline was determined to be most accurate. The other half of interviewed participants (53%) were characterized such that an existing or stated alternative technology was determined to be the most appropriate baseline. These existing or stated alternative technologies varied in terms of function (heating and/or cooling), service, fuel and efficiency. Discussions have not yet been completed with the Massachusetts' Program Administrators as to the correct definition of this blended baseline for the COOL SMART program, however the conclusion of this work rests on the fact that a standard efficiency DMSHP is not the correct baseline equipment for high-efficiency DMSHPs. DMSHPs are unique in the amenities that they provide and a blended baseline that includes standard efficiency equipment, existing conditions and stated

alternative technologies offers the best opportunity to correctly capture the savings associated with the installation of a high-efficiency DMSHP.

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