Residential Ducted Mini-Splits vs. Ductless Heat Pumps

Contents

BPA asked the WSU Energy Program to research residential ducted mini-split (DMS) systems to determine the potential to expand BPA's current ductless mini-split heat pump (DHP) incentive programs to include a category of DMS systems. This paper evaluates insights from stakeholders on how DMS systems compare to DHPs in specific segments of the electrically heated housing sector: single- and low-rise, multi-family new and existing, and site-built and factory-built.

WSU conducted informal discussions via email, phone, and meetings with key HVAC industry and utility stakeholders. These manufacturers, utility and other stakeholders (listed in Appendix A) provided technical and market information. Results from a WSU Energy Library literature search on utility programs and short duct run DMS systems, stakeholder discussions related to demonstration/research case studies, and other correspondence are provided in the appendices.

This information was used to address four primary research questions:

1. What types of DMS units and manufacturers have been most successful?
2. What are the estimated energy savings compared to a single head DHP baseline?
3. Have the DMS units been offered in utility programs and, if so, where?
4. What barriers to adoption were identified by early adopters of DMS in the Pacific Northwest?

Background

Highly efficient and effective, DHP mini-split systems are the ideal primary heating and cooling solution for homes with electric resistance (ER) baseboard heaters, wall heaters, or ER furnaces. DHPs are ultra-quiet and designed to provide maximum comfort, control, and efficiency while cutting ER heating costs and providing AC.

DMS heat pump systems use outdoor units similar to DHP systems, with a small indoor fan coil unit and ductwork typically installed in suspended ceiling "chase" areas in the conditioned space to deliver heating and cooling to different rooms (e.g., bedrooms on the same hall). Heating or cooling rooms through one zone in a short-run ducted system is less expensive than individual DHPs for each room because two or more zones use the same fan coil unit.

DMS systems can be used in both retrofit and new construction. Due to the logistics of duct installation, DMS application in new construction is easier and likely more cost-effective (at least on the incremental cost side of the equation). Short-run duct systems can be less expensive than multiple head and/or multiple single-splits. For HVAC retrofits and remodels, DMS systems can solve problems in houses where performance of existing ducts is inadequate. While not more difficult to install than other types of indoor units, DMS systems introduce added complexity and potential quality issues when ducting is involved.

DMS concealed units are not as efficient as DHPs due to fan energy required to overcome the additional static pressure of the ducts that are connected to the DMS. Ducts must be properly sized and installed to overcome the system's inherent lower external static pressure (ESP).

DMS system types

The typical types of DMS systems are one that requires the construction of a rectangular ductwork (Figure 1) and one designed to connect to short runs of round flex ducting for two to four zones (Figure 2). These are often referred to as "concealed," "slim duct," and "horizontal ducted" low-profile units, respectively. These units have smaller fans (typically in the 0.2-0.4 ESP range) than typical central forced-air heat pumps. They are ideal for smaller apartments and homes with low heating loads, where there is adequate room to install ductwork in the conditioned space to deliver conditioned air to bedrooms and main living area to offset ER heat that may be required by code to maintain comfort in all zones.

A third type of DMS system is designed for use with larger ductwork systems (Figure 3). These are much higher in cost with multi-position air handling units with higher ESP (0.5 to 0.8) to accommodate the needs of larger ducted distribution systems. Feedback from key stakeholders suggests this type of DMS is less optimal for new construction, low-load homes or apartment retrofits from an energy efficiency standpoint, and have significantly higher cost and lower efficiencies if used with existing typical ducting systems outside the conditioned space. These types of systems may show promise in larger homes to replace conventional ducted heat pump systems, due to their multi-positioning capability and a larger indoor fan (0.5 to 0.8 ESP) to serve larger central ducted systems. These issues may limit their adoption into the HVAC market that is displacing ER heating as compared to systems shown in Figures 1 and 2. These larger air handler type systems may be more applicable in larger existing and new homes, where the typical system is a central DHP.

Figure 1. Panasonic Concealed Duct, Low-Profile DHP (MM Type): SEER 14, HSPF 9.8 	List price for 2-ton unit: (indoor $1,936) + (outdoor $3,114) = $5,050 + ductwork and finished duct chase. Parts warranty: 7 years on compressor, 5 years on indoor and outdoor unit parts. Labor warranty: 1 year, contingent on trained and certified installer.
Figure 2. Panasonic Concealed Duct, Low-Profile, Medium Static DHP (MF Type): SEER 14, HSPF 9.0 	List price for 2-ton unit: (indoor $2,949) + (outdoor $3,114) = $5,363 + ductwork and finished duct chase. Parts warranty: 7 years on compressor, 5 years on indoor and outdoor unit parts. Labor warranty: 1 year, contingent on trained and certified installer.
Figure 3. Panasonic Multi-Position Air Handler Unit (MVA type): SEER and HSPF unavailable 	List price for 2-ton unit: unavailable. Parts warranty: 7 years on compressor, 5 years on indoor and outdoor unit parts. Labor warranty: 1 year, contingent on trained and certified installer. Note: System similar to a high efficiency air source “fully ducted” heat pump

The DMS units shown in Figures 1, 2, and 3 tend to have lower HSPF (9-10) than typical inverter-driven, wall-mounted DHPs with 11-12 HSPF (Figure 4). Although these DMS units have lower efficiencies than wall-hung DHP units, they may provide additional energy savings by displacing more ER heat outside the main living area, such as bedrooms, but at a much higher cost (almost double equipment cost plus ductwork installation), which significantly impacts cost effectiveness and may make it difficult to justify including DMS systems in residential utility programs.

HSPF and SEER vary based on the configuration of outdoor units or compressors, their capacity, and the number or type of indoor units used. For example, an outdoor unit with an indoor wall unit may have a higher efficiency than the same compressor used with a concealed DMS unit due to the need for additional fan energy to overcome the pressure drop of the ductwork, filters, and grills.

Figure 4. Panasonic Wall-Mounted Heat Pump (ECONAVI Brand): Baseline SEER 19, HSPF 10

List price for 2-ton unit: (indoor $1,181) + (outdoor $1,810) = $2,991 + labor to mount on wall.

Parts warranty: 7 years on compressor,
5 years on indoor and outdoor unit parts.

Labor warranty: 1 year, contingent on trained and certified installer.

DMS system design and installation considerations

The need for guidance on duct design is a challenge for DMS systems. In addition to their significantly higher cost and slightly lower efficiency, DMS systems must be engineered to reduce pressure drop within the conditioned space (for lower ESP). Locating ducts in the conditioned space is especially challenging in the existing home market – often logistically and cost prohibitive unless undertaken as part of a substantial remodeling effort.

Key Product Development Issues

PNW stakeholder discussions suggest that the DMS market is still small relative to the DHP residential market. The DHP market under NEEA's Northwest Ductless Heat Pump Initiative, continues to grow (Conzemius, 2015).

A key product development issue for DMS manufacturers is ensuring that a market exists: "If we build it, will they come?" Discussion with some HVAC manufacturers suggests that more efficient DMS units may be available in the future, but dialogue and needs assessments with utility program planners are needed to help stimulate more robust market conditions so manufacturers can justify these improvements. Development of these product refinements by more DMS manufacturers may require utility/industry stakeholder discussions of the following topics:

- An outdoor unit designed and listed for single DMS indoor head (current outdoor units are typically listed for multiple indoor heads).
- Improving compressor efficiency to even higher inverter-driven variable refrigerant technologies with cold climate (e.g., Hyper-Heat) type performance as needed.
- Eliminating expensive and more complicated commercial type zoning capabilities not typically needed in residential.
- Using ECM fans on indoor units with engineered ducts sized to ESP of indoor fan.

- Adding filter change indicator light and guidance on acceptable replacement filters.
- Providing design and installation training on duct design.
- Providing commissioning training on balancing zone flow rates and controls commissioning protocol.
- Developing controls that may further limit other ER heaters (e.g., bath heat lamps).
- Evaluating installed systems of early adopters to optimize the applications in the field and inform training.
- Conducting a needs assessment to further evaluate market scenarios and first cost and additional installation challenges for a variety of multiple-head system approaches in new and existing dwellings.

What are the types of DMS units and manufacturers?

Three different types of DMS systems that could be appropriate for use in specific segments of the housing sector were identified in this effort. Most of the manufacturers make very similar products.

What are the estimated DMS energy savings compared to single-head DHP

A preliminary review from stakeholders and the WSU Energy Library review of cost-effectiveness analyses did not locate any significant work on this topic that has been completed. Conversations were held with specialists from the Florida Solar Energy Center, where DMS testing in an existing home retrofit is underway as part of the DOE Building America program. The preliminary report is provided in the appendix. The Next Step Homes program has some homes where DMS systems are employed here in the PNW.

DMS systems tend to be more expensive and require significant investment (at least $500 to over $5,000) for conditioned space ductwork design, installation, and balancing. These costs are higher in existing homes, resulting in no cost saving from eliminating ER heaters in bedrooms (typically $100-$200 per room) that are displaced by the DMS system but not by DHP single-head, wall-mount units.

Is there a place for DMS units in utility programs?

As expected, most of the regional and national utility incentive programs are focused on wall-mounted DHP units. It is unclear if DMS systems would qualify for any of these incentives, and they are not specifically noted in the review of information linked in Appendix E. This WSU library literature review did not identify significant research or utility programs that are specifically looking at market transformation ventures for residential DMS systems. Some PNW utilities may offer incentives that are not part of the BPA program. Midwest and East Coast utilities offer incentives for DHP but it is not clear if DMS systems also qualify, other than as offered by Minnesota Power, detailed in Appendix D.

Also in Appendix D, Peter McPhee at the Massachusetts Clean Energy Center indicated via email that to date, DMS products do not meet that agency's performance requirements due to cold weather issues. [Units such as Mitsubishi Hyper-Heat (M-series), which may qualify, require two indoor heads. WSU's research focused on one indoor head.] David Lis of the Northeast Energy Efficiency Partnerships stated that he is not aware of incentivized installations of DMS systems, but is aware that contractors are installing DMS. While DMS systems will be included in all of the programs listed on the NEEP list of incentives for DHPs, the real issue is that no DMS systems currently on the market meet NEEP's "cold climate" program specifications. However, the private HVAC market is beginning to utilize DMS where appropriate (Appendix J).

Stakeholder discussions of the benefits and challenges of integrating DMS systems into utility energy efficiency incentive programs offer valuable insights. Opportunities were identified to collaborate with national utilities, California utilities, the Massachusetts Clean Energy Center, the Northeast Energy Efficiency Partnerships, ASHRAE, ACCA, DOE Building America, and DOE national lab research. These opportunities may focus on the RD&D of DMS systems in markets that displace high-cost ER heat, propane, and oil.

Conversations with Bruce Wilcox suggest that Pacific Gas & Electric is testing residential mini-split pumps. Bruce notes, “We have some performance results and are measuring more in the next year in a PG&E-financed study. We know nothing about costs. Our current project will generate a lot of what you are interested in, but not before the end of the year.”

Conversations with Kohta Ueno from BSC examined ongoing testing of DHP with some discussion of DMS as part of the DOE Building America program. A research report is provided in Appendix B along with more research by Marc Rosenbaum on a DMS case study.

What are the barriers to adoption in the PNW?

The following factors (from Conzemius, 2015) should be considered when evaluating future market potential of DMS systems.

- Installers and participants cite DHP aesthetics as a barrier, but residents indicate they quickly move past aesthetic concerns after installation.

  Stakeholder Observations: DMS may enable builders of new homes to attract potential homebuyers who have fewer concerns about the aesthetics of DMS than of DHP wall-hung units.

- Average residential installation costs for a single indoor head, single outdoor unit (1:1) system remains steady at about $4,000. Suppliers do not believe NEEA’s Northwest DHP Initiative rebates are inflating prices in the region nor do they expect costs to decrease significantly in the near future.

  Stakeholder Observations: There will be a significant higher cost for DMS systems. The list price for DMS equipment is over $5,000, which does not include the ductwork costs. Minimal savings from eliminating zonal ER heaters is another factor. However, the cost is comparable to the additional cost of multiple indoor head systems or multiple single head systems to space condition the non-main living areas. More research is suggested to compare DMS to multiple indoor head systems using either single or multiple outdoor heads, as well as options that combine wall hung and short ducted systems.

- Households that installed DHPs continue to have high satisfaction with the product and recommend the product to others. Almost 95% of participants said they were satisfied or very satisfied with their DHP. In addition, over 75% of respondents say they have recommended a DHP to others.

  Stakeholder Observations: There is reason to believe that satisfaction will be similar for DMS installations. DMS systems require more careful design and installation, and may introduce noise issues from poorly designed short duct runs to bedroom zones. Vance Payne at NIST may be evaluating noise issues of various systems in future 2016 testing at their HVAC testing facilities. These issues may need to be considered by Master Installer training programs for DMS systems that focus on duct design, location, and proper register and filter design and specification. Information for consumers, installers, builders, and utilities may be needed to emphasize the importance of maintaining clean filters and avoiding the use of higher MERV-rated pressure drip filters (e.g., pleated, HEPA).

- Assuming the eligible PNW market of existing single-family homes with electric zonal heat and forced air is 728,047 households, the penetration of DHPs in the market is currently 13% (97,149 11/728,047 eligible households). It appears optimistic to assume that number could grow to a target regional zonal market saturation of 85% in just 14 years (Conzemius, 2015).[1]

  Stakeholder Observations: The rate of penetration may be accelerated if cost-effective, comparably efficient DMS systems were included in the NEEA Northwest DHP Initiative as well as other market transformation efforts by private consumers and affordable housing stakeholders resulting from new home energy efficiency programs, energy codes, and retrofit/renovations in existing homes and apartments.

- Some key "lost opportunities" markets may be associated with new single- and multi-family construction, especially in low-rise, multi-family units without AC and zonal ER heating, where the cost of all-electric systems are much less ($3,000 based on TPU). However, the new construction market is much smaller than the existing home market in terms of overall size, and energy savings potential is reduced due to the lower space-heating use.

Benefits and Challenges

Stakeholders identified the following benefits and challenges of DMS systems over single and/or multi-head DHP.

DMS benefits

1. Provides a "conditioned space" short duct (and even larger) solution (see Appendix J) for smaller, new manufactured homes and factory-built homes that displaces more ER heaters in living area and bedroom zones.
2. Provides an option to replace a visible indoor head with a concealed unit to reduce aesthetic concerns and perceived zonal HVAC distribution comfort issues.
3. Provides a more common ducted option for heating and cooling to HVAC contractors, builders, and occupants/homeowners.
4. Reduces the need for less efficient and less aesthetic "window shaker" AC units, and meets a growing market demand for AC in the PNW.
5. Ideal for new construction, high-performance home, utility-supported efforts such as Next Step Homes, ENERGY STAR, and state energy code-compliant homes with very energy-efficient thermal distribution systems.
6. Provides a lower-cost solution than having multi-head, wall-hung units in living room and bedroom zones.

[1] The total eligible homes identified in the NEEA RBSA plus those homes that received DHP incentives through the DHP pilot period that occurred prior to the completion of the NEEA RBSA totaled 222,981 electric forced air furnace homes and 505,066 zonal heat homes, for a total market of 728,047 eligible homes in the region prior to the launch of the DHP pilot or full Initiative.

DMS challenges

1. More expensive to install than single zone, wall-mounted DHP units, which reduces cost effectiveness.
2. Some DMS systems are lower HSPF and not available with inverter-driven compressors and/or ECM motors.
3. DMS systems with inverter-driven compressors have a lower SEER and HSPF values than inverter-driven DHP units, which reduce cost effectiveness.
4. Difficult to design and install in existing homes due to floor plan and installation logistics.
5. Requires engineered low pressure drop duct design that locates the DMS and duct runs in conditioned space to reduce HVAC noise and maximize energy savings and performance.
6. Duct design limitations, especially the low profile, concealed DMS with fan ESP at 0.2-0.4 required to maximize energy savings.
7. Some DMS outdoor units designed and listed for multiple indoor heads will require further engagement of HVAC manufacturers to develop/list the outdoor unit more compatible with a single indoor DMS head.
8. Manufacturers must be engaged to enhance the product for a smaller new construction market because they see existing homes as their key market. Potential areas for enhancement may include improving fan ESP, heating capacity, and HSPF outdoor unit listed for a single indoor head.
9. Potential need for ER heat back-up for emergency heat and/or when winter heating design capacity exceeds the heat pump balance point, such as in large homes and/or in more severe climates, where no ER zone heaters are employed. At least one Panasonic manufacturer specification suggests that ER heat can be field added to the multi-point ducted-type equipment (0.5 to 0.8 ESP) shown in Figure 3. This would require some type of outside temperature lockout above the heat pump balance point (e.g., >35°F) as required in utility heat pump programs like PTCS and energy codes for typical fully ducted air source heat pumps with electric resistance heat.
10. Poor filter selection and/or maintenance may cause excessive pressure drop, requiring design specifications for filters and enhanced occupant instructions.

Looking Ahead

Continued engagement of HVAC manufacturer stakeholders on specific product development items is needed. Affordable housing stakeholders, such as public housing authorities (PHA) and other not-for-profit affordable housing organizations are potential research partners that are also interested in energy savings and incremental costs to help assess cost-effectiveness. Other potential research stakeholders identified include DOE Building America and ASHRAE.

This project identified the potential to conduct demonstration research efforts that compare DMS and DHP installs in existing all-electric apartments. For example, PHAs such as King Country Housing Authorities and their ESCO partners are installing thousands of wall-mounted DHPs in existing apartments to displace zonal ER heating loads.

Research partnership may provide an ideal opportunity for utility billing analysis because PHAs track utility bills and have a large, robust baseline utility data sample to help determine measured energy savings, and installed incremental cost of DMS over wall-hung DHPs.

Other research opportunities may exist to conduct research on new construction, such as continuing BPA-funded DHP research with current partners like Habitat for Humanity of Pierce County and Tacoma Power. Some production builders like New Traditions Homes have begun to use DMS in homes where AC is needed as part of utility-supported new construction programs such as EPA ENERGY STAR Homes and NEEA's Next Step Homes program.

Preliminary discussion with national HUD-code manufactured housing (MH) industry experts and HVAC suppliers/manufacturers also suggest potential national interest in DMS systems, which may help PNW MH plants provide options to displace all-electric furnaces in NEEM/HPMH RD&D efforts (Lubliner, 2015). Creating a large national market in this sector, where most homes use centrally ducted electric furnaces and AC, and are moving to heat pumps to comply with future MH energy codes and ENERGY STAR program requirement may be leveraged by the MH industry buying power, helping to create a more robust market in this first-cost conscious affordable housing sector.

Summary observations

- The lower HSPF vs. wall mounts may be as big as the savings from displacing more ER heat when compared to hybrid systems. DMS may have lower energy efficiency than DHP, but this may be offset by the additional potential to displace ER zonal heat in single-family and multi-family homes or forced-air furnace heat in manufactured homes.
- The cost of the system will be the most challenging aspect to achieving cost-effective market transformation.
- All-electric new homes, apartments, and manufactured homes should be a major target group, and tend to be smaller units than may be served with single head DMS.
- Other focus should be High Performance Homes like NEEA's Next Step Homes program.
- Successful DMS as part of the DHP new construction utility and supported program and subsidized low income housing must consider the following criteria:
  - Ducts must be in conditioned space, or mitigated (buried?).
  - Ducts shall be engineered to minimize ESP. Zonal ESP design flow rates and max. ESP shall be specified and be confirmed as needed during commissioning (maybe 3rd party)
  - Inverter technologies employed that meets a minimum HSPF

- Consider a W/CFM metric if needed especially for ECM blowers
- All systems equipment flowrates, ESP, and controls operation are required in commissioning
- Training needs: design, installation, and commissioning by HVAC industry in communication with utility stakeholder/sponsors.
- Equipment oversizing factors and implications on energy performance need to be addressed.
- More testing is needed of installations designed and installed by trained HVAC contractors working with HVAC manufacturers and utilities.
- More research is needed on factory-built homes where the DMS replaces the central furnace.
- DMS may provide additional indoor air quality (IAQ) air mixing benefits to bedrooms over hybrid systems with ER and no central heat recovery units. Research into the IAQ benefits of distribution and air filtration should also be explored.

Resources

Conzemius, S., 2015. Northwest Ductless Heat Pump Initiative: Market Progress Evaluation Report #4. Prepared for Northwest Energy Efficiency Alliance. July 23, 2015 (Report #E15-318).
http://neea.org/docs/default-source/reports/ductless-heat-pump-market-continues-to-increase-dhp-mper-4.pdf?sfvrsn=12

Lubliner, M., 2015. Informal communications between Mike Lubliner, manufacturers, and industry experts. August and September, 2015.

Appendix A: Stakeholder Contributors

Ducted Mini-Split/ HVAC stakeholder discussions included the following indivduals: Michael Lubliner

Fist Name	Last Name	Organization	Category
Scott	Bergford	Scott Homes	Builder - custom
Jeffrey	Legault	Skyline Corp	Builder - factory
John	Weldy	Clayton Homes	Builder - factory
Manny	Santana	Cavco Industries	Builder - factory
Dan	Auer	King Co. Housing Authority	Builder - Not for Profit
Ed	Brown	Habitat for Humanity	Builder - Not for Profit
Lisa	Espinosa	King Co. Housing Authority	Builder - Not for Profit
Steve	Tapio	New Tradition Homes	Builder - production
Dean	Gamble	US Environmental Protection Agency	Federal Government
Eric	Werling	USDOE Building America	Federal Government
Janice	Peterson	BPA	Federal Government
Mark	Johnson	BPA	Federal Government
Michael	Blanford	US Dept. of Housing & Urban Developn	Federal Government
Michael	Freedberg	US Dept. of Housing & Urban Developn	Federal Government
Bruce	Wilcox	Bruce Wilcox PE	HVAC Engineer/Utility
Dan	Perunko	Balance Point HP	HVAC Installer
Gavin	Healy	Balance Point HP	HVAC Installer
John	Semmelhack	Think Little	HVAC Installer
Bryan	Rocky	Johnson Controls	HVAC Manufacturer
Cameron	Vreeland	Mitsubishi Electric US Inc.	HVAC Manufacturer
David	James	Mitsubishi Electric US Inc.	HVAC Manufacturer
Don	Stevens	Panasonic Home and Enviroment Co.	HVAC Manufacturer
Ken	Nelson	Panasonic Home and Enviroment Co.	HVAC Manufacturer
Kevin	DeMaster	Mitsubishi Electric US Inc.	HVAC Manufacturer
Roy	Crawford	Trane	HVAC Manufacturer
Sam	Beeson	Mitsubishi Electric US Inc.	HVAC Manufacturer
Glenn	Hourahan	Air Conditioning Contractors of America	HVAC Research, Training and Standards
ASHRAE	Standard 90.2	Mechnical subcommittee	HVAC Research, Training and Standards
Jeff	Pratt	The Heat Pump Store	HVAC Supplier/trainer
Vance	Payne	National Institute for Standards & Techi	HVAC Testing Laboratory
Bruce	Manclark	Clear Results	HVAC trainer, etc.
Tim	OLeary	IDA-Star Energy Services	Inspector
Ben	Larsen	Ecotope Inc.	Researcher
Bob	Davis	Ecotope Inc.	Researcher
Brady	Peeks	Northwest Energy Works	Researcher
Charlie	Stephens	Northwest Energy Efficiency Alliance	Researcher
David	Baylon	Ecotope Inc.	Researcher
Duncan	Prahl	IBACOS Inc.	Researcher
Eric	Martin	Florida Solar Energy Center	Researcher
Iain	Walker	Lawrence Berkeley National Laboratory	Researcher
Jon	Winkler	National Renewable Energy Laboratory	Researcher
Kohta	Ueno	Building Science Corp	Researcher
Kristen	Heinemeier	US Davis Western Cooling Center	Researcher
Marc	Rosenbaum	Energysmith	Researcher
Roderick	Jackson	Oak Ridge National Laboratory	Researcher
Gary	Nelson	The Energy Conservatory	Testing Equipment Manufacturer
David	Butler	Optimal Building Systems LCC	trainer/blogger
David	Keefe	Vermont Energy Investment Corp	Utililty Program
Rem	Hustad	Puget Sound Energy	Utililty Program
Emanuel	Levy	Systems Built Research Alliance	Researcher

Appendix B: FSEC Preliminary DHP Research Report for DOE Building America

This report was prepared by the Florida Solar Energy Center, Florida Power and Light, and DOE Building America.

Please double-click to open the file.

FSEC_DuctedMultisplit_Draft.pdf

Appendix C: Panasonic 2015 Heat Pump Suggested Retail Price List

Panasonic

Confidential List Price November 1, 2014

Ceiling Suspended Heat Pumps

System Model No.	Unit Type	Model No.	Cooling Btu/h	SEER	EER	HSPF	Remote Type	List Price	System Price
26PET1U6	Indoor	S-26PT1U6	24,400	14.5	8.5	9.4	Wired	$ 2,112.00	$ 5,226.00
	Outdoor	U-26PE1U6						$ 3,114.00	
36PET1U6	Indoor	S-36PT1U6	39,000	15.1	8.1	8.8	Wired	$ 2,631.00	$ 6,308.00
	Outdoor	U-36PE1U6						$ 3,677.00	
42PET1U6	Indoor	S-42PT1U6	42,000	15.6	9.4	9.5	Wired	$ 2,808.00	$ 7,949.00
	Outdoor	U-42PE1U6						$ 5,141.00	

ECONAVI Ceiling Recessed Heat Pumps

System Model No.	Unit Type	Model No.	Cooling Btu/h	SEER	EER	HSPF	Remote Type	List Price	System Price
E12RB4U	Indoor	CS-E12RB4UW	11,900	18.0	10.3	9.0	Wireless	$ 1,459.00	$ 3,353.00
	Outdoor	CU-E12RB4U						$ 1,561.00	
	Grille	CZ-BT20U						$ 333.00	
E18RB4U	Indoor	CS-E18RB4UW	17,500	16.0	9.4	8.5	Wireless	$ 1,500.00	$ 3,904.00
	Outdoor	CU-E18RB4U						$ 2,071.00	
	Grille	CZ-BT20U						$ 333.00	

Ceiling Recessed Heat Pumps

System Model No.	Unit Type	Model No.	Cooling Btu/h	SEER	EER	HSPF	Remote Type	List Price	System Price
KE12NB41	Indoor	CS-KE12NB41	11,900	16.0	9.4	8.5	Wireless	$ 1,459.00	$ 3,353.00
	Outdoor	CU-KE12NK1						$ 1,561.00	
	Grille	CZ-18BT1U						$ 333.00	
KE18NB4U	Indoor	CS-KE18NB4UW	17,500	16.0	9.4	8.5	Wireless	$ 1,500.00	$ 3,904.00
	Outdoor	CU-KE18NKU						$ 2,071.00	
	Grille	CZ-18BT1U						$ 333.00	
26PEU1U6	Indoor	S-26PU1U6	24,800	14.1	8.5	9.6	Wired	$ 1,860.00	$ 5,421.00
	Outdoor	U-26PE1U6						$ 3,114.00	
	Grille	CZ-24KPU1U						$ 447.00	
36PEU1U6	Indoor	S-36PU1U6	32,600	14.6	8.1	8.4	Wired	$ 2,235.00	$ 6,520.00
	Outdoor	U-36PE1U6						$ 3,677.00	
	Grille	CZ-36KPU1U						$ 608.00	
42PEU1U6	Indoor	S-42PU1U6	39,500	14.6	8.7	9.7	Wired	$ 2,413.00	$ 8,162.00
	Outdoor	U-42PE1U6						$ 5,141.00	
	Grille	CZ-36KPU1U						$ 608.00	

Concealed Duct Heat Pumps

System Model No.	Unit Type	Model No.	Cooling Btu/h	SEER	EER	HSPF	Remote Type	List Price	System Price
26PEF1U6	Indoor	S-26PF1U6	24,000	14.0	9.1	9.0	Wired	$ 2,249.00	$ 5,363.00
	Outdoor	U-26PE1U6						$ 3,114.00	
36PEF1U6	Indoor	S-36PF1U6	31,200	13.9	7.8	8.5	Wired	$ 2,804.00	$ 6,481.00
	Outdoor	U-36PE1U6						$ 3,677.00	

ECONAVI Concealed Duct Heat Pumps

System Model No.	Unit Type	Model No.	Cooling Btu/h	SEER	EER	HSPF	Remote Type	List Price	System Price
26PEF2U6* ECONAVI	Indoor	S-26PF2U6	24,000	16.5	9.5	9.8	Not Included	$ 1,936.00	$ 5,050.00
	Outdoor	U-26PE1U6						$ 3,114.00	
36PEF2U6* ECONAVI	Indoor	S-36PF2U6	31,200	15.6	8.9	9.0	Not Included	$ 2,491.00	$ 6,168.00
	Outdoor	U-36PE1U6						$ 3,677.00	

* PEF2U6 — Wired Remote (CZ-RTC3 / CZ-RTC4) and ECONAVI sensor (CZ-CENSC1) sold separately

Model No.	Description	List Price
CZ-RTC3	High Spec Remote w/ECONAVI function	$ 360.00
CZ-RTC4	Wired Timer/Remote Controller w/ECONAVI function	$ 300.00
CZ-CENSC1	ECONAVI Sensor	$ 200.00

*Specifications and prices are subject to change without notice.

Panasonic

Confidential List Price November 1, 2014

Multi System - Dual Zone Heat Pump



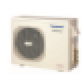
Model No.	Unit Type	Cooling Btu/h	SEER	EER	HSPF	Remote Type	List Price
CS-ME7QKUA	Indoor Wall	6,900	-	-	-	Wireless	$ 636.00
CS-E9NKUAW	Indoor Wall	8,500	-	-	-	Wireless	$ 669.00
CS-E12NKUAW	Indoor Wall	12,000	-	-	-	Wireless	$ 748.00
CS-ME7RKUA ECONAVI	Indoor Wall	7,000	-	-	-	Wireless	$ 636.00
CS-E9RKUAW ECONAVI	Indoor Wall	9,000	-	-	-	Wireless	$ 669.00
CS-E12RKUAW ECONAVI	Indoor Wall	12,000	-	-	-	Wireless	$ 748.00
CS-E12RB4UW	Indoor Ceiling Recessed	11,900	-	-	-	Wireless	$ 1,459.00
CZ-BT20U	Grille						$ 333.00
CU-2E18NBU	Outdoor	16,700	18.0	11.5	8.8	-	$ 2,015.00

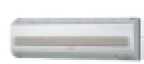
Multi System - 5 Zone Heat Pump



Model No.	Unit Type	Cooling Btu/h	SEER	EER	HSPF	Remote Type	List Price
CS-ME7QKUA	Indoor Wall	6,900	-	-	-	Wireless	$ 636.00
CS-E9NKUAW	Indoor Wall	8,600	-	-	-	Wireless	$ 669.00
CS-E12NKUAW	Indoor Wall	10,900	-	-	-	Wireless	$ 748.00
CS-E18NKUA	Indoor Wall	17,100	-	-	-	Wireless	$ 996.00
CS-E24NKUA	Indoor Wall	24,000	-	-	-	Wireless	$ 1,181.00
CS-ME7RKUA ECONAVI	Indoor Wall	7,000	-	-	-	Wireless	$ 636.00
CS-E9RKUAW ECONAVI	Indoor Wall	9,000	-	-	-	Wireless	$ 669.00
CS-E12RKUAW ECONAVI	Indoor Wall	11,500	-	-	-	Wireless	$ 748.00
CS-E18RKUAW ECONAVI	Indoor Wall	18,000	-	-	-	Wireless	$ 996.00
CS-E24RKUAW ECONAVI	Indoor Wall	24,000	-	-	-	Wireless	$ 1,181.00
CS-E12RB4UW	Indoor Ceiling Recessed	11,900	-	-	-	Wireless	$ 1,459.00
CS-E18RB4UW	Indoor Ceiling Recessed	17,500	-	-	-	Wireless	$ 1,500.00
CZ-BT20U	Grille						$ 333.00
CU-5E36QBU	Outdoor	36,000	18.5	9.6	10.0	-	$ 3,982.00

Flexi Multi Heat Pumps






Model No.	Unit Type	Cooling Btu/h	SEER	EER	HSPF	Remote Type	List Price
CS-MKE7NKU	Indoor Wall	7,500	-	-	-	Wireless	$ 439.00
CS-MKE9NKU	Indoor Wall	9,000	-	-	-	Wireless	$ 469.00
CS-MKE12NKU	Indoor Wall	11,900	-	-	-	Wireless	$ 500.00
CS-MKE18NKU	Indoor Wall	17,500	-	-	-	Wireless	$ 636.00
CS-MKE24NKU	Indoor Wall	24,200	-	-	-	Wireless	$ 696.00
CS-MKE9NB4U	Indoor Ceiling Recessed	9,000	-	-	-	Wireless	$ 1,222.00
CS-MKE12NB4U	Indoor Ceiling Recessed	11,900	-	-	-	Wireless	$ 1,244.00
CS-KE18NB4UW	Indoor Ceiling Recessed	17,500	-	-	-	Wireless	$ 1,500.00
CZ-18BT1U	Grille						$ 333.00
CU-3KE19NBU	Outdoor	17,000	18.0	12.0	8.8	-	$ 2,610.00
CU-4KE24NBU	Outdoor	22,400	18.0	11.5	8.5	-	$ 3,150.00
CU-4KE31NBU	Outdoor	28,600	17.2	11.2	9.3	-	$ 5,001.00

*Specifications and prices are subject to change without notice.

Appendix D: Midwest and East Coast Rebate Program Information

Minnesota Power Rebate

Mitsubishi Products Qualifying For Minnesota Power Ductless Heat Pump Rebate

MITSUBISHI ELECTRIC
COOLING & HEATING
Live Better

Single Zone Systems

Outdoor Model #	Indoor Model #	AHRI #	SEER	HSPF	EER	Minnesota Power Rebate
MUZ-FE09NA-1	MSZ-FE09NA	4908219	26	10	15.5	$500
MUZ-FE09NAH	MSZ-FE09NA	5377911	26	10	15.5	$500
MUZ-FE12NA1	MSZ-FE12NA	4934170	23	10.5	12.9	$500
MUZ-FE12NAH	MSZ-FE12NA	5378525	23	10.1	12.9	$500
MUZ-FE18NA	MSZ-FE18NA	4217888	20.2	10.3	14.2	$500
MUZ-FH09NA	MSZ-FH09NA	7002062	30.5	13.5	16.1	$500
MUZ-FH09NAH	MSZ-FH09NA	7002504	30.5	12.5	16.1	$500
MUZ-FH12NA	MSZ-FH12NA	7002063	26.1	12.5	13.8	$500
MUZ-FH12NAH	MSZ-FH12NA	7002578	26.1	12	13.8	$500
MUZ-FH15NA	MSZ-FH15NA	7002444	22	12	12.5	$500
MUZ-FH15NAH	MSZ-FH15NA	7002594	22	11.5	12.5	$500
MUZ-FH18NA	MSZ-FH18NA	8111727	21	12	12	$500
MUZ-FH18NAH	MSZ-FH18NA	8107718	21	11	12	$500
MUZ-GE09NA2	MSZ-GE09NA	7064983	23.2	11	13.6	$500
MUZ-GE09NAH	MSZ-GE09NA	5378526	21	10	13.6	$500
MUZ-GE09NAH2	MSZ-GE09NA	7064989	23.2	10.1	13.6	$500
MUZ-GE12NA2	MSZ-GE12NA	7064987	22.7	11.4	12.5	$500
MUZ-GE12NAH	MSZ-GE12NA	5378528	20.5	10	12.5	$500
MUZ-GE12NAH2	MSZ-GE12NA	7064990	22.7	10.8	12.5	$500
MUZ-GE15NA-1	MSZ-GE15NA	4934349	21	10	13	$500
MUZ-GE15NA2	MSZ-GE15NA	7064988	21.6	11.2	13	$500
MUZ-GE15NAH	MSZ-GE15NA	5378527	21	10	13	$500
MUZ-GE15NAH2	MSZ-GE15NA	7064991	22.7	10.8	13	$500
MUZ-GE18NA-1	MSZ-GE18NA	4939870	19.2	10	10.5	$500
MUZ-GE18NAH	MSZ-GE18NA	5380362	19.2	9.5	10.5	$500
MUZ-GE24NA	MSZ-GE24NA	4217872	19	10	12.5	$500
MUZ-HE09NA	MSZ-HE09NA	7065526	18	8.5	12	300*
MUZ-HE15NA	MSZ-HE15NA	7065528	18	8.5	12	300*

minnesota power
AN ALLETE COMPANY

Air Source Heat Pumps (ASHP)

power of one
a conservation program

Participation Requirements

- Only applies to new installations. This includes mini-split ductless heat pumps with electric baseboard/radiant heating, slab heating or electric boiler as the primary heating system. The mini-split system must have a minimum of two indoor units.
- Ductless systems less than (16 SEER / 9 HSPF) qualify for the Energy Star Equipment Rebate*(14.5 SEER / 8.2 HSPF / 12 EER) and Non-Energy Star Proper Installation Rebate** (14.0 SEER / 8.0 HSPF / 11 EER)
- Customer must be a retail customer of a participating utility.The system must be installed by a program participating contractor. In order to offer MN Power rebates to your GSHP, ASHP, ECM customers, you'll need to take the trainings relevant to each technology. The trainings are at this link: www.mnpower.com/ tweportal
- Have a program participating contractor install a new qualifying system (SEER 16—measure of cooling efficiency and HSPF 9—measure of heating efficiency) in your home before December 31, 2015.
- Mitsubishi Electric is not responsible for actual rebate amounts. Please check with Minnesota Power for details and updates

Data compiled April 2015

Multi-Zone Systems

MXZ-2B20NA	Non-Ducted	3577580	18	8.9	12	300*
MXZ-2B20NA	MSZ-GE09NA(2)	3589025	18	8.9	12.5	300*
MXZ-2C20NAHZ	Non-Ducted	7451974	17	9.8	13.5	$500
MXZ-2C20NAHZ	Ducted	7451979	15	9.5	11	50**
MXZ-2C20NAHZ	Mixed	8111731	16	9.65	12.25	$500
MXZ-3B24NA	Non-Ducted	3885922	17.5	9.3	12	$500
MXZ-3B24NA	MSZ-GE06NA(2)+MSZ-GE09NA	3949963	17.5	9.3	12.5	$500
MXZ-3B24NA	MSZ-GE06NA(2)+MSZ-GE12NA	3896180	17.5	9.3	12.5	$500
MXZ-3B30NA	Mixed	3895957	16	10	8.65	$500
MXZ-3B30NA	Non-Ducted	3837727	17.5	10.5	9.1	$500
MXZ-3C24NA	Mixed	8063926	18	9.5	12.4	$500
MXZ-3C24NA	Non-Ducted	7505787	20	9.8	13.6	$500
MXZ-3C24NA	Ducted	7505788	16	9.2	11.2	$500
MXZ-3C24NAHZ	Non-Ducted	7451969	19	10	13.5	$500
MXZ-3C24NAHZ	Mixed	8111732	17.25	9.5	11.75	$500
MXZ-3C30NA	Mixed	8111733	17.6	10.1	10.1	$500
MXZ-3C30NA	Non-Ducted	7505824	19	10.6	10.6	$500
MXZ-3C30NA	Ducted	7505825	16.2	9.6	9.6	$500
MXZ-3C30NAHZ	Non-Ducted	7451794	18	11	12.5	$500
MXZ-3C30NAHZ	Ducted	7451968	16	9.8	10.3	$500
MXZ-3C30NAHZ	Mixed	8111734	17	10.4	11.4	$500
MXZ-4B36NA	Non-Ducted	3885942	18	9.3	9.4	$500
MXZ-4B36NA	Mixed	3895959	16.5	9.15	9.05	$500
MXZ-4C36NA	Mixed	8111735	17.6	10.4	9.05	$500
MXZ-4C36NA	Non-Ducted	7505994	19.2	11	9.4	$500
MXZ-4C36NA	Ducted	7506176	16	9.8	8.7	$500
MXZ-4C36NAHZ	Non-Ducted	7434482	19.1	11.3	14	$500
MXZ-4C36NAHZ	Ducted	7434485	15.8	10.1	11.3	50**
MXZ-4C36NAHZ	Mixed	7434486	17.45	10.7	12.65	$500
MXZ-5B42NA	Non-Ducted	6748815	18.4	9.8	8.5	$500
MXZ-5B42NA	Mixed	6748817	16.45	9.25	8.95	$500
MXZ-5C42NA	Non-Ducted	7451984	19.7	10.3	9.2	$500
MXZ-5C42NA	Mixed	8111736	17.45	9.7	9.1	$500
MXZ-5C42NAHZ	Non-Ducted	7434477	19	11	13.4	$500
MXZ-5C42NAHZ	Mixed	7434481	17	10.55	12.1	$500
MXZ-8C48NA	Non-Ducted	7432927	18.9	11.4	12	$500
MXZ-8C48NA	Mixed	7432940	16.8	10.75	10.75	$500
MXZ-8C48NAHZ	Non-Ducted	7432944	18.9	11	12	$500
MXZ-8C48NAHZ	Mixed	7432948	16.8	10.5	10.75	$500

P & S Systems

PUMY-P60NKMU	Non-Ducted	3610462	16.7	10.6	12.2	$500
PUMY-P60NKMU	Ducted	3610463	16.5	10.8	11.3	$500
PUMY-P60NKMU	Mixed	3673103	16.6	10.7	11.75	$500
PUMY-P60NKMU	PKFY-P24NKMU-E2.TH(2)+PKFY-	3677635	16.7	10.6	12.5	$500
PUZ-A24NHA4(BS)	PCA-A24KA	4385500	16.8	10.9	10.3	$500
PUZ-A24NHA4(BS)	PEAD-A24AA	4392696	16	10.2	10	$500
PUZ-A24NHA4(BS)	PKA-A24KA(L)	4385499	17	10.8	10.6	$500
PUZ-A24NHA6***	PCA-A24KA*	8004916	16.8	10.9	10.3	$500
PUZ-A24NHA6***	PEAD-A24AA*	8004918	16	10.2	10	$500
PUZ-A24NHA6***	PKA-A24KA*	8004717	17	10.8	10.6	$500
PUZ-HA30NHA4	PCA-A30KA	4385514	16.1	9.3	12.1	$500
PUZ-HA30NHA4	PEAD-A30AA	4392937	16.5	9.5	12	$500
PUZ-HA30NHA4	PKA-A30KA(L)	4385513	16.5	9.5	12	$500
PUZ-HA30NHA4	PLA-A30BA	4385515	15.6	9.4	12.2	$300
PUZ-HA30NHA4	PVA-A30AA*	8052676	17	9.7	12	$500
PUZ-HA36NHA4	PCA-A36KA	4385518	16.6	10.3	12.1	$500
PUZ-HA36NHA4	PEA-A18AA(2)	4393024	16.8	10.4	12.5	$500
PUZ-HA36NHA4	PEAD-A36AA	4392938	16.8	10.4	12.1	$500
PUZ-HA36NHA4	PKA-A36KA(L)	4385517	16.2	10	12	$500
PUZ-HA36NHA4	PLA-A36BA	4385516	17	10	12.6	$500
PUZ-HA36NHA4	PVA-A36AA*	8052677	17.8	11	12.2	$500
SUZ-KA09NA	SEZ-KD09NA	3837466	15	10	12	300*
SUZ-KA09NA	SLZ-KA09NA	4415024	15	9.6	12	300*
SUZ-KA12NA	SEZ-KD12NA	3837467	16	10	12.5	$500
SUZ-KA12NA	SLZ-KA12NA	4415252	15.4	9.6	12	$300
SUZ-KA15NA	SEZ-KD15NA	3837469	15.5	10	12	$300
SUZ-KA15NA	SLZ-KA15NA	4415364	16	9.6	10.2	$500
SUZ-KA18NA	SEZ-KD18NA	3837470	17.5	10	12.5	$500

Participating Utilities in Minnesota Power Ductless Rebates

To be eligible for rebates, you must be a retail customer of Minnesota Power or one of the electric utilities listed below: http://www.mnpower.com/EnergyConservation/HVACUtilities

- Brainerd Public Utilities
- Ely Public Utilities
- Grand Rapids Public Utility
- Minnesota Power
- Mountain Iron Public Utility

Correspondence about DMS Incentives – Massachusetts Clean Energy Center and Northeast Energy Efficiency Partnerships

From: Martha Plummer
Sent: Thursday, September 24, 2015 11:02 AM
To: Karen Janowitz
Cc: Michael Lubliner; Melinda Spencer
Subject: FW: Incentives for ducted mini-splits

Karen,

I spoke with David Lis (NEEP) yesterday afternoon. He is not aware of any actual incentivized installations of ducted mini-split, but he said that in talking to contractors he was hearing that some were being installed. What I am now realizing is that although he told me that ducted mini-splits would be included in all of the programs that are listed on the NEEP list of incentives for ductless heat pumps, the real issue is that there are currently no ducted mini-splits on the market that meet their "cold climate" program specifications.

David suggested we contact Peter McPhee at the Massachusetts Clean Energy Center (it is one of the programs on the NEEP list). I sent him an email message, to which he responded. See his response below. In it he clarifies the "cold climate" issue.

I've done a little more web and database searching and am not finding anything relevant. And I'll see if I can find a contact at Efficiency Maine (suggested by Peter McPhee).

Martha

From: Peter McPhee [mailto:PMcPhee@MassCEC.com]
Sent: Thursday, September 24, 2015 10:28 AM
To: Martha Plummer
Cc: Meg Howard
Subject: RE: Incentives for ducted mini-splits

Hi Martha,

Thanks for getting in touch. To date, there have not been mini-ducted products that have met our performance requirements, so we do not have any projects that we could put you in touch with.

We have heard that some manufacturers may be introducing products this winter that may meet our requirements, at which time we might have projects that we could set you up with.

I do not know of programs that have supported these technologies. I don't believe that the MA utility programs support them. You may consider reviewing programs run by Efficiency Maine, who has historically had different performance thresholds than we do.

What kind of research are you looking to do?

Thanks,
Peter

Peter McPhee
Director of Renewable Heating & Cooling Programs
Massachusetts Clean Energy Center

63 Franklin Street, 3rd Floor, Boston, MA 02110
From: Martha Plummer [mailto:PlummerM@energy.wsu.edu]
Sent: Thursday, September 24, 2015 12:47 PM
To: Peter McPhee
Subject: Incentives for ducted mini-splits

Hello Peter,

I was given a referral to you by David Lis at NEEP. We are working on a research project on ducted mini-split systems (ductless heat pumps with short duct runs).

We would like to find incentive programs that include ducted mini-splits, and more importantly, leads to programs that have actually installed and incentivized them.

Can you help, or have suggestions for others we can contact?

Thank you.

Martha

Martha Plummer
Energy Program
Washington State University
PO Box 43169
Olympia, WA 98504-3169
Phone: 360-956-2159
Email: PlummerM@energy.wsu.edu

Appendix E: WSU Energy Library Literature Review on Utility Rebate Programs

PNW Region:

Idaho Falls Power
https://www.idahofallsidaho.gov/city/city-departments/idaho-falls-power/services-for-your-home/heat-pump-program.html

Idaho Power
https://www.idahopower.com/EnergyEfficiency/Residential/Programs/ductlessHeatPumps/default.cfm

Kootenai Electric Cooperative
http://www.kec.com/content/ductless-heat-pumps

Central Lincoln PUD
http://clpud.org/high-efficiency-home-heating/

Energy Trust of Oregon
http://energytrust.org/residential/incentives/heating-and-cooling/ductless-heat-pumps

Eugene Electric and Water Board
http://www.eweb.org/saveenergy/home/ductless

Portland General Electric
http://www.eweb.org/saveenergy/home/ductless

Mason County PUD
http://www.masonpud3.org/conservation/residentialheating.aspx

Oregon Department of Energy
http://www.oregon.gov/energy/cons/pages/res/tax/hvac-ductlesshp.aspx

Chelan PUD
http://www.chelanpud.org/ductless.html

Peninsula Light, Gig Harbor, WA
http://www.penlight.org/ductless-heat-pump-rebates/

Program Handout: http://www.penlight.org/wp-content/uploads/2014/02/PLC_DuctlessHP_Handout.pdf
Puget Sound Energy
http://pse.com/savingsandenergycenter/Rebates/Heating/Pages/Ductless-heat-pump-rebate.aspx

Seattle City Light
http://www.seattle.gov/light/ductless/

Snohomish PUD
http://www.snopud.com/conservation/weatherization/dhp.ashx?p=1604

Tacoma Power
https://www.mytpu.org/your/ways-to-save/save-heating-cooling.htm

Midwest and East Coast:

New Jersey Clean Energy Program – Not a utility per se, but NJ administer of energy efficiency programs
http://www.njcleanenergy.com/residential/programs/cooladvantage/heat-pumps

Clean Heating and Cooling Program, Massachusetts Clean Energy Center
http://www.masscec.com/solicitations/residential-air-source-heat-pumps
Note: Program manual mentions Ducted and ductless systems (both single and multi-head)

Baltimore Gas & Electric Smart Energy Savers Program
http://www.bgesmartenergy.com/residential/heating-cooling

Cedar Falls Utilities, Iowa
http://www.cfu.net/webres/File/Ductless%20Mini%20Splits%20-%20Dec%202014.pdf

Appendix F: WSU Energy Library Literature Review on Short Duct Run Research

This literature review did not indicate much in the way of published research, other than PNW efforts and Building Science Corporation (BSC) research for USDOE Building America. WSU met with BSC to discuss DMS research and suggestions for this white paper.

1) Ueno, K. and H. Loomis, 3.4 Experience With Multi-Head Systems and 3.5 Transformations' Future Space Conditioning Equipment Options, Long-Term Monitoring of Mini-Split Ductless Heat Pumps in the Northeast, Building America, U.S. Department of Energy-- See page 37-40 of the PDF – discusses "a multi-head system, and a "ducted air handler MSHP indoor unit" application. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/monitoring-mini-split-ductless-heatpumps.pdf
2) Integrated Ductless Heat Pump Analysis: Developing an Emerging Technology into a Regional Efficiency Resource [Ecotope & NEEA], ACEEE Summer Study on Energy Efficiency in Buildings, 2012 – mentions on pages 2, 3, and 11 multiple or zoned air handlers for ductless heat pumps. http://aceee.org/files/proceedings/2012/data/papers/0193-000064.pdf
3) Text-Alternative Version of a webinar: High Performance Space Conditioning Systems: Part I, NREL, October 21, 2014. http://energy.gov/eere/buildings/text-alternative-version-high-performance-space-conditioning-systems-part-i

***Kohta**:[2] Okay. I'll just jump to my conclusions here. So actually, two things, so one of the things that you want to point out is we actually did calculate out how many square feet per head we had. This is not mentioned, like, some general guidance sizing information but it's a work well bit of information to realize. You can see most of these houses were, like, 600 to 800, 900 square feet per head in this comfort complaint houses, we're in the 1100, 1200, we added that second head, we're down to the 600 branch per head.*

So just a little bit of things to think about when you're trying to design with a system like this. So, further work that we're going to do with Transformations, we'd like to possibly implement a different type of system for the second floor. Those comfort complaints at East Hampton and they had to change to 3 to 1 indoor to outdoor mini split system on the second floor. Basically, one head per bedroom to ensure that these comfort complaints would not happen again. They ended up with more costly equipment and its lower efficiency and as a result, they lost a really big energy incentive on each house. So what they're hoping to do is change to a small ducted air handler in second floor hallway, a short duct run to each bedroom. There, we solve the whole open/door close problem and we're providing space conditioning to heat the bedroom as result.

This just shows a small image of the type of air handler that we're talking about. The problem is that this kind of equipment does not quite exist yet but I believe that it is coming online sometime in the next couple of months. So, conclusions. Mini split heat pumps can work very well to single point heating in Zone 5A, two point heating works great in many cases. But the problem cases that we saw included problem geometries, that bonus room, exterior conditions on five sides. a single point in a two-story house that one air rises problem heating versus cooling, extended periods with the bedroom doors close and the setback is cycling your system on and off. And also worse energy efficiency to boot. When we are pushing well north of 1100 square feet per mini split head, those were the cases where we did have problems for reference. If other people have data, I'd love to see it. Oversizing mini split heads is probably a reasonable strategy for heating. And use of small air handlers on the second floor, the whole door open/door close thing will no longer be a worry.

[2] This transcription is from the October 21, 2014 High Performance Space Conditioning Systems webinar, presented by Kohta Ueno, Senior Associate with Building Science Corporation. WSU used red text to highlight the section pertinent to this paper.

Appendix G: Conversations with BSC on BA and Marc Rosenbaum Massachusetts DMS Research

BA-1407: Long-Term Monitoring of Mini-Split Ductless Heat Pumps in the Northeast

http://www.buildingscience.com/documents/bareports/ba-1407-long-term-monitoring-mini-splits-northeast/view?topic=doctypes/bareports

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Michael Lubliner wrote:

Kohta,

Thanks for the info and the useful discussion this AM on the white paper that WSU is developing on short duct run mini-splits or we prefer to call them ducted mini-splits (DMS).

I will contact Marc now as suggested and hope that you and I and Mark R and David B and hope we can discuss at summer camp!

Sure! I'd be happy to talk at summer camp.

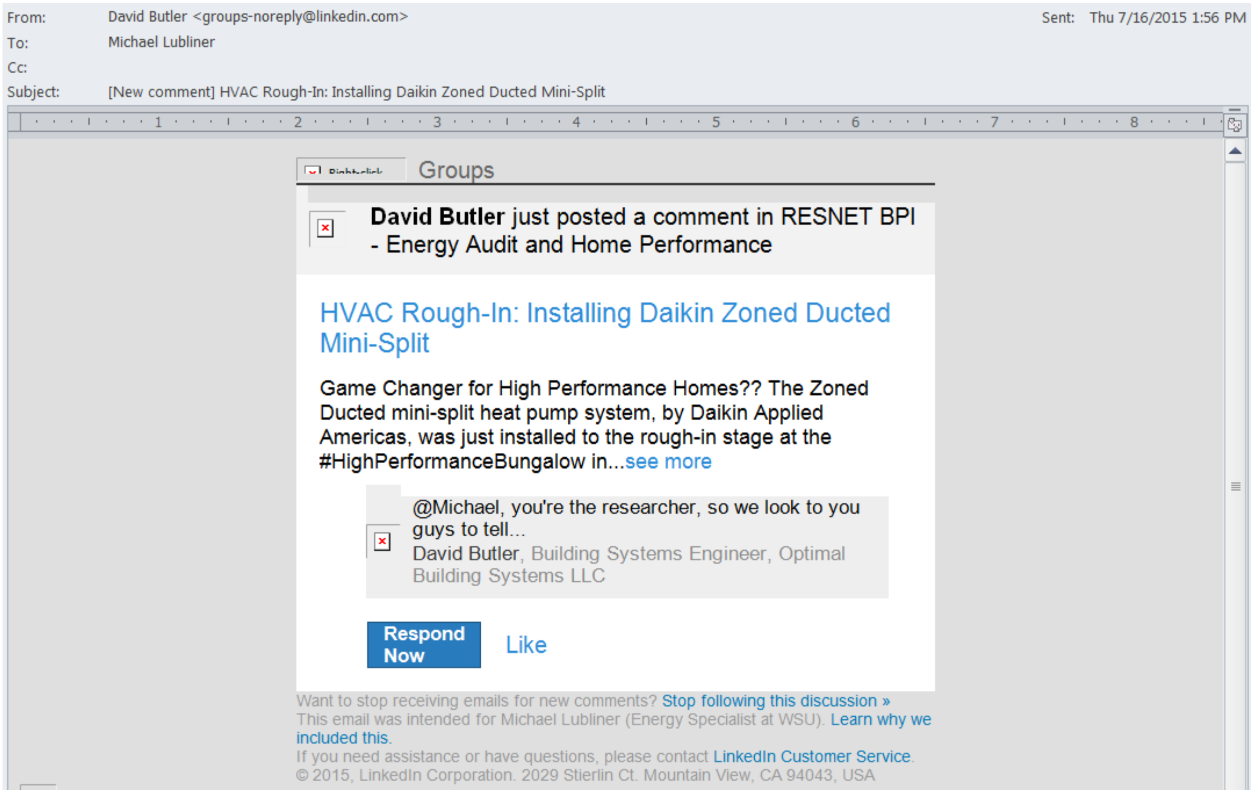
To add another person to the list--Chris Laumer-Giddens sometimes comes to Summer Camp, and he has worked with ducted MSHPs--he's written up some nice blog posts about them:

http://lgsquaredinc.com/2013/07/31/what-ducted-mini-splits-look-lik/
http://lgsquaredinc.com/2014/09/17/mini-split-heat-pumps-quirky-capacity/

Please click to open the presentation:

2015-07-16 Rosenbaum Minisplit Heat Pumps BE2015.pdf

Appendix H: LinkedIn in Discussion on DMS with David Butler et al.



From: David Butler <groups-noreply@linkedin.com> Sent: Thu 7/16/2015 1:56 PM
To: Michael Lubliner
Cc:
Subject: [New comment] HVAC Rough-In: Installing Daikin Zoned Ducted Mini-Split

Groups

David Butler just posted a comment in RESNET BPI - Energy Audit and Home Performance

HVAC Rough-In: Installing Daikin Zoned Ducted Mini-Split

Game Changer for High Performance Homes?? The Zoned Ducted mini-split heat pump system, by Daikin Applied Americas, was just installed to the rough-in stage at the #HighPerformanceBungalow in...see more

@Michael, you're the researcher, so we look to you guys to tell...
David Butler, Building Systems Engineer, Optimal Building Systems LLC

Respond Now Like

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This email was intended for Michael Lubliner (Energy Specialist at WSU). Learn why we included this.
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Appendix I: Key Issues from a Utility Planning and Implementation Perspective

The following quotes, taken from conversations with Charlie Stephens at NEEA, summarize key issues from a utility planning and implementation perspective, seem to support the findings of this effort, and suggest that additional field research and engagement with the HVAC industry are critical to increase market share of cost-effective DMS systems in new and existing homes and apartments.

> *"Frankly, there isn't all that much to doing a ducted mini split system correctly (single zone, anyway) if you do the ducting right and select the right equipment for the job."*

> *"The ducted mini splits are the way to go, so anything you did in that area would be very welcome. And anything you learn might apply to multifamily and smaller site-built single family homes, too."*

> *"One serious issue for NEEA (and for the region) when it comes to multi-zone systems is that we're struggling to make the single-zone systems cost-effective. And each zone added to the first one makes the whole system progressively less cost-effective. So utilities won't be able to provide any incentives for these – they're often too expensive for the savings they provide. That's one reason why the ducted mini split systems become more competitive as you start to think about adding more zones. Ducting is cheaper than adding another indoor unit, within reason."*

> *"…The MVZ DMS HAS to have a second zone because it's designed to work only with their outdoor units that provide for two or more zones, and you have to have an indoor unit on both zones. In other words, you can't install a two-zone outdoor unit and* not *install a second indoor unit. This is unfortunate because that air handler can handle a whole building. But the cost will tend to be high – $10-12k for a system, not counting the ducting, for a 2-ton or 2.5-ton system. So it's really nothing more than an expensive, variable capacity heat pump system (albeit one that doesn't require any strip heat back-up, even though I believe the air handler is set up for that). Your choice to include it or not, but I don't think it's a good choice for the markets you're looking at."*

> *"Indoor units vary a lot in capability when it comes to ESP, so the contractor needs to choose carefully. Some manufacturers do a MUCH better job of programming their cycling behavior under low-load conditions (Fujitsu is by far the best so far, and Mitsubishi is the worst). If you plan on replacing a factory furnace in an MH, you'd best be careful. The only obvious product for this (so far) is the Mitsubishi MVZ, but it's way too expensive for this market, or any market in the 'affordable' category. I don't know about the others, but they're not configured for it in any obvious way. You need VERY efficient fans for all units, and VERY capable outdoor units for the coldest climates (e.g., Mitsubishi Hyper-Heat and Fujitsu Halcyon). There are also air mixing potential IAQ benefits – wouldn't it be cool to be able to optimally integrate ventilation, too."*

> *"There is no valid test procedure for these systems – they're all on DOE waivers for using a variation of AHRI 240, where they just lock the inverter frequency at 3 or 5 points and record capacity and power input. That isn't how they work in the field. The Canadians will solve that problem soon, I think, but for now, HSPF and SEER ratings are probably a poor representation of relative performance, especially since there are no real rules about how to specify system capacity, for testing purposes. That's one reason why there are so many capacity numbers in the spec sheet. We're working on all of that and should have something useful in a year."*

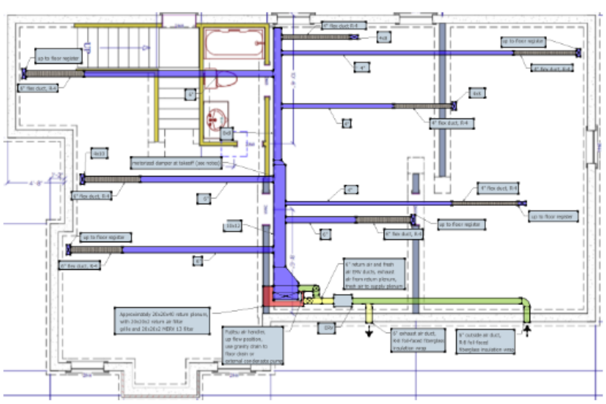
Appendix J: Remodel in Virginia with Quality Ductwork Design Using Two DMS

HVAC contractor and energy expert John Semmelhack at Think Little has significant relative experience with DMS systems, in new high performance homes and deep energy retrofits as shown in the following three examples:

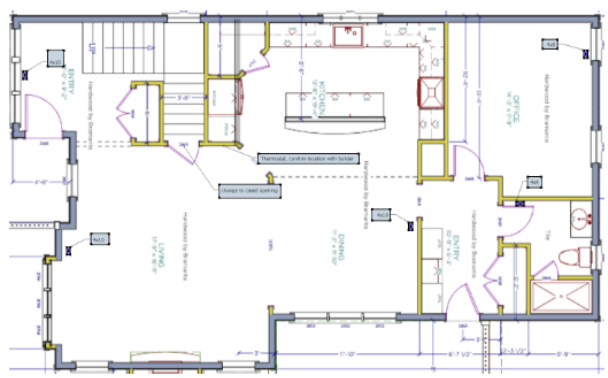
John Semmelhack@think-Little.com] wrote:

Traditional-looking" spec house (~4,000ft2, including unfinished basement), designed to be net-zero energy….2 Fujitsu ducted systems (one 12k and one 9k). As you can see, the ductwork is reasonably extensive…I certainly wouldn't call it "short runs". I'm attaching a photo of the house and some nice install photos of the air handler and duct details.



Basement



1st floor

Heat Pump #1 Duct Details						
Run/Trunk	Design-cfm	Size	Takeoff	Boot/Box	Grille/Register	Filter, damper, other
basement storage	30	4	4" with manual damper	8-4-4 right angle boot	4x8 Hart & Cooley #618OB ceiling register	
future rec room	85	6	6" with motorized damper	10-4-6 right angle boot	4x10 Hart & Cooley #618OB ceiling register	Honeywell ARD6, 6" motorized damper, wired to simple heat/cool thermostat in room, damper open when call for heat or cool. Provide power to thermostat.
future basement bed	20	4	4" with manual damper	8-4-4 right angle boot	4x8 Hart & Cooley #618OB ceiling register	
kitchen+dining	75	6	6" with manual damper	10-4-6 right angle boot	4x10 Hart & Cooley #210 floor register	
office	40	4	4" with manual damper	8-4-4 right angle boot	4x8 Hart & Cooley #210 floor register	
mudroom + powder	30	4	4" with manual damper	8-4-4 right angle boot	4x8 Hart & Cooley #210 floor register	
living	80	6	6" with manual damper	10-4-6 right angle boot	4x10 Hart & Cooley #210 floor register	
entry	80	6	6" with manual damper	10-4-6 right angle boot	4x10 Hart & Cooley #210 floor register	
Supply plenum	440	Approx. 24x6				
trunk - 1st section	440	10x12				
trunk - 2nd section	170	8x8				
Return plenum	440	Approx. 20x20x40			20x20x2 return air filter grille	20x20x2 MERV 13 filter (BestAir Pro)
ERV ducts	80	6				

Design Loads			
	Heating load - Btu/hr (18F outdoor / 70F indoor)	Sensible cooling load - Btu/hr (91F DB, 74.4FWB outdoor / 75F, 50%RH indoor)	Latent Cooling Load - Btu/hr (90F DB, 73WB outdoor / 75F, 50%RH indoor)
Heat pump #1 (Basement + 1st floor)	16,366	10,030	1,995

Equipment Information	
	Heat pump 1 (lower)
Outdoor unit	Fujitsu #AOU12RLFC
Indoor unit	Fujitsu #ARU12RLF
ERV	Renewaire EV90
Heating @ design conditions	19,709 Btu/hr
Sensible cooling @ design conditions	10,053 Btu/hr
Latent cooling @ design conditions	2,348 Btu/hr

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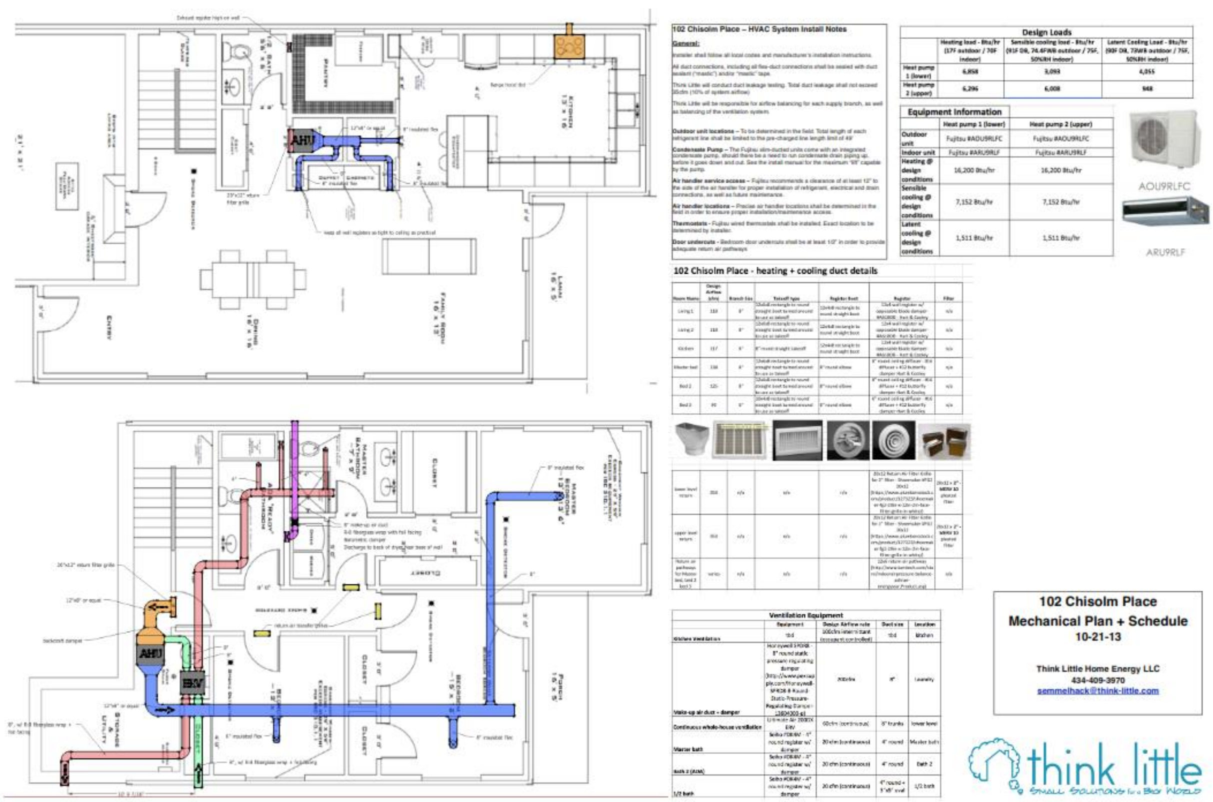
HVAC Plan + Schedule 5-21-15

Think Little Home Energy LLC
434-409-3970
semmelhack@think-little.com

Chisolm Place; DOE Award Winning Home – HVAC Plan in Virginia with Quality Ductwork Design
http://energy.gov/eere/buildings/doe-tour-zero-charlottesville-infill-promethean-homes

John Semmelhack@think-Little.com] wrote:

This one has two 9k ducted units. I have great pictures of the house…but none of the air handlers and ductwork. I do have an HVAC plan for you to look at, though - see attached.



8 Duplex Apartments Designed to Be Net-Zero Energy:

https://www.communityhousingpartners.org/444/275/grissom-lane-zero-energy-apartments-in-blacksburg-virginia.html

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John Semmelhack@think-Little.com wrote:

We have circuit-level energy monitoring on all 8 units using E-Gauge monitors since early March. I need to check back in on the data to see in detail how the heat pumps faired over the summer. We also have Temp/RH% monitors (Hobo w/ bluetooth connection) in each unit. After a quick look at the summertime data, it looks like RH% was running high (over 60% for considerable parts of the summer in some units). I'll probably adjust the total airflow down 10-15% next spring in order to increase the latent fraction. These apartments have very small sensible cooling loads. You can see the heat pumps short cycling on some summer days.

This brings up a couple of things I don't like about these units:

1) Air handler do not use variable speed EC motors, and I can't set a separate speed tap for summer vs. winter.

2) Turn-down ratio on the air-handler does not match the compressor. Air handler on it's lowest speed is about 75% of max speed. Compressor at lowest speed in cooling mode is less than 20% of max. This leads to a much warmer coil and less moisture removal. (WSU note: Not a key issue in PNW climate)

This project would be a good candidate for an in-field COP study (if there were funds), since the energy monitoring is already set up courtesy of the owner/developer.





Appendix K: NIST/ASHRAE Heat Pump Research Potential

(Please read in chronological order – from the bottom up.)
Text in red is reply from NIST.

From: Payne, Vance (Wm.) [mailto:vance.payne@nist.gov]
Sent: Thursday, September 17, 2015 5:15 AM
To: Michael Lubliner
Subject: RE: Sharing Heat Pump research at ASHRAE

Mike,

I do not have an RTAR/WS, but I would be very interested in seeing this kind of study.

I will do a quick literature search next week to see what I come up with related to ductless and ducted mini splits.

ASHRAE 8.7 are the VRF (variable refrigerant flow) guys; they know the performance is bad when they have to add blower power. They just don't want to advertise it because DOE doesn't force them to put that info out there.

Regards,
Vance

From: Michael Lubliner [mailto:LublinerM@energy.wsu.edu]
Sent: Wednesday, September 16, 2015 4:14 PM
To: Payne, Vance (Wm.)
Cc: Ben Larson
Subject: RE: Sharing Heat Pump research at ASHRAE

Vance,

Sorry I missed your call. The email feedback is great!

I will make a point of letting them know "I am not aware of any research. I wanted to do this type of testing to compare the ductless to ducted, but was not funded by DOE". Maybe we can get support. Do you have a draft RTAR or WS that I can share? I think this is something that 90.2 may be interested in supporting as well. I'm a voting member and mech. sub committee chair.

PS – I'm CCing Ben, since he is one of our regions "go to DHP guys", who has been also looking at comparing performance of ducted and unducted mini splits.

Best Regards,
Mike Lubliner
Cell 360-951-1569

From: Payne, Vance (Wm.) [mailto:vance.payne@nist.gov]
Sent: Wednesday, September 16, 2015 12:10 PM
To: Michael Lubliner
Subject: RE: Sharing Heat Pump research at ASHRAE

SEE BELOW in RED

From: Michael Lubliner [mailto:LublinerM@energy.wsu.edu]
Sent: Tuesday, September 15, 2015 1:31 PM
To: Payne, Vance (Wm.)
Cc: Mike Lubliner (lublinerm@wsu.edu)
Subject: RE: Sharing Heat Pump research at ASHRAE

Vance,

Per my VM today, I'm working on a brief white paper for BPA related to the use of ducted mini-split (DMS) applications in new and existing single and low rise multi-family homes. We would like to benchmark these systems against wall hung ductless heat pump (DHP) mini-splits, that are very comment in the PNW HVAC residential market. We are focused on typically the 1 to -3 tons size range.

We are looking at three types of DMS, two are the "concealed duct" units, and one is designed as an ducted air-handler for larger ducted systems.

A) Concealed duct "low profile" low static (0.2 ESP) box size (8"x 30"x 25") designed to be connected to a rectangular duct system

B) Concealed duct medium static (0.4 ESP) box size (12"x27"x25") designed to be connected to 2-4 round 8" duct runs

C) Multi-position air hander unit (0.5 to 0.8 ESP) designed to serve as the central ducted HVAC system, with optional electric heater

I'd like to provide some information that shows the difference in HSPF and SEER between the DHP and the DMS, we are mostly interested in HSPF. It seems like the concealed duct units are in the 9-10 HSPF range as compared to the Energy Star DHP units at 11-12 HSPF, and a higher difference in SEER.

- Is this HSPF difference a reasonable generalization for HSPF? What about SEER?

I think this level of HSFP and SEER reduction may be accurate. The units are mostly (if not all) variable speed so they will still use some kind of variable speed indoor blower motor (most likely an ECM). The ECM is much better than a Split Capacitor motor, but you still have power demands that are five times higher than the ductless. I saw this in my study of the Mitsu multi-split.

- How much of this HSPF difference about the indoor fan energy vs. the compressor?

I think it all comes from the added indoor blower power. My most recent tests with a 2 ton ECM unit operating in a well-designed duct system shows 90 W at low speed (650 cfm @ 0.2 inH2O) and 220 W at high speed (850 cfm @ 0.5 inH2O).

- I understand that these products efficiencies are being improved with adding an ECM indoor fan, what is your take on these future improvements?

I think they are already using ECM's in most, but I am not sure of this. I don't have any experience with ducted minisplits.

- What is your take on the difference in potential sound levels of DMS vs. wall hung DHP?

My experience with the ECM 2 ton blower system on our 2 speed compressor heat pump shows that noise levels are very low at the registers and at the unit because the system operates low speed most of the time. Even at high speed, you can't hear it running at the register unless everything is quiet in the house and you listen closely. I have not measured sound levels, but we will do that next year.

- What are the details in the testing that need to be considered in terms of the real world (duct losses, fan energy cycling?)

As for as testing for ratings, there is nothing special about testing the ducted units; in fact it may be easier for most labs that are more familiar with ducted testing. Lab testing does not capture the true fan power seen in most duct systems because the rating tests for ducted indoor units operate at very low external statics that are not realistic for real world installed systems.

- Are you aware of any research on this topic completed, underway or planned (ASHRAE RTAR?)

I am not aware of any research. I wanted to do this type of testing to compare the ductless to ducted, but was not funded by DOE.

- What are the apples to oranges caveats when comparing ducted to ductless?

I don't have any enough experience with the ducted minis to offer any advice for comparing the two types. You most certainly will always have the lower efficiency with the ducted versions just due to the indoor blower power demand and added heat. If you had some actual ratings tests data, you could examine the effect of adding more indoor blower power (and heat) to the variable speed SEER and HSPF calculations; that would be a good place to start and make generalizations.

Best regards, Vance

Please feel free to call or send me your thoughts, and I'm on a short timeline.

Best Regards,
Mike Lubliner
Cell 360-951-1569

From: Payne, Vance (Wm.) [mailto:vance.payne@nist.gov]
Sent: Tuesday, February 14, 2012 4:34 AM
To: Michael Lubliner
Subject: RE: Sharing Heat Pump research at ASHRAE

Michael,

I will have a paper about my multi-split testing.

Thanks,
Vance

From: Michael Lubliner [mailto:LublinerM@energy.wsu.edu]
Sent: Monday, February 13, 2012 4:09 PM
To: B Davis; Ben Larson; Bruce Manclark; Payne, Vance (Wm.)

Cc: David Hales; Ken Eklund
Subject: Sharing Heat Pump research at ASHRAE

Bob, Dave, Bruce, Ben, and Vance,

Here is what I have planned for potential ASHRAE programs on heat pumps for Denver, June 2013

- Programs for Denver: Seminar: Co-sponsorship with TC6.3 "Cold Blow: Fact or Fiction". An old term for heat pumps in cold climates. Part of the cold blow is driven by the selection of register locations. Contact Mike if you would like to participate in this seminar.

Bob/Bruce please let me know if you are interested in presenting at seminar on ideas to improve defrost and impacts it may have on energy savings, comfort and "Cold Blow".

- Program for Denver: Conference or Technical papers: Experience with Ductless Mini-split Heat Pump Lab and Field Study Results; papers by Mike Lubliner, NIST (Vance Payne), and Ecotope.

Ben/Vance had discussed mini-split technical papers, and hopefully the results will be ready to publish as peer reviewed papers.

Please feel free to call me to discuss.

Regards,
Mike Lubliner
Cell 360-951-1569

Appendix L: Conversations with Jeff Pratt – The Heat Pump Store

Jeff Pratt is a very important leading DHP industry stakeholder, with valuable feedback to share. Of the thousands of DHP units his company has sold, only 12 so far were ducted, due in part to his company's current business (KISS) model. As a leader in PNW market transformation efforts with DMS heat pumps, with significant wisdom and experience, Jeff **does** see an important role for DMS in the PNW's future.

Jeff's top five issues:

- **Higher Cost**: Higher cost of equipment (concealed 20% to 30% more) plus more HVAC duct labor and good duct design needed with master contractor-type training to reduce "bubba" factor on these systems, which are more complicated than DHP. DMS installation typically takes a full day; two DHP systems can be installed per day.
- **Lower HSPF/SEER and lower heating capacity**: Typical 1-2 HSPF delta, plus duct loss penalty and lower output than DHP (12 vs 15 Btu/hr).
- **Duct Design**: Need good diffuser selection. DMS duct design does not have options for air distribution/mixing as DHP does (such as multi-van).
- **Zoning**: Just like typical single, centrally ducted, thermostat-controlled HVAC systems, DMS systems rely on a central thermostat unless a more expensive, complicated zoning option is used (typical in commercial or high-end residential). Compare to zonal control like zone bedroom heaters and main living area DHP hybrid or multi indoor head (1:1 or 1:2 in:out) type systems.
- **Utility Incentives**: Utility incentives for an efficient DMS will help "level the market playing field" in the PNW new and retrofit markets, and drive better and more uniform equipment specs. Incentives will expand options and reach markets not effectively served by DHPs. Incentives should require good equipment performance specs and DMS systems that have tight ducts inside, are designed for ESP, and are installed by and commissioned by trained HVAC professionals. The current incentive structure for DHP discourages DMS by making them a more expensive option

Other takeaways from discussion and market wisdom:

- Multi-direction ducted (0.5 to 0.8 ESP) DMS systems have a huge upside for changing the single speed, air source ducted heat pump market in new and existing homes. Daiken/Goodman may be developing a downdraft (multi-directional) option like others with current airflow direction unit.
- Single head outdoor units needed (KISS single head in/out – his wisdom) and explore use of multi-head on single-head applications.
- HUD-code manufactured homes should consider DHP w/standard electric furnace as another solution to baseboard zone heating in bedrooms and also look at DMS options when there are "tight" belly ducts in R33 floor (e.g. NEEM, MAP, ENERGY STAR).