HOW DO DUCTLESS HEAT PUMPS REALLY PERFORM?

BETTER BUILDINGS BY DESIGN

February 4, 2015

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NEEP Heat Pump Meta-Study

- http://www.neep.org/ductless-heat-pump-meta-study-2014
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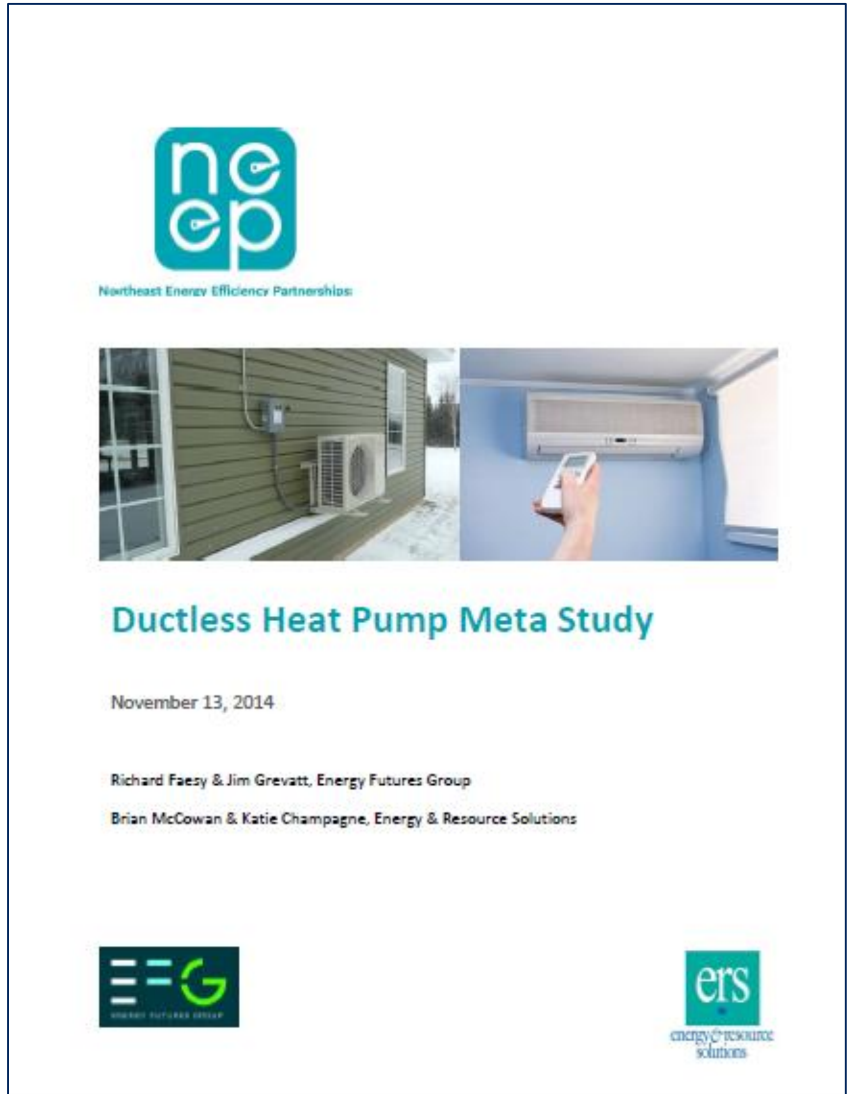
Northeast Energy Efficiency Partnerships

Ductless Heat Pump Meta Study

November 13, 2014

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Overview

- Introduction
  - Project and Process Overview
  - Data Collection
- Performance Analysis
- Market Analysis
- Manufacturer/PA/Contractor Interviews
- Conclusions and Recommendations
- Future Research

Introduction

Project Process Overview

- "Ductless heat pumps" (DHP) focus of study
- 40+ DHP evaluation studies reviewed for performance and market findings
- Interviews of manufacturers, contractors and program administrators
- Final work product:
  - Slide deck
  - Spreadsheets of synopses from studies
  - Report

Data Collection – Studies Examined

- BHE-EMT Heat Pump Interim Report 2013
- BPA- ACEEE Performance of DHP in the Pac. NW 2010
- BPA DHP Engineering Analysis (Res) 2012
- BPA DHP Retrofits Comm. Bldgs. 2012
- BPA Variable Capacity Heat Pump Testing 2013
- Cadmus DMSHP Survey Results 2014
- CCHRC ASHP Report 2013
- CSG DHP Performance in the NE 2014
- CSG Mini-split HP Efficiency Analysis 2012
- DOE DHP Expert Meeting Report 2013
- DOE DHP Fujitsu and Mitsubishi Test Report 2011
- DOER Renewable Heating & Cooling Impact Study 2012
- DOER Renewable Thermal Strategy Report 2014
- Ductless Mini-Split Heat Pump Customer Survey Results
- Eliakim's Way 3 Year Energy Use Report 2013
- EMaine Case Study (Andy Meyer) 2014
- Emaine EE Heating Options Study 2013
- Emaine LIWx Program Checkup 2014
- Emera Maine Ductless Heat Pump Pilot Program 2014
- KEMA Ductless Mini Pilot Study & Update 2009-2011
- Mitsubishi Heat Pump Market Data 2011
- Mitsubishi Indoor Unit Brochure 2011
- Mitsubishi M-series Features & Benefits 2011
- NEEA DHP Billing Analysis Report 2013
- NEEA DHP Evaluation Field Metering Report 2012
- NEEA DHP Final Summary Report 2014
- NEEA DHP Impact Process Eval Lab Testing Report 2011
- NEEA DHP Market Progress Eval 2 2012
- NEEA DHP Market Progress Eval 3 2014
- NEEP DHP Report Final 2014
- NEEP incremental cost study
- NEEP Strategy Report 2013
- NREL Improved Residential AC & Heat Pumps 2013
- Rocky Mountain Instit. DHP Paper 2013
- SCEC DHP Work Paper 2012
- Synapse Paper 2013 Heat-Pump-Performance
- VEIC Mini Split Heat Pump Trends 2014
- VELCO Load Forecast with Heat Pumps 2014

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Performance Analysis

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Cold Weather Performance – Field & Laboratory Testing Demonstrate…

- Heating at outdoor temperature ranges consistent with manufacturer specifications for Mitsubishi and Fujitsu tested models
- Ability to deliver heat as low as -20°F for some models
- Performance degrades in terms of total thermal output and COP as temperature drops
- Tested models capable of delivering heat at approximately 60% of rated output at lowest rated operating temperature ranges

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Cold Weather Performance – Field & Laboratory Testing (cont'd)

- Defrost cycle results in a parasitic energy penalty (typically less than 10%) during low temperature operation
  - Difficult to quantify as both temperature and humidity are factors, and studies have not isolated this usage
  - Drain pan heaters, optional on some cold weather models, standard on others, also produce a small parasitic loss. Usage not isolated in the reviewed studies

Cold Weather Performance – Customer Surveys Demonstrate…

- Used for heating down to rated temperature ranges
- General satisfaction regarding heating performance at low temperatures
- Mixed reporting of ability to rely on DHP at low temperatures without utilizing other heating systems
  - DHPs often oversized allowing units to satisfy loads at reduced output levels
- Reported increased reliance on DHPs for heating during cold conditions as users gain experience with the systems

Coefficient of Performance (COP)

- DHP COP Definition: Useful energy delivered / electrical energy input
- Laboratory Testing Concluded:
  - Independent testing of COP in general agreement, although typically somewhat lower than manufacturer reported performance
  - COP varies significantly with temperature

Outdoor Temperature	COP
≥40°F	≥ 3.5
10°F to 20°F	≈ 2.5 to 3.5
-10°F to -20°F	≈ 1.4
Average Seasonal	2.4 – 3.0

Coefficient of Performance (COP) – Field Testing

- All studies reported difficulty in attempting to accurately field test for COP
  - Standard COP testing protocol is for steady state testing
  - DHPs are designed to operate in continuous modulation
  - Difficulty in accurately recording supply temperature without obtrusive measuring protocols
  - Difficulty in determining fan speed/air delivery
  - Interval power monitoring produces limited data points for continuously modulating systems
- When field study COP was reported – general agreement with lab test data, but wider range with many caveats

HSPF & SEER

- Not typically determined from field studies
  - Both HSPF (heating) and SEER (cooling) are seasonal performance ratings derived from COP at multiple operating conditions
  - As in-situ COP was reported to be somewhat lower than manufacturer performance reports, HSPF and SEER are also assumed to be somewhat lower
- Mfgs. report HSPF test results for one heating zone (geographic area) only
  - Actual heating performance will be somewhat lower north of that zone (mid-Atlantic region)
  - HSPF does not include testing at temperatures below 17°F
- SEER also reported for one zone only. Reported to be not fully accurate for DHPs

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Cost Factors

- Installed Costs Single Zone 1-Ton (12,000 Btu) units:
  - Range of \$2,500 - \$5,000 for cold climate models (≈ \$3,500-\$4,000)
  - 10-20% less for 0.75 Ton units
  - 10-20% more for 1.5 Ton units
  - Lowest installed costs; Maine
    - Large program participation & contractor competition
  - Highest installed costs; California (reported at ACEEE Summer Study 2014):
    - Immature CA market due to predominance of central AC & HPs
- Incremental Costs

HSPF Base	HSPF Improvement	Incremental Cost
8.2 HSPF std.	11.0 HSPF high eff.	\$400 - \$600
11.0 HSPF high eff.	12.0+ HSPF CC	≈ \$300
8.2 HSPF std.	12.0+ HSPF CC	\$700-\$900

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System Sizing

- Majority of studies – heating climates
- Typical cold climate sizes: .75, 1.0 and 1.5 tons
- Most systems oversized for heating loads of the space served:
  - Currently few multi-zone models for cold climate
  - Heat multiple rooms with one unit
  - No efficiency penalty for oversizing; dramatic oversizing can introduce cycling
- Cooling – systems oversized in heating dominant climates as systems are sized for heating loads
  - One unit – two tasks
  - Cooling performance good at part load

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Energy Usage

- Highly variable (weather and operational factors)
- Field monitoring studies*

Season – in Heating Dominated Climate	kWh Usage per Ton		
	Low	**High**	**Average**
Cooling	≈90	≈500	≈350
Heating	≈1,800	≈4,000	≈2,200
Total Annual Heating & Cooling	≈1,900	≈4,500	≈2,500

* Many reviewed studies did not identify system sizes installed making direct comparisons difficult

- Cooling Season, cooling dominant climate
  - Small increase (Maine: +0.14 on peak kW) but net impacts unknown

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Energy Savings

- Highly variable
  - Weather
  - System replacement vs. partial displacement
  - Zoning factors
  - Operating modes
  - "Take back" – cost, convenience, comfort (biomass usage)
- Total heating & cooling (field monitoring studies)
  - Heating season
    - Range of ≈1,200 to 4,500 kWh per ton, annual savings*
  - Cooling season
    - Awaiting studies

* Many reviewed studies did not identify system sizes installed making direct comparisons difficult

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Fuel Switching Potential – Oil & NG

- Oil-fired heating systems
  - Replacement – significant operating cost savings
  - Displacement – often effectively used with oil-fired system
    - DHP serving part of living spaces
    - Or DHP used as primary source except during extremely cold temperatures
    - Maine: oil savings of $585 - $226 electric = $359 net average savings (modelled savings per participant, not per ton)
- Natural Gas-fired heating systems
  - Replacement – small operating cost savings
  - Displacement – AC usage, some heating
    - DHP used to heat specific space or addition
    - Knowledge gap – DHP & gas heat at various temperatures

Fuel Switching Potential – Other

- Propane heating systems
  - Replacement – significant operating cost savings
  - Displacement – potential cost savings displacing propane central and space heating
    - DHP serving part of living spaces
    - Or DHP used as primary source except during extremely cold temperatures
- Kerosene fired space heating systems
  - Replacement/Displacement of direct-vent K-1 space heat
    - Significant operating cost savings

Demand and Load Shape

- Systems rarely operate at full rated input power
- Energy demand continuously modulates
- Typical heating demand range is typically 20-80% of rated input power
- In cold climates, cooling demand range is typically 5-25% of rated input power – sporadic/variable
- NEEP study: summer load shape coincident with NE-ISO peak periods, but averages well below rated output
- Maine: increases in summer peak demand by .14kW and winter peak by 0.35 kW per DHP

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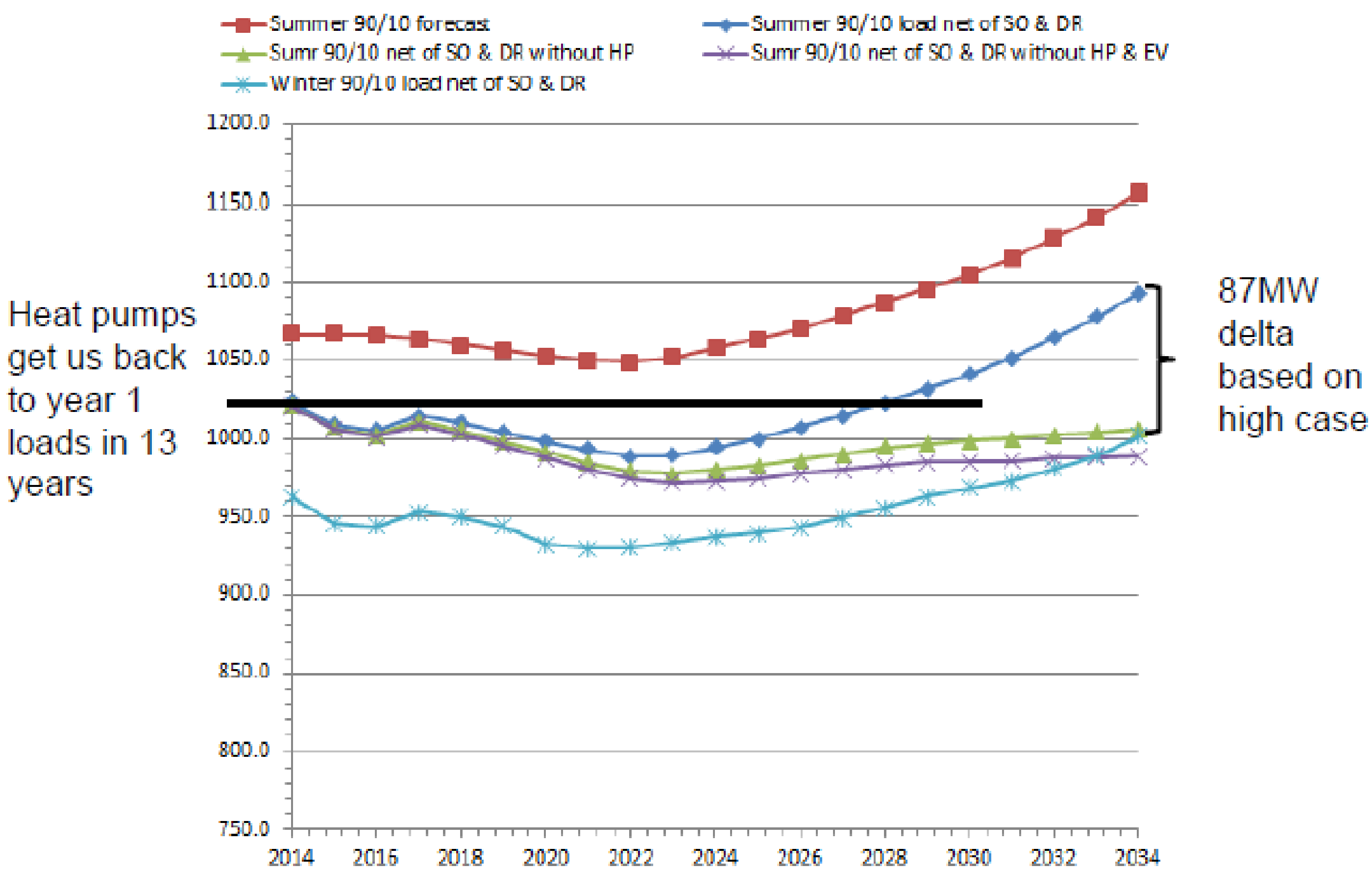
VELCO Load Forecast with 25% DHPs



Cooling Season Load Building

- Heating dominant climate (PNW & Northern NE):
  - Majority of homes have existing AC
  - Many DHP customers initially sought central AC
  - DHPs often replace less efficient window AC units
  - Result: Little evidence of summer load building – net effect; some cooling load savings for a given customer population
- Moderate climates – DHPs nearly always replace less efficient AC
- Knowledge Gap – Final disposition of replaced AC (discarded, stored, installed elsewhere, etc.)

Market Analysis

Market Characteristics

Region	Electric Heat	Oil Heat	Central A/C
Northeast	12.5%	31%	30%
Mid-Atlantic	26%	6%	65%

- Maine 2013 – 20% awareness of heat pumps pre-program
  - 4% already had a DHP installed

Who are the customers and why do they buy DHP?

- Very limited publicly available data – Maine, Massachusetts, and Pacific Northwest (PNW)
- In Maine and PNW, customers chose DHP primarily to reduce heating costs (program was targeted to electric resistance in the Northwest)
- We believe, from interviews, that this is not the case in Maryland, where natural gas is widely available
- In Massachusetts, a survey of "Cool Smart" program participants reported higher cooling usage than heating (program targets cooling installations)
- Some contractors also said that people call looking for cooling, but then take advantage of the heating savings

Market Barriers

- Market barriers vs. program barriers
- Market barriers vary with maturity of market, and can change quickly
- Usual suspects in less developed markets: price, lack of awareness, lack of understanding of benefits, hard to find qualified contractors, etc.
- Visual objections to indoor units (leading to increased use of short-run/concealed duct units in NW)
- Lack of multi-head for cold climates

Market Opportunities

- NEEA 2009 market assessment – successful weatherization programs in the past had not been able to address electric heat replacement because of the high cost of distribution for central systems
- NEEA 2014- Key is heating DISplacement, not REplacement
- From interviews DHP is taking off in markets where there is greater experience – 10% to 30% growth
- Alaska 2013 – installers reported a surge of interest in DHP and no need for advertising

Are they happy?

- Yes!
- NEEA 2014 – 92% reported high levels of satisfaction
- Maine Pilot 2013 – Would you recommend the program? 9.7 on a 1 to 10 scale
- CT/MA pilot 2009-11, 38 out of 40 participants rate a 4 or 5 on a 5 point scale
- MA 2014 survey – 91% reported overall satisfaction; some dissatisfaction with heating performance of non-cold climate systems
- Widely satisfied with cooling, sometimes less so with heating, especially at lower temps – but often with older studies, they weren't cold climate systems

What about comfort?

- BPA 2012 – 20 homes, 15 very satisfied with comfort, 5 satisfied
- CT/MA pilot 2009-11, Focus groups identified increased comfort as a key benefit (less so with large rooms or complicated room shapes)
- MA 2014 survey – increased comfort was key motivator for purchase
- NEEA 2014 – most participants reported increased comfort
- Alaska 2006-11, small sample but most reported increased comfort due to heat being provided to areas that weren't heated well before

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Interviews

Who Did We Talk To?

- **Manufacturers (3)**
  - Daikin
  - Fujitsu
  - Mitsubishi
- **Program Administrators (5)**
  - CT
  - MA/RI
  - ME
  - NY
  - VT
- **Contractors (8)**
  - DE
  - MA
  - ME
  - NH
  - PA
  - VT

Manufactures – Poised for Growth

- Have been making DHPs for 30-50 years, selling in the U.S. for between 10-30 years
- All expect10-50% growth over foreseeable future
- Contractors are trained and ready for growth in the NE
- What is now driving demand?
  - Used to all be pushed by the contractors
  - Utilities are starting to stir interest and legitimize DHPs for consumers
  - High oil prices drive consumers to ask contractors for solutions

Manufacturers – Future Developments

- Future technical developments:
  - Multi-head cold climate units soon (by 2015)
  - Integrated heat pump water heaters by the end of 2015
  - Controls and integration into existing central systems
  - Utility controls of building level systems for DR
  - New technologies and more cold climate performance with higher efficiencies
  - Lower prices with more competition and new products at different price points
  - Increased mix and match flexibility of indoor and outdoor units, while simplifying installation for contractors
  - Slim lines, different heads, hidden cassettes, etc. for more applications and acceptable aesthetics

Manufacturers – Program Suggestions

- Consider leasing and rental programs (like solar PPAs)
- Pursue commercial buildings
  - Manufacturers are putting a lot of resources into commercial
- Better integration of smart communications for demand-response programs
- Focus on better control options, including remote controls and total system integration
- Need to figure out the right cold climate standards and work with AHRI to institute
- Look at warrantee length (e.g., 10-12 years) as a way to promote quality products
- Continue to evaluate field performance and share the data

Manufacturers – Program Elements

- Consumer education and *awareness campaigns*
- Offer and promote *incentives*
  - Some would rather have lower incentive with more promotion and education than higher incentives
  - Some prefer tiered incentives, others a single threshold tier
- Contractor and manufacturer *education* on installation and programs
- *Simplify* program offering and paperwork processes
- *Coordinate* and integrate promotion, education and training efforts with manufacturers

PAs – DHPs Are New Territory

- DHPs are really new to PAs:
  - PAs are learning about the DHP market as they go; haven't really done any market assessments
  - Learning about how customers use DHPs, but this is evolving and changing
- Typical usage in programs:
  - Increasingly installed as supplemental to displace expensive oil, propane and electric heat
  - Some new home installations

PAs – Anticipating Growth

- Customer awareness of DHPs is limited…
  - …but increasing with program efforts and contractor training and familiarity and comfort selling the DHP systems
- Expecting significant growth, but still barriers…
- Program barriers:
  - Equipment cost
  - Savings calculations and attribution
  - Contractor awareness, familiarity, comfort with a new technology and faith that the DHPs will perform
  - Lack of consumer awareness, information, and demand

PAs – Customer Focus

- Customers want:
  - Heating bill reductions
  - Year-round comfort and affordability
  - Distinguishing a quality product that will work in cold climates vs. an inferior product
- Incentives:
  - $300-$1000
  - Tiered by efficiency, but don't complicate it too much
  - Thinking about incentivizing controls

PAs – Eligibility and Savings

- Driving demand
  - Show contractors that there is a market and set them loose
  - There are some great examples of tips, videos and other materials available
- Eligibility is mostly just based on being an electric utility customer without gas
- Savings: most calculate based on incremental electric efficiency over a baseline DHP, assuming it would have been installed anyhow

PAs – Outreach and Promotion

- Support the contractor market with training, outreach, direct contractor (rather than homeowner) incentives
- Customer education and advertising to drive demand
- Coop marketing with distributors
- Website presence
- Working with manufactures and reps to train counter people, train distributors to make more sales
- Social marketing, blogging
- Conference, workshop and home show presence to address homeowner and contractor questions and build confidence in the technology

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PAs – Next Steps for Success

- Establish the “cold climate” DHP standard
- Work with manufacturers, distributors and contractors to bring in products that operate reliably in our climate and then distinguish the "cheap crap" from quality cold climate DHPs
- Coordinate closely with manufacturers and distributors
- Determine how to calculate savings
- Fully understand your market before launching a program

Contractors – Poised for Growth

- Primarily full-service HVAC contractors
  - Some smaller niche contractors
  - One weatherization contractor who has branched into DHPs
- 1 to 28 years experience, most with 10 years
- Growing at 20-30% per year

Contractors – DHP Likes and Dislikes

- Likes:
  - High efficiency
  - Versatility for multiple applications
  - Space conditioning for cold/hot rooms, additions
  - Profitable
- Dislikes
  - Do not work well in leaky homes
  - Slow recovery
  - No cold climate multi-head models (yet)

Contractors – DHP Market

- Positive features:
  - Adaptable and flexible to install
  - Very reliable and durable; virtually no call-backs
  - Excellent customer satisfaction
  - Good to excellent manufacturer support
- Cooling:
  - 80% of homes with DHPs going in replace window AC
- Heating:
  - North – Most (70-80%) are looking to offset oil or propane
  - South – Still focused on cooling

Contractors – DHP Performance

- Controls
  - Most provide some limited education, but controls remain an issue
  - Some push integrated controls
  - Contractors would welcome better controls
- Customer complaints
  - Thousands installed and only a few complaints
  - Some better contractors picking up bad installations done by others
- For the most part, very few performance issues

Contractors – Customer Interests

- Comfort and savings
- Most call the contractor looking for a heating or cooling or a zoned comfort solution
- Seasonal interests (winter – heating, summer – cooling)
- Oil cost reductions in the North
- Cooling solutions in the South

Contractors – Program Interactions

- Where there are programs, customers hear about DHPs and contact the contractors
- Most contractors work with local programs, but not all due to paperwork and low incentives
- Incentives help drive interest and demand
- Program endorsement helps legitimize DHPs
- Affordable financing would be helpful
- Figure out better controls and incentivize
- Encourage more small commercial projects

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Conclusions & Recommendations

Conclusions – Anticipate DHP Growth

- The market in the Northeast is poised for DHP growth
  - Manufacturers, distributors and contractors are ready to step in
  - Homeowners are looking for alternatives to high oil and propane bills
- Homeowners aren't very aware of DHPs and look to contractors for their heating and cooling solutions
- PAs can play a useful role in this market

Conclusions – DHPs are Performing

- Cold climate models will continue to expand the market across the northern US and Canada
- Field tested performance is generally consistent with manufacturer performance data, but somewhat lower than rated performance
- HSPF and SEER rating procedures are not fully suited to variable-speed DHPs
- Variability of usage makes predicting/modeling savings difficult

Recommendations – Support DHPs That Perform

- Support premium efficiency and durable DHPs
- NEEP DHP specification by collaborative stakeholder group:
  - Performance Requirements
  - Compressor must be variable capacity
  - Indoor and outdoor units must be part of an AHRI matched system
  - ENERGY STAR Certified
  - COP @5°F >1.75 (at maximum capacity operation)
  - HSPF >10 for Single-zone systems or HSPF >9 for Multi-zone systems
  - Engineering data for each system must be reported through the "Cold Climate Air-Source Heat Pump Performance Information Tables

Recommendations – Encourage Performance Transparency

- Support development of revised HSPF with AHRI that includes lower temperature ranges and is aligned with inverter based modulating operation
- Encourage manufacturers to report HSPF for all heating climate zones
- Support development of a simple DHP savings calculator similar to HeatCalc
- Encourage all-fuels programs with GHG emissions reduction as a key metric

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Recommendations – Educate & Incentivize Customers

- Provide outreach and education to customers on the benefits of DHPs to increase awareness
- Keep the programs simple and focused on DHPs
- Consider financial incentives based on incremental costs
  - Possible to reduce incentives with improved market acceptance
  - Prepare the market for inevitable future ramp-down of incentives

Recommendations – Support the DHP Industry & Keep Researching

- Coordinate efforts with manufacturers and distributors
- Train and promote quality contractors
- Include residential, commercial and rental properties
- Fund further field studies focusing on metered/billing data
  - Further field testing for COP has limited value
- Conduct on-going research to fill the knowledge gaps

Knowledge Gaps

- Measure Life
  - No evidence to suggest variance from other HVAC
  - Warranty not reasonable determinant
  - Replaceable components
- Parasitic losses (drain heaters, frost cycles, etc.)
- Effects of different control strategies (wall thermostats, remotes, modes)
- Demand response suitability
- Disposition of replaced window AC units
- Cost-effectiveness of displacing gas heat at various outside temperatures
- Net GHG effects of replacing various fuels
- Reliability and accuracy of HSPF & SEER test data for DHPs by climate zone
- More load shape information, especially with multi-head systems
- Performance and savings in different climate zones

Future Research

Research Suggestions

- Fund further field studies focusing on metered/billing data and actual fossil fuel reductions to better understand DHP usage and savings across various cold climates;
- As multi-zone cold climate models become available, perform field research on performance and customer satisfaction;
- Develop a DHP energy use, cost and savings calculator for programs, contractors, suppliers and homeowners to input some information about their house and certain parameters;
- Research and address all of the knowledge gaps identified above.

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