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

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

<table>
<thead>
<tr>
<th>Outdoor Temperature</th>
<th>COP</th>
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<tr>
<td>≥40°F</td>
<td>≥ 3.5</td>
</tr>
<tr>
<td>10°F to 20°F</td>
<td>≈ 2.5 to 3.5</td>
</tr>
<tr>
<td>-10°F to -20°F</td>
<td>≈ 1.4</td>
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<tr>
<td>Average Seasonal</td>
<td>2.4 – 3.0</td>
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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
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

<table>
<thead>
<tr>
<th>HSPF Base</th>
<th>HSPF Improvement</th>
<th>Incremental Cost</th>
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</thead>
<tbody>
<tr>
<td>8.2 HSPF std.</td>
<td>11.0 HSPF high eff.</td>
<td>$400 - $600</td>
</tr>
<tr>
<td>11.0 HSPF high eff.</td>
<td>12.0+ HSPF CC</td>
<td>≈ $300</td>
</tr>
<tr>
<td>8.2 HSPF std.</td>
<td>12.0+ HSPF CC</td>
<td>$700-$900</td>
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</tbody>
</table>
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 no 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
Energy Usage

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

<table>
<thead>
<tr>
<th>Season – in Heating Dominated Climate</th>
<th>kWh Usage per Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Cooling</td>
<td>≈90</td>
</tr>
<tr>
<td>Heating</td>
<td>≈1,800</td>
</tr>
<tr>
<td>Total Annual Heating &amp; Cooling</td>
<td>≈1,900</td>
</tr>
</tbody>
</table>

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

- Cooling Season, cooling dominant climate
  - Awaiting data from two studies (NY and Mass)
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
    - TBD; awaiting data from two studies

* Many reviewed studies did not identify system sizes installed making direct comparisons difficult
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 0.14kW and winter peak by 0.35 kW per DHP
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.)
DHP Scenarios – Existing Buildings

1. Replacement/displacement of electric resistance heat
   a) Window AC replaced
   b) Or; central AC displaced
      Baseline – Electric resistance (COP 1) & std. AC

2. Replacement of central heat pump
   a) HP & electric resistance coil (heating below 17°F)
      Baseline – Heat pump @ existing or std. HSPF (includes resistance factor)

3. Displacement of oil, gas, propane central heat
   a) Variable heating usage – climate and user discretion
   b) Window AC replaced
   c) Or; central AC displaced
      Baseline options:
      1. Std. efficiency DHP
      2. Window AC @ existing or std. EER & partial heating fuel displacement
DHP Scenarios – New Construction

1. **New Construction – standard home**
   a) Multiple zone heating and cooling

Baseline options:
1. Std. DHP
2. Std. central heat pump

2. **New Construction – extremely efficient home**
   a) Single or multiple zone heating and cooling – may serve as the only installed heating/cooling system

Baseline: Std. DHP

3. **Other**
   a) Interfaced with central heating system
   b) Heating with biomass supplement
   c) Small commercial applications
   d) Interfaced with PV
Market Analysis
Market Characteristics

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Electric Heat</th>
<th>Oil Heat</th>
<th>Central A/C</th>
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<tbody>
<tr>
<td>Northeast</td>
<td>12.5%</td>
<td>31%</td>
<td>30%</td>
</tr>
<tr>
<td>Mid-Atlantic</td>
<td>26%</td>
<td>6%</td>
<td>65%</td>
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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 (any day now....)
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
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 expect 10-50% 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
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
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
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

☐ Development of cold climate DHP specification by collaborative stakeholder group is underway:
  - Draft recommendation (October 2014):
    - Compressor must be variable speed
    - Indoor and outdoor units must be part of an AHRI matched system
    - HSPF >10 (exact value undecided)
    - COP @5° F >2.0 (exact value undecided) (at maximum capacity operation)
  - All equipment must be tested and reported through proposed “Cold Climate Heat Pump Performance Information Table”
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
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.
Discussion

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