Heating and Cooling with Mini Splits in the Northeast

October 23, 2014
Background
Overview

- Transformations, Inc. currently building net-zero homes in Massachusetts
- Mini split heat pumps (MSHPs) part of builder’s strategy: tradeoff package
- Single point of heating/cooling on each floor
- BA study of temperatures throughout house, energy use of MSHPs
Full Report Available

- 140 page brick of a report
- Reports has details, presentation is overview
- Currently in final review
- If taking notes… relax
Transformations, Inc. Enclosure/Shell

- Triple glazed windows
- 1 ACH 50 typical

- 2x10 rim joist
- 2x4 studs @ 16” o.c.
- Capillary break applied to top of foundation wall

- 1/2” gypsum board (optional)
- 2x4 P.T. studs @ 24” o.c. (optional)

- Intumescent paint
- High density spray foam insulation

- 6 mil polyethylene
- 2” XPS rigid insulation

- Gravel (no fines)
- Perforated perimeter drain

- Capillary break: dampproofing, cementitious coating, or membrane-applied to top of footing

- 10” x 20” concrete footing

- Compacted fill

- Free-draining backfill

- Dampproofing below grade

- Filter fabric

- 4” concrete slab

- 10” concrete foundation wall

- 12” low density spray foam cavity insulation (R-47)

- 2x4 studs @ 16” o.c.

- 1/2” gypsum board

- ZIP System® wall sheathing

- 1/2” gypsum board

- 18” cellulose insulation

- High density spray foam insulation

- 4” concrete slab

- 10” x 20” concrete footing

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Mini-Split Heat Pumps (MSHPs)

- Installations in Asia/Europe for 40+ years
- More expensive per ton BUT if ductless...
- Mitsubishi equipment: full heat capacity @ -5°F
  - Rated to -13°F, still operating at -20°F (H2i/HyperHeat)
- Modulates to meet load
  - Best performance @ part load (worst @ full load)
- COPs in 2.5-3 range in cold winter conditions
Builder’s MSHP Experience

- Low load houses: 10-18 kBtu/hour heating
- All production has MSHPs as single heat source (one per floor, ~1800 sf houses typical)
- Savings from mechanicals into enclosure
  - ~$15,000 enclosure upgrade cost (Δ$)
  - ~$5000 savings on simplified mechanicals (Δ$)
- Trouble-free operation—few equipment callbacks
Monitoring Overview
Monitoring Timeline

- Eight houses, two sites
- Mixed monitoring package—various sensors (T/RH, doors, power) at different houses
Monitoring Package

- Interior temperature/RH
- MSHP Electrical Use
- Door Open/Closed Status
- Door Open/Closed Status
Monitoring Package: 8 Houses, 2 Sites

Second floor head retrofitted August 2012
Operating Patterns
Temperature & Power Use Plot

- Varying wattage draw-modulation (5 min data)
- First vs. second floor; comparison to max 2000 W
- Second floor doing most of cooling
- Started running first floor unit—more even Ts?
Equipment Capacity
Did MSHPs Meet Setpoint? (Capacity)

- Heat pumps as a single source of heating in Massachusetts (Zone 5A) (design T +2, -2°F)
- NREL testing (2011)—matches equipment specs
- **Monitored data: no sign of low equipment capacity** (i.e., long runtimes/high wattage and declining indoor temperature)—excess available
- Included winter 2013-2014 (“Polar vortex”): 6730 HDD 65°F vs. 6220 HDD 65°F normal
- When temperature was down, unit wasn’t running (or other issues)
Equipment Sizing

- Oversizing provides heating capacity at low Ts
- Oversizing not as big of a problem with MSHPs—modulating.

<table>
<thead>
<tr>
<th>Location</th>
<th>Lot</th>
<th>A.G. Square Feet</th>
<th>Heating Design Load kBtu/hr</th>
<th>Installed Equipment Capacity kBtu/hr</th>
<th>Oversizing Factor</th>
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</thead>
<tbody>
<tr>
<td>Devens 3</td>
<td>1728</td>
<td>16.8</td>
<td>25.0</td>
<td>149%</td>
<td></td>
</tr>
<tr>
<td>Devens 4</td>
<td>1728</td>
<td>16.3</td>
<td>25.0</td>
<td>153%</td>
<td></td>
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<tr>
<td>Devens 7</td>
<td>1952</td>
<td>18.2</td>
<td>37.5†</td>
<td>206%</td>
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<tr>
<td>Devens 8</td>
<td>1524</td>
<td>13.0</td>
<td>25.0</td>
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<tr>
<td>Easthampton 13</td>
<td>1728</td>
<td>12.1</td>
<td>22.0</td>
<td>182%</td>
<td></td>
</tr>
<tr>
<td>Easthampton 17</td>
<td>1239</td>
<td>11.0</td>
<td>11.0 [22.0]‡</td>
<td>100% [200%]</td>
<td></td>
</tr>
<tr>
<td>Easthampton 23</td>
<td>1132</td>
<td>10.0</td>
<td>11.0 [22.0]‡</td>
<td>110% [220%]</td>
<td></td>
</tr>
<tr>
<td>Easthampton 30</td>
<td>2266</td>
<td>18.1</td>
<td>22.0 [33.7]*</td>
<td>121% [186%]</td>
<td></td>
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</table>

Original installed capacity [Retrofitted Equipment Capacity]
Simplified (2-Point) Space Conditioning
Simplified Space Conditioning

- Takes advantage of low heat loss enclosure ("superinsulated buildings")
- Heat “filters through” interior (partitions, floors, open doorways, interior gains) as fast as is lost through exterior shell
- Previous work: best with smaller houses, bedroom doors open often, constant setpoint
- Being “completely safe”—with a fully ducted system—you still see temperature variations between spaces (but it is “standard practice”!)
ACCA Manual RS (4ºF Difference)

- Highest - lowest temperature
- Omitted bonus room and basements

96% of hours below 4ºF requirement
### Simplified Space Conditioning

<table>
<thead>
<tr>
<th>Location</th>
<th>Lot</th>
<th>Square Feet</th>
<th>% Under 4°F</th>
<th>Sub-Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devens</td>
<td>3</td>
<td>67%</td>
<td>Full data set; bonus room omitted</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>73%</td>
<td>Winter 2012-2013, MSHP on</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>19%</td>
<td>Winter 2013-2014, MSHP on</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>91%</td>
<td>Summer 2013</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>96%</td>
<td>Summer 2012</td>
<td></td>
</tr>
<tr>
<td>Easthampton</td>
<td>13</td>
<td>1795</td>
<td>96%</td>
<td>Full data set</td>
</tr>
<tr>
<td>Easthampton</td>
<td>17</td>
<td>1348</td>
<td>86%</td>
<td>Full data set</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95%</td>
<td>After 2(^{nd}) MSHP retrofitted</td>
<td></td>
</tr>
<tr>
<td>Easthampton</td>
<td>23†</td>
<td>1620</td>
<td>75%</td>
<td>Full data set</td>
</tr>
<tr>
<td></td>
<td></td>
<td>82%</td>
<td>After 2(^{nd}) MSHP retrofitted</td>
<td></td>
</tr>
<tr>
<td>Easthampton</td>
<td>30</td>
<td>2151</td>
<td>Not analyzed (1 head per bedroom)</td>
<td></td>
</tr>
</tbody>
</table>

- Many houses 70%+ under 4\(^{\circ}\)F, complaints rare
- Devens 4, 7, 8 not analyzed—missing data
- Summer performance better than winter—BUT low SHGC, glazing ratios
Two Stories, One MSHP
One Mini Split, Two Floors?

- Design Heating & Cooling Loads:
  - 11 kBtu/hr heating (left); 10 kBtu/hr heating (right)
  - 12.5 kBtu/hr mini split heating capacity at 5 F
- Second floor unit rarely runs (20 F days)
- Design: single mini-split head on first floor
One Mini Split, Two Floors?

- Comfort problems even with “redistribution fan” (continuous exhaust fan from MSHP to master bedroom, ~40 CFM)
- Redistribution fan—edge cases vs. bad cases
Retrofitted MSHPs on 2nd Floor

- Thermal buoyancy matters for distribution, even in very airtight houses (~1.0 ACH 50)!
- 1 MSHP & 2 floors = choose heating or cooling
- Or a really big redistribution system!
Bonus Room Geometry
Comfort Complaint

- Many superinsulated/airtight houses running successfully with two mini split heads
- Comfort complaint in Central MA house
- Custom house plan (first floor bump out, bonus rm)
Comfort Complaint

- Downstairs Ts even
- Constant setpoint
- Front BR warmest
- Rear BR colder
- Bonus room ~50 F (homeowner)
- Worse w. garage open
- BR doors open/closed
- ~300 CFM 50 (0.8 ACH 50)
- Not capacity problem: 2nd floor = 6200 Btu/hour load
Comfort Complaint

Can calculate room relative heat loss/gain at various outdoor temperatures (SWA work)
- But open door data—many hours within 4F of hallway—but warmer exterior temperatures
Bonus Room Not Always Problem

- Comfort complaint → bonus room ≠ Bonus room → comfort complaint!

![Graph showing temperature and electrical use over time for different rooms.](chart.png)
On-Off Temperature Control/Setbacks
Constant-Setpoint Operation

- MSHP works at best efficiency—no big “slug of heat” required (max ~1000 W)
- Single point works best @ constant—heat “filters out” to exterior rooms from the core
On-Off Setpoint Operation

- Temperature swings between 60 and 70 F
- System turned off, “coasting” down, then max capacity
- Many hours near maximum capacity (2000 W)
On-Off vs. Constant Setpoint Energy Use

- Hourly kWh vs. outdoor temperature
- Constant setpoint—max ~1500 W for hour
- On-off—many hours 2000 W+
- Little relationship with outdoor T
On-Off vs. Constant Setpoint Energy Use

- Setbacks and on/off usually “done to save energy”
- Superinsulation + airtightness → less benefit from setback (less energy lost during “off” cycle)
- MSHP → recovery from setback (max capacity) is lowest efficiency operation, at worst time of day
- Winter 2012-2013 heating use:
  - 1200 sf constant setpoint = 1385 kWh
  - 1100 sf on-off operation = 2561 kWh
- On off operation—worst outlier vs. REM/Rate prediction (157% of prediction)
Other Items
MSHP Heads per Square Foot

- Square footage sizing methods are suspect
- But square footage per head—provided for reference
- Not intended as “general guidance”

<table>
<thead>
<tr>
<th>Model</th>
<th>AG Square Feet</th>
<th># MSHPs</th>
<th>sf/MSHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victorian</td>
<td>1728</td>
<td>2</td>
<td>864</td>
</tr>
<tr>
<td>Farmhouse</td>
<td>1728</td>
<td>2</td>
<td>864</td>
</tr>
<tr>
<td>Custom Saltbox</td>
<td>1952</td>
<td>3</td>
<td>651</td>
</tr>
<tr>
<td>Ranch</td>
<td>1524</td>
<td>2</td>
<td>762</td>
</tr>
<tr>
<td>Farmhouse</td>
<td>1728</td>
<td>2</td>
<td>864</td>
</tr>
<tr>
<td>Small Saltbox</td>
<td>1239</td>
<td>1 [2]</td>
<td>1239 [620]</td>
</tr>
<tr>
<td>Cottage</td>
<td>1132</td>
<td>1 [2]</td>
<td>1132 [566]</td>
</tr>
<tr>
<td>Custom Home</td>
<td>2266</td>
<td>2 [4]</td>
<td>1133 [567]</td>
</tr>
</tbody>
</table>

Original installed capacity [Retrofitted Equipment Capacity]
Snow Blockage

- Heat pumps: risks of snow blockage of outdoor unit cutting heating capacity in winter
- No evidence of issues at two Zone 5A sites
- Riser blocks or wall brackets recommended

![Image of outdoor air conditioning units with snow blockage on the left and clear units on the right.](image-url)
Summer Dehumidification

- MSHPs modulate → size matched to house load, less oversizing causing humidity problems
- # hours over 60% RH inside measured
- Summer hours over 60% RH
  - 10-20%; 15-25%; 2-10% for various houses
- **MSHPs not a panacea for controlling RH BUT:**
  - Data not compared with 1 or 2 speed ducted systems
  - No complaints
  - No sign if used MSHP “dry mode”
  - Northeast window opening/night cooling
Future Work With Transformations

- At Easthampton, change to 3:1 indoor: outdoor MSHPs on 2nd floor
  - More costly equipment (+50%), less efficient
  - Loss of Massachusetts energy incentive ~$5750/house
- Small ducted air handler in second floor hallway
Conclusions

- MSHPs as single heating source in Zone 5A
- Two-point heating works great in many cases, but problems cases included:
  - Problem geometries (exterior conditions on 5 sides)
  - Single point in two-story houses
  - Extended bedroom door closures
  - Setbacks and on/off cycling (worse energy use too!)
- ~1100+ sf/head were the problem cases
- Oversizing MSHPs for heating okay strategy
- Use of small air handler on second floor—door closures no longer a concern
Questions?

Kohta Ueno
kohta [at] buildingscience [dot] com
Single Floor Distribution Issues
Single Floor Distribution

- Temperature/RH Sensor
- Door Closure Sensor

First Floor
- Bathroom

First Floor T
- Kitchen

First Floor BR
- Living-Dining

Stairs T
- Upstairs

11 CFM
- 41 CFM
Think about the path that thermally buoyant or denser/cooled air will take!

In general, open floor plans had few problems—point air leak issue instead
- First winter—basement uninsulated
- First floor vs. second floor unit
Hourly Power Use vs. Temperature

- Winter design T
- Summer design T
- Spare Capacity @ Design

Heating input kW
Cooling input kW

Outdoor T (F) vs. Hourly kWh Sum (Avg kW)
Mini split “blowing into open door?”