Background

Supporting Zero Energy Ready Homes

- Transformations, Inc. currently building net-zero homes in Massachusetts
- Mini split heat pumps (MSHPs) part of builder’s strategy: tradeoffs
- Single point of heating/cooling on each floor
- Researching how well does this work? How widely can it be applied?

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. Construction

- Triple glazed windows
- 1 ACH 50 typical
- Tankless DHW

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

Mini-Split Heat Pumps (MSHPs)

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

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

**Monitoring Package: 8 Houses, 2 Sites**

**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)

<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>
</tr>
</thead>
<tbody>
<tr>
<td>Devens</td>
<td>3</td>
<td>1728</td>
<td>16.8</td>
<td>25.0</td>
<td>149%</td>
</tr>
<tr>
<td>Devens</td>
<td>4</td>
<td>1728</td>
<td>16.3</td>
<td>25.0</td>
<td>153%</td>
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<tr>
<td>Devens</td>
<td>7</td>
<td>1952</td>
<td>18.2</td>
<td>37.5†</td>
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<tr>
<td>Devens</td>
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<td>1524</td>
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<tr>
<td>Easthampton</td>
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<td>1728</td>
<td>12.1</td>
<td>22.0</td>
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<tr>
<td>Easthampton</td>
<td>17</td>
<td>1239</td>
<td>11.0</td>
<td>11.0 [22.0]*</td>
<td>100% [200%]</td>
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<tr>
<td>Easthampton</td>
<td>23</td>
<td>1132</td>
<td>10.0</td>
<td>11.0 [22.0]*</td>
<td>110% [220%]</td>
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<tr>
<td>Easthampton</td>
<td>30</td>
<td>2266</td>
<td>18.1</td>
<td>22.0 [33.7]*</td>
<td>121% [186%]</td>
</tr>
</tbody>
</table>

Original installed capacity [Retrofitted Equipment Capacity]

Equipment Sizing

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

Hourly Power Use vs. Temperature

Operating Patterns
- Varying wattage draw-modulation
- First vs. second floor; comparison to max 2000 W

- Second floor doing most of cooling
- Started running first floor unit—more even Ts?
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 (4°F Difference)

- Highest - lowest temperature
- Omitted bonus room and basements

Monthly Energy Use

- First winter—basement uninsulated
- First floor vs. second floor unit
### 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>Winter 2012-2013, MSHP on</td>
</tr>
<tr>
<td></td>
<td></td>
<td>73%</td>
<td>Winter 2013-2014, MSHP on</td>
<td>Summer 2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19%</td>
<td>Summer 2013</td>
<td>Summer 2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>91%</td>
<td>Summer 2012</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></td>
<td>17</td>
<td>1348</td>
<td>86%</td>
<td>Full data set</td>
</tr>
<tr>
<td></td>
<td>23F</td>
<td>1620</td>
<td>75%</td>
<td>After 2nd MSHP retrofitted</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>2151</td>
<td>-</td>
<td>Not analyzed (1 head per bedroom)</td>
</tr>
</tbody>
</table>

- Many houses 70%+ under 4°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

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

### 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
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)

**Temperature & Door Status Monitoring**

- But open door data—many hours within 4°F of hallway—but warmer exterior temperatures

**Bonus Room Not Always Problem**

- Comfort complaint → bonus room ≠ Bonus room → comfort complaint!
**Bonus Room Not Always Problem**

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

**On-Off Temperature Control/Setbacks**

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

**Constant-Setpoint Operation**

**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)

Single Floor Distribution Issues
Single Floor Distribution

- 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

### 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>
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<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>
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<tr>
<td>Ranch</td>
<td>1524</td>
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<td>762</td>
</tr>
<tr>
<td>Farmhouse</td>
<td>1728</td>
<td>2</td>
<td>864</td>
</tr>
<tr>
<td>Small Saltbox</td>
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<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**
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 operation (would increase interior moisture levels)

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?

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