BUILDING ENERGY 15
MARCH 3-5, 2015 AT THE SEAPORT WORLD TRADE CENTER

AIA Provider: Northeast Sustainable Energy Association

Provider Number: G338

Minisplit Heat Pumps: Lessons from the Field

Course Number

Marc Rosenbaum and Kohta Ueno

March 5, 2015

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Course Description

Minisplit heat pumps are now used in most high performance homes in New England. Kohta monitored eight homes built by Transformations and Marc has over sixty homes and non-residential buildings with minisplits. After a brief overview of system types, we'll share energy use data as well as comfort and distribution studies, and cover issues with installation, sizing, setbacks, and some of the quirks of this nifty technology. Have fun with two MIT nerds!

Learning Objectives

At the end of the this course, participants will be able to answer:

1 At the end of this session, attendees will be able to identify different configurations of minisplit heat pumps

2 At the end of this session, attendees will understand the range of energy performance achieved by minisplit heat pumps in New England

3 At the end of this session, attendees will understand considerations in selecting a cold climate minisplit heat pump

4 At the end of this session, attendees will understand comfort considerations with non-ducted minisplit heat pumps

Kohta Ueno

Minisplit Heat Pumps:

Lessons from the Field

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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
- Posted on BSC website
- If taking notes… relax

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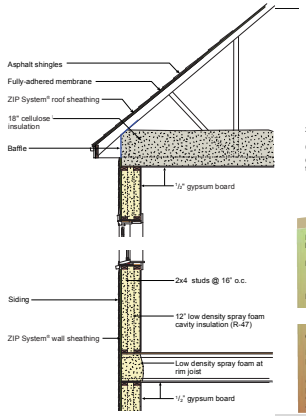
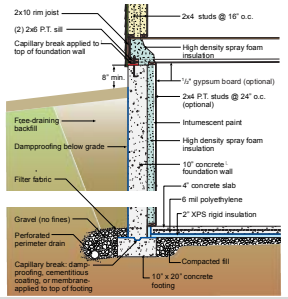
Transformations, Inc. Construction





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

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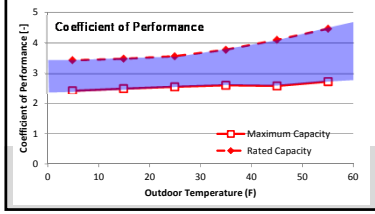
Mini-Split Heat Pumps (MSHPs)

- Installations in Asia/Europe for 40+ years
- More expensive per ton BUT if ductless…
- Mitsubishi equipment: full heat capacity @ -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

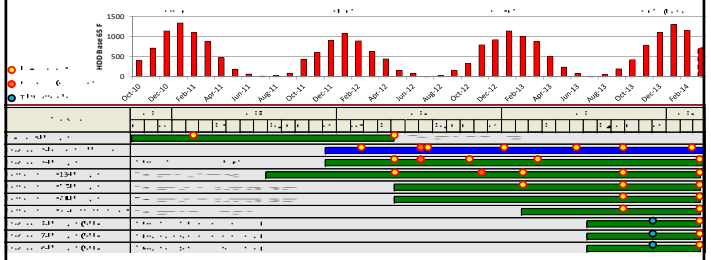


Builder's MSHP Experience

- 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

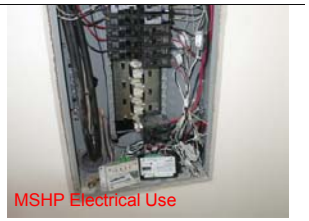
Monitoring Timeline

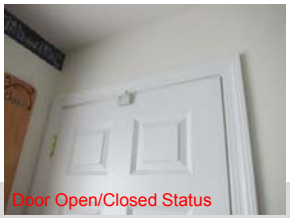


- Eight houses, two sites
- Mixed monitoring package—various sensors (T/RH, doors, power) at different houses

Monitoring Package

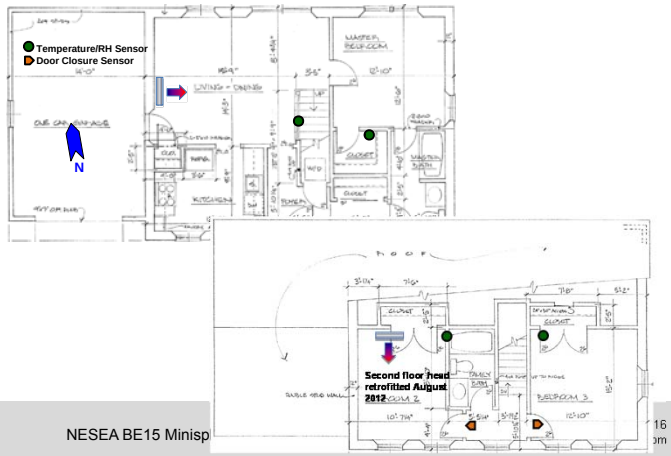

Interior temperature/RH


MSHP Electrical Use


Door Open/Closed Status


Door Open/Closed Status

Monitoring Package: 8 Houses, 2 Sites

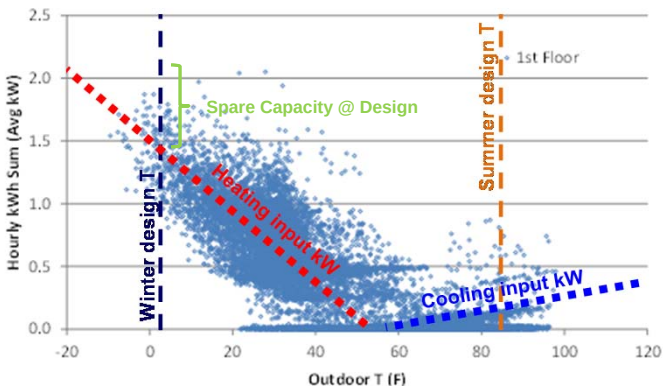


Equipment Capacity

Did MSHPs Meet Setpoint? (Capacity)

- Heat pumps as a single source of heating in Massachusetts (Zone 5A) (design T +2, -2ºF)
- 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 65ºF vs. 6220 HDD 65ºF normal
- When interior temperature was low, unit wasn’t running (or other issues)

Hourly Power Use vs. Temperature



Equipment Sizing

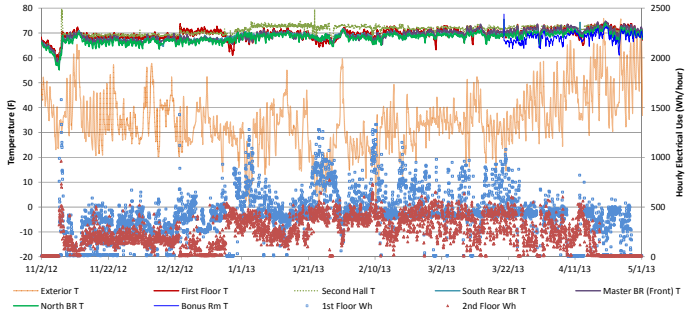
- Oversizing provides heating capacity at low Ts
- Oversizing not as big of a problem with MSHPs—modulating. Short cycling at moderate temps?

Location	Lot	A.G. Square Feet	Heating Design Load kBtu/hr	Installed Equipment Capacity kBtu/hr	Oversizing Factor
Devens	3	1728	16.8	25.0	149%
Devens	4	1728	16.3	25.0	153%
Devens	7	1952	18.2	37.5†	206%
Devens	8	1524	13.0	25.0	192%
Easthampton	13	1728	12.1	22.0	182%
Easthampton	17	1239	11.0	11.0 [22.0]‡	100% [200%]
Easthampton	23	1132	10.0	11.0 [22.0]‡	110% [220%]
Easthampton	30	2266	18.1	22.0 [33.7]*	121% [186%]

Original installed capacity [Retrofitted Equipment Capacity]

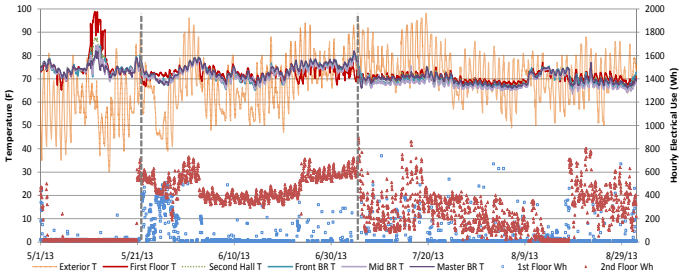
Operating Patterns

Temperature & Power Use Plot



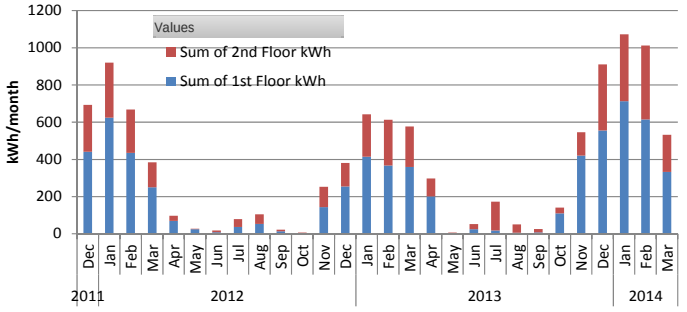
- Varying wattage draw-modulation
- First vs. second floor; comparison to max 2000 W

Temperature & Power Use Plot-Cooling



- Second floor doing most of cooling
- Started running first floor unit—more even Ts?

Monthly Energy Use



- First winter—basement uninsulated
- First floor vs. second floor unit

Simplified (2-Point) Space Conditioning

Simplified Space Conditioning

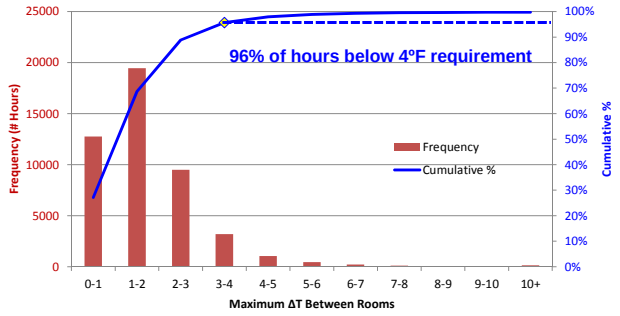
- Takes advantage of low heat loss enclosure ("superinsulated buildings")
- Heat "filters through" interior (partitions, floors, open doorways, interior gains) as fast as is lost through exterior shell
- Previous work: best with smaller houses, bedroom doors open often, constant setpoint
- Being "completely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

Single Point Heating Background

- Used successfully with other superinsulated projects (~R-40 walls, triple glazed windows)
- SWA work: small distribution fans to bedrooms (81 CFM total)
- Conclusion: distributes ventilation air, not heat
- Need ventilation fan when bedroom doors are closed for good ventilation distribution
- Doors closed, ventilation fan on, outdoors ~20° F: Bedrooms dropped ~5° F overnight

ACCA Manual RS (4ºF Difference)

- Highest - lowest temperature
- Omitted bonus room and basements



Simplified Space Conditioning

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

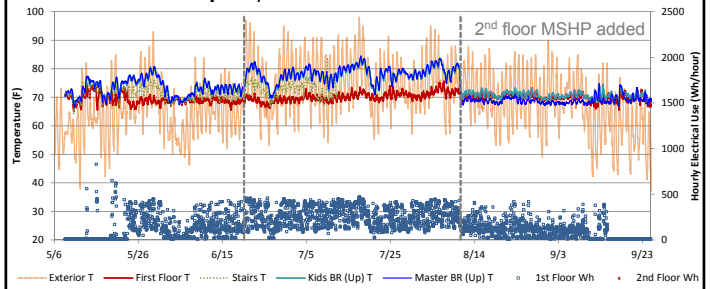
- Many houses 70%+ under 4ºF, complaints rare
- Devens 4, 7, 8 not analyzed—missing data
- Summer performance better than winter—BUT low SHGC, glazing ratios

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)

View from Southeast

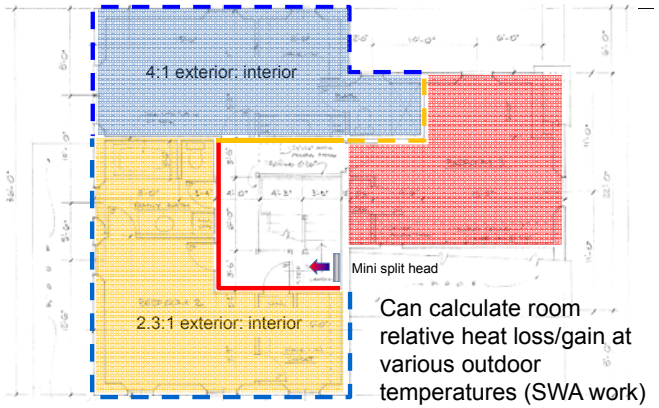
View from Northeast

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

View from East (front)

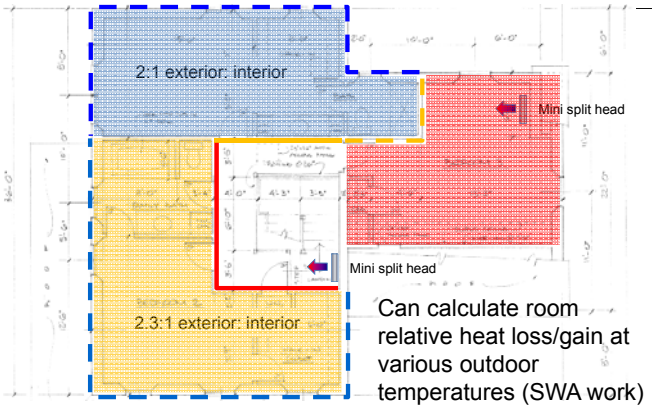
Comfort Complaint



Can calculate room relative heat loss/gain at various outdoor temperatures (SWA work)

NESEA BE15 Minisplit Heat Pumps: Lessons from the Field 37 © buildingscience.com

Comfort Complaint



Can calculate room relative heat loss/gain at various outdoor temperatures (SWA work)

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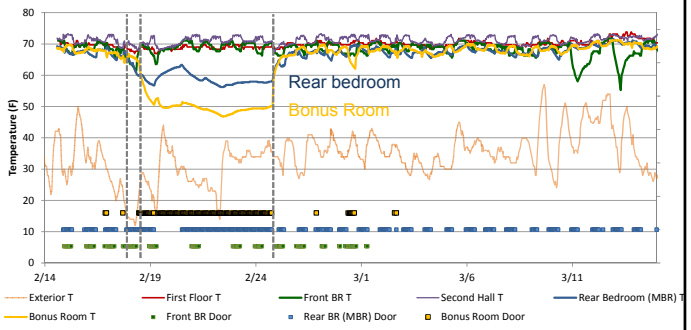
Temperature & Door Status Monitoring



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

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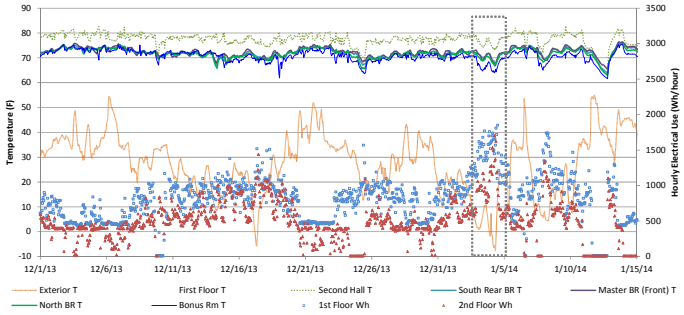
Mini split “blowing into open door?”

Bonus Room Not Always Problem

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



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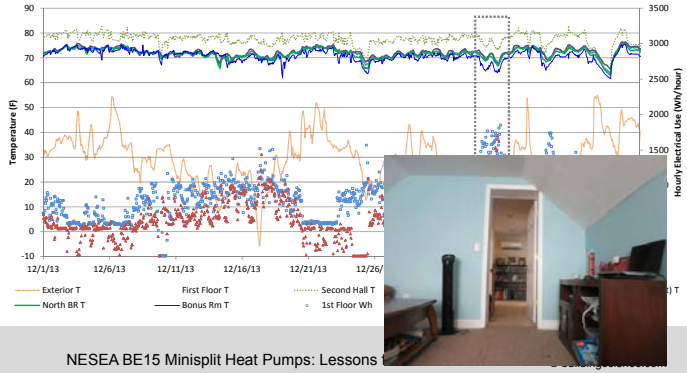
Bonus Room Not Always Problem

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



NESEA BE15 Minisplit Heat Pumps: Lessons

On-Off Temperature Control/Setbacks

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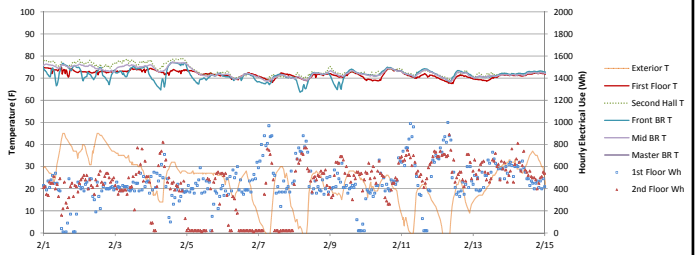
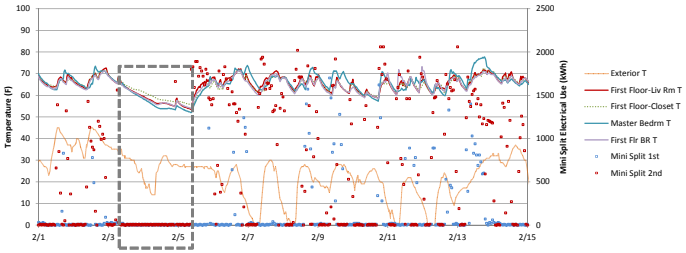
Constant-Setpoint Operation



- 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

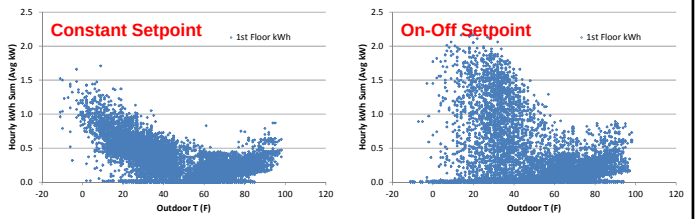
NESEA BE15 Minisplit Heat Pumps: Lessons from the Field 44 © buildingscience.com

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



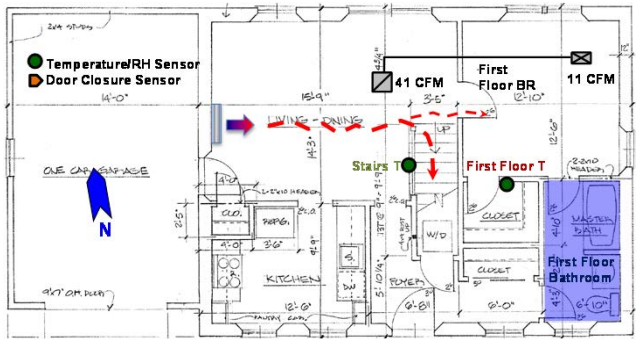
- Hourly kWh vs. outdoor temperature
- Constant setpoint—max ~1500 W for hour
- On-off—many hours 2000 W+
- Little relationship with outdoor T

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



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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

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Other Items

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MSHP Heads per Square Foot

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

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

Original installed capacity [Retrofitted Equipment Capacity]

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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

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

Full report available:

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

NESEA BE15 Minisplit Heat Pump

This concludes The American Institute of Architects Continuing Education Systems Course