Kohta Ueno

Heating and Cooling with Mini Splits in the Northeast

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Building Science Corporation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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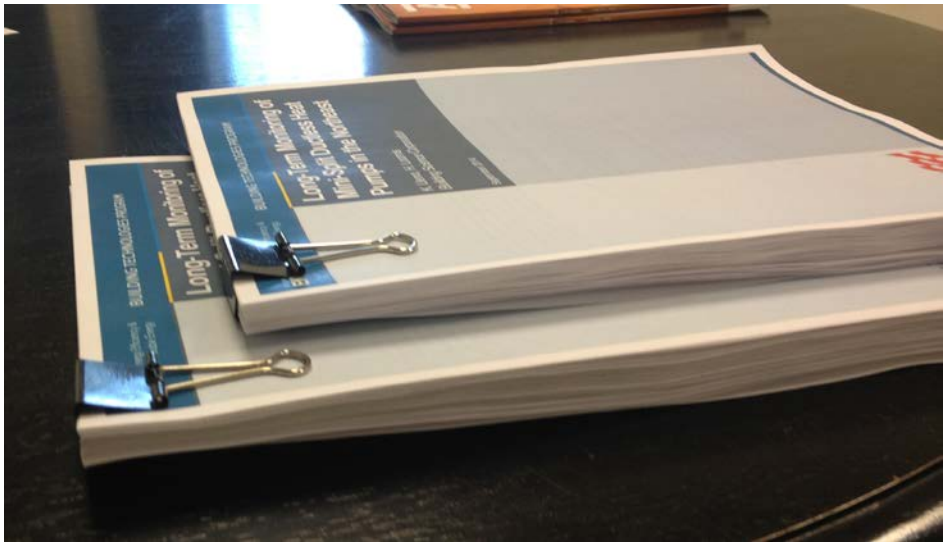
Background

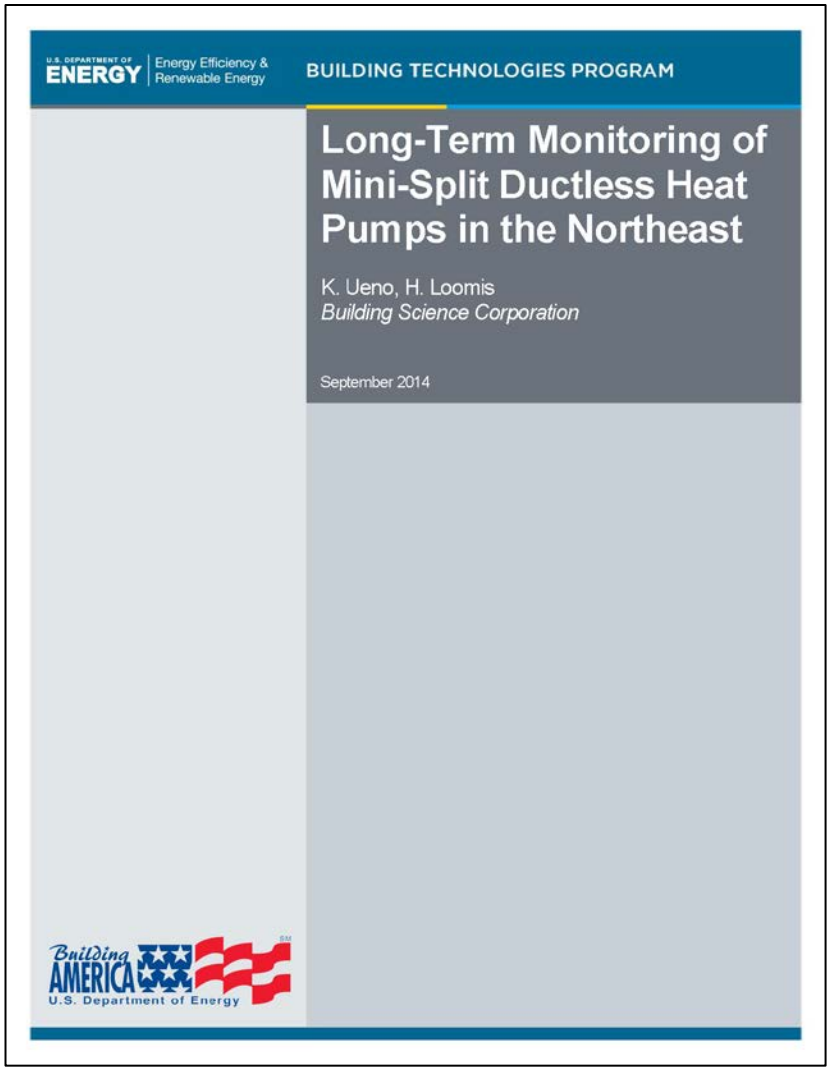
Overview

- 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

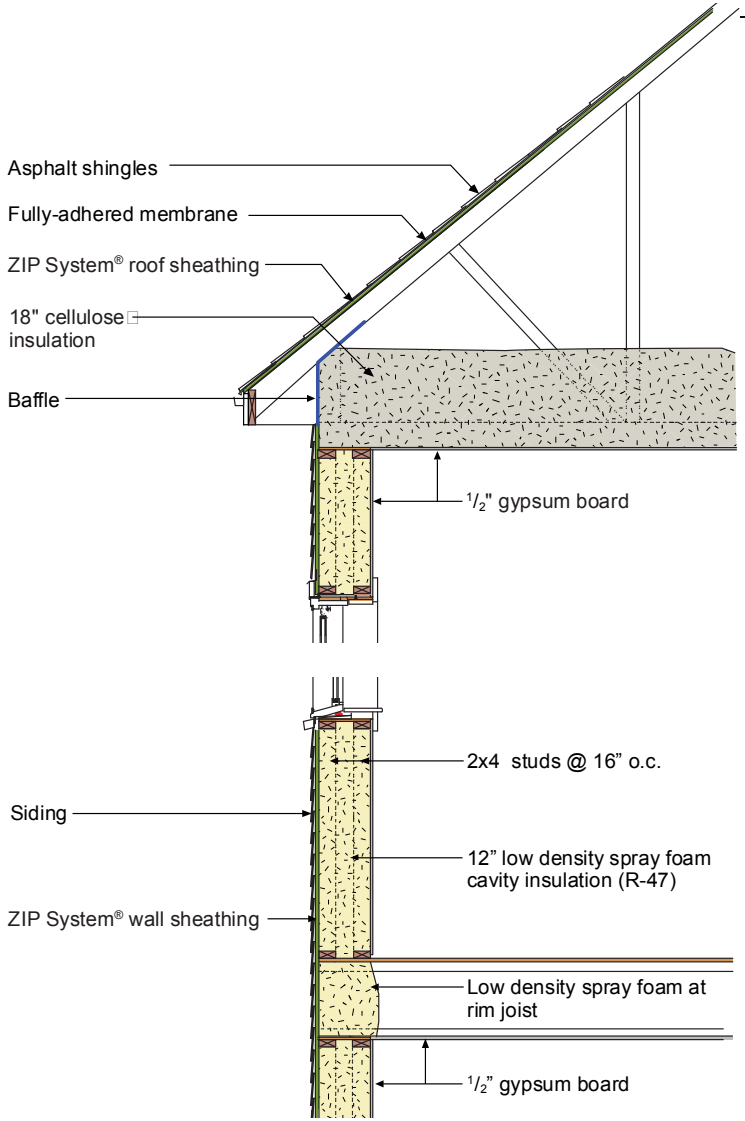
- 140 page brick of a report
- Reports has details, presentation is overview
- Currently in final review
- If taking notes… relax

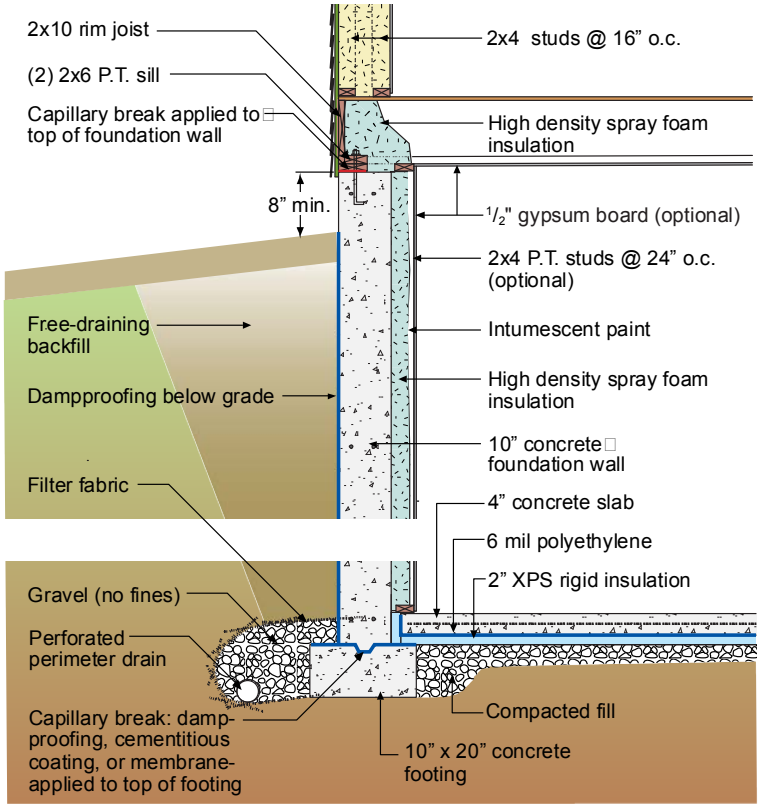




Transformations, Inc. Enclosure/Shell

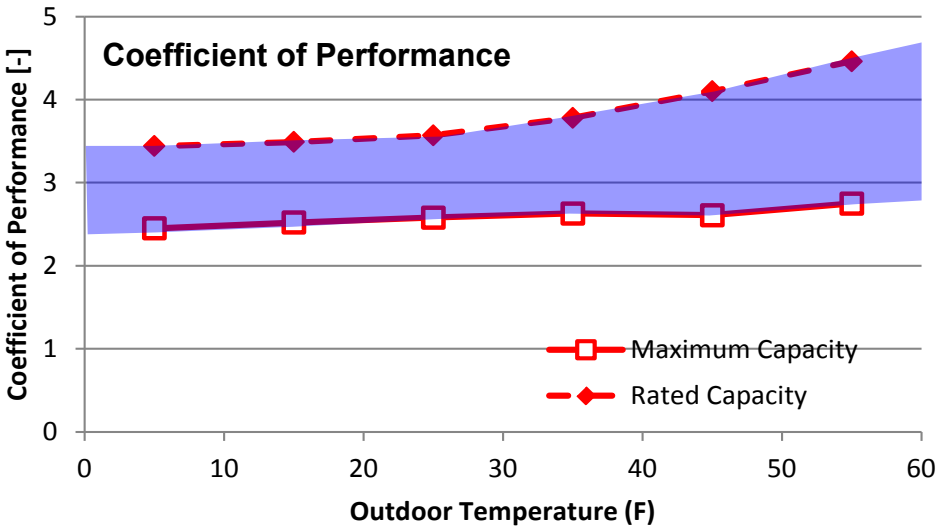
- Triple glazed windows
- 1 ACH 50 typical





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

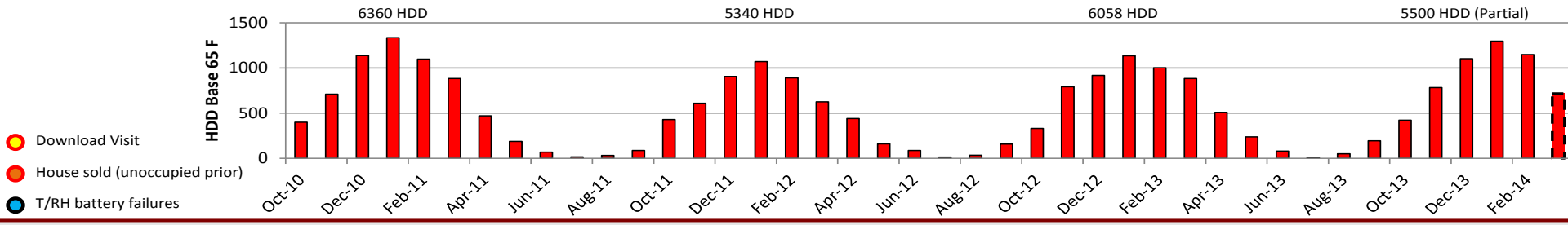


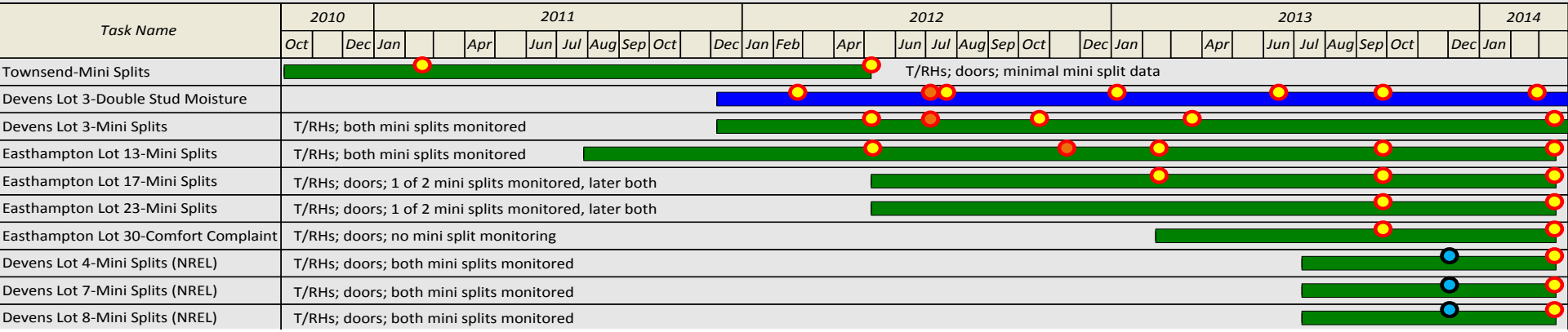
Builder's MSHP Experience

- 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

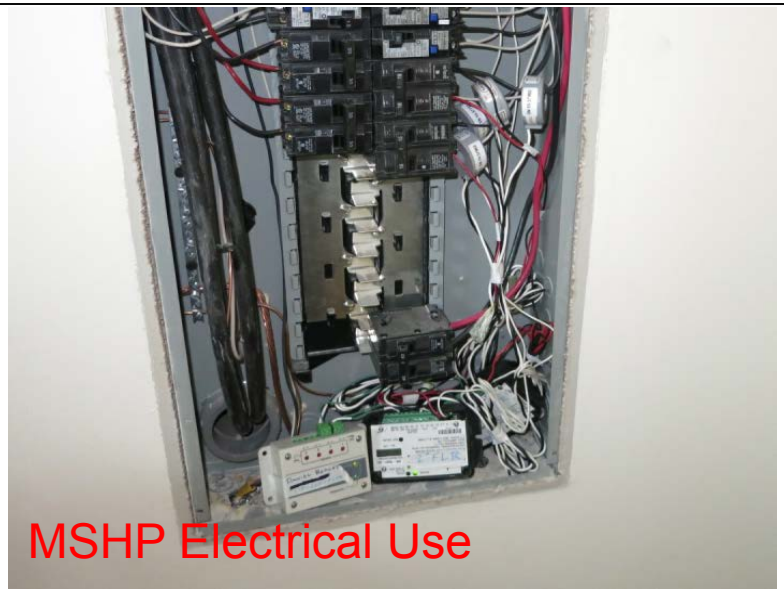


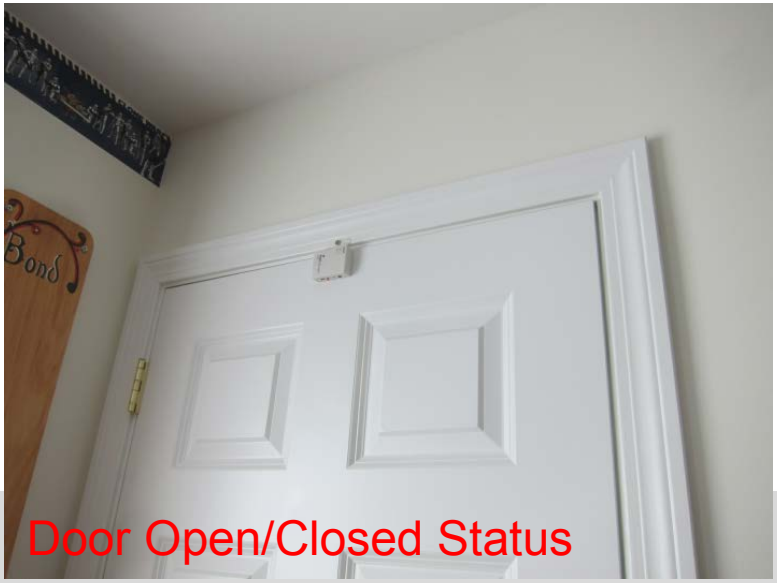


- Eight houses, two sites
- Mixed monitoring package—various sensors (T/RH, doors, power) at different houses

Monitoring Package


Interior temperature/RH

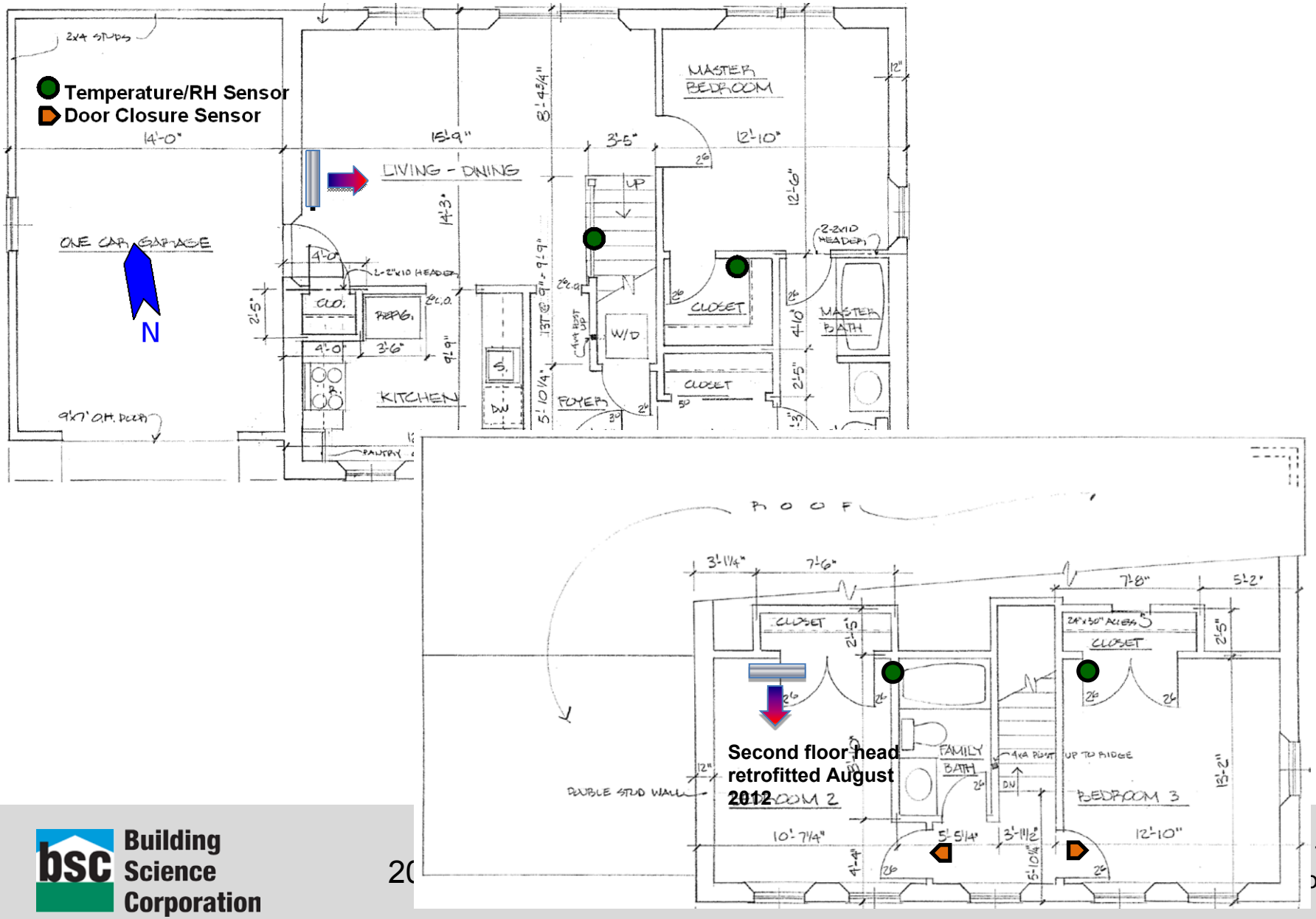

MSHP Electrical Use



Door Open/Closed Status

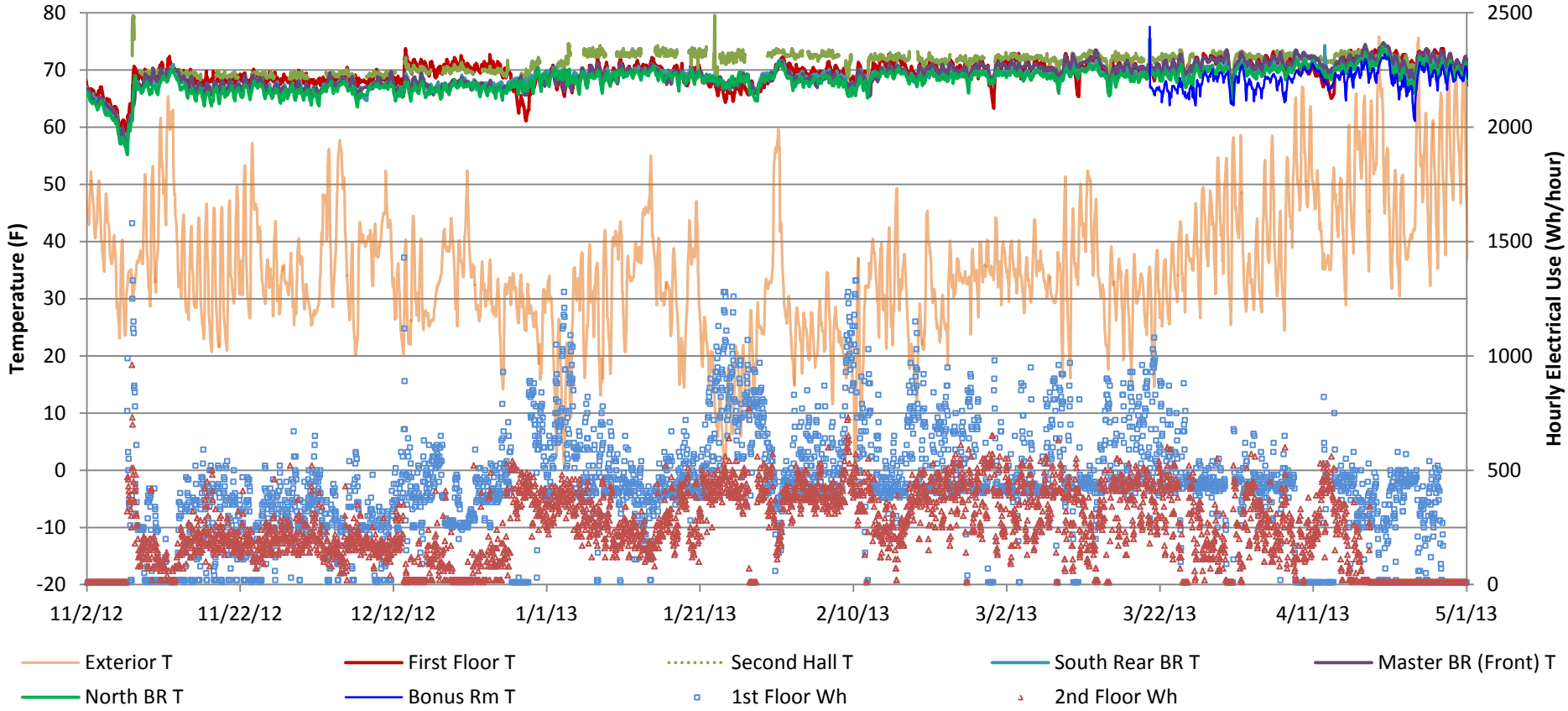

Door Open/Closed Status

Monitoring Package: 8 Houses, 2 Sites



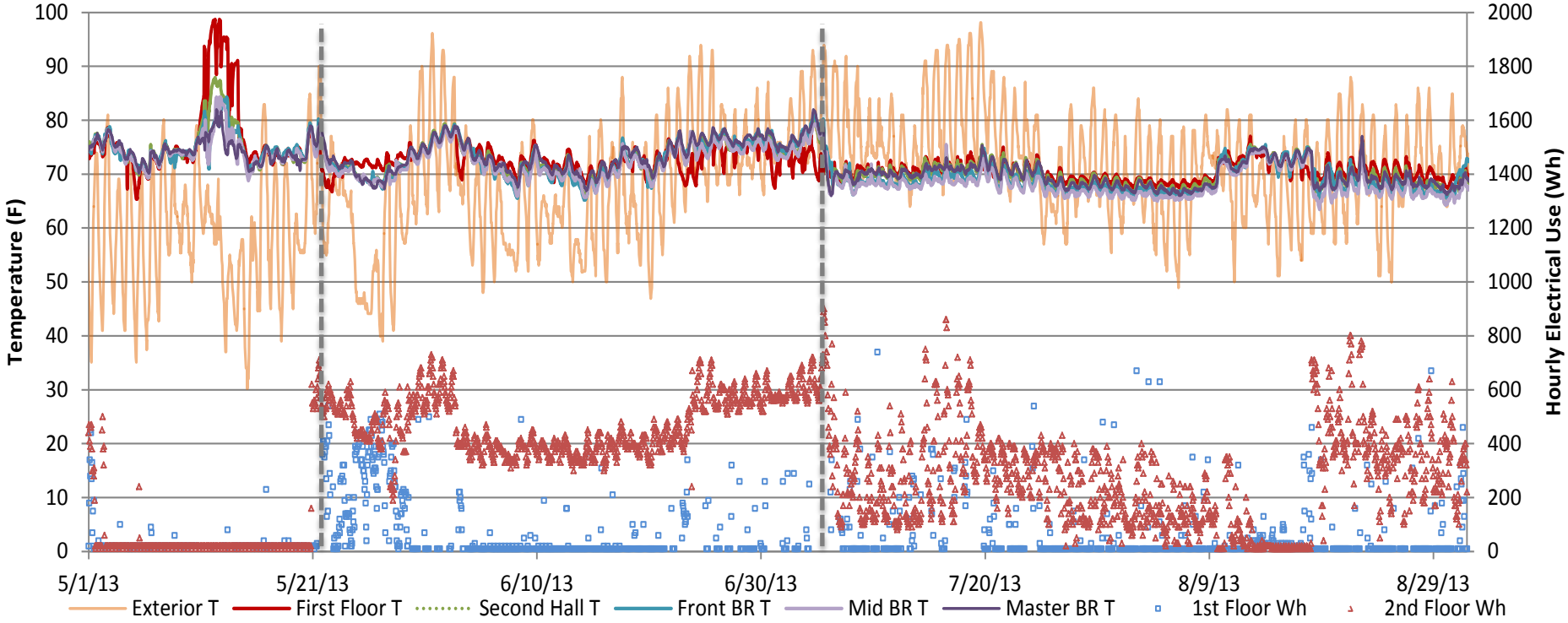
Operating Patterns

Temperature & Power Use Plot



- Varying wattage draw-modulation (5 min data)
- 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?

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 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.

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]

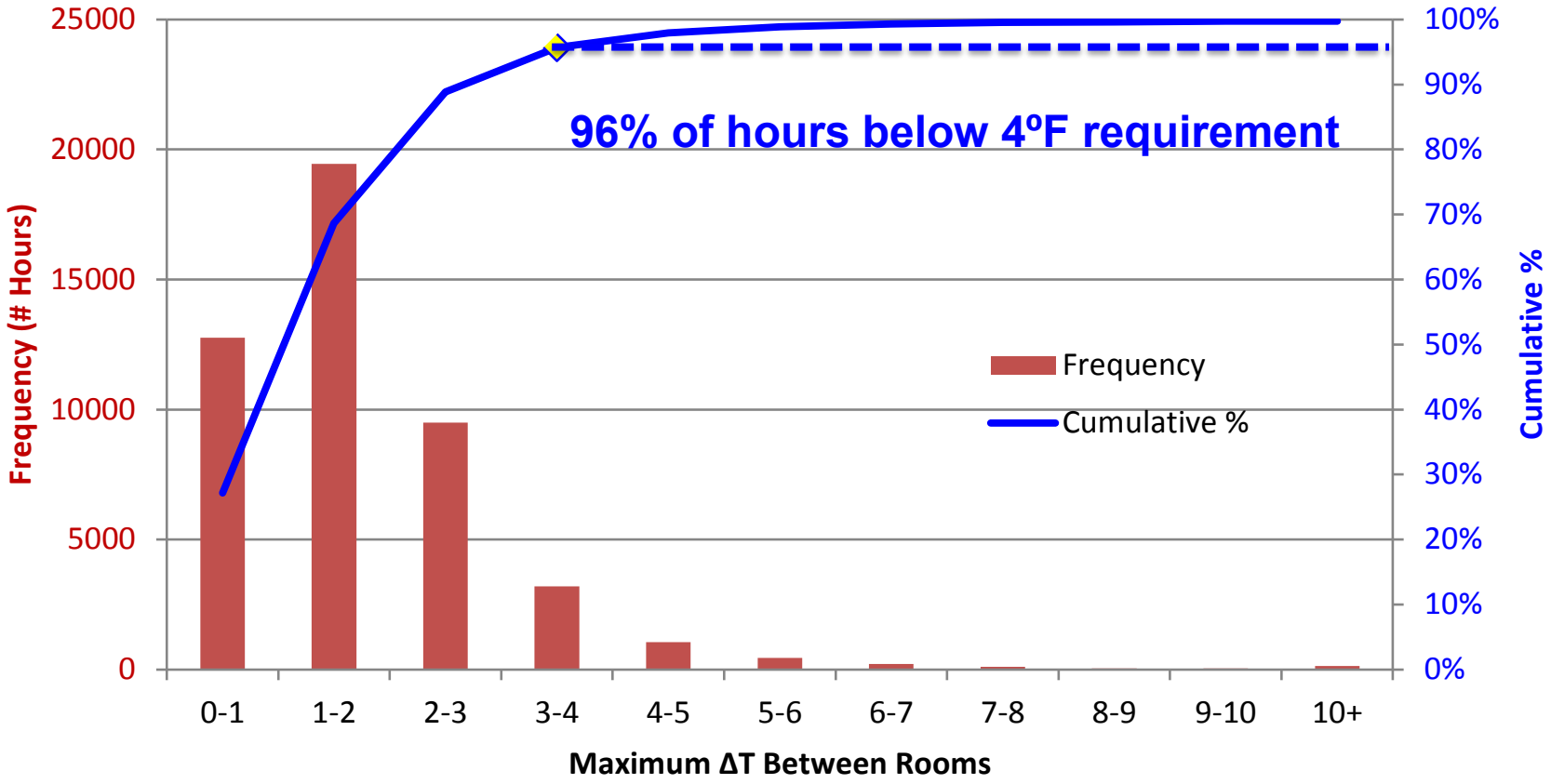
Simplified (2-Point) Space Conditioning

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



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)

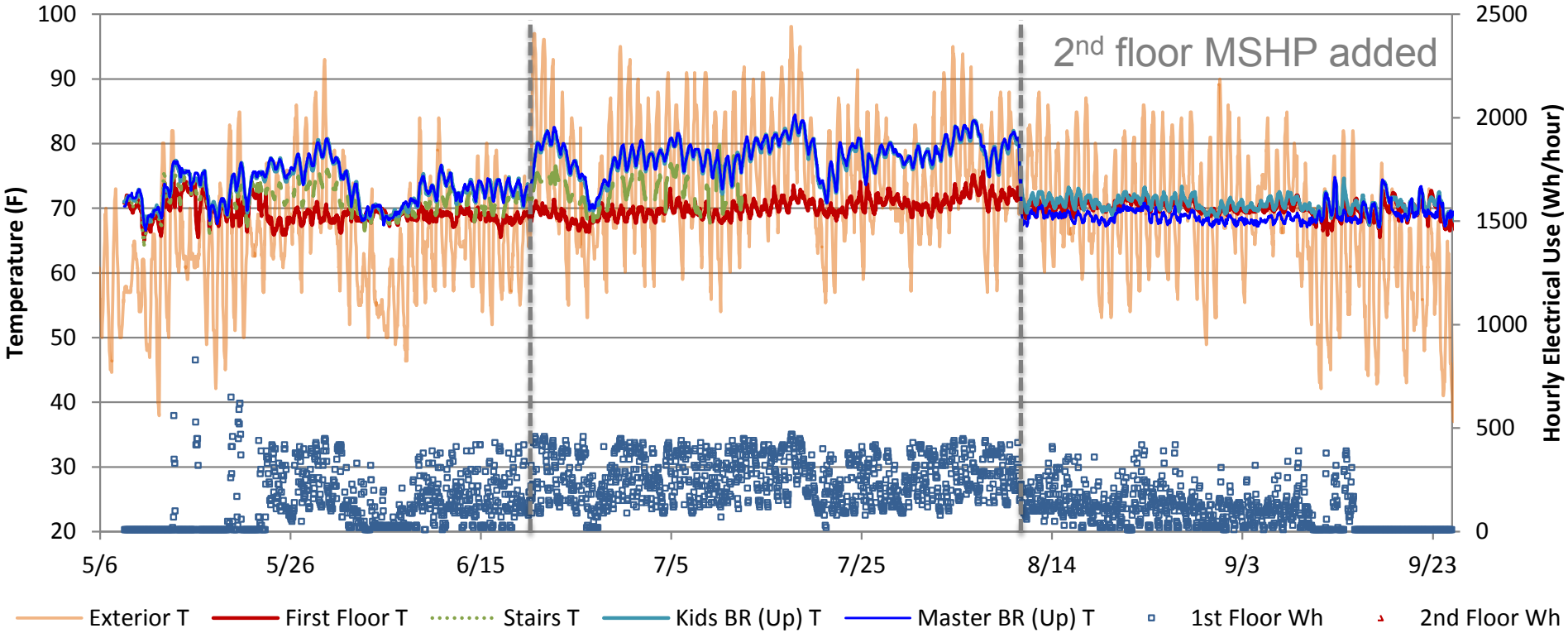
- Many houses 70%+ under 4ºF, complaints rare
- Devens 4, 7, 8 not analyzed—missing data
- Summer performance better than winter—BUT low SHGC, glazing ratios

Two Stories, One MSHP

One Mini Split, Two Floors?

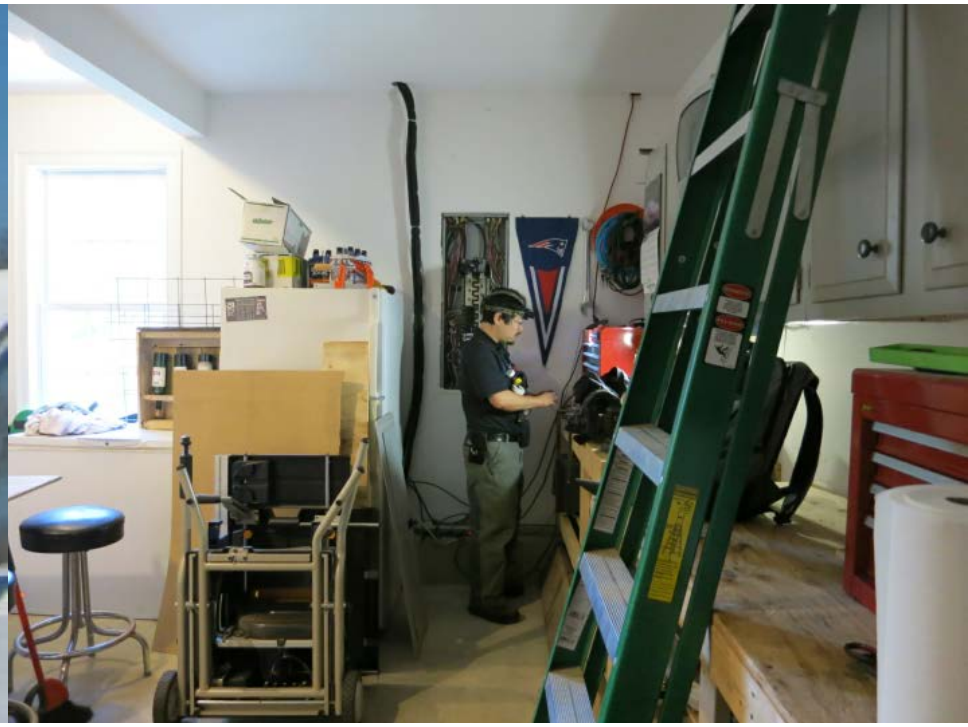
- Design Heating & Cooling Loads:
  - **11 kBtu/hr** heating (left); **10 kBtu/hr** heating (right)
  - **12.5 kBtu/hr** mini split heating capacity at 5 F
- Second floor unit rarely runs (20 F days)
- Design: single mini-split head on first floor

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

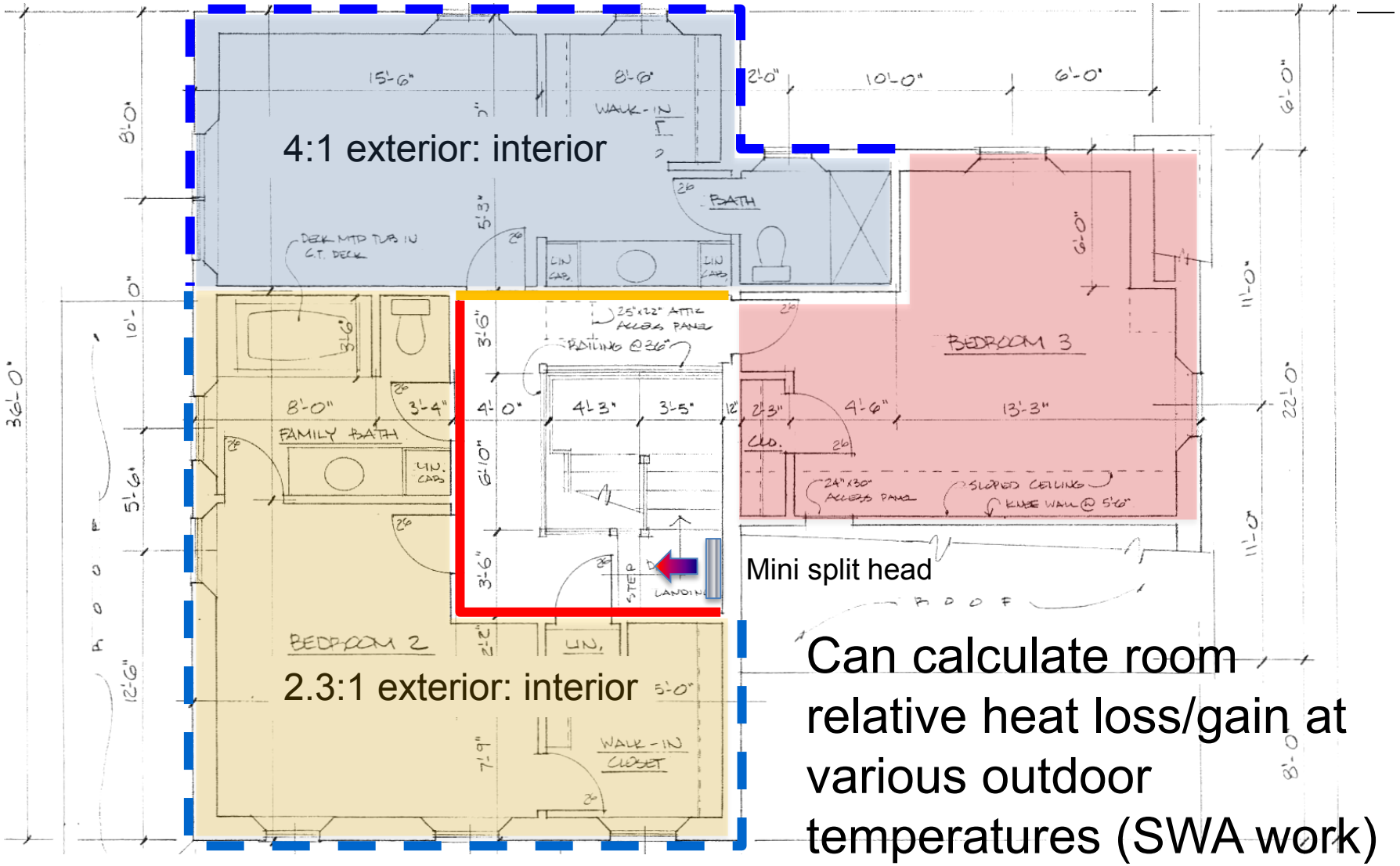
View from Northeast

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

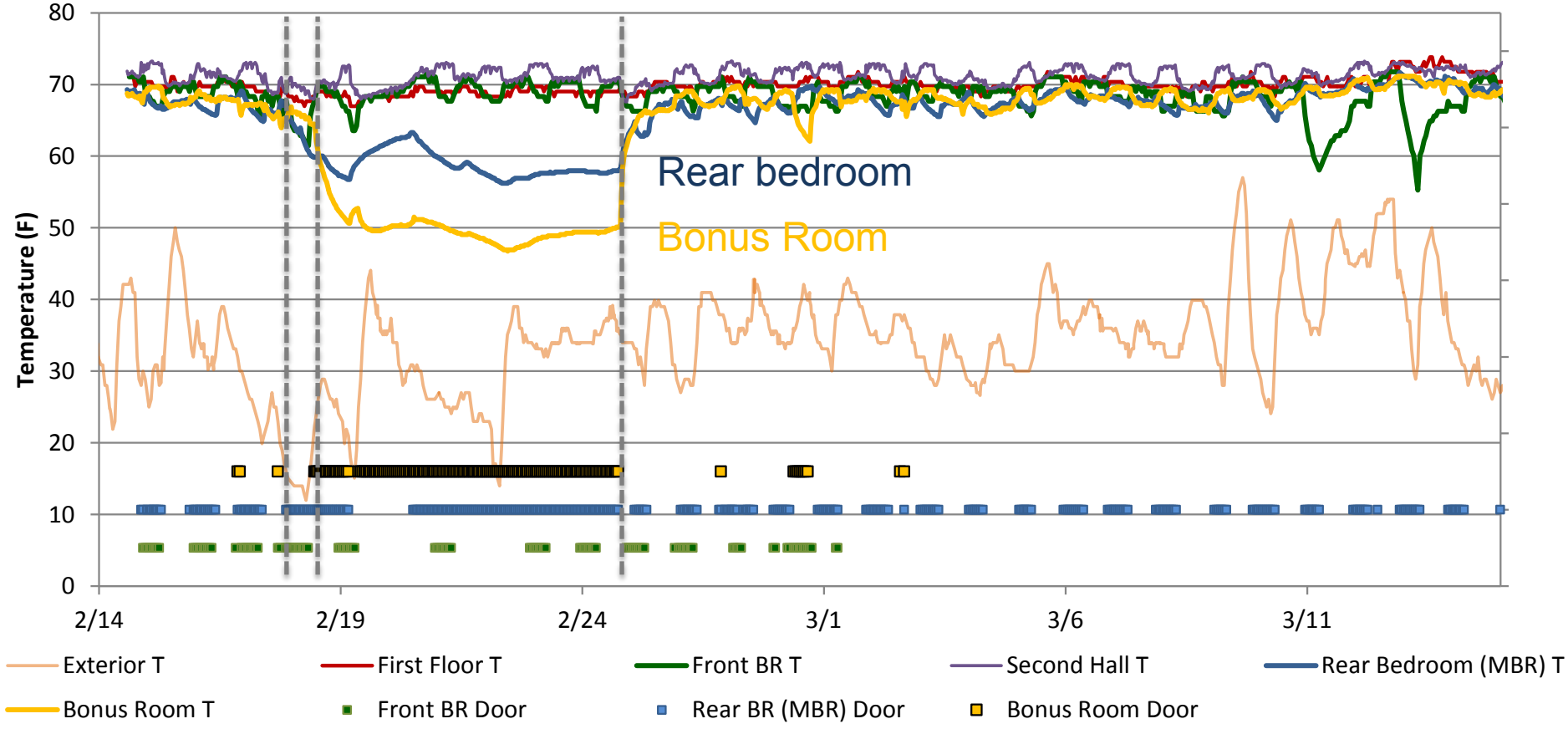

View from East (front)

Comfort Complaint



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

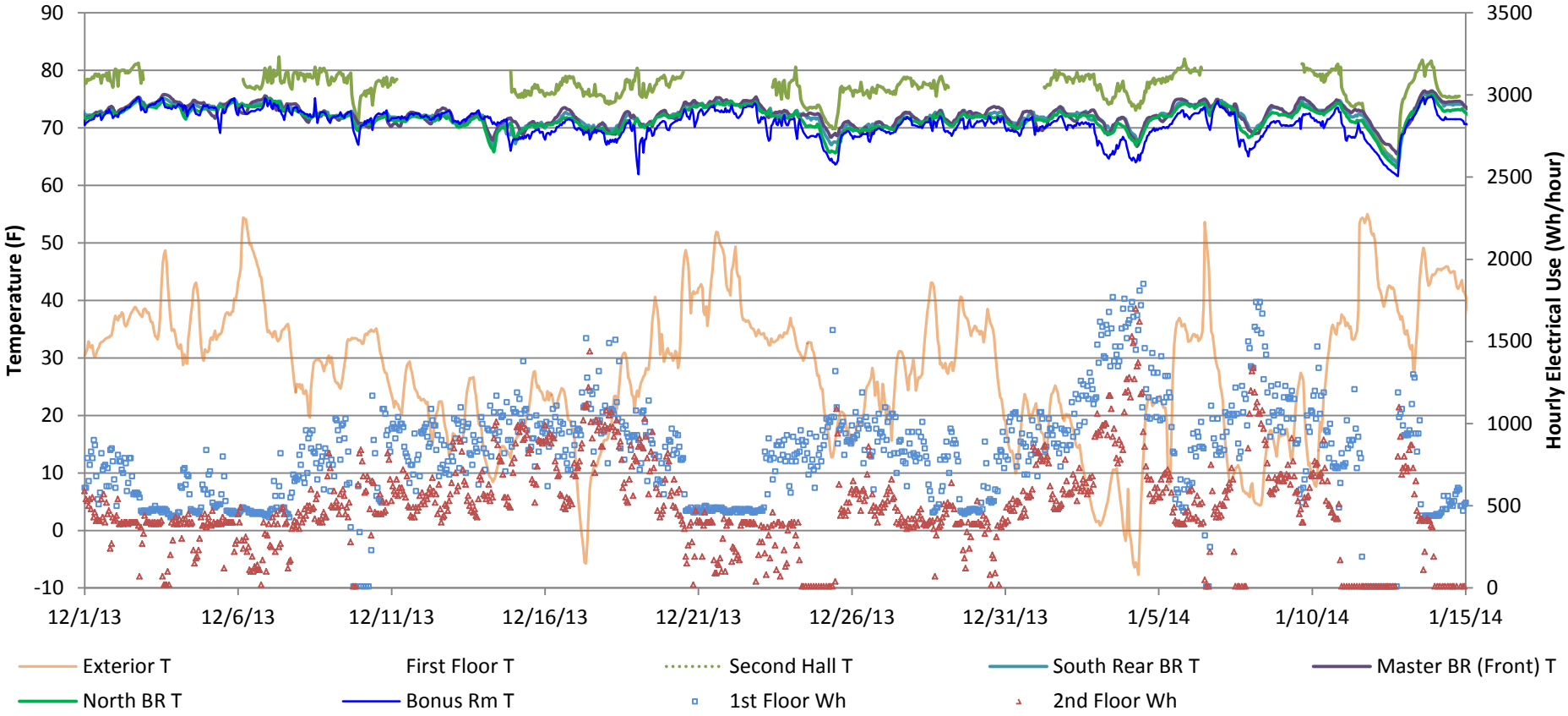
Temperature & Door Status Monitoring



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

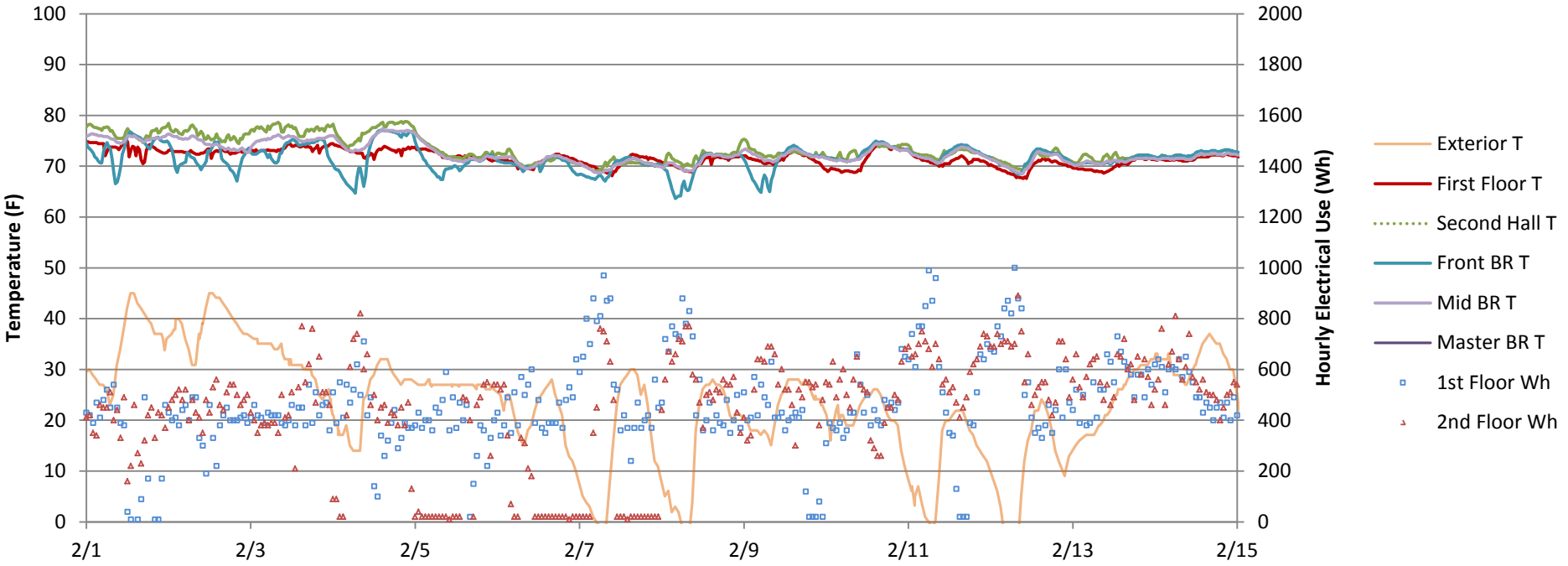
Bonus Room Not Always Problem

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



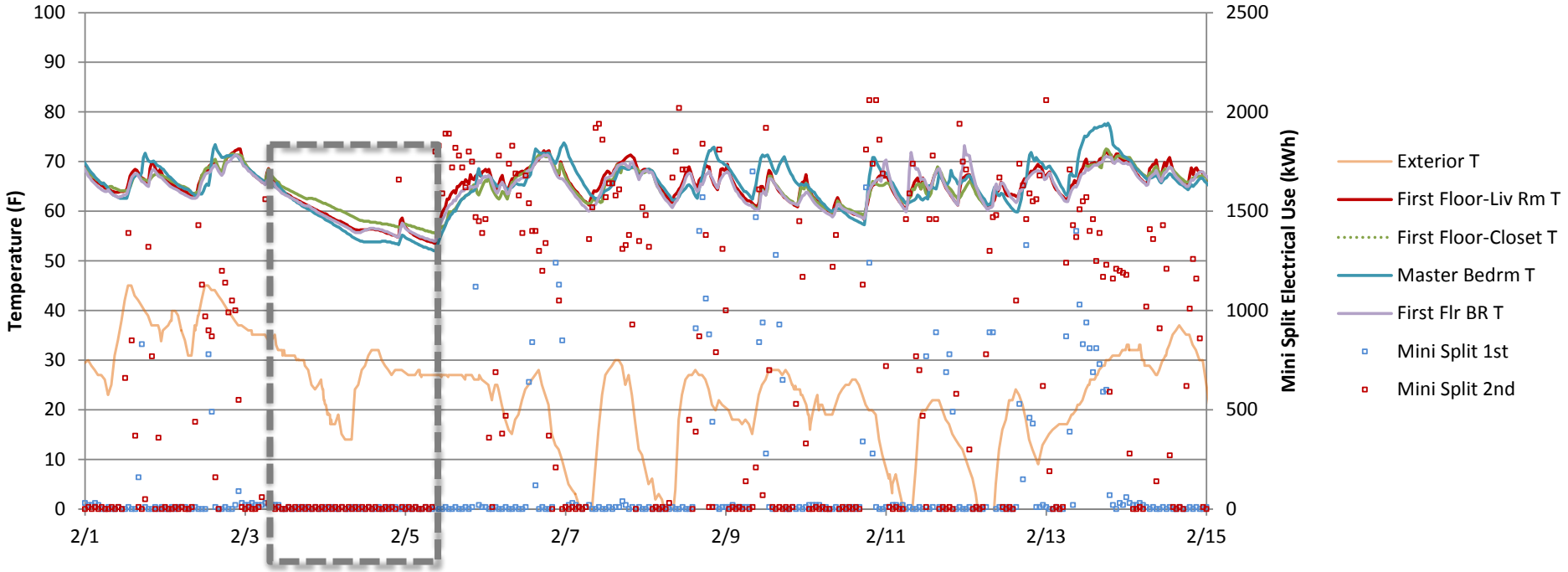
On-Off Temperature Control/Setbacks

Constant-Setpoint Operation



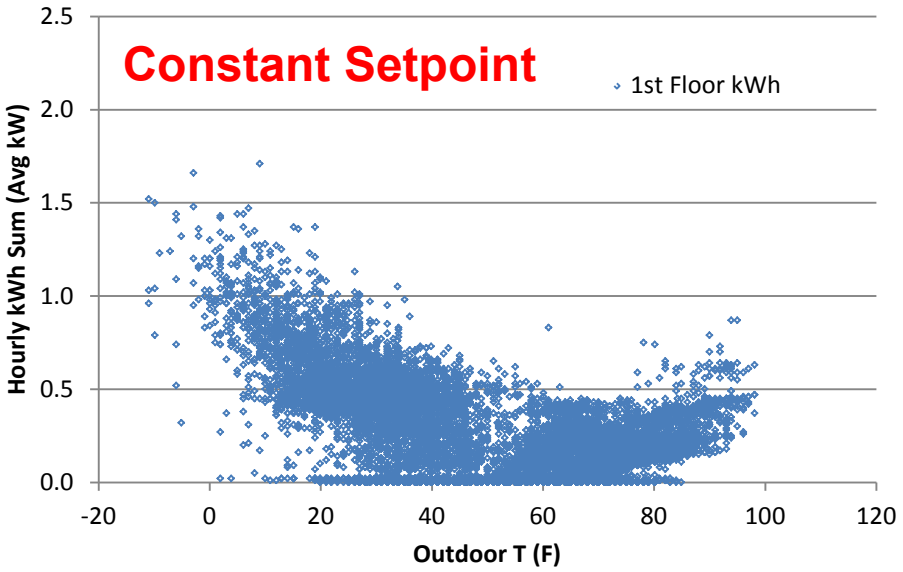
- MSHP works at best efficiency—no big "slug of heat" required (max ~1000 W)
- Single point works best @ constant—heat "filters out" to exterior rooms from the core

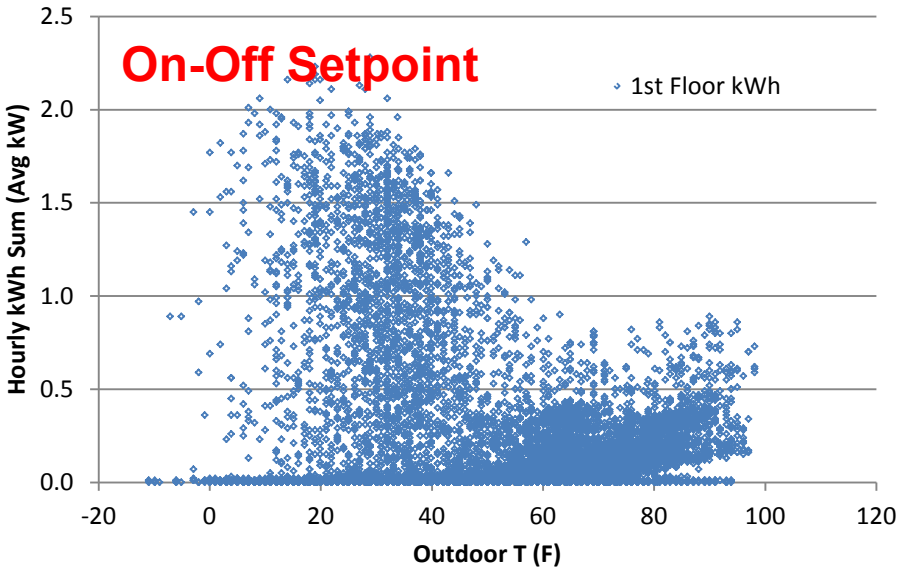
On-Off Setpoint Operation



- 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”

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]

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

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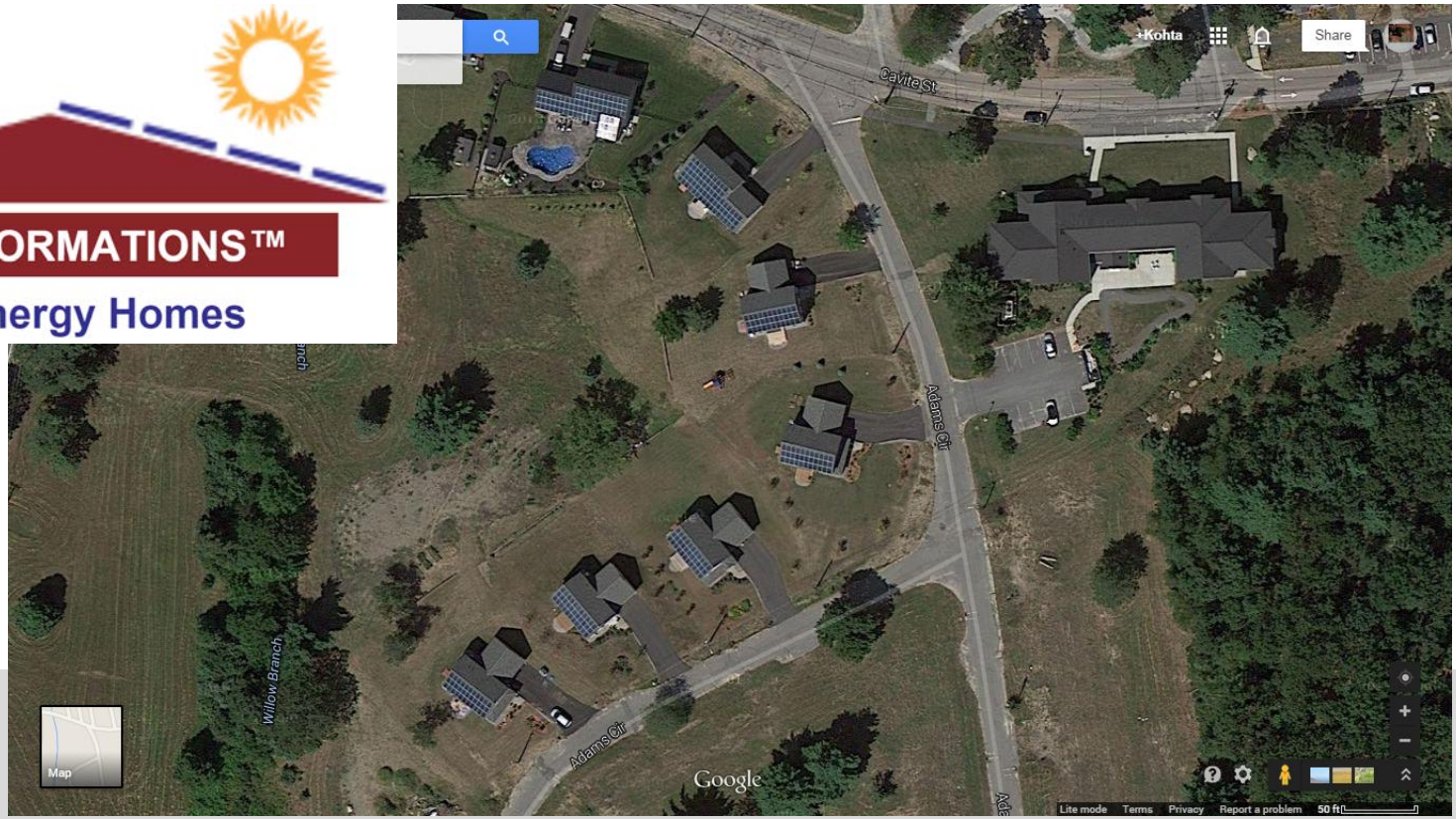

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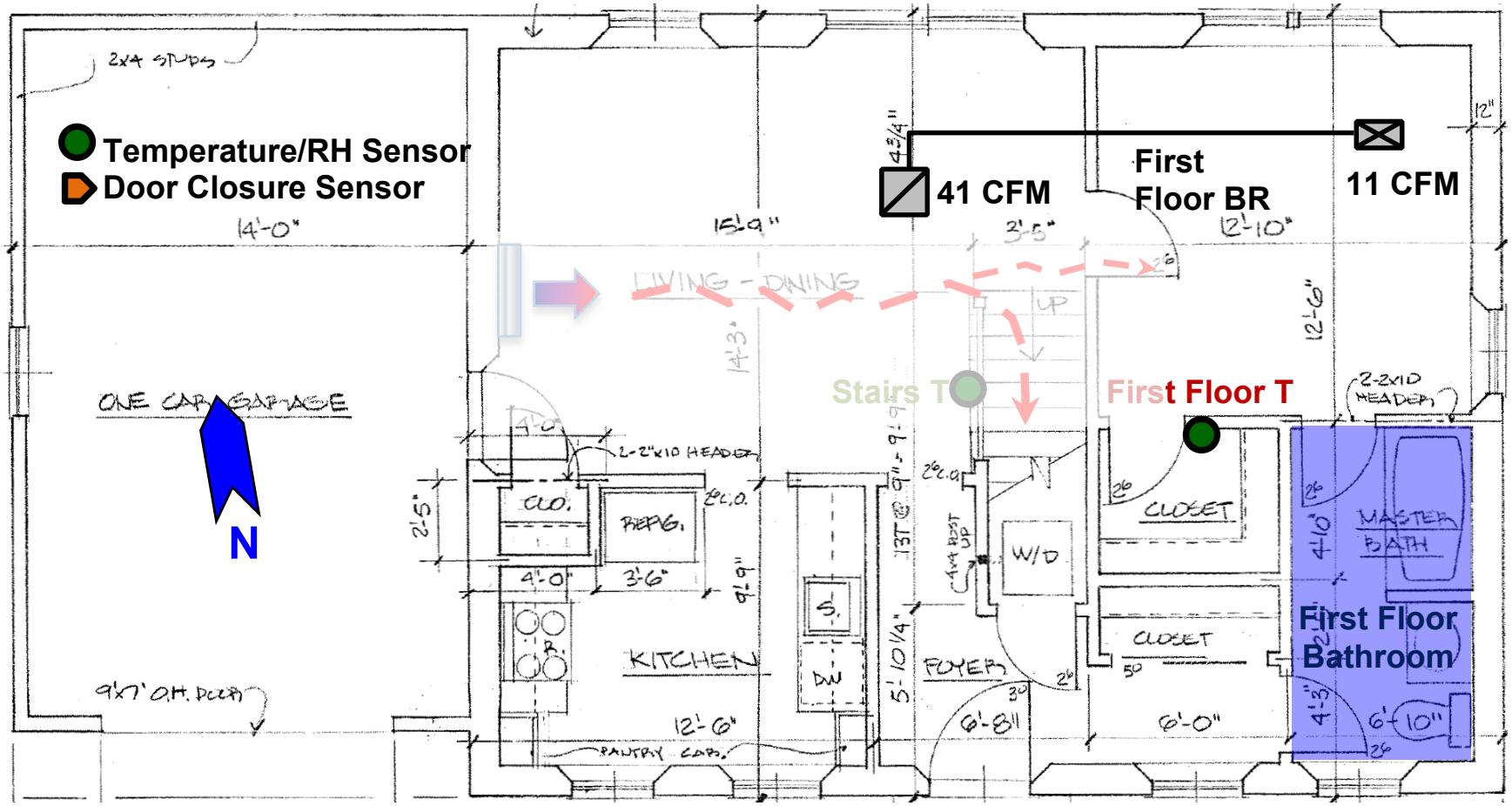
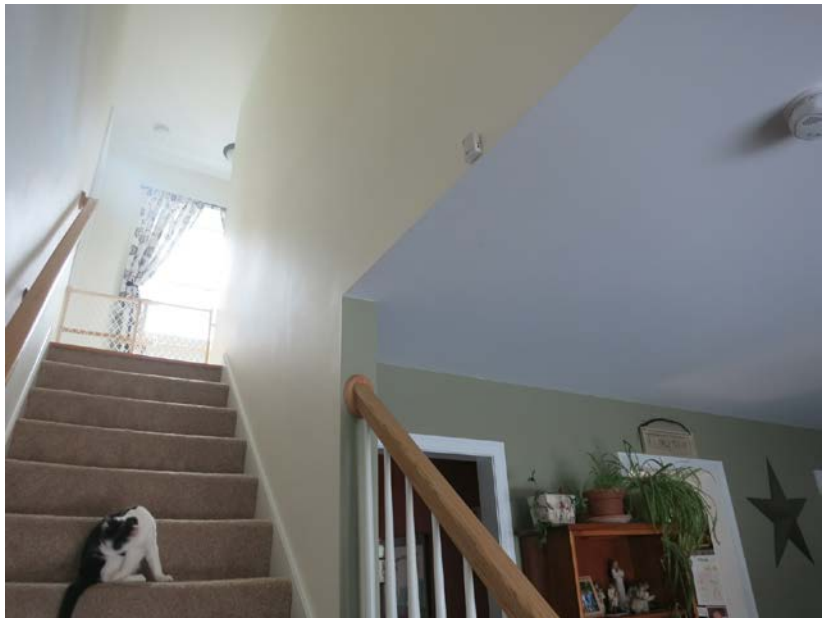
Single Floor Distribution Issues

Single Floor Distribution

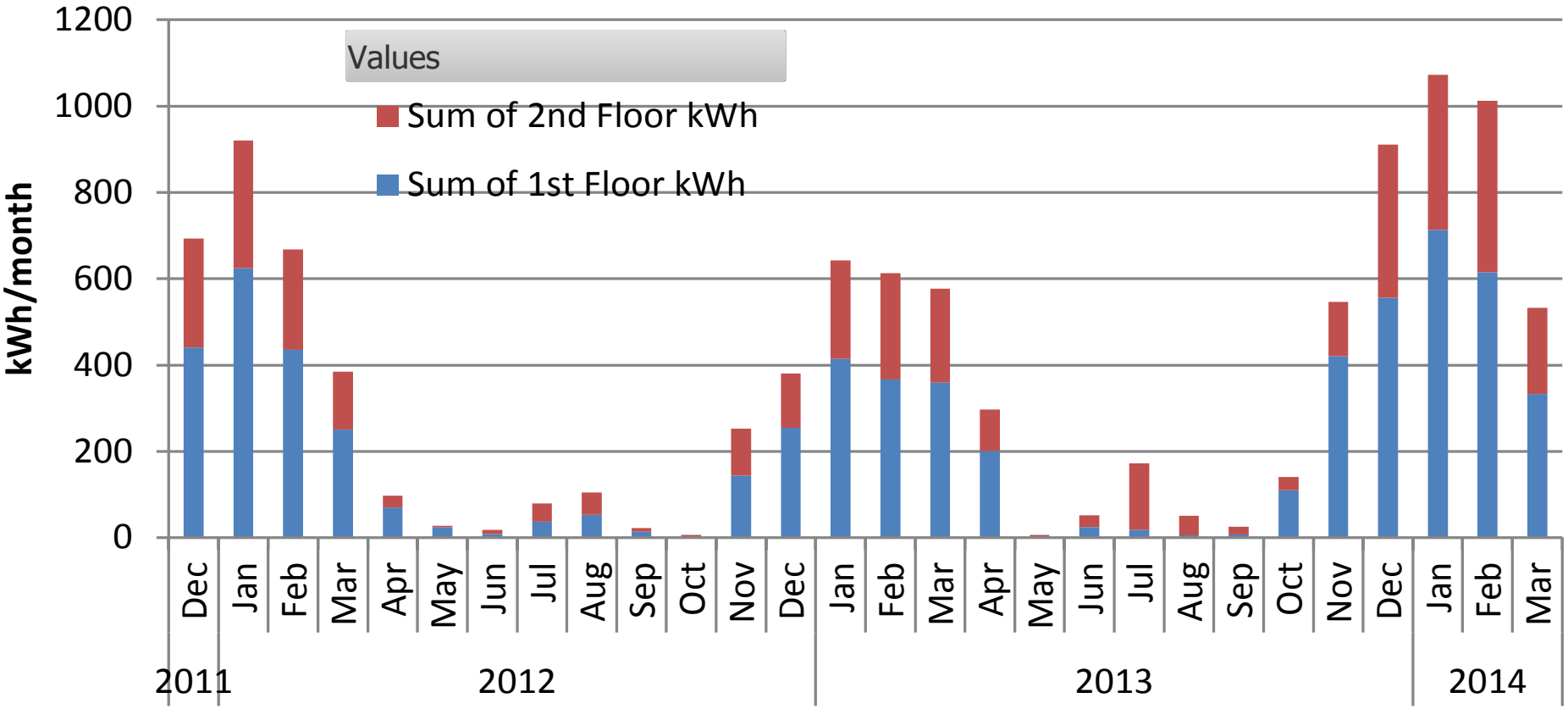


Single Floor Distribution



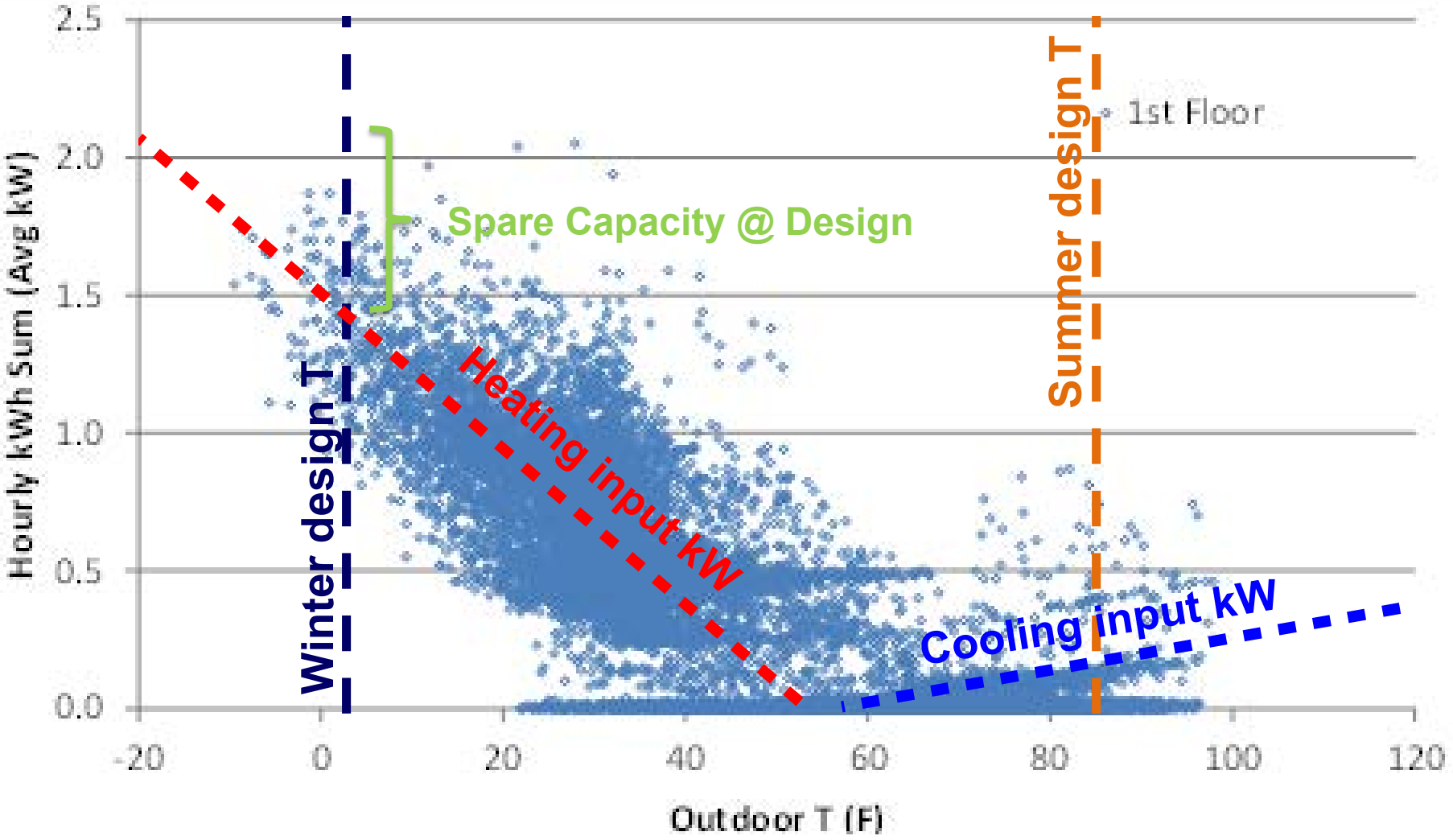
- Think about the path that thermally buoyant or denser/cooled air will take!
- In general, open floor plans had few problems—point air leak issue instead

Monthly Energy Use



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

Hourly Power Use vs. Temperature



Mini split “blowing into open door?”