Kohta Ueno

Residential Deep Energy Retrofits: Lessons Learned

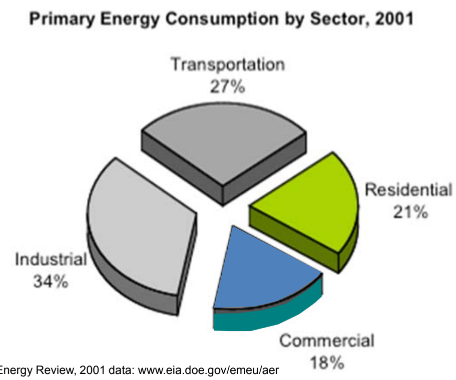
November 16, 2017

Building Science Corporation

AIA New Hampshire

Introduction

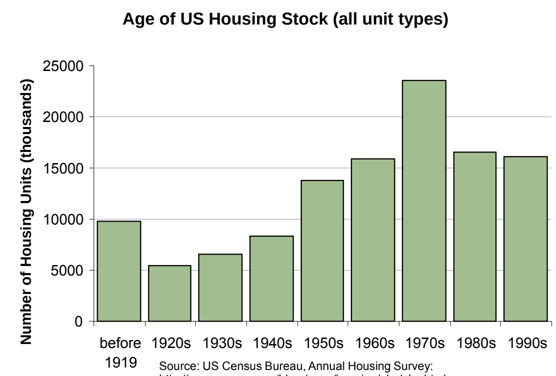
Building Energy Use



Source: EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer

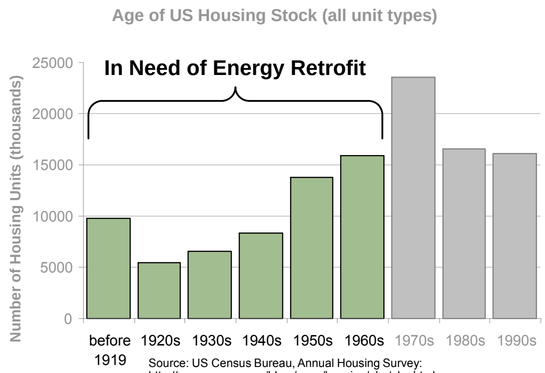
---

Existing Housing Stock



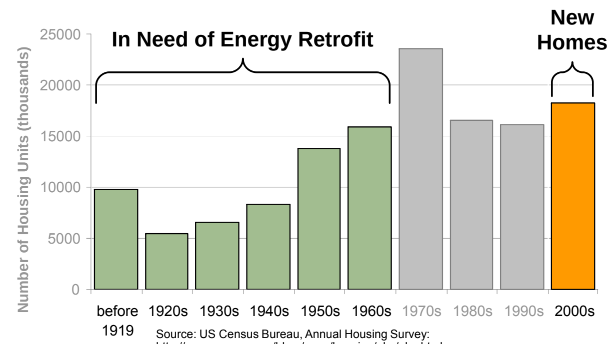
Source: US Census Bureau, Annual Housing Survey: http://www.census.gov/hhes/www/housing/ahs/ahs.html

Existing Housing Stock



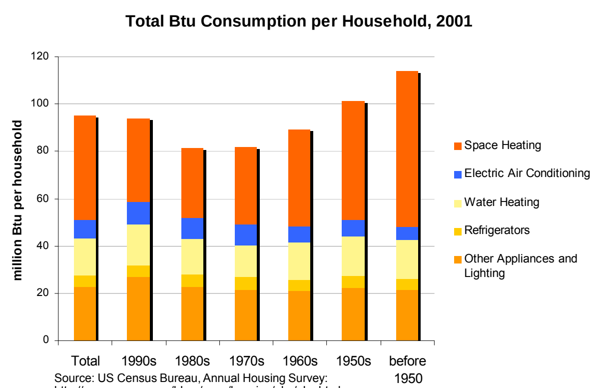
Source: US Census Bureau, Annual Housing Survey: http://www.census.gov/hhes/www/housing/ahs/ahs.html

Existing Housing Stock



Source: US Census Bureau, Annual Housing Survey: http://www.census.gov/hhes/www/housing/ahs/ahs.html

How Old and New Houses Use



Source: US Census Bureau, Annual Housing Survey: http://www.census.gov/hhes/www/housing/ahs/ahs.html

Deep Energy Retrofits

- Significant upgrades are incrementally less expensive
  - Small upgrades very cost effective, but small (10-25% reductions)
  - mid-range upgrades (15-50%) usually really expensive per energy saved
- Deep retrofits (>50%) secure buildings future
  - Allow for new styles, use, etc.
  - Leap frog current housing

National Grid DER Pilot Program

- Residential deep energy retrofit (DER) pilot program
- Incentives ~$35 to $60 K
- R-60 roof, R-40 walls, R-20 bsmt wall, U≤0.2 windows
- 30+ projects
- BSC provided technical guidance for program
- Mass Save DER Guide

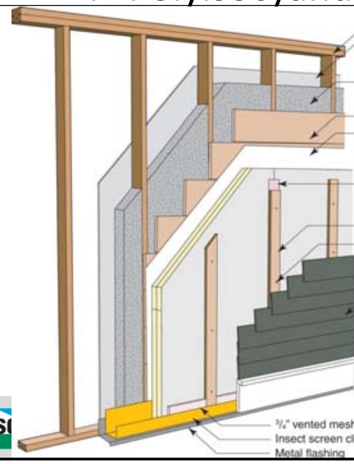
nationalgrid
THE POWER OF ACTION

Walls

Exterior Insulation Retrofits

- Going beyond nominal R-13/R-19 walls = thicker walls
- Exterior retrofit advantages
  - Insulation outboard of vulnerable structure
  - Interior is habitable during retrofit
  - Retain interior finishes (lose exterior finishes)
  - No loss in interior square footage
  - Can inspect condition of enclosure (during cladding removal)
  - Interior stairwells (code minimum widths)

4" Polyisocyanurate Foam



4” Polyisocyanurate Foam

4” Polyisocyanurate Foam

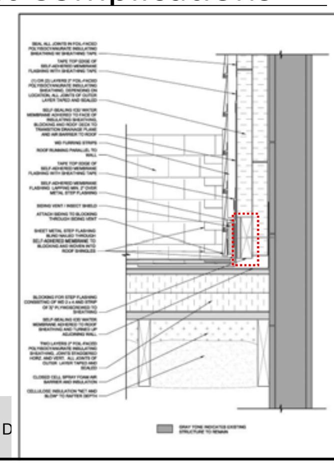
Foam Sheathing Cladding Attachment

250 lbs/113 kg load (7.8 psf): <0.003” deflection

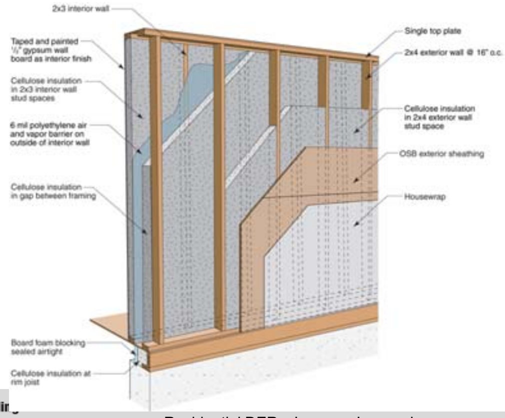
Wood siding ~2 psf
Fiber cement 2-3 psf
Stucco 8-10 psf

Image c/o Petersen Engineering

Exterior Retrofit Complications



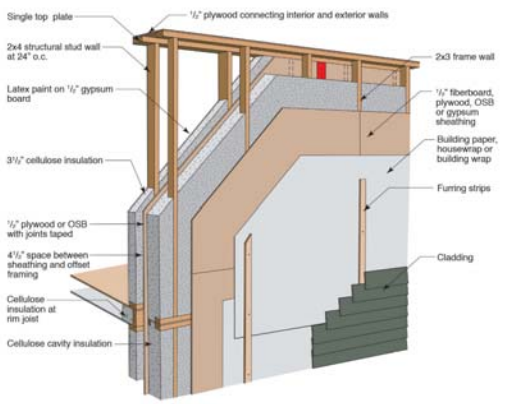
Double Stud Walls (Risky?)



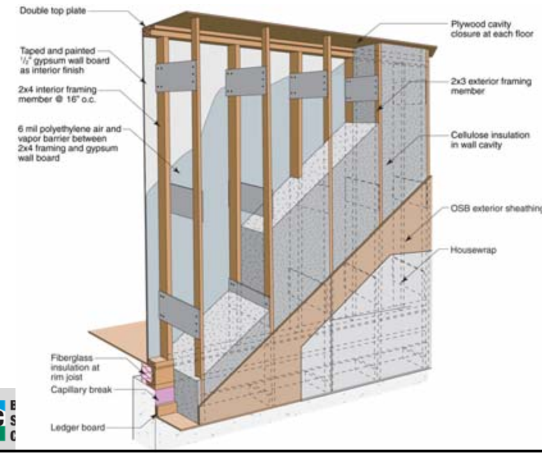
Double Stud Walls

- Double stud wall advantages:
  - High R values
  - Simplifies exterior detailing
    (few changes to standard practice)
  - Lower cost vs. other high-R walls?
- Moisture risks due to interstitial condensation?
  - Most common failure, after rain control issues
  - Air barrier imperfections—increase risk
  - Air permeable low-density insulations—increase risk (including convective looping)
  - Air impermeable insulations—decrease risk
  - Reduce risk with "skim" of spray foam at sheathing?

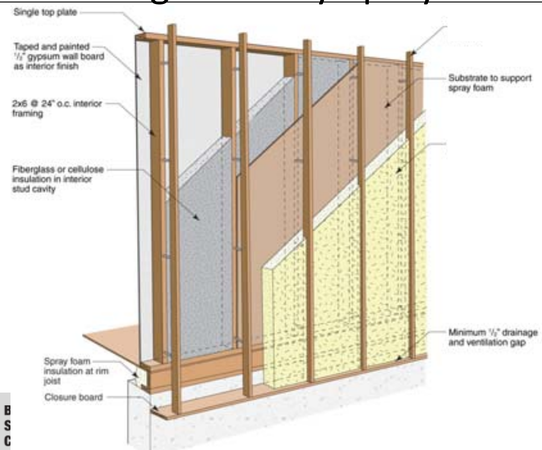
Double Stud Wall w. Robust Air Barrier



Larsen Truss



4-½” High Density Spray Foam



21

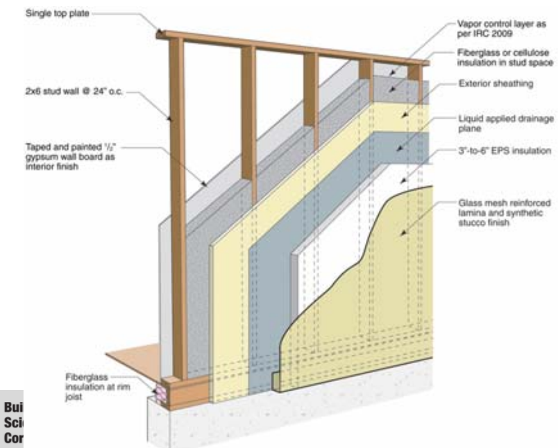
Building Science Corporation

22

Building Science Corporation

23

EIFS Overclad



27

EIFS Overclad

- Insulation
- Protection of existing wall
- Aesthetic improvement?

Metal Panel Overclad

Roofs

Fully Ventilated Attics

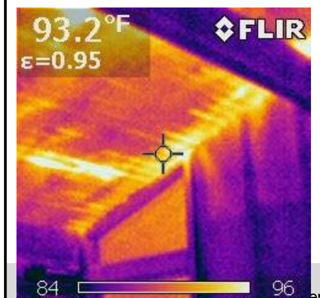
- Can re-roof whenever, with whatever
- Deal with moisture, then add insulation
  - Rain leaks, air leaks
- If possible, keep ventilated attic
  - Inspect ceiling plane, plug all holes with caulking and foam
  - Consider 1" of spray foam air barrier
  - Blow in minimum R60 cellulose, R75-R100 sensible

Fully Ventilated Attics

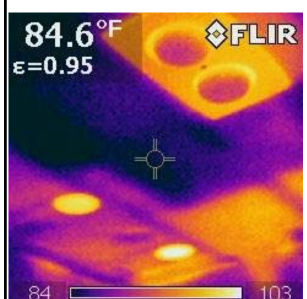
Fully Ventilated Attics

Why an Unvented Roof?

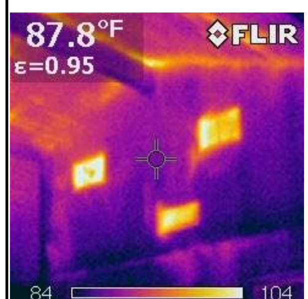
- Difficult air barrier to retrofit @ ceiling plane?
- Leaky ductwork and AHU in attic?
- More space (dormers, bedrooms in attic)?

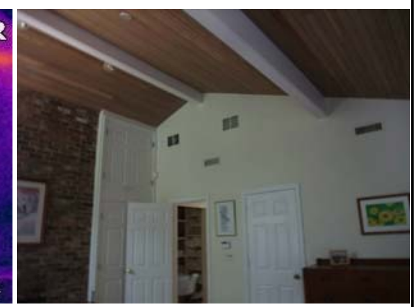


Why an Unvented Roof?

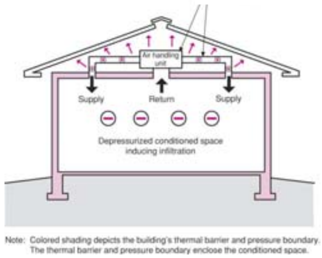


Why an Unvented Roof?

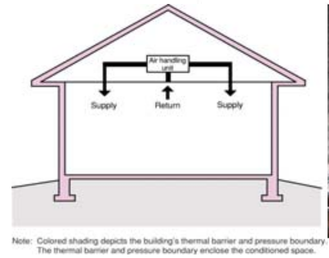




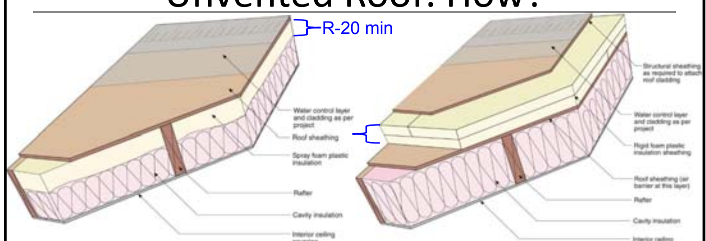
Why an Unvented Roof?



Why an Unvented Roof?



Unvented Roof: How?



- 2006 IRC: R806.4 Unvented attic assemblies
- Minimum R-value of “air impermeable insulation”
- Zone 5: R-20 required (or 40% of R-value)
- Nail base needed with rigid foam on roof deck

Windows

Water Control: Pan Flashings

- Deep energy retrofits (addition of insulation at existing wall) can make the wall more vulnerable to water leakage
- Previously "survivable" leaks may no longer be able to dry out.

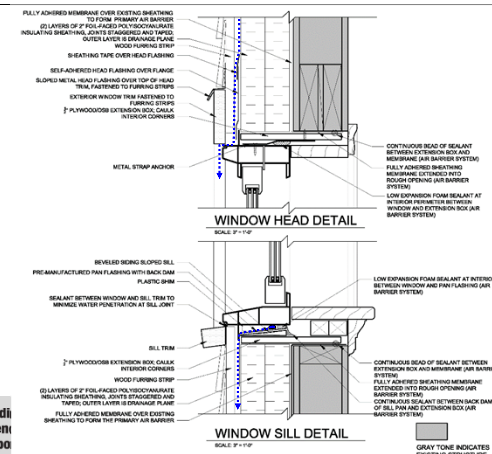
Retrofitting "Superwindows"

U=0.25 to ~0.18 for triple glazed + low E films + Krypton fill gas + warm edge spacers

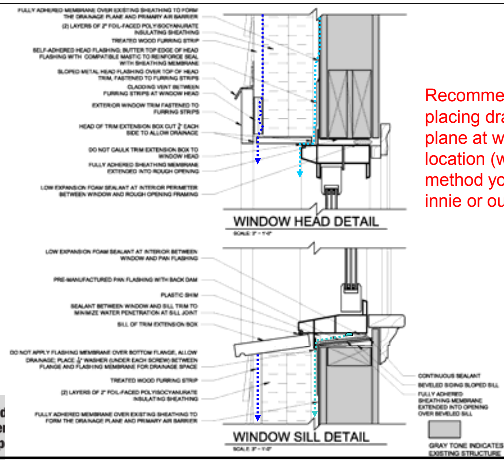
Comparison U=0.35 double glazed, low E, fill gas (?)

"Innie" and "Outie" Windows

"Outie" Window



“Innie” Window



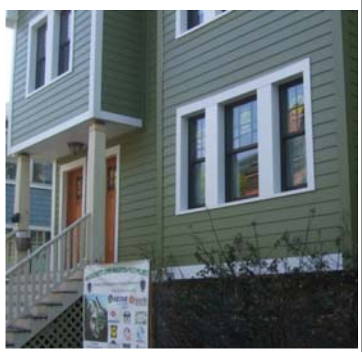
Recommend placing drainage plane at window location (whichever method you use—innie or outie)!

“Innie” vs. “Outie” Windows

- “Outie” Advantages
  - Simpler drainage plane connections/geometry
  - Lower cost (extension trim is interior material)
  - Similar appearance to conventional construction

“Innie” vs. “Outie” Windows

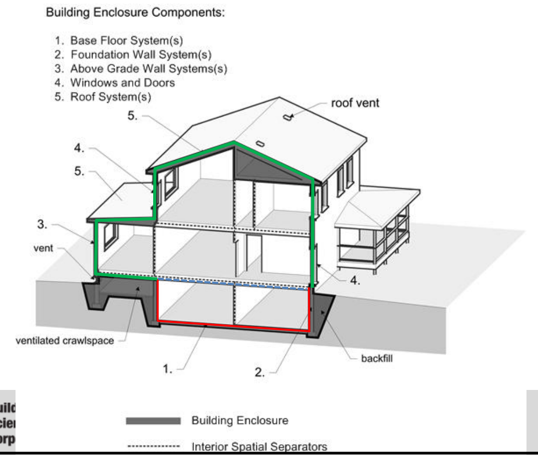
- “Innie” Advantages
  - Window supported by lumber frame (foam install)
  - Greater protection from wind-driven rain (inset)
  - Less condensation risk (?)
  - Can use existing window trim
  - Solar shading (advantage or disadvantage)



“Outie” Window Installation Options

Foundations

Basement Insulation Location

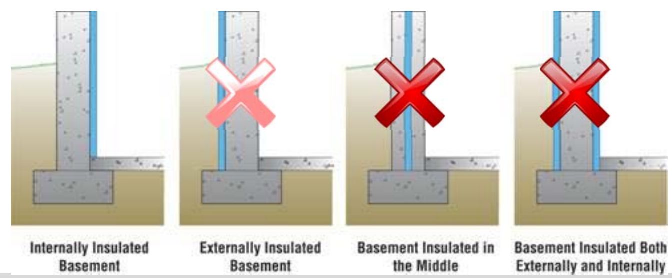


Basement Insulation Location

- 4.6 ACH50; 2129 CFM 50 total;
  1100 CFM 50 through floor
- 8.5 ACH50; 3590 CFM 50 total;
  1740 CFM 50 through floor

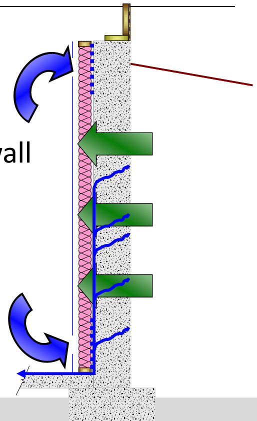
Insulation Location Choices

- Retrofits: interior insulation is often the only available option



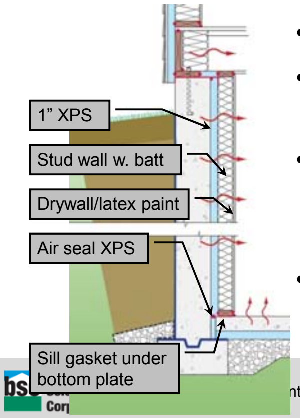
Basement Insulation Problems

- Wintertime interior moisture condensation (like above-grade walls)
- Condensation at bottom of wall (thermal lag of soil)
- Lack of drying of assembly (moisture from concrete and soil); soil is at 100% RH
- Liquid water through wall



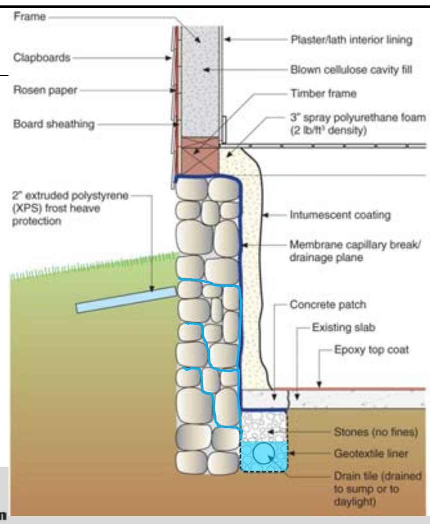
Building Science Corporation Residential DERs: Lessons Learned 53

Recommended Wall Assembly



- XPS is moisture tolerant
- Wintertime condensation controlled
- Summertime (bottom of wall) condensation controlled
- Concrete can dry through XPS at a safe rate

Building Science Corporation Residential DERs: Lessons Learned 54



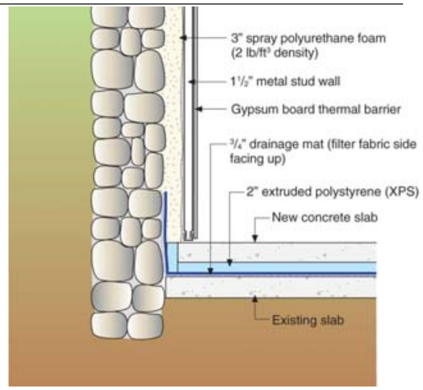
Building Science Corporation 55

Interior Rubble Retrofit

Building Science Corporation Residential DERs: Lessons Learned 56

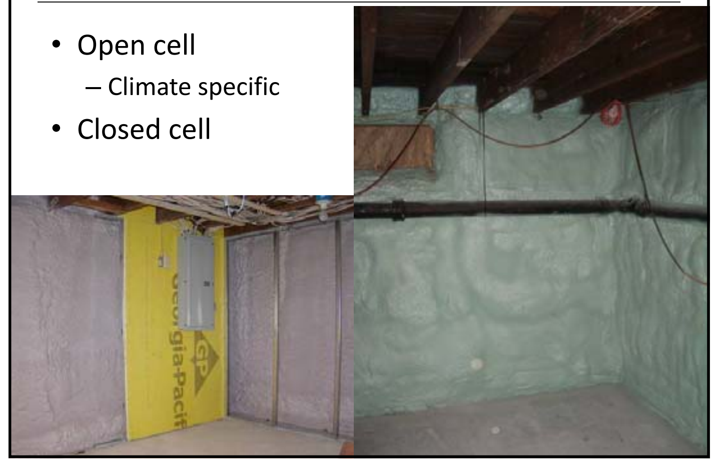
Alternate Details

- Insulated slab on top of existing slab
- No membrane up wall surface
- Wet vs. dry basement?
- Light gauge steel framing interior wall



Spray foam basement insulation

- Open cell
  - Climate specific
- Closed cell



Spray Foam "Bathtub"

Air Barriers

Retrofitting Exterior Air Barriers



Bedford, MA "Farmhouse"	Arlington, MA "Duplex"	Jamaica Plain, MA
6.2 ACH 50	5.0 ACH 50	2.4 ACH 50
No secondary air barrier (housewrap w. connections); mediocre roof-wall connections	Basement compartmentalized? (1000 CFM 50 vs. 2129 CFM 50 total)	Vented space under existing slate roof; spray foam. All spray foam basement ("bathtub"). No clear failure points.

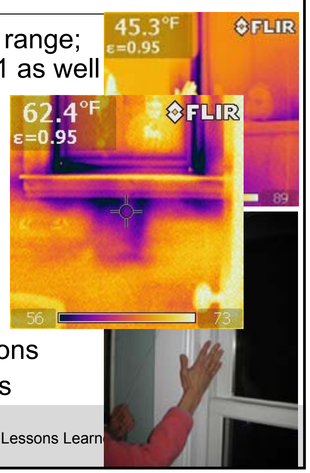
Retrofitting Exterior Air Barriers



St. Agatha, ON	Belmont, MA	Northampton, MA
~1 ACH 50	0.7 ACH 50	0.75 ACH 50
Spray foam on exterior; all windows well air sealed; casement/ awning typical	Rigid foam as air barrier, "chainsaw" retrofit of roof overhangs/eaves, meticulous air barrier, blower door tests in progress	Taped ZIP wall air barrier layer roof & walls; spray foam basement. 40% new construction

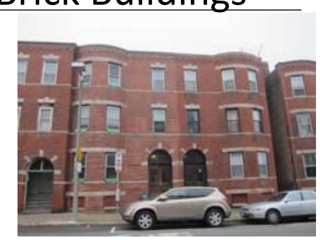
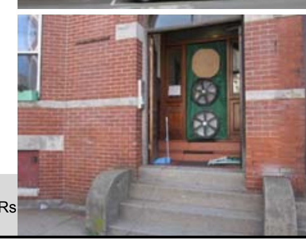
Retrofitting Exterior Air Barriers

- Other projects in 1.5 ACH 50 range; ~3-5 ACH 50 outliers, under 1 as well
- Roof-wall connections
- Roof geometries
- Wall-foundation connections
- Window air leakage
- Wall-window connections
- Porch/deck attachments
- Mechanical system penetrations
- Rigid air control layer on walls



Air Barriers and Brick Buildings

- Pre-retrofit test
- Brick (2-wythe); front and rear exposed, party walls
- Vinyl replacement windows
- Whole-building test
  - 11.7 ACH 50
  - 0.9 CFM 50/sf enclosure
- Roof, chimneys, window-wall interfaces?

Mechanicals

Mechanical Retrofit

- Range of approaches
- Often similar to new construction
- After enclosure upgrade
  - Much smaller and quieter systems can be chosen
- Air-based can be replaced with hydronic
- Low-temperature (more efficient) systems can be used (e.g., steam → hot water)
- For ventilation load add HRV (or ERV)

Heating: Steam to Hydronic

- Removed hazardous material
- Freed valuable floor space
- More even control
- Efficient, sealed combustion
- Provided option for more efficient water heater

Heating: Steam to Hydronic

Manifold Distribution – home run to every radiator

Heating: Steam to Hydronic

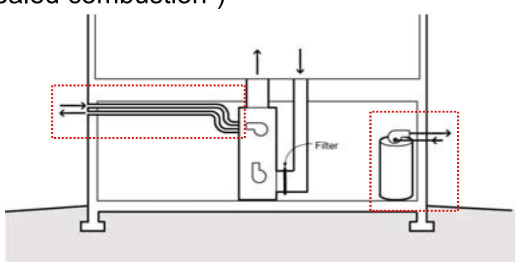
PEX tubing:
Minimally destructive distribution

Heating: Steam to Hydronic

Thermostatic Radiator Valves (TRVs): every radiator its own zone

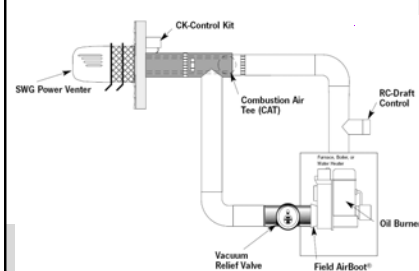
Combustion Safety

- Backdrafting risk in tighter houses
- Combustion air should be drawn from outside ("sealed combustion")



Sealed Combustion

Retrofit atmospherically vented?
- Maybe boilers
- Not water heaters
- Is it worth it?



Mini-Splits

Mini-split non-ducted head

Mini-split short ducted system

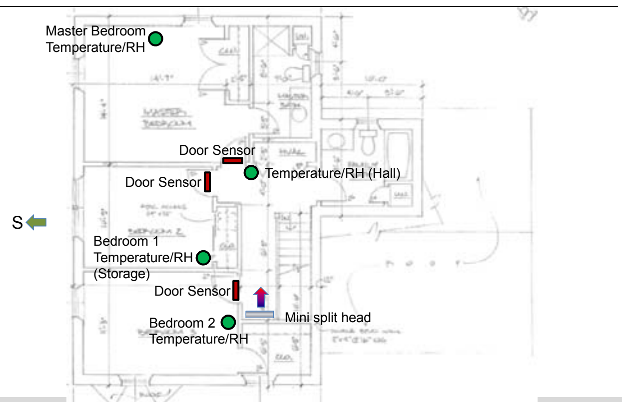
- Both heating & cooling
- Multi-splits (single outdoor unit)
- Systems with SEER=26 and HSPF=11 available

Mini-split outdoor unit

Mini-Splits Heating/Cooling in Cold Climate

- 1818 sf house, solar-oriented, superinsulated (12" spray foam walls, R-80 roof), triple glazed windows, very airtight
- Central Massachusetts location
- Net zero performance

Mini-Split Heat Pumps



Mini Split Heating Conclusions

- Single point heating per floor can keep rooms close to setpoint (~5-7° F)
- Deep heating setbacks cause greater differences
- Leaving doors closed increases temperature differences
- Deep setbacks result in long runtimes for mini split heat pumps
- "Acceptable sizing" data inconclusive, but other practitioners in colder climates have hard data
- Effective trade-off for superinsulated enclosure

- Provides for both heating & cooling; 11,000 BTU heating load
- Installed costs in the 1,818 square foot “Farmhouse” was $6,850
- Two 9,000 BTU heads upstairs, One 12,000 BTU head downstairs
- Electric heater back up, no heat production below zero degrees outside

Building Science Corporation

Residential DERs: Lessons Learned 77

Mitsubishi SEZ Ducted Indoor units

- Provides for both heating and cooling, 17,000 BTU peak heating load
- Installed costs in the 4 BR 2,612 square foot “Carlisle” model was $7,600
- One 15,000 BTU heads upstairs, One 18,000 BTU head downstairs
- 20,000 BTU gas fireplace as back up heating system

Questions?

Kohta Ueno
kohta@buildingscience.com

U.S. Department of Energy | Energy Efficiency & Renewable Energy

Building America U.S. Department of Energy

nationalgrid THE POWER OF ACTION www.powerofaction.com/der

Building Science Corporation

Residential DERs: Lessons Learned 79