



Kohta Ueno  
**Residential Deep Energy Retrofits:  
Lessons Learned**  
November 16, 2017



**bsc** Building Science Corporation  
**AIA** New Hampshire

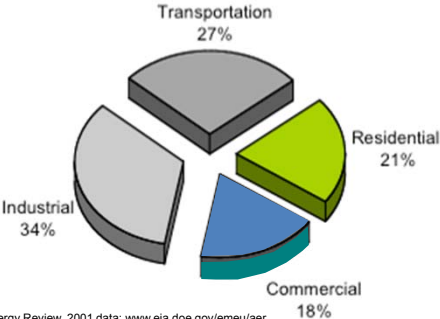
# Introduction



Residential DERs: Lessons Learned 2


## Building Energy Use

Primary Energy Consumption by Sector, 2001



Sector	Percentage
Industrial	34%
Transportation	27%
Residential	21%
Commercial	18%

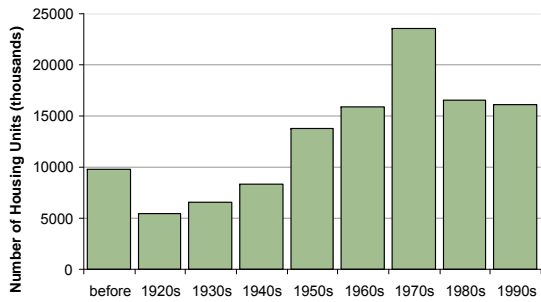
Source: EIA, Annual Energy Review, 2001 data: [www.eia.doe.gov/emeu/aer](http://www.eia.doe.gov/emeu/aer)



**bsc** Building Science Corporation  
Residential DERs: Lessons Learned 3


## Existing Housing Stock

Age of US Housing Stock (all unit types)

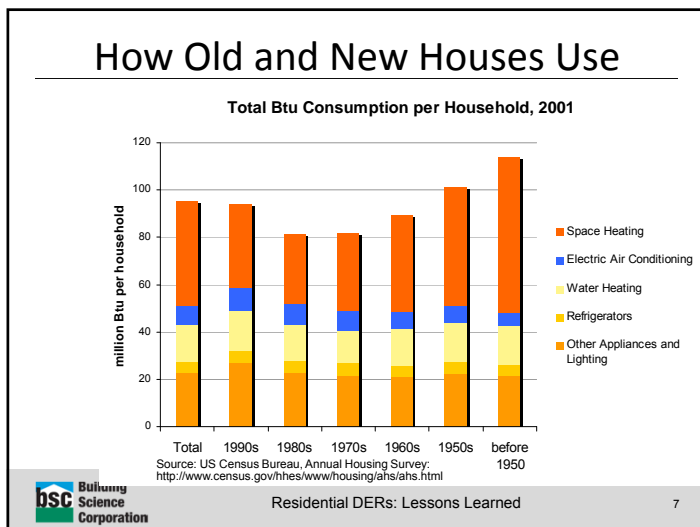
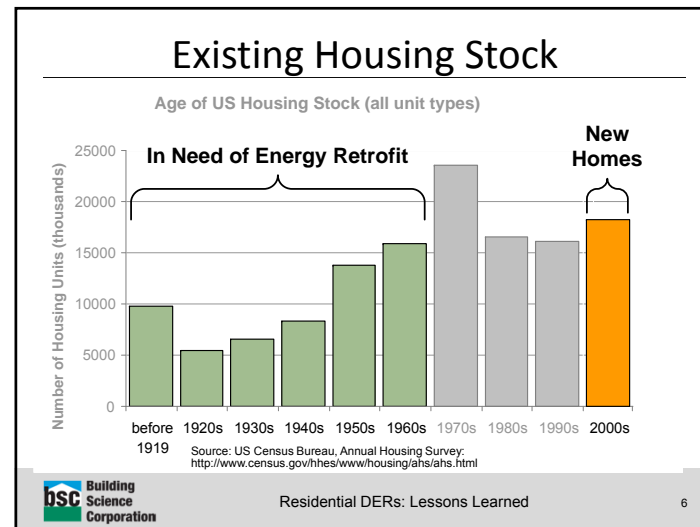
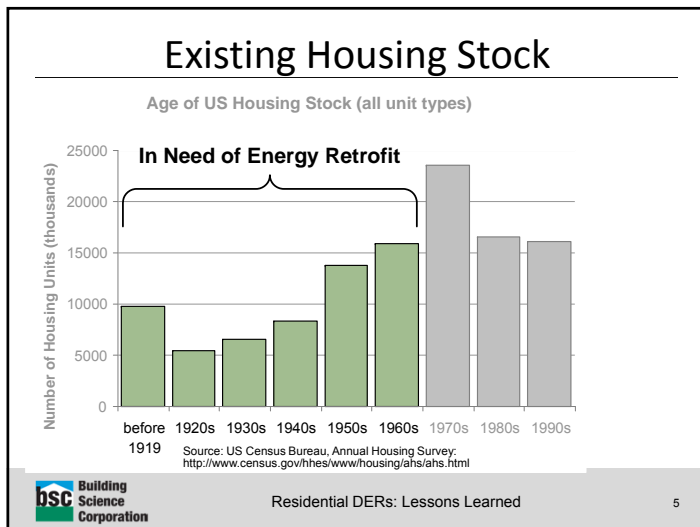


Decade	Number of Housing Units (thousands)
before 1919	10,000
1920s	5,000
1930s	6,000
1940s	8,000
1950s	14,000
1960s	16,000
1970s	23,000
1980s	16,000
1990s	16,000

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





**bsc** Building Science Corporation  
Residential DERs: Lessons Learned 4




- ### 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
- Residential DERs: Lessons Learned 8

### 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,  $U \leq 0.2$  windows
- 30+ projects
- BSC provided technical guidance for program
- Mass Save DER Guide

# Walls




Residential DERs: Lessons Learned

10

### Exterior Insulation Retrofits

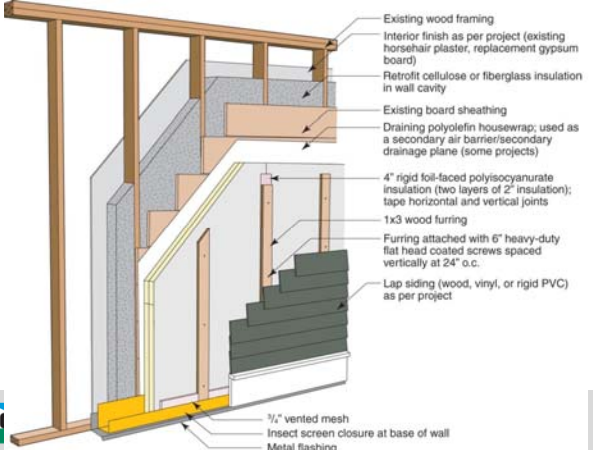
- Going beyond nominal R-13/R-19 walls = thicker walls
- Exterior retrofit advantages
  - Insulation outboard of vulnerable structure
  - Interior is habitable during retrofit
  - Retain interior finishes (lose exterior finishes)
  - No loss in interior square footage
  - Can inspect condition of enclosure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




Residential DERs: Lessons Learned

11

### 4" Polyisocyanurate Foam



- Existing wood framing
- Interior finish as per project (existing horsehair plaster, replacement gypsum board)
- Retrofit cellulose or fiberglass insulation in wall cavity
- Existing board sheathing
- Draining polyolefin housewrap; used as a secondary air barrier/secondary drainage plane (some projects)
- 4" rigid foil-faced polyisocyanurate insulation (two layers of 2" insulation); tape horizontal and vertical joints
- 1x3 wood furring
- Furring attached with 6" heavy-duty flat head coated screws spaced vertically at 24" o.c.
- Lap siding (wood, vinyl, or rigid PVC) as per project
- 1/2" vented mesh
- Insect screen closure at base of wall
- Metal flashing



12

### 4" Polyisocyanurate Foam



Residential DERs: Lessons Learned

13

### 4" Polyisocyanurate Foam



Residential DERs: Lessons Learned

14

### Foam Sheathing Cladding Attachment



250 lbs/113 kg load (7.8 psf): <math>< 0.003''</math> deflection

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

Image c/o Petersen Engineering



Residential DERs: Lessons Learned

15

### Exterior Retrofit Complications



### Double Stud Walls (Risky?)

Labels in diagram: 2x3 interior wall, Taped and painted 1/2" gypsum wall board as interior finish, Cellulose insulation in 2x3 interior wall stud spaces, 6 mil polyethylene air and vapor barrier on outside of interior wall, Cellulose insulation in gap between framing, Board foam blocking sealed airtight, Cellulose insulation at rim joist, Single top plate, 2x4 exterior wall @ 16" o.c., Cellulose insulation in 2x4 exterior wall stud space, OSB exterior sheathing, Housewrap.

**bsc** Building Science Corporation Residential DERs: Lessons Learned 17

### 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?

**bsc** Building Science Corporation Residential DERs: Lessons Learned 18

### Double Stud Wall w. Robust Air Barrier

Labels in diagram: Single top plate, 2x4 structural stud wall at 24" o.c., Latex paint on 1/2" gypsum board, 3 1/2" cellulose insulation, 1/2" plywood or OSB with joints taped, 4 1/2" space between sheathing and offset framing, Cellulose insulation at rim joist, Cellulose cavity insulation, 1/2" plywood connecting interior and exterior walls, 2x3 frame wall, 1/2" fiberboard, plywood, OSB or gypsum sheathing, Building paper, housewrap or building wrap, Furring strips, Cladding, 2x4 exterior framing member @ 16" o.c.

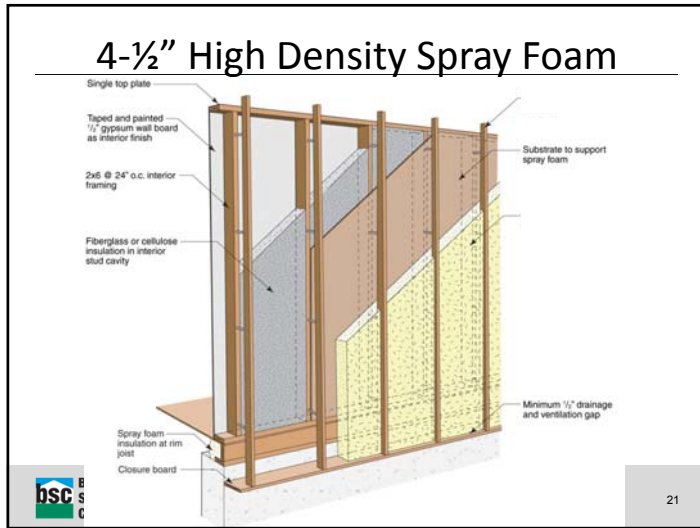
**bsc** Building Science Corporation Residential DERs: Lessons Learned 19

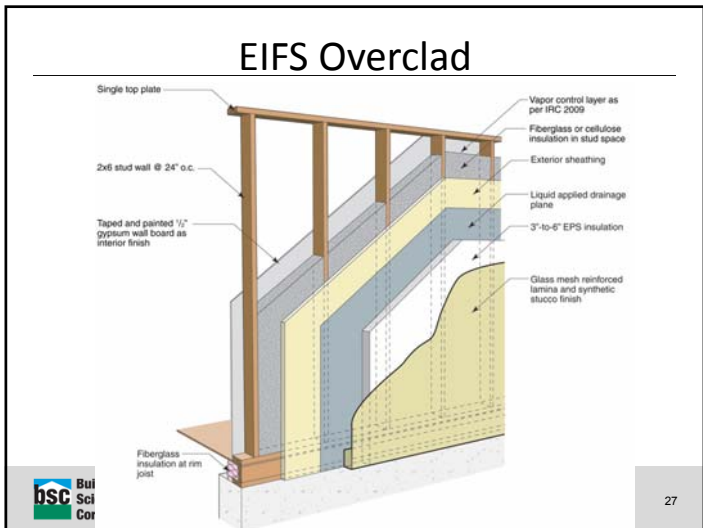
### Larsen Truss

Labels in diagram: Double top plate, Taped and painted 1/2" gypsum wall board as interior finish, 2x4 interior framing member @ 16" o.c., 6 mil polyethylene air and vapor barrier between 2x4 framing and gypsum wall board, Fiberglass insulation at rim joist, Capillary break, Ledger board, Plywood cavity closure at each floor, 2x3 exterior framing member, Cellulose insulation in wall cavity, OSB exterior sheathing, Housewrap.

**bsc** Building Science Corporation Residential DERs: Lessons Learned 20







### EIFS Overclad

- Insulation
- Protection of existing wall
- Aesthetic improvement?

The block contains three photographs illustrating EIFS overclad applications:

- A large brick building with a chimney, showing a full-scale application.
- A multi-story apartment building with a mix of brick and EIFS overclad.
- A close-up view of a brick wall with EIFS overclad installed over a window.

bsc  
Les

## Metal Panel Overclad



## Roofs



Residential DERs: Lessons Learned

30

## 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



Residential DERs: Lessons Learned

31

## Fully Ventilated Attics



Residential DERs: Lessons Learned

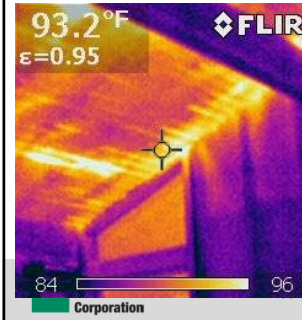


## Fully Ventilated Attics

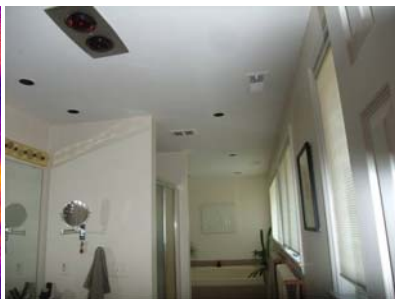
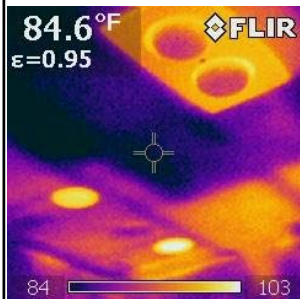


## Why an Unvented Roof?

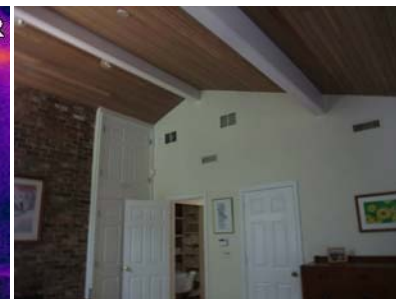
- Difficult air barrier to retrofit @ ceiling plane?
- Leaky ductwork and AHU in attic?
- More space (dormers, bedrooms in attic)?



## Why an Unvented Roof?



## Why an Unvented Roof?



### Why an Unvented Roof?

Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Residential DERs: Lessons Learned 37

### Why an Unvented Roof?

Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Residential DERs: Lessons Learned 38

### 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

Residential DERs: Lessons Learned 39

# Windows

Residential DERs: Lessons Learned 40

### 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.

dential DERs: Lessons Learned 41

### Retrofitting "Superwindows"

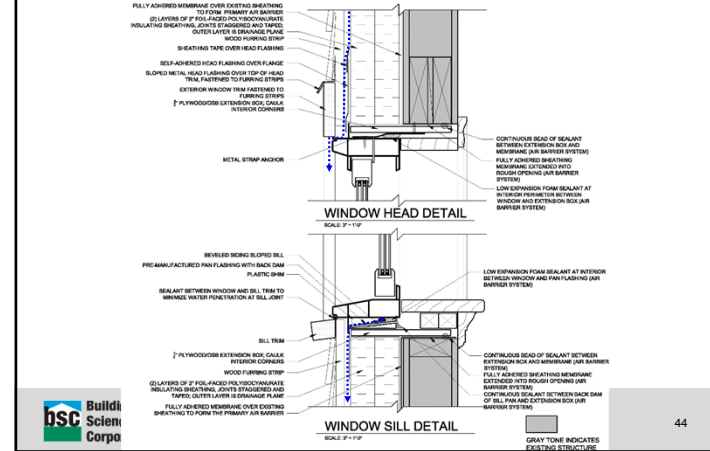
U=0.25 to ~0.18 for triple glazed + low E films + Krypton fill gas + warm edge spacers  
 Comparison U=0.35 double glazed, low E, fill gas (?)

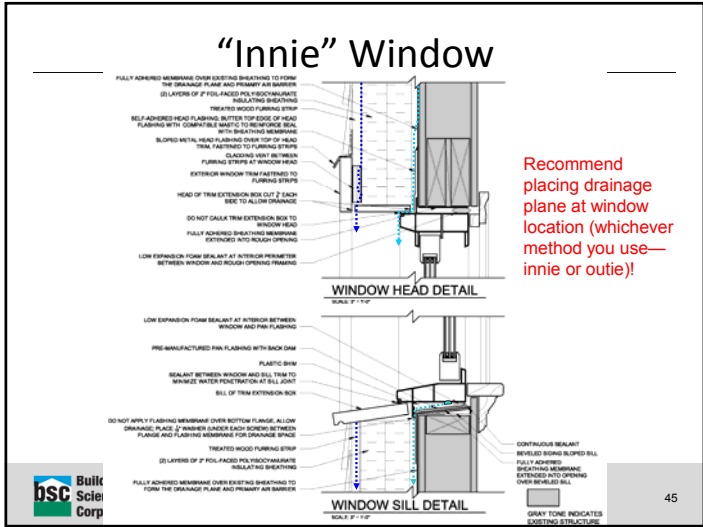
Corporation

### "Innie" and "Outie" Windows



### "Outie" Window





### “Innie” vs. “Outie” Windows

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

**bsc** Building Science Corporation

Residential DERs: Lessons Learned

46

### “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)

**bsc** Building Science Corporation

Residential DERs: Lessons Learned

47

### “Outie” Window Installation Options


**bsc** Building Science Corporation

48



# Foundations

---



Residential DERs: Lessons Learned

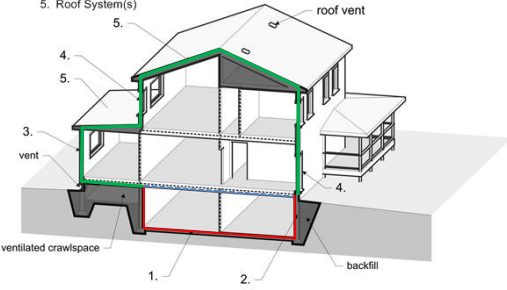
49


## Basement Insulation Location

---

Building Enclosure Components:

1. Base Floor System(s)
2. Foundation Wall System(s)
3. Above Grade Wall System(s)
4. Windows and Doors
5. Roof System(s)





50

## 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



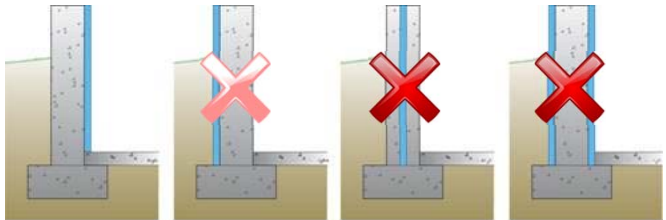
Residential DERs: Lessons Learned


51

## Insulation Location Choices

---

- Retrofits: interior insulation is often the only available option



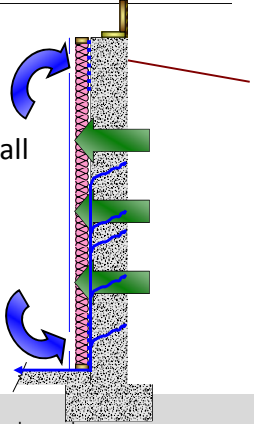



Residential DERs: Lessons Learned

52

### 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

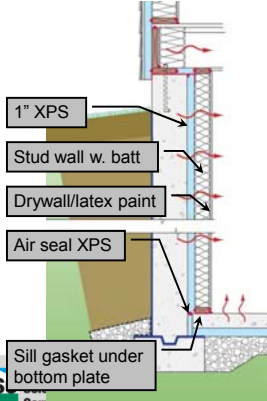





Residential DERs: Lessons Learned

53

### Recommended Wall Assembly

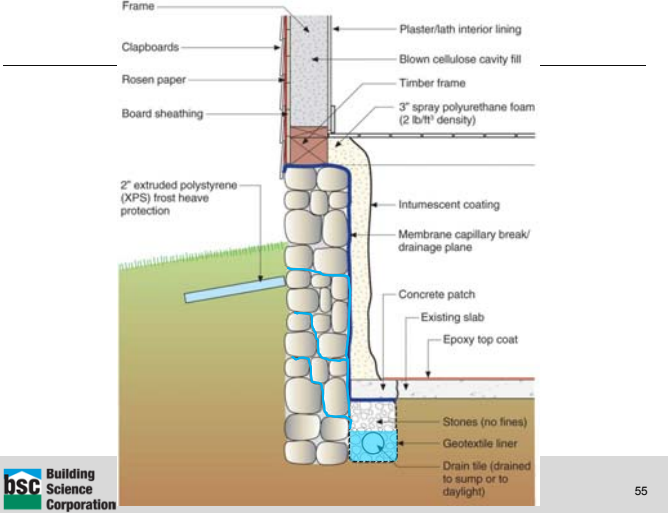



- XPS is moisture tolerant
- Wintertime condensation controlled
- Summertime (bottom of wall) condensation controlled
- Concrete can dry through XPS at a safe rate



Residential DERs: Lessons Learned

54







Residential DERs: Lessons Learned

55

### Interior Rubble Retrofit





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

Residential DERs: Lessons Learned 57

### Spray foam basement insulation

- Open cell
  - Climate specific
- Closed cell

Residential DERs: Lessons Learned 60

### Spray Foam “Bathtub”



© 2011 by Byggmeister; reprinted with permission


Residential DERs: Lessons Learned 59

# Air Barriers

Residential DERs: Lessons Learned 60

### 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.

 Building Science Corporation Residential DERs: Lessons Learned 61

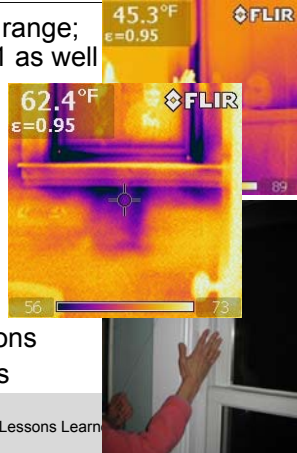
### Retrofitting Exterior Air Barriers


		
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

 Building Science Corporation Residential DERs: Lessons Learned 62

### 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




 Building Science Corporation Residential DERs: Lessons Learned

### 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?



 Building Science Corporation Residential DERs



# 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



Residential DERs: Lessons Learned

69

### Heating: Steam to Hydronic



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

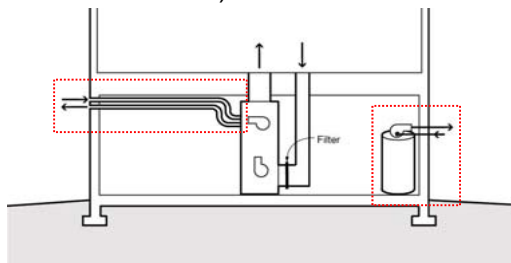


Residential DERs: Lessons Learned

70

### Combustion Safety

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



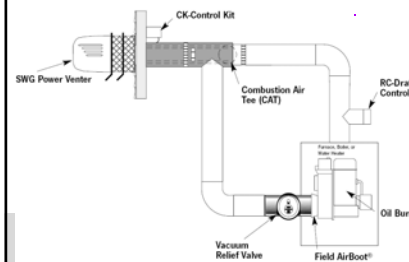
Residential DERs: Lessons Learned

71

### Sealed Combustion

Retrofit atmospherically vented?


- Maybe boilers
- Not water heaters
- Is it worth it?




Residential DERs: Lessons Learned

72

## 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

Residential DER



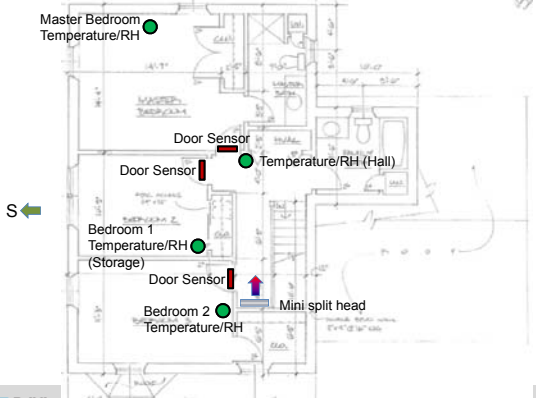
### Mini-Splits Heating/Cooling in Cold Climate


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



74

## Mini-Split Heat Pumps






Residential DERs: Lessons Learned

75

## 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



Residential DERs: Lessons Learned

76



- 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



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@building science.com



Residential DERs: Lessons Learned

79