Introduction

Residential Deep Energy Retrofits: Lessons Learned

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Building Energy Use

Primary Energy Consumption by Sector, 2001

- Transportation 27%
- Commercial 18%
- Industrial 34%
- Residential 21%

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

Existing Housing Stock

Age of US Housing Stock (all unit types)


Number of Housing Units (thousands)

Before 1919 1920s 1930s 1940s 1950s 1960s 1970s 1980s 1990s

- 2000
- 1500
- 1000
- 500
- 0
Residential DERs: Lessons Learned

Existing Housing Stock

Age of US Housing Stock (all unit types)

In Need of Energy Retrofit

Number of Housing Units (thousands)

before 1919 1920s 1930s 1940s 1950s 1960s 1970s 1980s 1990s 2000s


How Old and New Houses Use

Total Btu Consumption per Household, 2001

Space Heating
Electric Air Conditioning
Water Heating
Refrigerators
Other Appliances and Lighting

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

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)

Walls

4” Polyisocyanurate Foam

- Existing wood framing
- Interior finish as per project (existing nonsanipier, replacement gypsum board)
- Retard perlite or fibreglass insulation in wall cavity
- Existing board sheathing
- Insulation polyisocyanurate used as a primary or barrier/secondary insulation plane (some projects)
- 4” rigid foil-faced polyisocyanurate (insulation/air barrier/structural joint)
- Non-combustible nailing jacks
- 1x3 wood furring
- Furring attached with 6” heavy-duty flat-head iron screws spaced vertically at 24” o.c.
- Lap siding (sheet, vinyl, or rigid PVC) as per project
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 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

- Bunker top plate
- vapour and jacketed
- Exterior siding
- Minimum thickness
- Fiberglass or cellulose insulation in interior stud framing
- Minimum 2” drainage and ventilation gap
- Spray foam applied at arm's length
- 1” closed cell spray foam
- Observe board

[Image of a building construction with spray foam applied]

[Image of a window with insulation]

[Image of a construction worker applying spray foam]

[Image of a detailed section of the building structure with spray foam]
EIFS Overclad

- Insulation
- Protection of existing wall
- Aesthetic improvement?
**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**

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

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**Why an Unvented Roof?**

- **Left Image:**
  - Temperature: 84.6°F
  - Emissivity: ε = 0.95

- **Right Image:**
  - Temperature: 87.8°F
  - Emissivity: ε = 0.95
Why an Unvented Roof?

- 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

Unvented Roof: How?

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

“Outie” Window Installation Options

- Housewrap layer

“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)
Foundations

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

**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

**Interior Rubble Retrofit**
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”
### Retrofitting Exterior Air Barriers

<table>
<thead>
<tr>
<th>Location</th>
<th>Project Name</th>
<th>ACH 50</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedford, MA</td>
<td>“Farmhouse”</td>
<td>6.2 ACH 50</td>
<td>No secondary air barrier (housewrap w. connections); mediocre roof-wall connections</td>
</tr>
<tr>
<td>Arlington, MA</td>
<td>“Duplex”</td>
<td>5.0 ACH 50</td>
<td>Basement compartmentalized? (1000 CFM 50 vs. 2129 CFM total)</td>
</tr>
<tr>
<td>Jamaica Plain, MA</td>
<td></td>
<td>2.4 ACH 50</td>
<td>Vented space under existing slate roof; spray foam. All spray foam basement (“bathtub”). No clear failure points.</td>
</tr>
<tr>
<td>St. Agatha, ON</td>
<td></td>
<td>~1 ACH 50</td>
<td>Spray foam on exterior; all windows well air sealed; casement/awning typical</td>
</tr>
<tr>
<td>Belmont, MA</td>
<td></td>
<td>0.7 ACH 50</td>
<td>Rigid foam as air barrier, “chainsaw” retrofit of roof overhangs/eaves, meticulous air barrier, blower door tests in progress</td>
</tr>
<tr>
<td>Northampton, MA</td>
<td></td>
<td>0.75 ACH 50</td>
<td>Taped ZIP wall air barrier layer roof &amp; walls; spray foam basement. 40% new construction</td>
</tr>
</tbody>
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### 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?
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
Residential DERs: Lessons Learned

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

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

Mini-splits:
- Mini-split non-ducted head
- Mini-split short ducted system
- Mini-split outdoor unit

Mini-Split Heat Pumps

- Bedroom 1 Temperature/RH (Storage)
- Bedroom 1 Temperature
- Bedroom 2 Temperature/RH
- Door Sensor
- Door Sensor
- Door Sensor
- Mini-split head

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 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

Questions?
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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