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Four Square Revisited Toward Zero Energy Renovation

Betsy Pettit, FAIA
Building Science Corporation
www.buildingscience.com

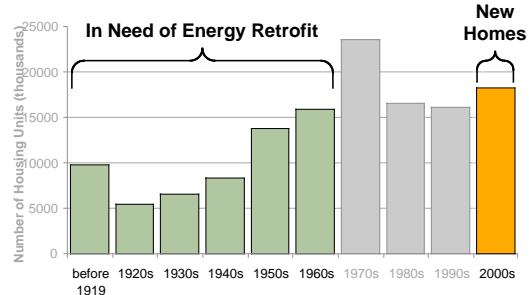


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Existing Housing Stock

Age of US Housing Stock (all unit types)



Number of Housing Units (thousands)

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

In Need of Energy Retrofit

New Homes

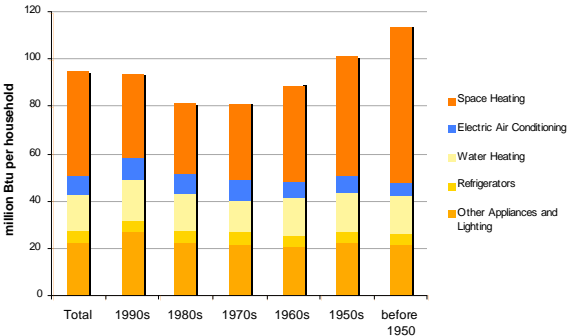
Source: US Census Bureau, Annual Housing Survey: <http://www.census.gov/hhes/www/housing/ahs/ahs.html>

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How Old and New Houses Use Energy

Total Btu Consumption per Household, 2001



million Btu per household

Total 1990s 1980s 1970s 1960s 1950s before 1950

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

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

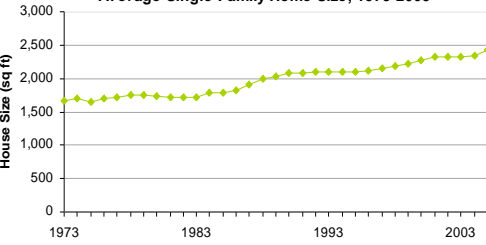
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Getting Bigger as Time Goes On

- Average House Size in 1940: ~1100 sq ft¹
- Average House Size in 1973: 1660 sq ft²

Average Single Family Home Size, 1973-2005



House Size (sq ft)

1973 1983 1993 2003

- Average House Size in 2005: 2434 sq ft

- Wilson, Alex and Jessica Boehland "Small is Beautiful" *Journal of Industrial Ecology*, Vol 9, No 1-2, 2005
- EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer

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bsc **How a 100 year old house is renewed to last an additional 100 years cost \$100/sq. ft.**

Building Enclosure	BEFORE	CONDITIONED SQ. FT. = 2,000
Air Leakage	10 sq. in. of leakage area per 100 sq. ft. of surface area	
Wall Insulation	Little to none	
Attic Insulation	R-19	
Windows	Single pane glass with storm window	

Building Enclosure	AFTER	CONDITIONED SQ. FT. = 3,600
Conditioned Attic	R-39 High Density Spray Foam on sheathing R-21 roof deck insulation – Total Roof R-60	
Walls	R-13 cellulose blown into existing 2x4 walls	
Wall Sheathing	4" Polyiso R-28 sheathing – Total Wall R-41	
Basement Floor	Under-slab 2" XPS, R-10	
Basement Walls	4" R-28 HD SPF on perimeter walls	
Windows	Andersen Woodwright Replacement Windows Weighted Average U=-0.33, SHGC=-0.33	
Infiltration	2.0 sq in leakage area per 100 sf of envelope	

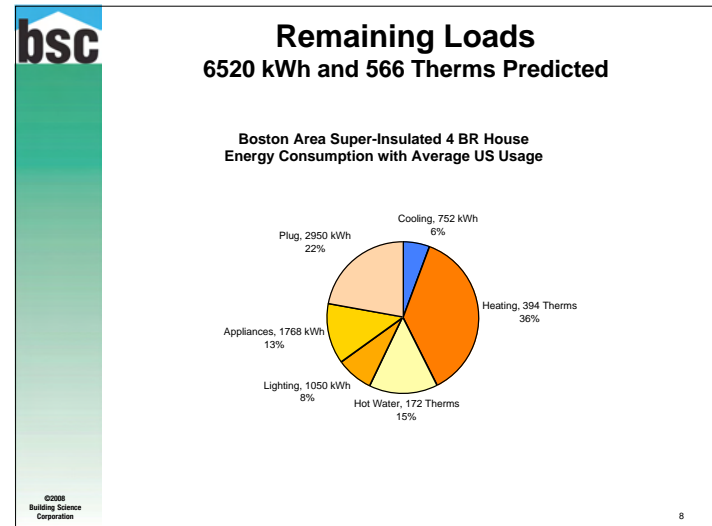
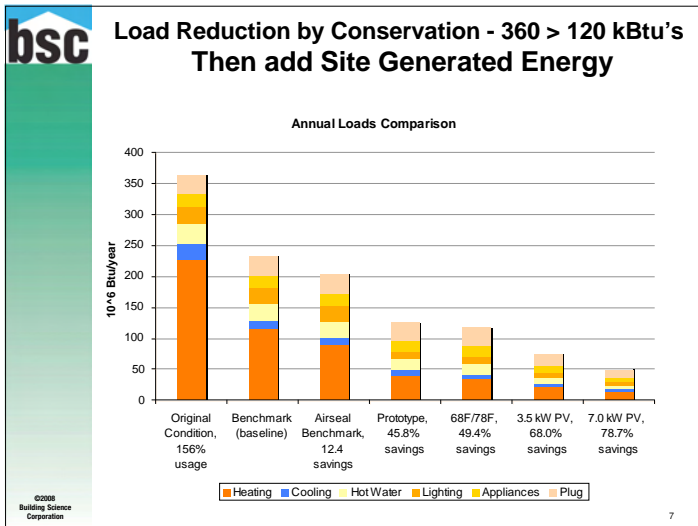
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bsc **How a 100 year old house is renewed to last an additional 100 years**

Mechanical Systems	BEFORE
Heating	60% AFUE for the old boiler -gas -delivered by radiators
Cooling	9 EER for the window units
DHW	0.4 EF for hot water efficiency. AVERAGE summer efficiency is much worse winter efficiency would be about at 60% (since the boiler is heating the house already)

Mechanical Systems	AFTER
Heat	Sealed combustion 92% AFUE gas boiler boiler in conditioned basement
Cooling	14 SEER split system in conditioned space
DHW	0.80 EF side-arm storage tank
Ducts	R-4.2 flex runouts in dropped ceiling or in floor joists
Leakage	none to outside (5% or less)
Ventilation	Fan Cyclor Supply-only system integrated with AHU 33% Duty Cycle: 10 minutes on; 20 minutes off 60-80 CFM continuous average flow
Return Pathways	Transfer grilles/jump ducts at bedrooms

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Actual First Year
3200 kWh and 570 Therms

Electric @ \$.15 /kWh Gas @ \$1.50/therm
Electric \$471 Gas \$858
Electric/mth - \$39 Gas/mth = \$71

Adding Photovoltaic

- The electric use was about 300 kWh per month
- A 4kW PV system will create about 300 kWh per month
- At \$4 per kW the system would cost \$16,000
- The electric bill over 32 year at this rate would be \$16,000
- \$16,000 at 5.6% will cost \$92 per month

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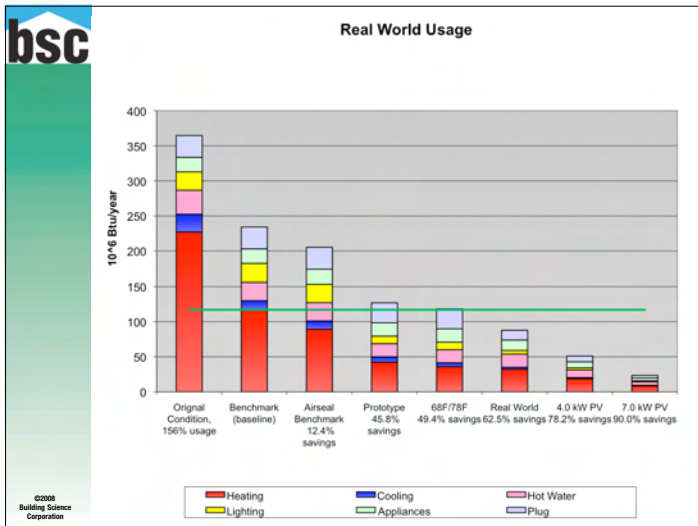
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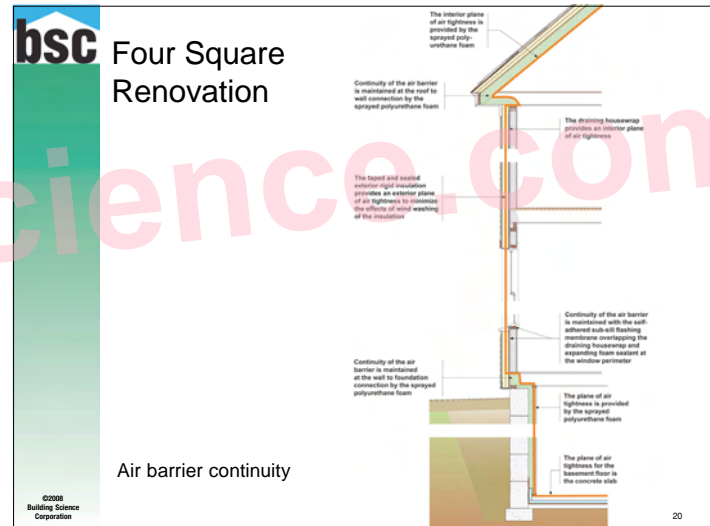
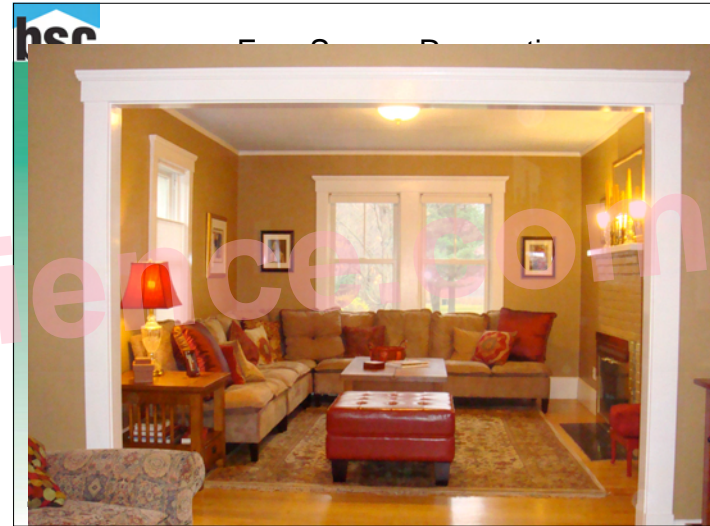
Adding Solar Hot Water

- A 64 sq. ft. glycol SHW installed with storage = \$6,000
- This would create about 180 therms
- At \$1.50 per therm the savings would be \$270 per year
- Over 22 years at this rate savings would = \$6,000
- \$6,000 at 5.6% would cost \$35 per month


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The interior plane of air tightness is provided by the sprayed polyurethane foam

Continuity of the air barrier is maintained at the roof to wall connection by the sprayed polyurethane foam

The draining housewrap provides an interior plane of air tightness

Air barrier continuity

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The taped and sealed exterior rigid insulation provides an exterior plane of air tightness to minimize the effects of wind washing of the insulation

Air barrier continuity

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Continuity of the air barrier is maintained at the wall to foundation connection by the sprayed polyurethane foam

Continuity of the air barrier is maintained with the self-adhered sub-sill flashing membrane overlapping the draining housewrap and expanding foam sealant at the window perimeter

The plane of air tightness is provided by the sprayed polyurethane foam

The plane of air tightness for the basement floor is the concrete slab

Air barrier continuity

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Rain water drains off roof and away from the foundation

Overhangs protect wall and window assemblies from direct rain water

Rain water drains down over the shingle-roofed siding. Small amounts of water that penetrate past the siding are drained on the insulating sheathing. Water that penetrates the insulating sheathing is carried down the wall on the draining housewrap.

The grade is sloped to drain water away from the foundation. (The layer of the hard-packed clay at foundation perimeter limits the amount of rain water absorbed by the ground.)

Water collected on the drainage mat is collected into an exterior sump pit and pumped outside if necessary


XPS limits interior moisture migration from the existing slab and soil

Moisture migrating to interior is directed downward and drains through drainage mat into an interior sump pit and pumped outside, if necessary

Drainage plane continuity

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Rain water drains off roof and away from the foundation

Overhangs protect wall and window assemblies from direct rain water

Drainage plane continuity


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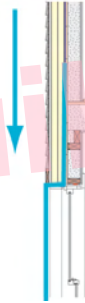


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Rain water drains down over the shingle-lapped siding. Small amounts of water that penetrate past the cladding are drained on the insulating sheathing. Water that penetrates the insulating sheathing is carried down the wall on the draining housewrap.





Drainage plane continuity



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The grade is sloped to drain water away from the foundation (Top layer of the hard packed clay at foundation perimeter limits the amount of rain water absorbed by the ground.)

Moisture migrating to interior is directed downward and drains through drainage mat into an interior sump pit and pumped outside if necessary

XPS limits interior moisture migration from the existing slab and soil

Water collected in the drainage mat is collected into an interior sump pit and pumped outside if necessary

Drainage plane continuity

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Thermal resistance of the roof assembly is made up of the two layers of 2-inch polyisocyanurate insulation and the sprayed polyurethane foam

Sprayed polyurethane foam used in hard to reach areas maintains the thermal continuity

The thermal resistance of the wall assembly is made up of the blown cellulose cavity insulation and the two layers of 2-inch rigid polyisocyanurate insulating sheathing

New windows with low-E squared glazing maintain the thermal continuity of the wall

The continuous exterior insulating sheathing eliminates thermal bridging

Sprayed polyurethane foam used in hard to reach areas maintains the thermal continuity

The thermal resistance of the foundation wall is provided by the sprayed polyurethane foam

The thermal resistance of the basement floor is provided by the 2-inches of rigid XPS below the slab

Thermal continuity

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Thermal resistance of the roof assembly is made up of the two layers of 2-inch polyisocyanurate insulation and the sprayed polyurethane foam

Sprayed polyurethane foam used in hard to reach areas maintains the thermal continuity

Thermal continuity

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New windows with low-E squared glazing maintain the thermal continuity of the wall

Thermal continuity

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The continuous exterior insulating sheathing eliminates thermal bridging

Sprayed polyurethane foam used in hard to reach areas maintains the thermal continuity

The thermal resistance of the foundation wall is provided by the sprayed polyurethane foam

The thermal resistance of the basement floor is provided by the 2-inches of rigid XPS below the slab

Thermal continuity

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Polysiocyanurate limits moisture flow from the interior during winter

Drying primarily to the interior

Polysiocyanurate elevates the surface temperature of the exterior sheathing during the winter to reduce the condensation potential

Semi-permeable interior latex paint finish on gypsum board reduces moisture flow from interior during winter yet still allows drying to the interior during summer

Cellulose insulation acts as a hygric buffer by safely storing moisture until it can dry to either the interior or exterior

Polysiocyanurate limits moisture flow from the interior during winter

Exposed portion of foundation wall able to dry to exterior

Sprayed polyurethane foam limits interior moisture migration

Drainage mat limits interior moisture migration from the existing slab and soil

Vapor barrier continuity

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Polysiocyanurate limits moisture flow from the interior during winter

Drying primarily to the interior

Vapor barrier continuity

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Polysiocyanurate elevates the surface temperature of the exterior sheathing during the winter to reduce the condensation potential

Semi-permeable interior latex paint finish on gypsum board reduces moisture flow from interior during winter yet still allows drying to the interior during summer

Cellulose insulation acts as a hygric buffer by safely storing moisture until it can dry to either the interior or exterior

Vapor barrier continuity

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Polyisocyanurate limits moisture flow from the interior during winter
 Exposed portion of foundation wall able to dry to the exterior
 Sprayed polyurethane foam limits interior moisture migration
 Drainage mat limits interior moisture migration from the existing slab and soil
 Vapor barrier continuity

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bsc New Windows

Photos courtesy of Dan Morrison, *Fine Homebuilding Magazine*

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Mechanical schematic

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Old Boiler to New Boiler plus air handlers,
outside air intake, filtration, and exhaust at
baths and kitchen



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