Four Square Revisited
Toward Zero Energy Renovation

Betsy Pettit, FAIA
Building Science Corporation

Better Buildings: Better Business Conference
March 6, 2008, Wisconsin Dells, Wisconsin

Assessing the Impact of US Housing
Background:
• Total Housing Units in 2001 (millions):
  - Single-Family Homes 73.7
  - Apartments (all buildings) 26.5
  - Mobile Homes 6.8
  107.0 million units
• Total Residential Energy Use in 2001:
  - 20,228,107 million Btu

Getting Bigger as Time Goes On
• Average House Size in 1940: ~1100 sq ft
• Average House Size in 1973: 1660 sq ft
• Average House Size in 2005: 2434 sq ft

Assessing the Impact of US Housing
Primary Energy Consumption by Sector, 2001
Transportation 27%
Residential 21%
Industrial 18%
Commercial 34%

Contribution to Climate Change
Carbon Dioxide Emissions from Energy Consumption by Sector, 2001
Transportation 32%
Residential 20%
Industrial 30%
Commercial 18%

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

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

**Age of US Housing Stock (all unit types)**

- **Before 1930s:** 5 Million
- **1930s:** 3 Million
- **1940s:** 1 Million
- **1950s:** 1 Million
- **1960s:** 1 Million
- **1970s:** 1 Million
- **1980s:** 1 Million
- **1990s:** 1 Million
- **2000s:** 1 Million

### In Need of Energy Retrofit

- **58 Million**


### How Old and New Houses Use Energy

**Total Btu Consumption per Household, 2001**

- **Total 1990s:** 80 Btu
- **Total 1980s:** 60 Btu
- **Total 1970s:** 40 Btu
- **Total 1960s:** 20 Btu
- **Total 1950s:** 10 Btu
- **Total before 1950:** 0 Btu

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

### 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

- **Mechanical Systems AFTER**
  - **Heating:** 95% AFUE for the high efficiency gas boiler
  - **Cooling:** None to outside (5% or less)
  - **DHW:** 0.80 EF side-arm storage tank

**Cost**
- **$100/sq. ft.**
- **Conditioned SQ FT. = 2,000**
- **Total Infiltration:** 20 sq. in. of leakage area per 100 sq. ft. of surface area
- **Air Leakage:** 10 sq. in. of leakage area per 100 sq. ft. of surface area
- **Acoustical Insulation:** R-19
- **Attic Insulation:** R-28 HD SPF on perimeter walls
- **Wall Insulation:** 4" R-28 HD SPF on perimeter walls
- **Floor Insulation:** 4" Polyiso R-28 sheathing – Total Wall R-41
- **Roof Insulation:** R-21 roof deck insulation – Total Roof R-60
- **Conditioned Attic:** R-39 High Density Spray Foam on sheathing

**Building Envelope BEFORE**
- **Air Leakage:** 10 sq. in. of leakage area per 100 sq. ft. of surface area
- **Acoustical Insulation:** R-19
- **Infiltration:** Single-pane glass with storm window

**Building Envelope AFTER**
- **Air Leakage:** 10 sq. in. of leakage area per 100 sq. ft. of surface area
- **Acoustical Insulation:** R-20 High Efficiency Spray Polyurethane Foam on external wall
- **Infiltration:** Single-pane glass with storm window

**EDP:**
- **Andersen Woodwright Replacement Windows**
- **Duct Efficiencies:**
  - **R-4.2 flex runouts in dropped ceiling or in floor joists**
  - **0.80 EF side-arm storage tank**

**Homes and Systems**
- **R-21 Wall Insulation**
- **4" R-28 HD SPF on perimeter walls**
- **R-13 cellulose blown into existing 2x4 walls**
- **R-39 High Density Spray Foam on sheathing**
- **R-21 roof deck insulation – Total Roof R-60**

**Residential Energy Use**
- **Cooling:** 8% of total
- **Heating:** 36% of total
- **Hot Water:** 15% of total
- **Refrigerators:** 12% of total
- **Other Appliances and Lighting:** 20% of total
- **Plugs:** 15% of total

**Remaining Loads**
- **6520 kWh and 566 Therms Predicted**

### Boston Area Super-Insulated 4 BR House

- **Energy Consumption with Average US Usage**
  - **Cooling, 752 kWh**
  - **6%**
  - **Heating, 394 Therms**
  - **36%**
  - **Hot Water, 172 Therms**
  - **15%**
  - **Lighting, 1050 kWh**
  - **8%**
  - **Appliances, 1768 kWh**
  - **13%**
  - **Plug, 2950 kWh**
  - **22%**

**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

**After:**
- **Heating:** 95% AFUE for the high efficiency gas boiler
- **Cooling:** None to outside (5% or less)
- **DHW:** 0.80 EF side-arm storage tank
Actual First Year
3200 kWh and 566 Therms

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

Boston Area Super-Insulated 4 BR House
Energy Consumption with Average US Usage

- Cooling, 752 kWh: 6%
- Heating, 394 Therms: 36%
- Hot Water, 172 Therms: 15%
- Lighting, 1050 kWh: 8%
- Appliances, 1768 kWh: 13%
- Plug, 2950 kWh: 22%

Annual Loads Comparison

- Original Condition, 156% usage
- Benchmark (baseline) Airseal Benchmark, 12.4 savings
- Prototype, 45.8% savings
- 68F/78F, 49.4% savings
- 3.5 kW PV, 68.0% savings
- 7.0 kW PV, 78.7% savings

Load Reduction by Conservation - 360 > 120 kBtu's
Then add Site Generated Energy

Four Square Renovation

First floor plan

Second floor plan

Cross section through house

Air barrier continuity

©2008 Building Science Corporation
Four Square Renovation

Vapor barrier continuity

Four Square Renovation

Vapor barrier continuity

Four Square Renovation

Vapor barrier continuity

Four Square Renovation

Vapor barrier continuity

New Windows

Photos courtesy of Dan Morrison, Fine Homebuilding Magazine

New Windows
Four Square Renovation

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