A Long-Term Case Study in Residential Sustainability

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Sustainability is …

- Low, predictable energy costs
- Using less city water, wasting less water
- Generating less waste for the landfill
- Low maintenance (cost, effort)
- Comfortable living (temperature, daylight)
- Permanent improvements

Sources: Active House Alliance Active House Specification v.2; Puget Sound Energy; The Rextor Group PLLC
Residential Energy Use Matters

Utilities & grid balancing agencies must build for peak load. Residential sector variation approximately equals baseline industrial sector load.

- **Summer peaks**
  - Summer peak is a/c.
  - Winter peak is lower due to other heating fuels.

- **Winter peaks**

- **Commercial peaks**
  - Smaller percentage of load is space heating.
  - Alternative fuels used for both heating and a/c.

- **Industrial peaks**
  - Most of load is manufacturing process, not space heating.
  - Economic variation matters more than weather.

Source: US Energy Information Administration, Electric Power Monthly
Project House

- Mixed-use: Residence & small business
- Located near schools, shops, library, transit, hospital, community park

- 1966 stick-built, 2-story, 334 m² (3600 ft²), 2x4 framing on 0.41 m (16”) centers
- Natural gas space heat, stove, oven, water heat, spa heat
- Electric air conditioner, spa pumps
- Recessed ceiling lights
- Fiberglass batt insulation in most walls; mineral wool in attic, bare over eaves

Photo: A Heidner.

300+ houses of similar construction
Comparing Energy Use
All sources: Electricity, Natural Gas, Other

Average US Detached SF House, 278 – 325 m² (3000 – 3499 ft²)

36.7 MWh (132 TJ)

Project House, 334 m² (3600 ft²)

57.1 MWh (206 TJ)

Source: US EIA 2009 Residential Energy Consumption Survey

Source: The Rextor Group PLLC
“Reusing” Energy

Energy $\alpha \Delta \text{height}$
- Power $\alpha \Delta \text{height} \cdot \text{flow}$

$\Delta \text{height}=15.8\text{m (52')}$

$\Delta \text{height}=26\text{m (85')}$

$\Delta \text{height}=57.6\text{m (189')}$

Energy $\alpha \Delta T$

- conversion loss
- transmission loss

Refrigerator
- $1.7\text{C (35F)}$ $\Delta T=18.8\text{C (34F)}$
- $20.5\text{C (69F)}$
- $-17.8\text{C (0F)}$

Freezer
- $\Delta T=38.3\text{C (69F)}$

Compressor cycle

Electrical Energy

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SusTech, 1 August 2013. © The Rextor Group PLLC
Sometimes simpler tools are the better choice.
Energy Use Baseline

- U-shape as expected for heating climate
- Summer base is water heat, cooking, clothes drying, spa heat
- ~ 15% higher than similar size houses in same urban area using natural gas heat

Sources: The Rextor Group PLLC, US EIA 2009 Residential Energy Consumption Survey

Sources: The Rextor Group PLLC, US EIA 2009 Residential Energy Consumption Survey
Temperature and Energy Use

- Summer base is water heat, cooking, clothes drying, spa heat
- Slope at medium temps indicates magnitude of thermal leakage through building envelope

- Expected a U-shape for heating climate, but … the huge slope for summer is ridiculous!

Sources: The Rextor Group PLLC, US EIA 2009 Residential Energy Consumption Survey
Opportunity List

• Reduce total use
  – Behavior: turn off lights, fax, shredder
  – Add timers or use sensors
  – Insulate and seal building envelope
  – Replace less efficient lights, appliances, toilets, etc.

• Reuse waste
  – Data center (servers, switches) heats house in winter *(but also in the summer)*
  – Hot water recirculation pump
  – Excavated rocks washed & used in concrete footings
  – Excavated dirt used to fill low spots in neighborhood yards

• Solar PV output to grid

• Recycle excess / use recycled products
  – Retrofit existing structure
  – Purchase used tools and fixtures when possible
Initial Targets

**Summer cooling load**
- Heat gain from attic to second floor
- Heat gain and hot air drafts through failing window frames

**Overall electric use**
- Daylighting
- Change lights from CFLs to LEDs
- Replace old appliances

**Prioritization**
- Opportunistic use of rebates and other incentives
- Set work sequence to “touch” any item only once
Saving Energy, But Increasing Waste

The house contains 85 light bulbs (permanent and lamps).

45 CFLs which failed (2-year period)

13 Incandescents which were finally replaced at the end of 2012 (only 1 failed, 12 which had not already been replaced by CFL or LED)

7 LEDs which failed (4-year period)

Sometimes improvements have unexpected side effects.
Insulation does not reach tops of ceiling joists

Recessed ceiling lights
- Not rated “in contact”
- Leak air and heat

Electric wiring in attic
- Blown-in insulation, reflective insulation
- Sequence critical

Daylight tube before connection to hall

14” cellulose insulation blown in (dropped ceiling in center)

Daylight tube connected and insulated, reflective insulation across bottom of rafters
Solar Energy

- Solar PV
  - Roof
  - Deck canopies
- Solar Thermal
  - Hot water pre-heat
  - Deck canopies reduce summer heat on south walls
- Daylight

**Solar PV panels**

- Provide summer shade to south-facing deck

Photo: A Heidner.

**Source:** The Rextor Group PLLC
Domestic Hot Water

- Measure usage
  - % hot water per month
  - Total flow

- Size for house
  - only 2 occupants currently, but 4 bedrooms
  - possibility of future hydronic heat

- Minimum flow to trigger tankless needs to be low

- Mixing valve between tank and tankless
  - Tank temperature may be higher than 120F with solar thermal water pre-heat

Reuse: wasted water waiting for the hot water to reach the tap -> hot water recirculation pump

Source: The Rextor Group PLLC
Thermal & Moisture Considerations

Moisture is a structural issue. Condensation occurs @ 6C (43F) with interior @ 21.1C (70F), 50% RH

Hot/Cold spots occur in odd places

Horizontal cross-section of walls with 2x4 studs:
Left: existing wall, L to R: cedar siding, felt, plywood, cavity, fiberglass, gypsum drywall.
Right: proposed wall, L to R: new siding, drainage with wood spacers, 2.5 cm (1") rigid insulation, drainage screen, house wrap, cavity, fiberglass, gypsum drywall.

Where will condensation occur? At the 6C isotherms (heavy black lines indicated with arrows).
Left, existing wall: Condensation will occur along the fiberglass-air interface inside the wall structure.
Right, proposed wall: The 6C isotherm runs in the middle of the rigid insulation, outside the wall structure. The rigid insulation is also moisture-impermeable; the actual condensation will occur on its outside surface.

Sources: The Rextor Group PLLC, Pacific Northwest Inspection Group
Air Infiltration & IAQ

Low infiltration -> higher impact of CO₂ and VOCs

A low-cost sensor yields information - and surprises.

Project house now has 2.8 ACH₅₀!

- Average US SF houses of similar age, ACH₅₀ = 10 to 40
- HRV needed
  - (ASHRAE 62.2-2010 requires mechanical ventilation if ACH₅₀ < 7.0)
- Humidity control must be considered

Effective leakage area for ACH₅₀ = 15

Effective leakage area for ACH₅₀ = 2.8

Effective leakage area for ACH₅₀ = 0.6 (PassivHaus)

One way of visualizing ACH50 is the size of the hole required to allow the same leakage through a perfectly sealed house.

CO₂ spikes from ~700 ppm to ~1500

Someone walked near the sensor wearing Old Spice stick deodorant.

Opening a window near the sensor.

CO₂ drops from ~1000 ppm to ~400
Energy Reduction Progress

Energy net ~ 38% less than similar size houses in same urban area using natural gas heat

- Base load is reduced
- U-shape is still there
- ~ 28% less than similar size houses in same urban area using natural gas heat
- Use is essentially flat year-round
- ~ 11% higher than similar size houses in same urban area using natural gas heat
- Electric use at US average for 11.2 m² (500 ft²) house
- PV production reduces amount used from grid each month

Sources: The Rextor Group PLLC, US EIA 2009 Residential Energy Consumption Survey
Temperature and Energy Results

- Summer base has decreased
- Slope at medium temps has decreased slightly

- Usage is basically flat year-round except for a few days when Thigh > 30C (86F)

Sources: The Rextor Group PLLC, US EIA 2009 Residential Energy Consumption Survey
Comfort Results

Insulating south eave and south wall top plate reduced temperatures inside the living quarters.

Reflective insulation (bottom of rafters) and blown-in attic insulation (R-49) reduce temperature of 2nd floor ceiling. PV shades south roof.
Energy Use Progress

Annual Combined Electricity & Natural Gas Use (MWh-eq)

- 57.1 (2007-2008)
- 31.0 (2012)
- 23.4 (2016)

- Space heating
- Water heating
- Space cooling
- Refrigerators
- Other
- Other Data Center

Source: The Rextor Group PLLC

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Questions?

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ADDITIONAL INFORMATION
Retrospective

What worked well?
• Solar PV
• Deck canopies (solar PV as summer shade)
• Daylight tubes
• Simple tools
• Thermostatically controlled shower valves

And what didn’t?
• Solar DHW has 40-year payback
• Attic insulation (reflective & blown-in cellulose) installation
  – Low-pitch roof
• TEDs unreliable (use something else!)
• Water recirc pump under kitchen sink
  – Noisy
  – Wastes energy circulating to the furthest tap (kitchen) when >75% of use is in center of house (3 bathrooms & laundry)
Other Saving Items (pre-2007)

- Seal & insulate behind baseboards
- Sealed fireplace inserts
- Caulking & foam insulation whenever any exterior wall or attic penetration is opened or touched
- Sealed & insulated electric-service entrance (early 2007)
- Garage door insulation
- Pipe [over-]insulation
- Garage wall insulation
- Insulate bedroom floor / garage ceiling
Total Waste Stream Reduction

• Garbage diverted to recycling and (more importantly) compost
  – Garbage service reduced from 360 liter (96 gal) in 2007 to 240 liter (64 gal) per week in 2012
  – Target by end of 2013: 120 liter (32 gal) per week

• CFLs – increased the waste stream
  – Failure rate was high; not meant to cycle on and off frequently (don’t turn off the lights when you leave the room?)

• Water use reduction
  – Low-flow toilets (varying degrees of satisfaction)
Water Use Points – Heidner Residence

Hot & Cold:
- Kitchen sink: 1.9 gpm
- Kitchen dishwasher: ___ gpm
- Blue bath sinks (2): 3.4 gpm
- Blue bath tub/shower: 7.4 gpm
- Master bath sink: 1.7 gpm
- Master bath shower (2 heads): 3.2 gpm
- Mauve bath sink: 1.3 gpm
- Mauve bath shower (2 heads): 3.3 gpm
- Washer: ___ gpm
- Hot H2O size: 22.2 + ____ gpm

Cold Only:
- Kitchen hot/cold tap
- Kitchen refrigerator door chiller
- Blue bath toilet
- Blue bath bidet seat
- Master bath toilet
- Master bath bidet seat
- Mauve bath toilet
- Front hose bib
- Front drippers & sprinklers
- Rear hose bib
- Rear drippers & sprinklers
- Meter size: ______ gpm
What’s Next?

Immediately

• HRV
• Continuous external rigid insulation
• Last remaining old window replacement
• Clothes dryer make-up air / pre-heat

Longer-term

• Replace natural gas furnace with more efficient model
  – Fan energy especially important, as it’s also used for HRV and a/c
  – Evaluate whether a/c is still needed
• More efficient refrigerator (last major appliance to upgrade)
• Replace / upgrade business servers (purchase used)
• HE dryer (when such appliances exist)
• Rain water collection
• Use data center (server) waste heat to heat spa water
• Replace coffee maker (when it dies) with one using a thermal carafe
Annual Energy Use
US Residences

Average US Housing Unit

27.1 MWh (97.6 KJ)

- Space Heating
- Water Heating
- Space Cooling
- Refrigerators
- Other

Project House

57.1 MWh (2007-2008)

- Space Heating
- Water Heating
- Space Cooling
- Refrigerators
- Other
- Other Data Center

Source: US EIA 2009 Residential Energy Consumption Survey
Source: The Rextor Group PLLC

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Total Energy Reduction Results 2012

- Summer peak gone
- Energy use still has U-shape for space heating (natural gas)
- Energy use ~ 17% less than similar size houses in same urban area using natural gas heat
- Energy net ~ 38% less than similar size houses in same urban area using natural gas heat

Sources: The Rextor Group PLLC, US EIA 2009 Residential Energy Consumption Survey

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Energy Efficiency & Demand Response

Available power at peak
Peak power used

5% or less
Load duration
20% higher

DR possible savings $$ without EE

Time of use billing or
Energy Efficiency (EE) lowers use

Without EE improvements
With EE improvements

Energy Efficiency (EE) lowers use

Without EE improvements
With EE improvements