



# A Long-Term Case Study in Residential Sustainability

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## Sustainability is ...



• 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.



Source: US Energy Information Administration, Electric Power Monthly



# **Proiect House**



- Mixed-use: Residence & small business
- Located near schools, shops, library, transit, hospital, community park
- 1966 stick-built, 2-story,
   334 m<sup>2</sup> (3600 ft<sup>2</sup>), 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



Source: US EIA 2009 Residential Energy Consumption Survey

Source: The Rextor Group PLLC







## Measure, Record, Plan

## Tools



## Sometimes simpler tools are the better choice.

## Measurements

- Electric power
   consumption of major
   appliances
- Daily weather (temperatures)
- Daily electric & natural gas consumption
- Attic air temperatures
- Total water consumption; consumption of sinks, showers, baths

Photos: D Heidner unless explicitly noted otherwise.



## **Energy Use Baseline**

Electricity (MWh/mo)

3

2

1.5

0.5

0

2.5

**Electricity** 

-2007

2008



- 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
- Expected a U-shape for heating climate, but ...

Jan Feb Jun Jun Sep Oct Nov Dec

- Peak use is summer!
- ~ 95% 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



## **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



- 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)



Sometimes improvements have unexpected side effects.



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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)



## **Attic Improvements**

Recessed ceiling lights •Not rated "in contact" •Leak air and heat

Daylight tube before connection to hall

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

Insulation does not reach tops of

ceiling joists

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



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



## Solar Energy

Daylight tubes in

baths, hall

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





# 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 preheat

Domestic Hot Water





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

Source: The Rextor Group PLLC



Measure usage

month

Size for house

Total flow

bedrooms

% hot water per

only 2 occupants

possibility of future hydronic heat

currently, but 4

•

•

## **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

#### Air quality trend 'Old Spice Classic'' Peak -- 100 example CO<sub>2</sub> spikes from ~700 ppm to ~1500 Someone walked near the sensor wearing Old Spice stick deodorant. 731 ppm Cit 11:06:19 11:18:20 11:30:21 11:42:21 11:54:22 12:06:23 12:18:24 12:30:25 12 7/4/2013 Air Monito Air quality trend Opening a window near the sensor. CO<sub>2</sub> drops from ~1000 ppm to ~400 Source: The Rextor Group PLLC

#### Project house now has 2.8 ACH<sub>50</sub>!

- Average US SF houses of similar age, ACH<sub>50</sub> = 10 to 40
- **HRV** needed
  - (ASHRAE 62.2-2010 requires mechanical ventilation if  $ACH_{50} < 7.0$ )
- Humidity control must be considered .

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





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Low infiltration -> higher impact of  $CO_2$  and VOCs

A low-cost sensor yields information - and surprises.

## **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

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



• 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 m<sup>2</sup> (500 ft<sup>2</sup>) house
- PV production reduces amount used from grid each month



## **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**



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Slide 20

Source: The Rextor Group PLLC



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GROUP

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## **Questions?**

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# **ADDITIONAL INFORMATION**



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## 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



Source: US EIA 2009 Residential Energy Consumption Survey

Source: The Rextor Group PLLC



## 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



## Energy Efficiency & Demand Response





#### Load duration

