Affordable Zero Energy Habitats

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OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Outline

- Process
- Site
- Foundation
- Envelope
- MEP
- Next two ZEBs under construction

Process

Integrate DOE Emerging Building Technologies, Building America and ZEB

- Space Conditioning & Refrigeration
- Envelope Systems & Windows
- Appliances
- Solid State and Hybrid Lighting

Rotatable guarded hot box in the Buildings Technology Center. The hot box is used to test the thermal performance of walls.

Wall Systems

- Developing next generation SIPs
- User agreements with industry partners on testing and analyses of >200 wall systems

“Drop-in” residential heat pump water heater

- New designs
  - Same electrical and plumbing “footprint” as conventional
  - Lower first cost
- COP
  - 1.5 to 2.5 compared to 0.95
  - Beta unit improved from 1.0 to 2.5 in BTC Lab
- DOE-sponsored field tests with utility partners across 10 states
  - 50% energy savings
  - Two-year payback potential
- Conducted extensive durability/reliability tests including the most recent drop-in and add-on models

Roofs

- Development and testing of reflective coatings:
  - 24 coatings tested, representing 75% of market
  - 35 sponsors, $1M (80% private $)
  - Cool colored coatings

- Shading benefits of photovoltaics being measured
- Roof energy savings calculator

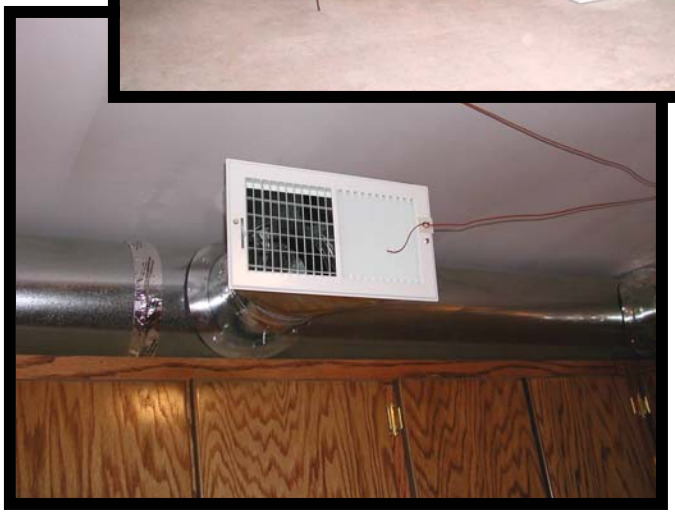
- Currently Extending calculator:
  - For residential roofs
  - To estimate peak reductions

Two identical Habitat Houses Side by Side for HVAC R&D

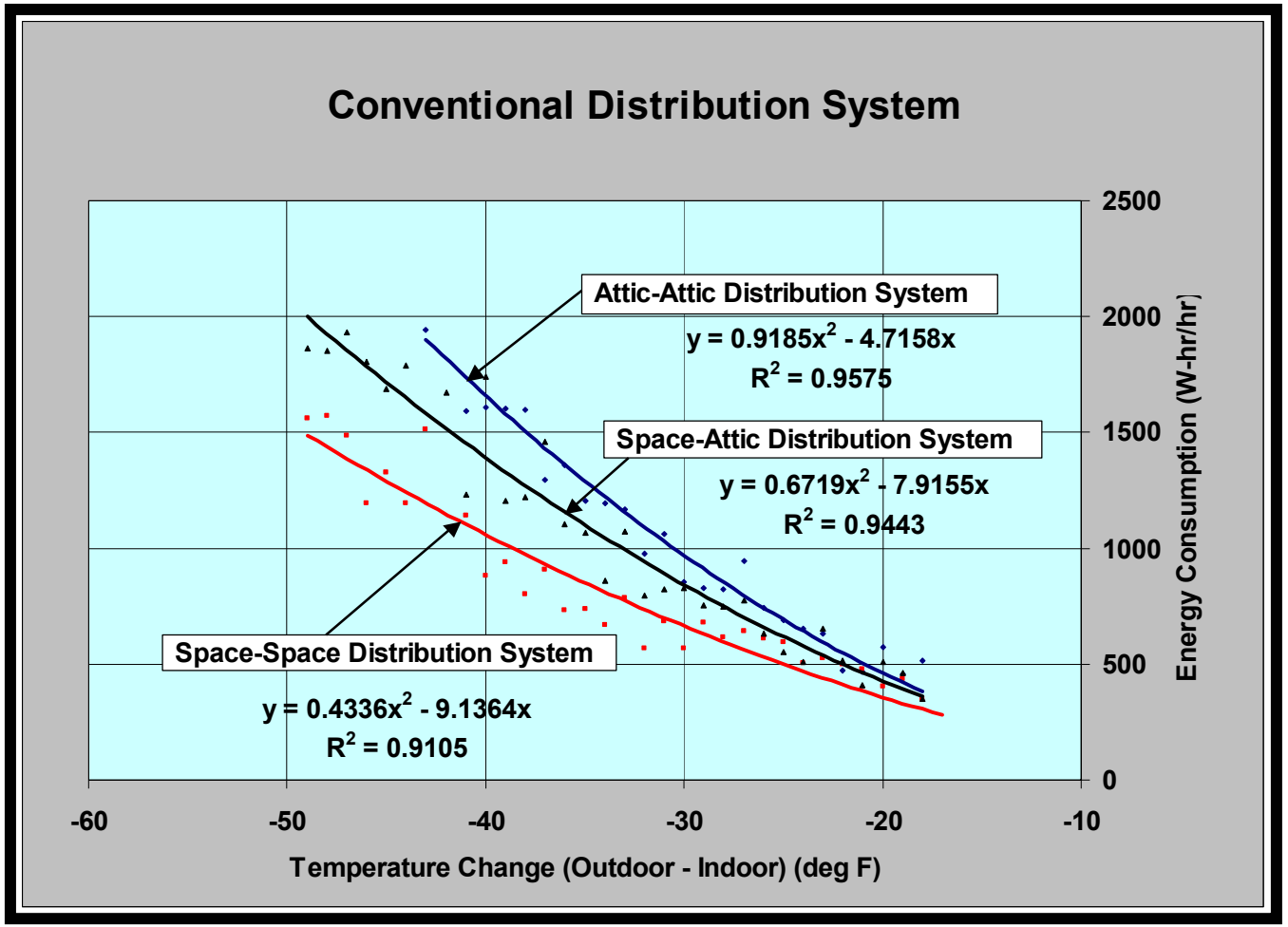
Ordinary Houses except for 3 Heat Pumps instead of one and weather station strapped to the back porch

Conventional Attic Duct System

Ducts and Indoor Coil in the Conditioned Space



Ducts and Indoor Coil in Conditioned Space saves 35% heating & cooling energy



Building America Green Power Partner National Showcase

HVAC Test Houses

1st ZEB House

Envelope Test House

Base House

Energy Right 20

Energy Star 30

Building America 40

BA 50

BA 60

BA 70

ZEB

Glen McCullough, Chairman TVA board

"Over the next three years
TVA will sponsor five homes
in Harmony Heights Building
America Habitat Neighborhood"

June 17, 2002

Built 1st affordable "Zero Energy" Test House June 2002

- The "Zero Energy" goal is for houses to produce as much energy as they use
- Advanced energy technologies being researched with Habitat for Humanity
- Up to 90% more efficient than typical Habitat for Humanity (HFH) homes
- Monitoring of zero-energy HFH house since November 2002

Solar panels on the roof will generate electrical power for the home.

1st Habitat BA Green Power Partner House drawing national attention, August 5,2003

- Established first Habitat BA ZEB collaboration
  - Building Science Corp.
  - IHP/FSEC
- Partners
  - DOE BA
  - TVA
  - Habitat
  - SIPA
  - Metal Roof Alliance
  - Andersen Windows
  - BP solar
  - Whirlpool
  - Dupont
  - EMI HPWH Manuf.

Features

- Air-tight floor, wall and ceiling SIPS
- All ducts inside conditioned space
- Mechanical ventilation- air-cycle
- 13.7 SEER 1.5 ton HP
- CFL and Energy Star Appliances
- Windows .34 U-value, .36 SHGF
- Reflective hidden metal seam roof
- Grid-connected 2 kW PV
- Heat recovery shower
- Integrated HPWH

Site

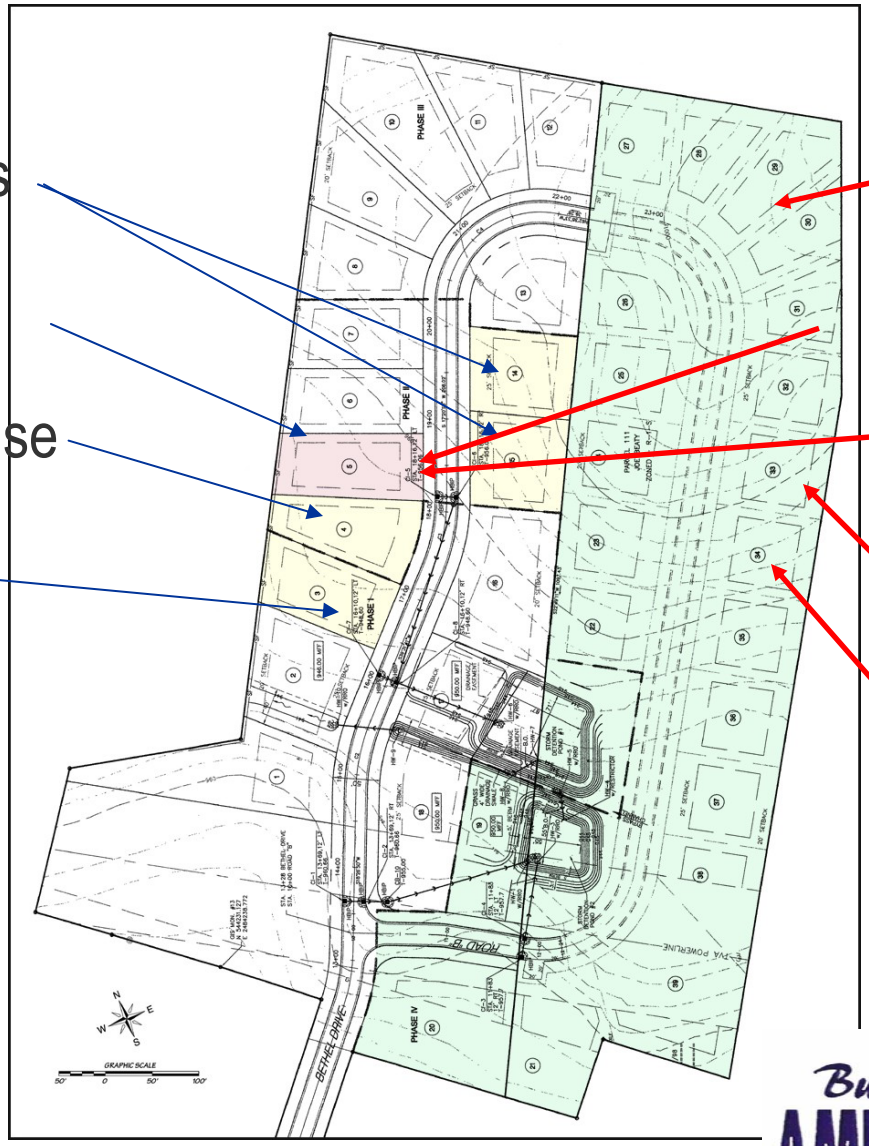
Building America Technology Innovations
Source; Lenoir City, TN.

HVAC Test Houses

1st ZEB House

Envelope Test House

Base House



IBACOS

Building Science

IHP

CARB ?

ConSol?

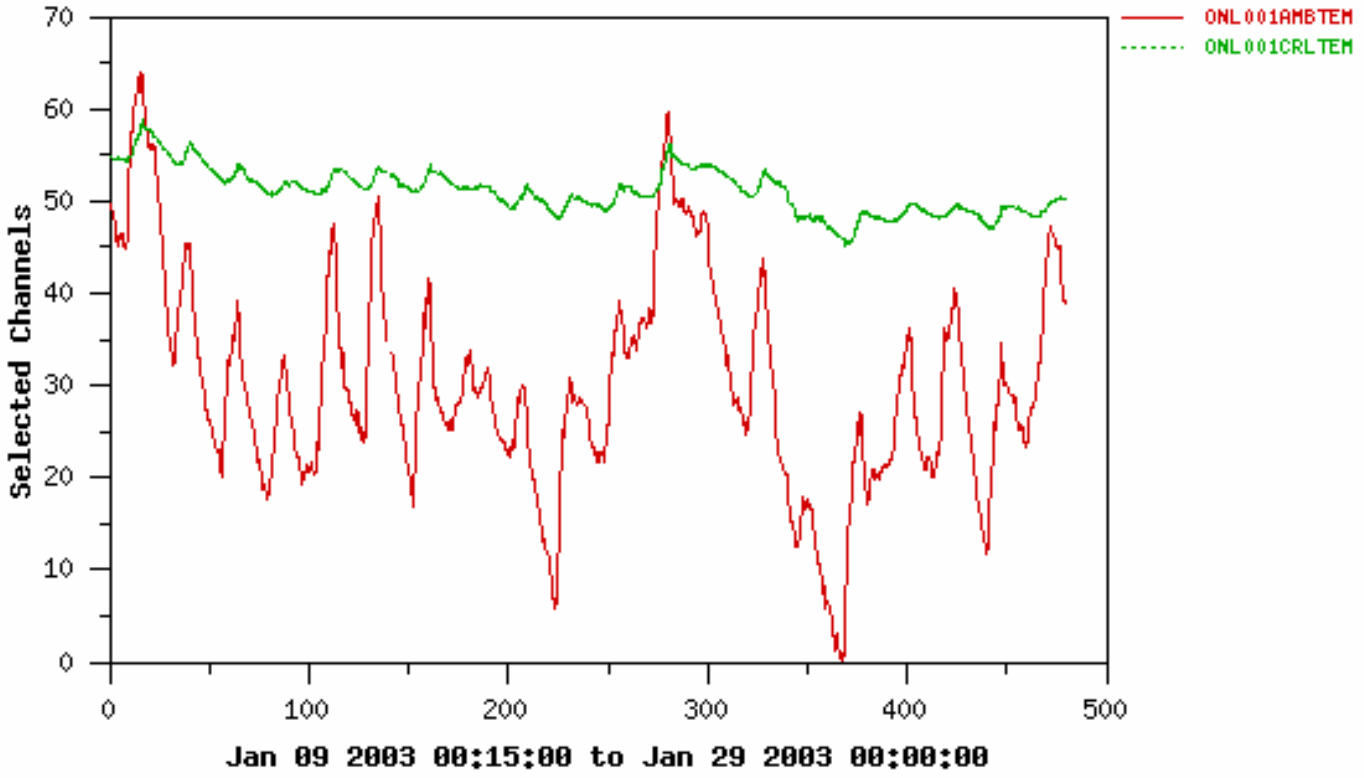
Building AMERICA

Foundation

Crawl space unvented and ground cover well sealed to wall

SIP Floor

Crawl Space remains warm throughout cold January weather



Envelope

SIP floor, wall and ceilings tested in the Large Scale Climate Simulator

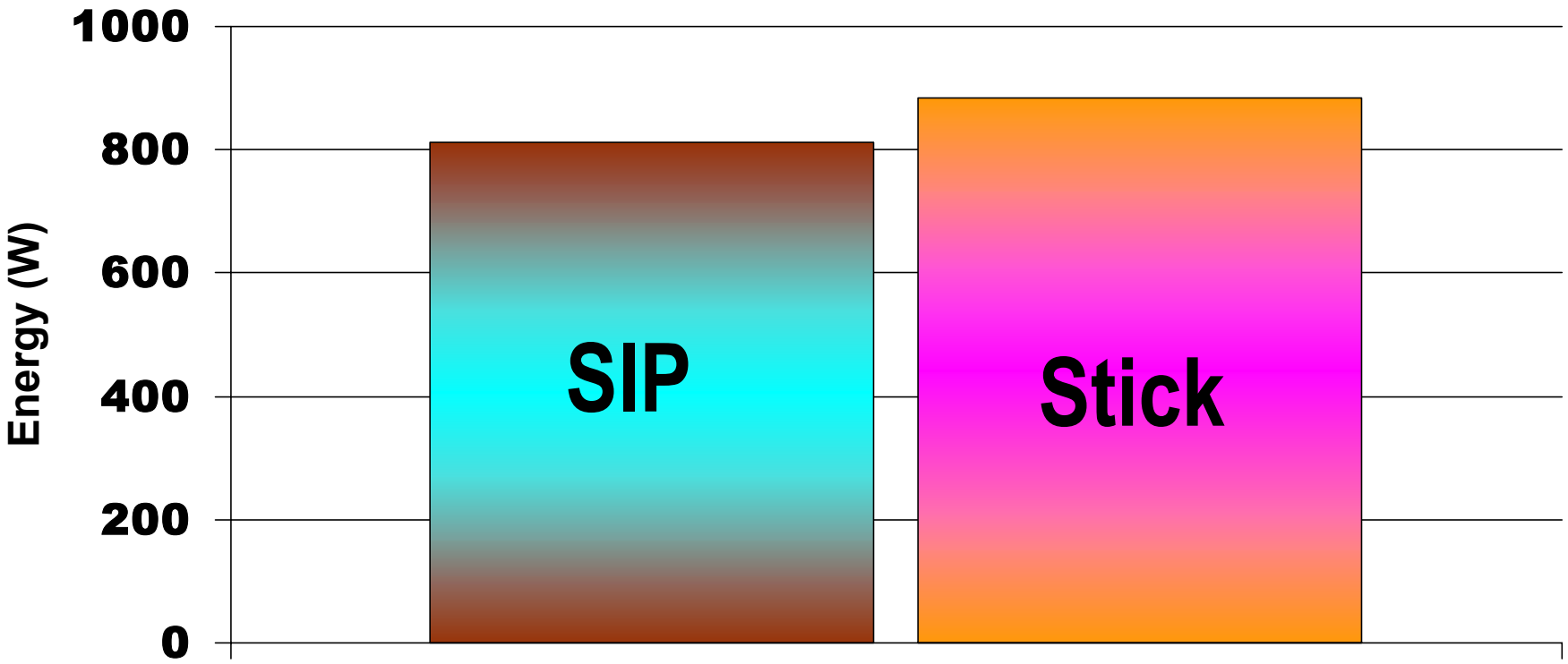
SIP Test Room Constructed in Similar Manner as full Scale House in the Laboratory

Identical 2 X 6 Stick Room tested under exact conditions as SIP

Both test rooms dry walled with 9 electrical boxes on inside and one outside

Same Andersen window and door installed in both test rooms

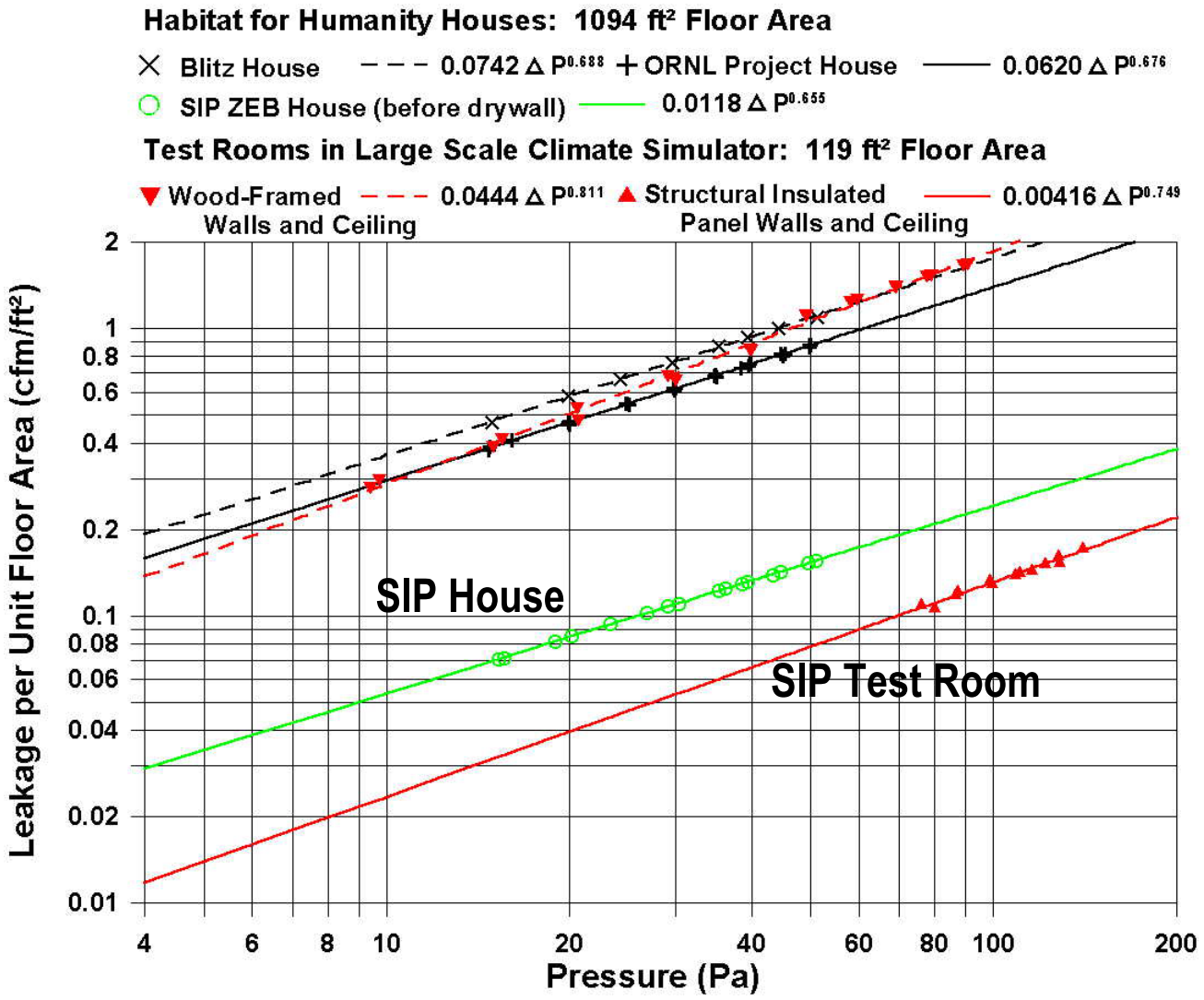
At 0ºF, 4.5 in. SIP uses 10% less energy to heat than 2 X 6 wood frame and 20% less floor area



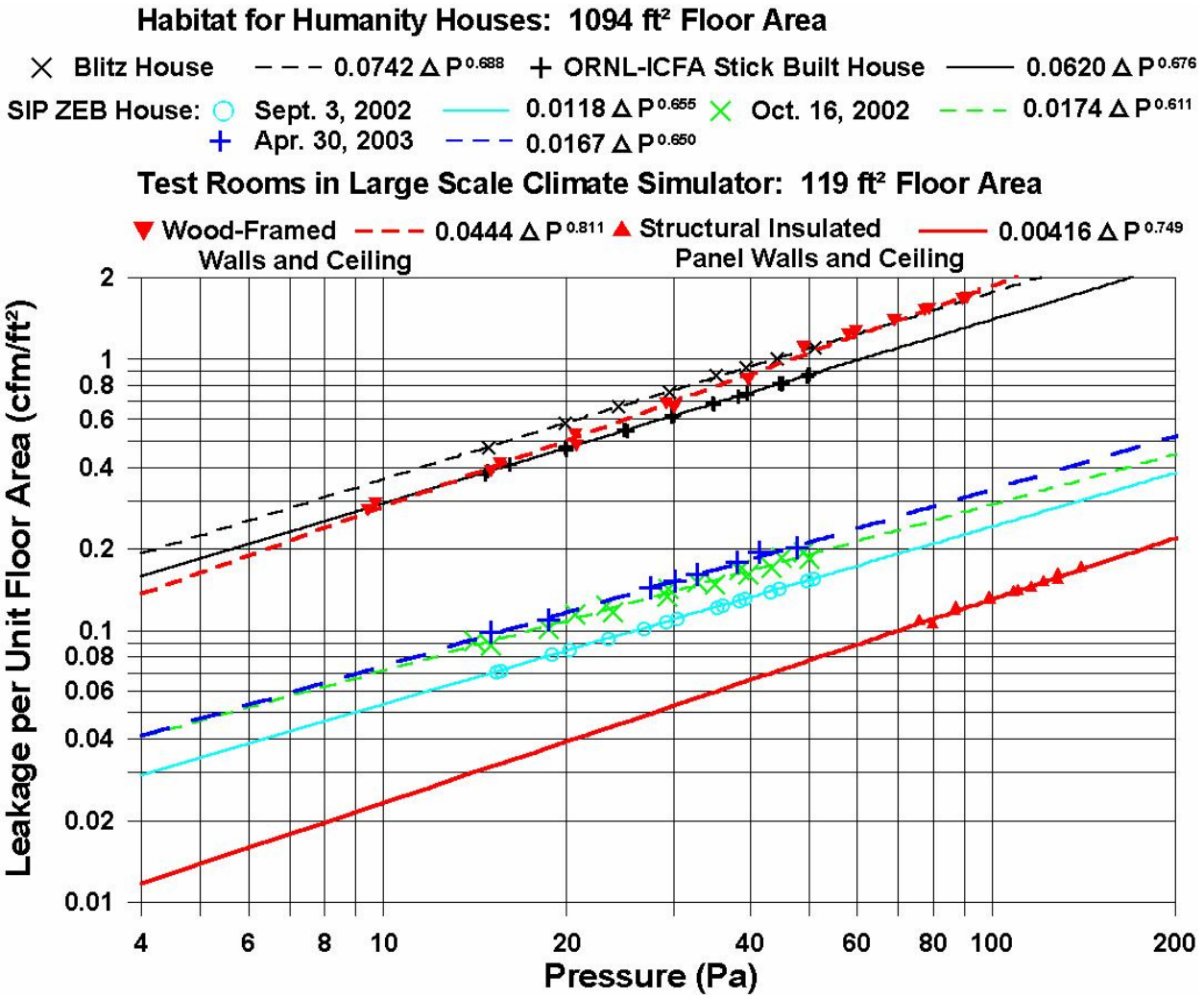
Same Structural Insulated Panel System used to built first attempt at net zero house; floor, walls and roof installed in 3 days

Blower door before drywall

SIP test room 95% more air tight than stick whole SIP house 85% at 50 pascals



SIP House Maintains Air-tightness



Raised metal seam roof holds PV modules; TVA offering Green Power Partnerships

Paying $0.15 kWh, retail rate $0.063

This is TVA's first partner.
David Garman to help celebrate August 5

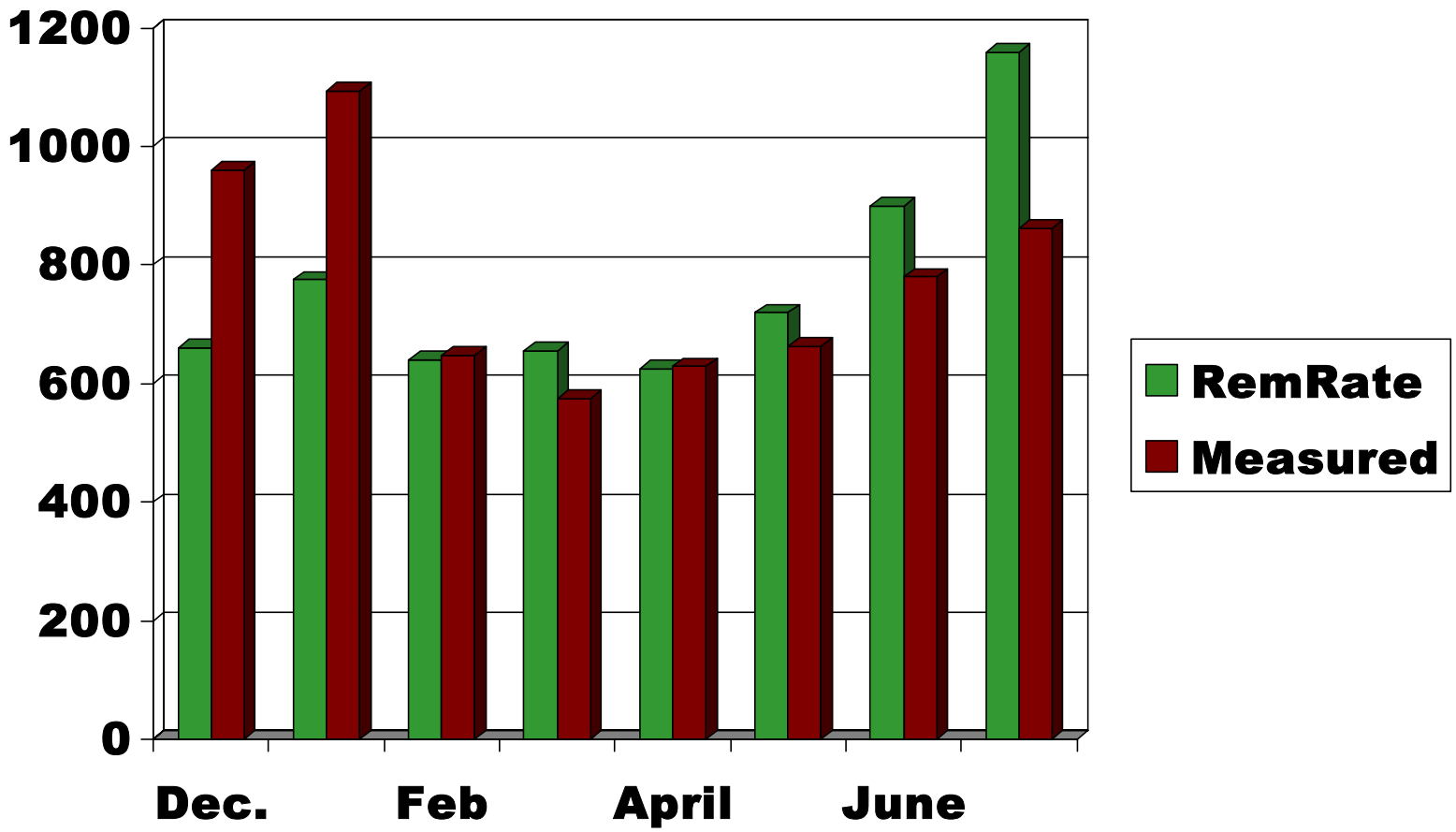
Mechanical, Electrical and Plumbing

Ventilation, supply ducts, wiring chase inside conditioned space

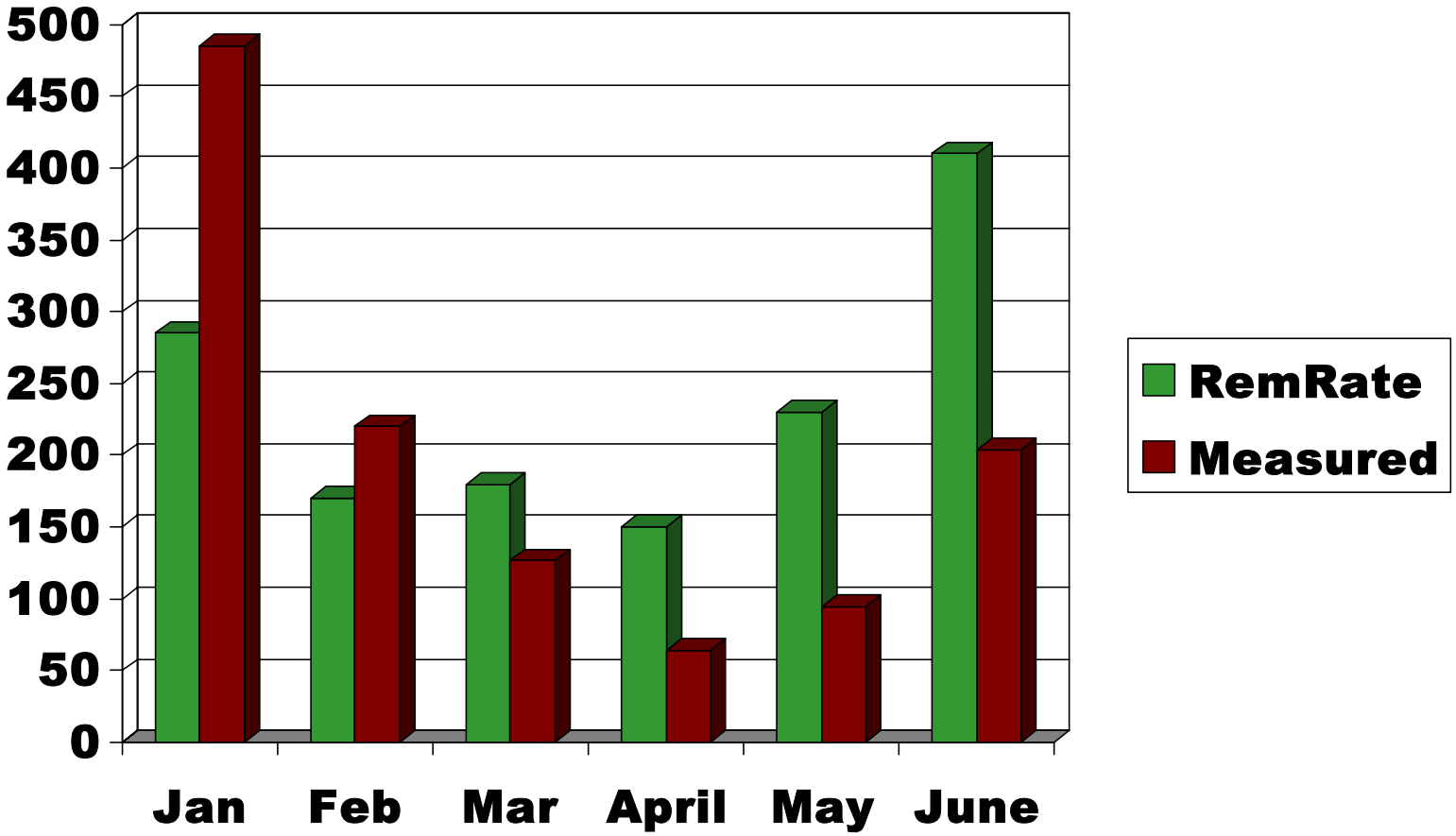
1st affordable ZEB has HERs Rating of 90.2; energy savings of 51% from code

- 100 m^2 (1067 ft^2) of gross floor area, 4 people, with a 13.7 SEER heat pump
- Air tightness 0.81 l/s m^2 (0.16 $cfm_{50}/ft^{2)}$ of floor area

Measured total energy close to BSC model prediction



Measured HVAC energy is 20% less than predicted by BSC model prediction



65% energy cost savings

- TVA's dual metering will pay $0.15 for every kWh
- Current residential rate = $0.063 kWh
- If A is net-meter and B is PV generation meter
- Net-meter (A) 6659 kWh (5457 7/28)
- Generate (B) 2000 kWh (1330 7/28)
- House will use total of (A + B) = 8659 kWh (6787)
- Annual energy charge = (A+B) X distributor retail rate = $545.51 ($427.58)
- Annual generation credit = B X $0.15 = $300 ($199.5)
- Annual energy cost =$245.51 or $20.46/month ($24.87/8mo)
- Base case house $58.83
- Energy cost savings = [(58.83-20.46)/58.83] x 100 = 65%
- Actual 2002-03 winter heating cost $0.50/day

National Solar Buildings Tour drew 70 lookers October 5, 2002

Integrated HPWH

During the heating season the HPWH pulls heat from the crawl space

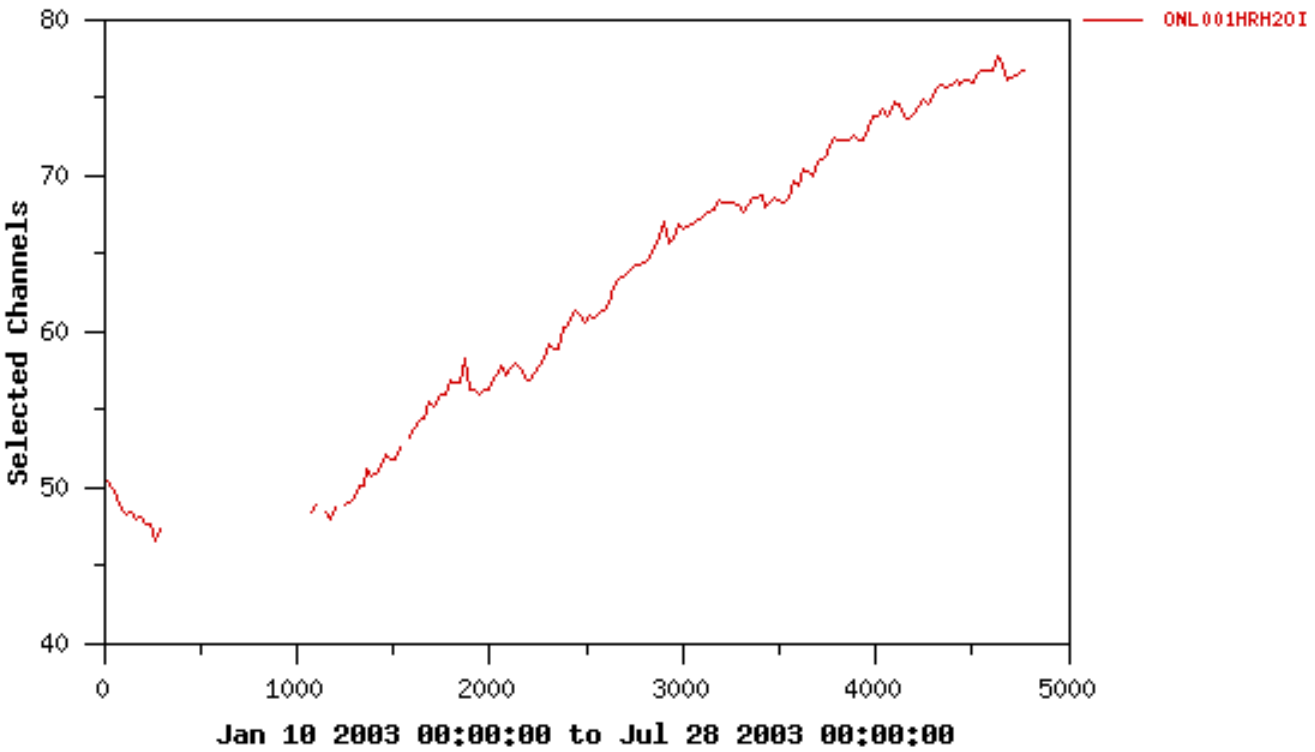
During the summer time heat comes from behind the fridge

Domestic Hot Water

- 70% of DHW used for showers and baths
- 39 gal/day average daily usage; 44% less than found in national HWHP field study
- 3.5 kWhr/day average energy; that is 32% less than found in national HWHP field study
- Coupling with refrigerator, crawl space, space cooling and dehumidification not optimized, yet
- Measured COP 1.4 compared to National field study of 2.0
- COP of 2.0 would save another 365 kWh/year
- 85 gal/day maximum usage
- Resistance heaters never needed

Shower waste water heat recovery

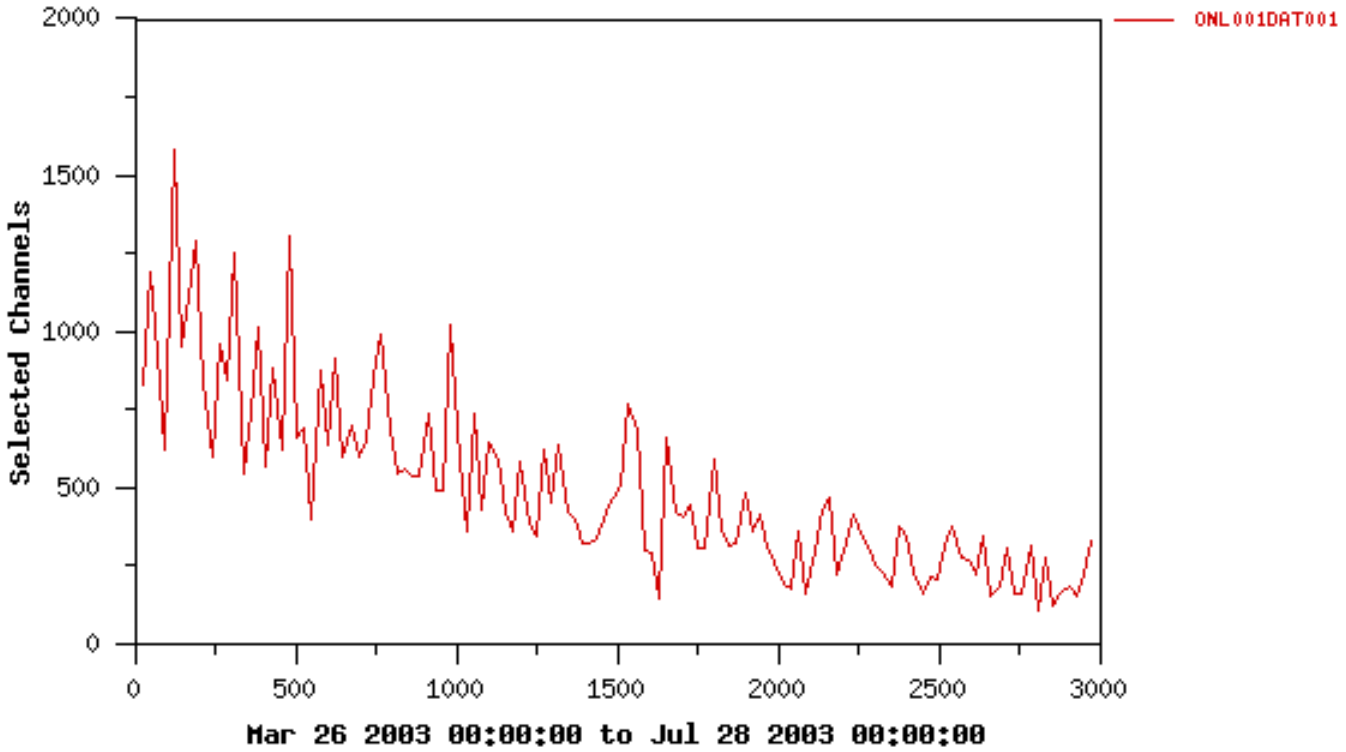
Water entering house at 48F in winter to 75F in summer



Shower water heat recovery

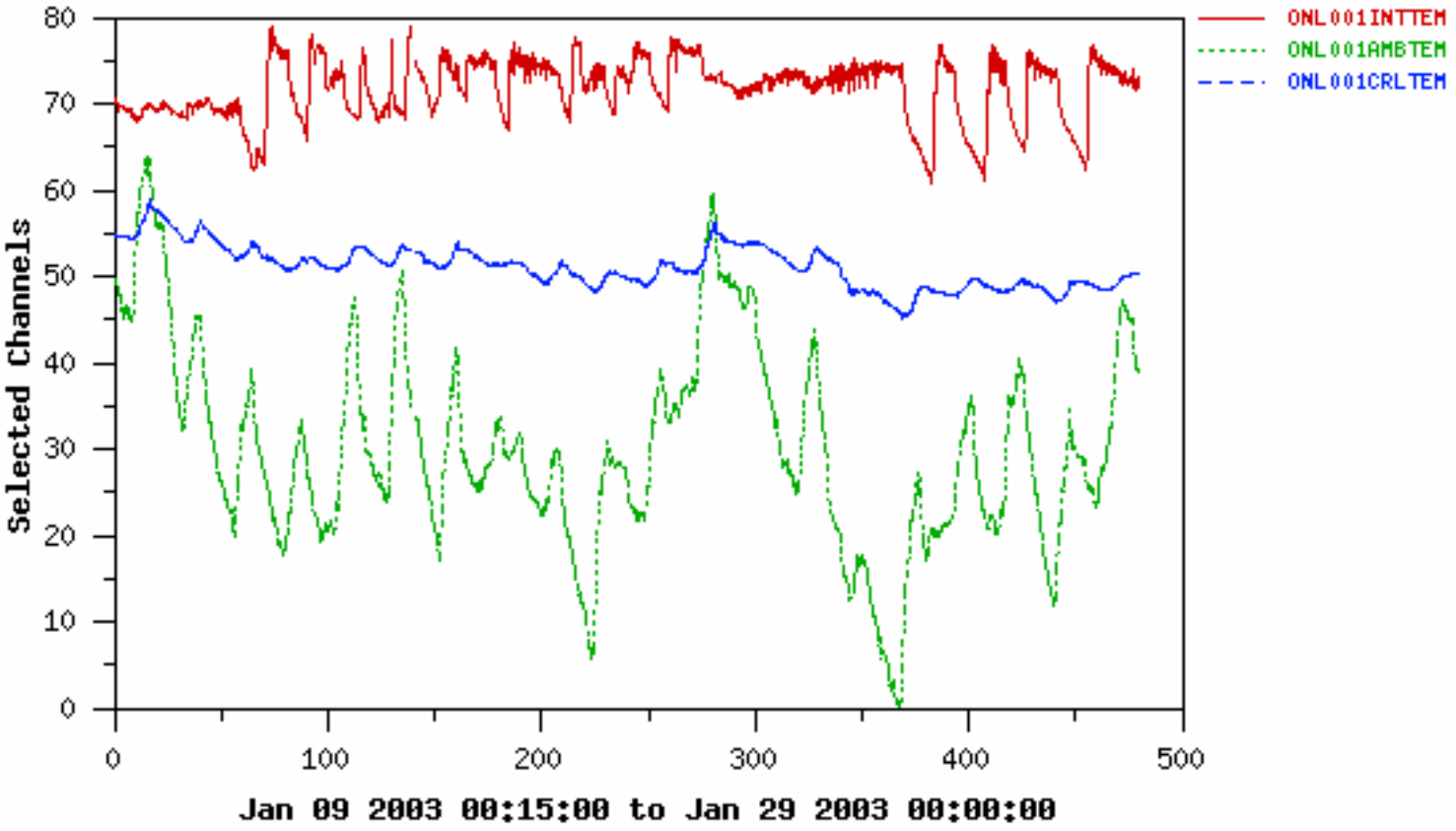
- Water drains at about 90 F
- Water picks up 4 F in winter ~6%
- Water picks up 2 F in summer ~4.5%
- 5% DHW savings 64 kW/yr, looking for more
- Insulating heat recovery unit before winter

Shower water heat recovery (BTU) data shows daily heat recovery April - July

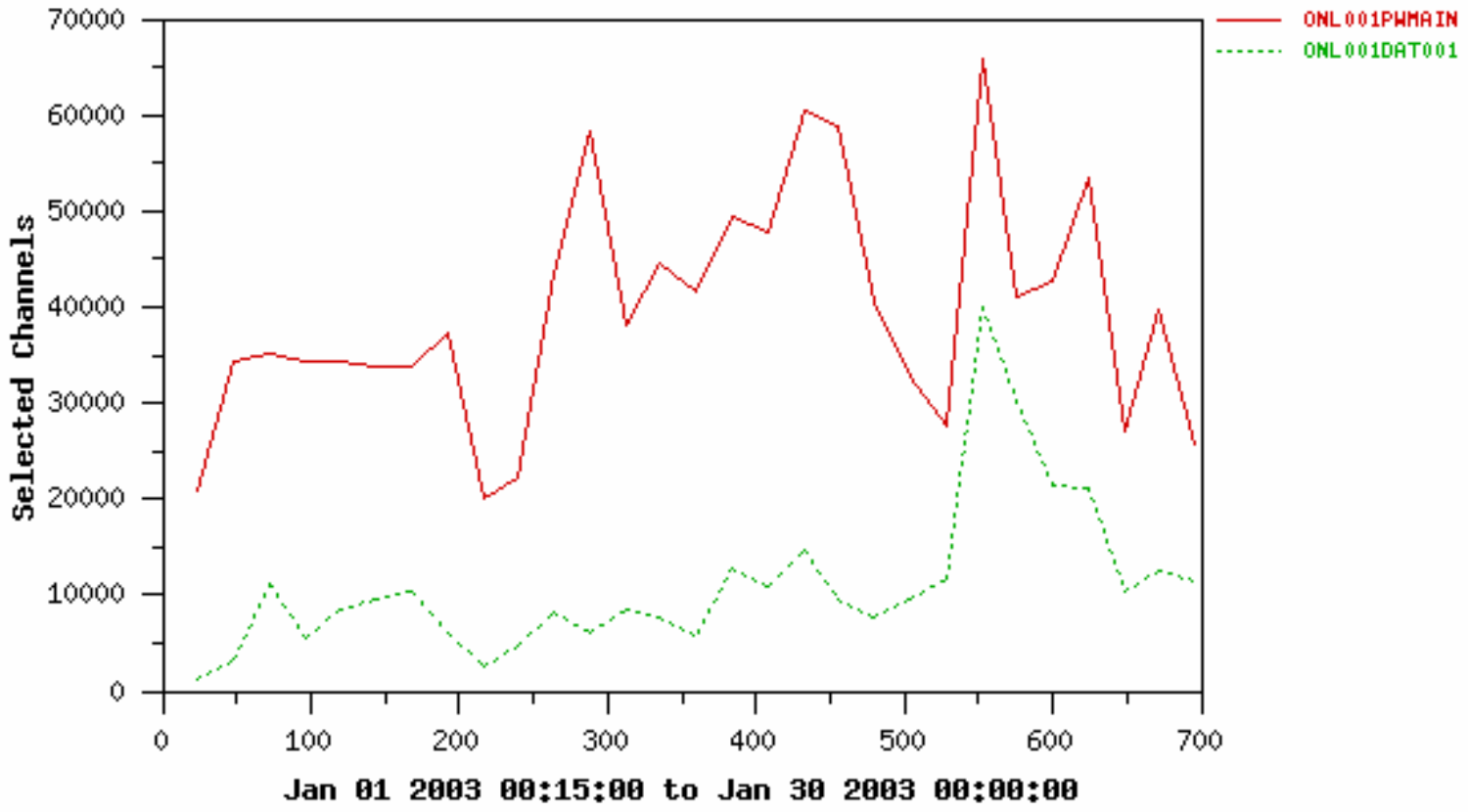


Zero Energy a Warm Thought in January

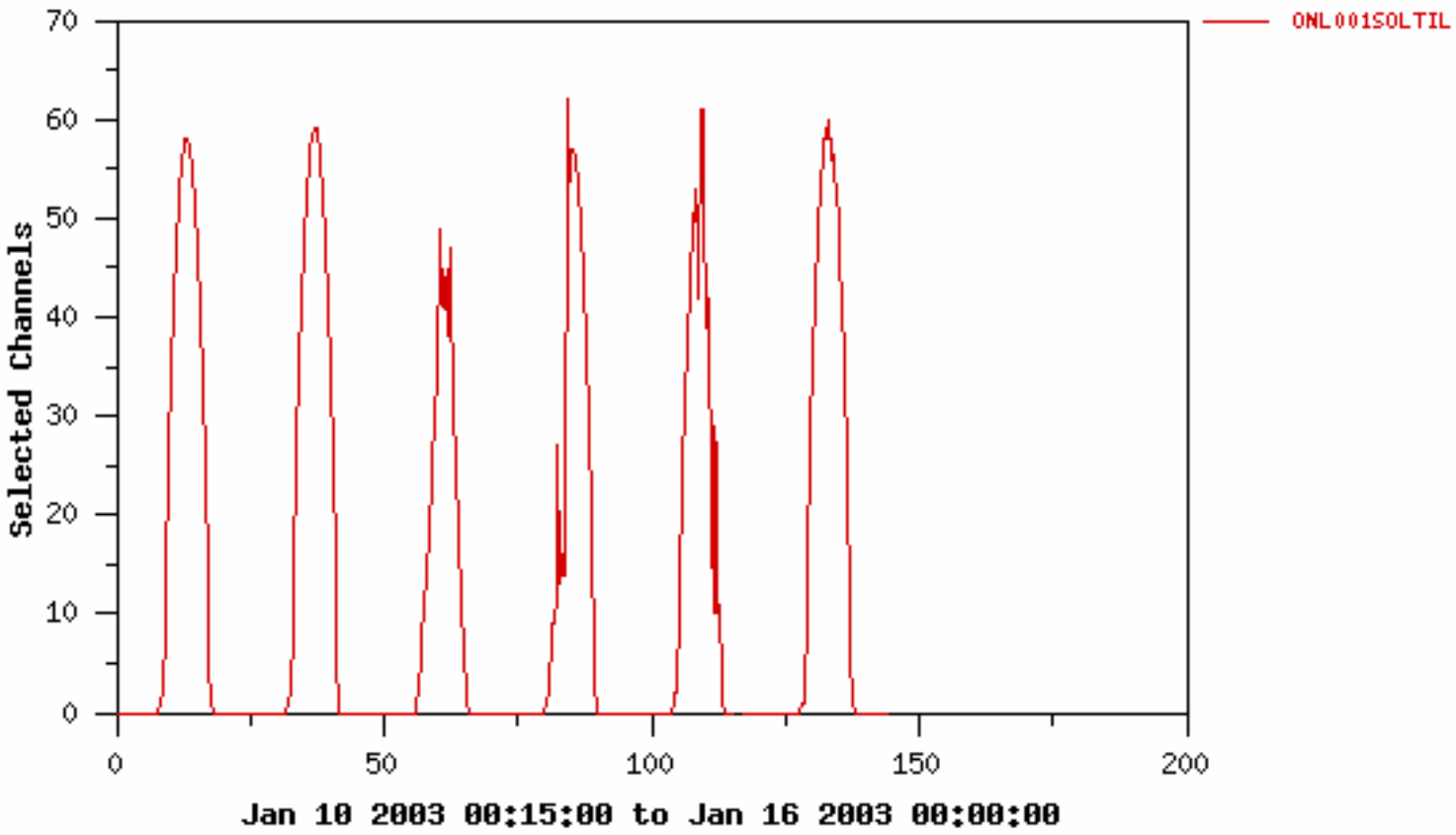
Interior, Crawl and Ambient Temp in January



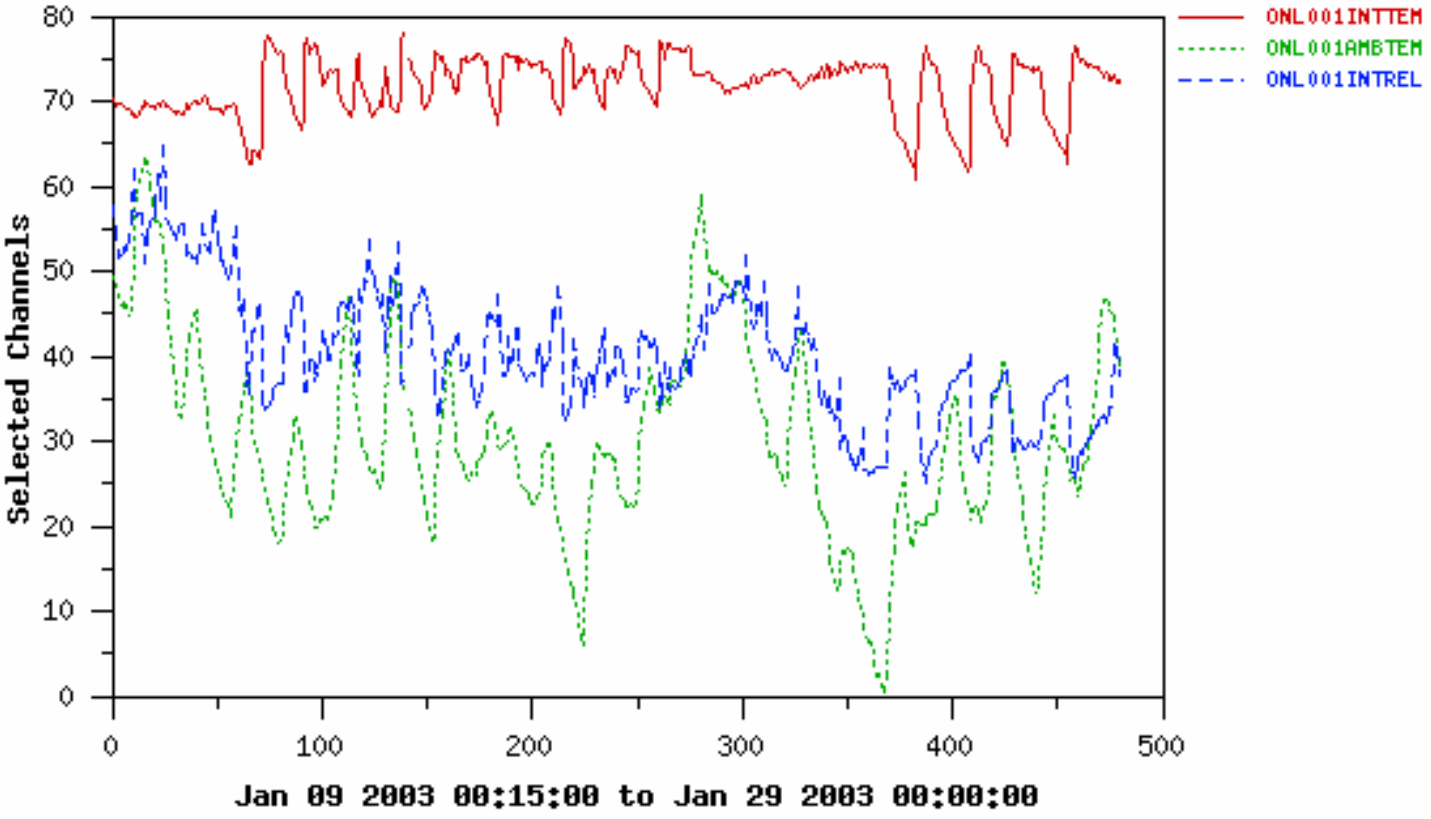
Daily Total and Space Heat Pump Power Used in January



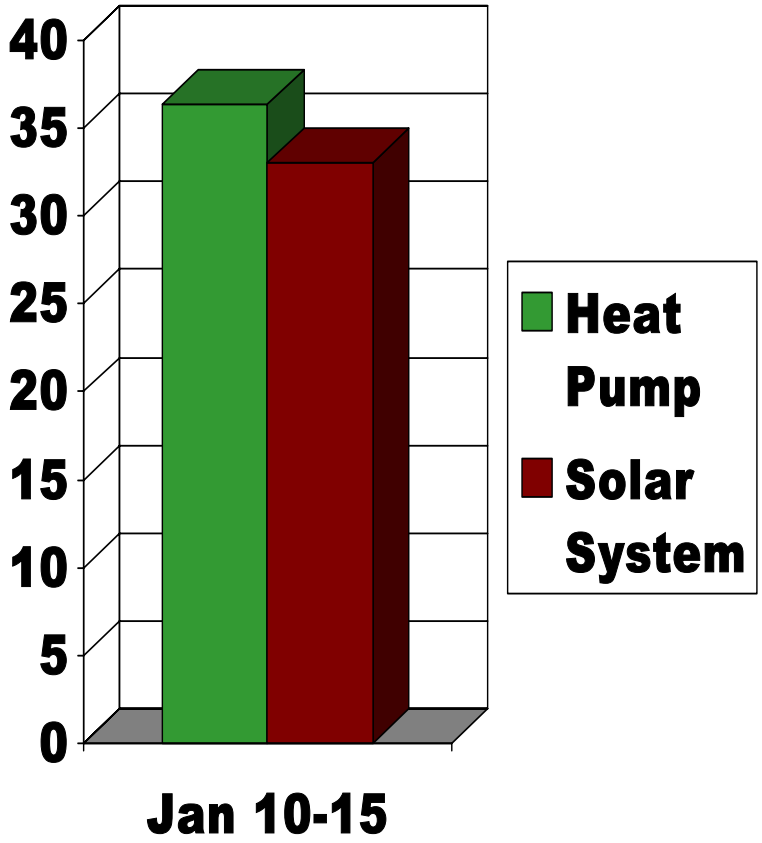
Solar available January 10 – 16, 2003



House does not dry up during heavy heating periods; RH stays around 40%

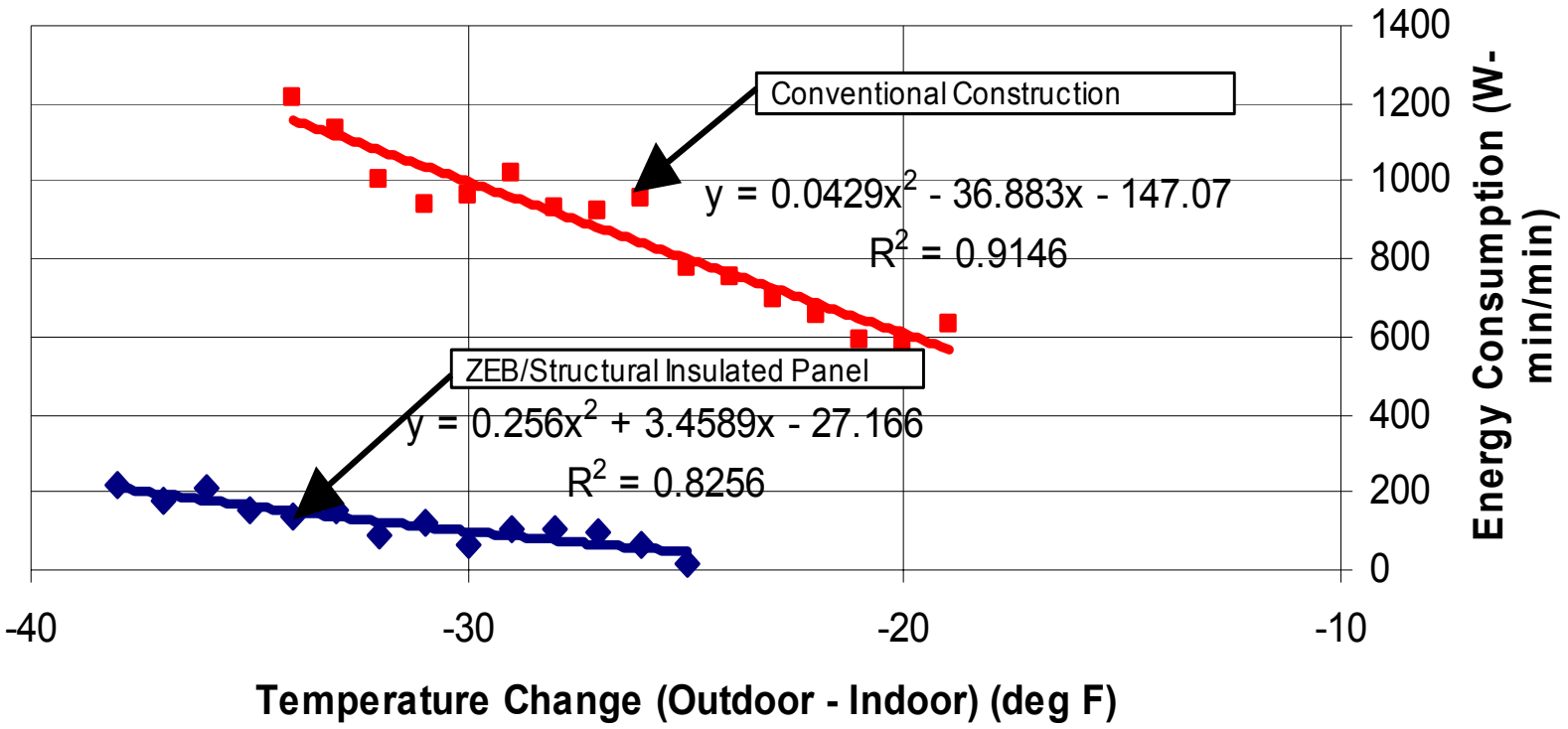


During cold sunny period in January; collected about as much power as needed to run the space heat pump

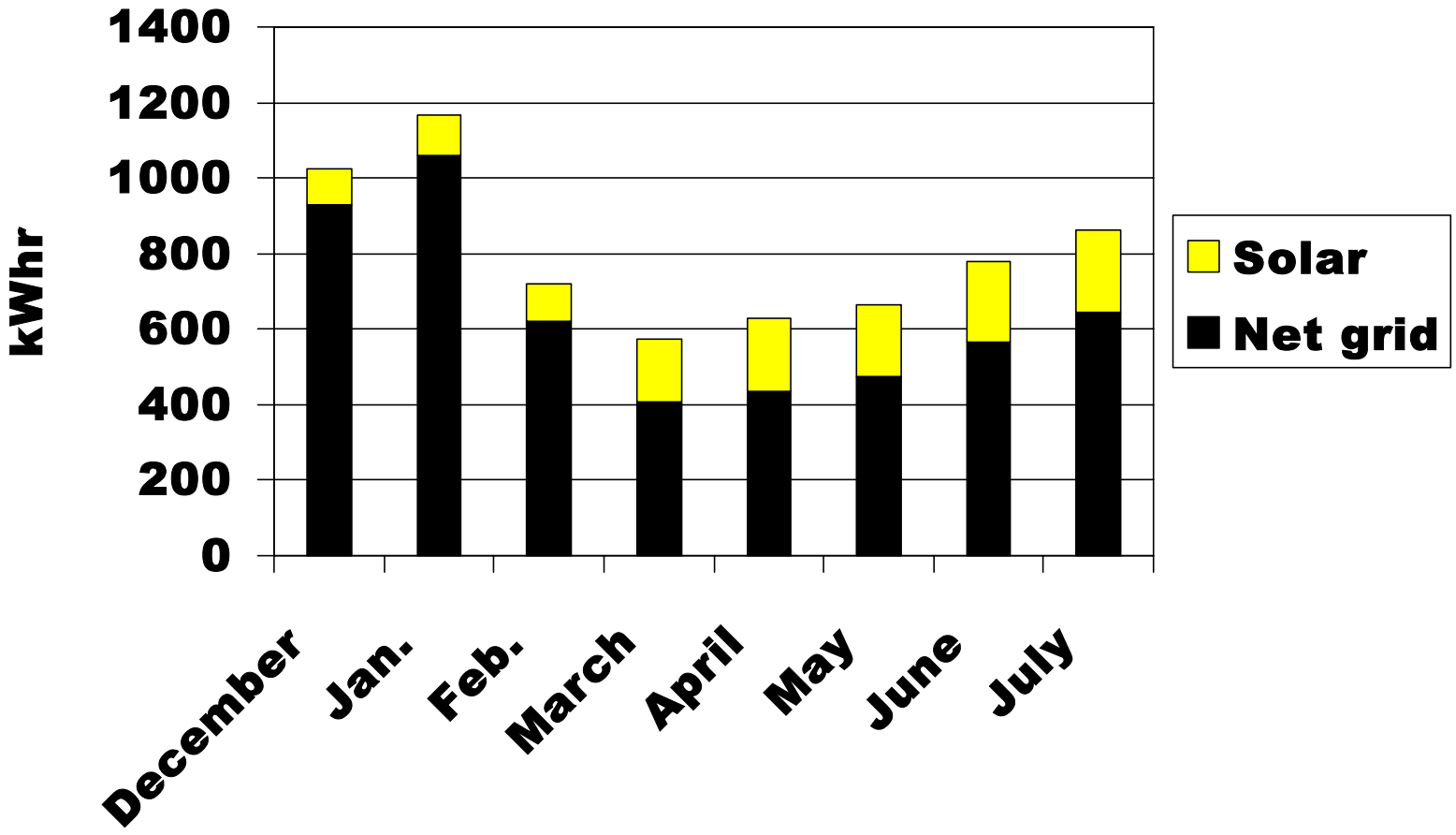


- Another 24.3 kWh needed for heating hot water
- If TVA was paying $0.15/kWh, could pay for both space and hot water heating for family of 5
  - Cost $3.76
  - Revenue $4.92

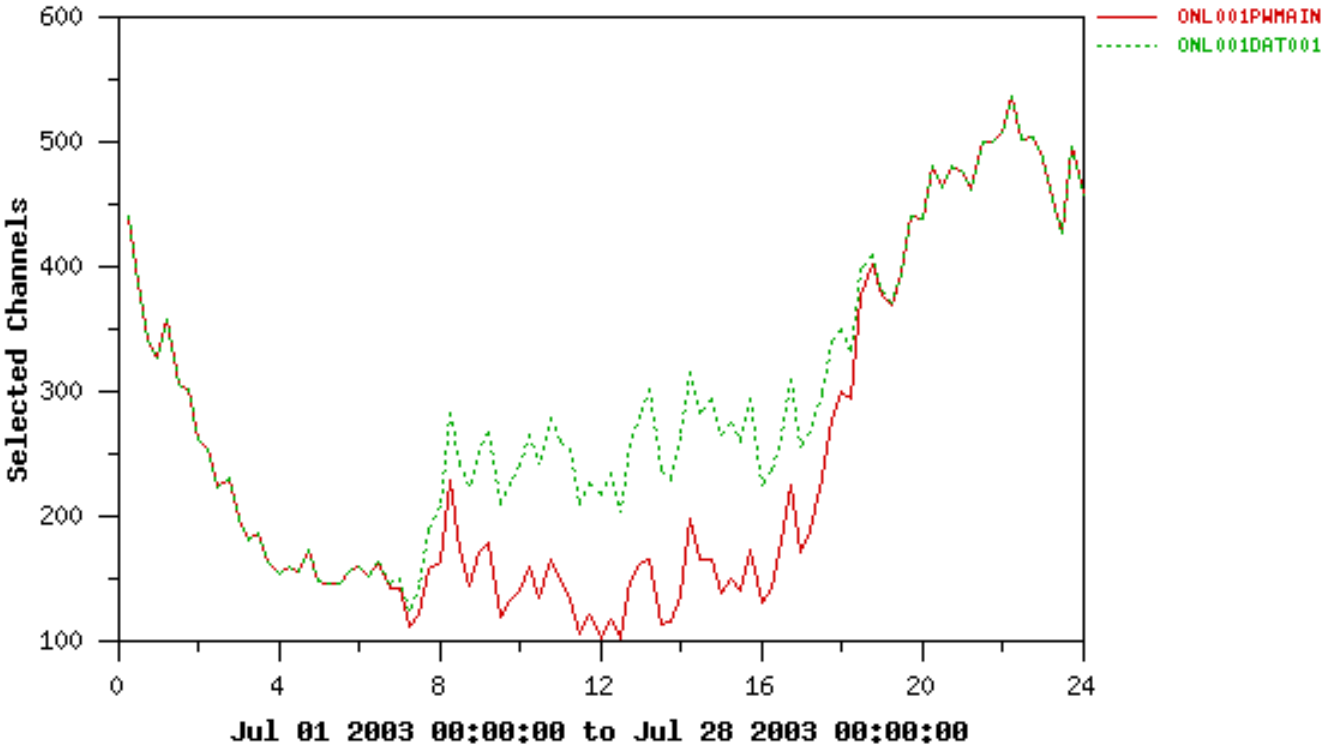
Heating the ZEB/SIP House takes 1/10th that of the Conventional Stick Habitat House Across the Street



Solar provides 20% of total so far



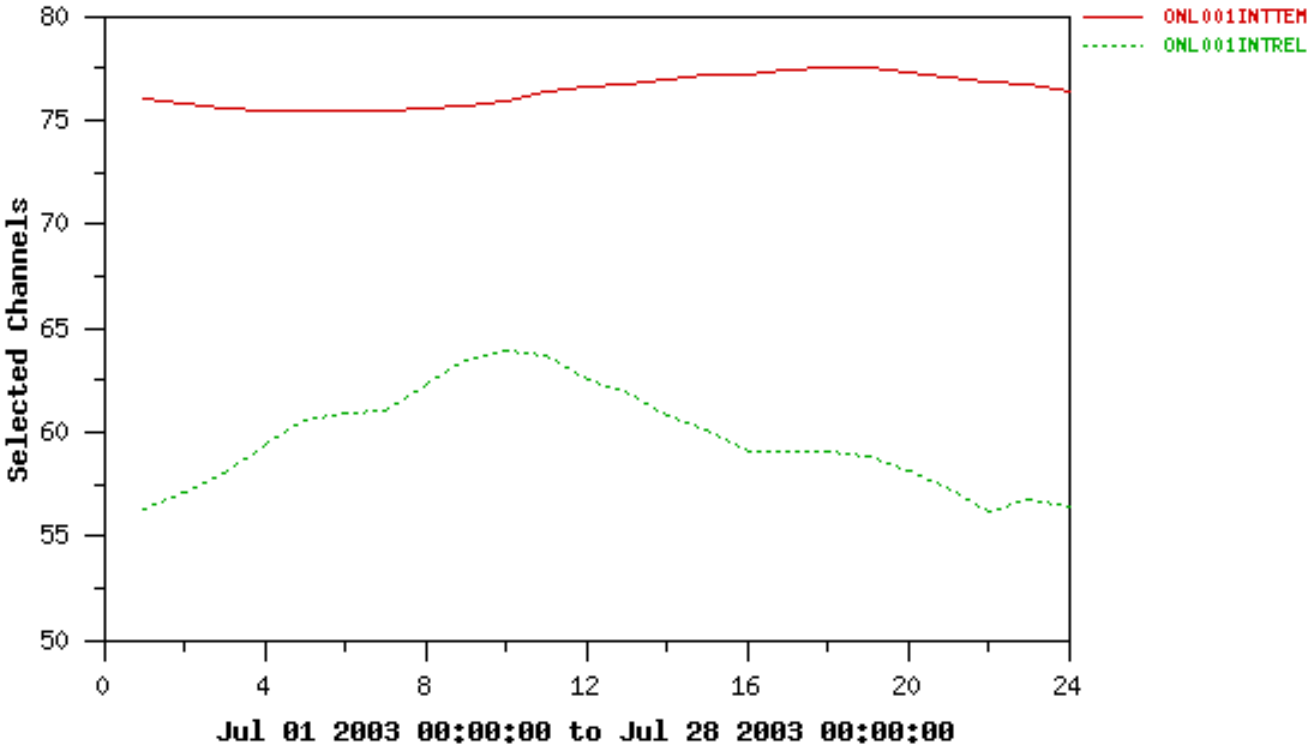
PV reduces summer PM peaks by ~40%



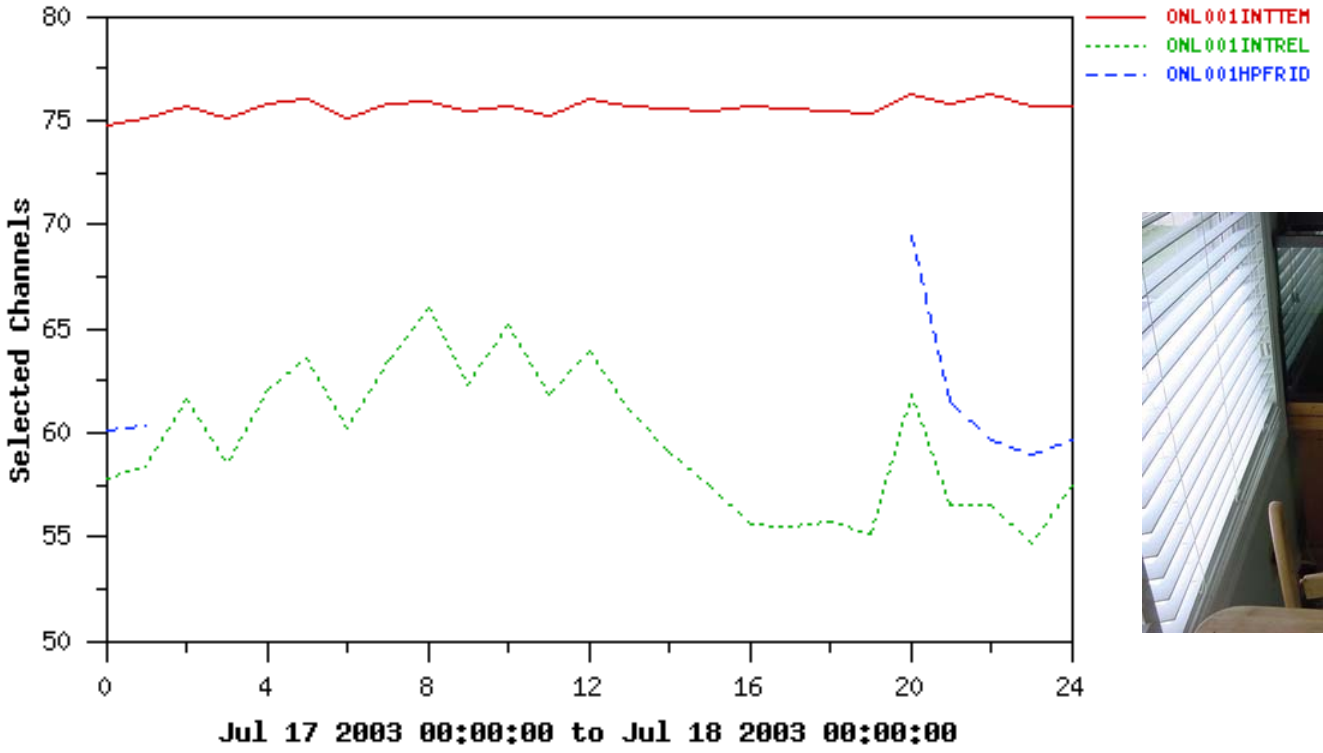
Green Power

- TVA buys all the solar AC for $0.15/kWh
- Maximum daily collection 11.2 kWh 6/22
- Maximum hourly collection 1.46 kWh 6/28 13:00
- 52% of solar goes to the grid.
- Solar reduces this houses average PM peak by 40%

Summer time RH running high but, homeowner said “we are very comfortable”



High interior RH and cold HPWH closet could grow mold if cool HPWH exhaust air is restricted



How far to net ZEB?

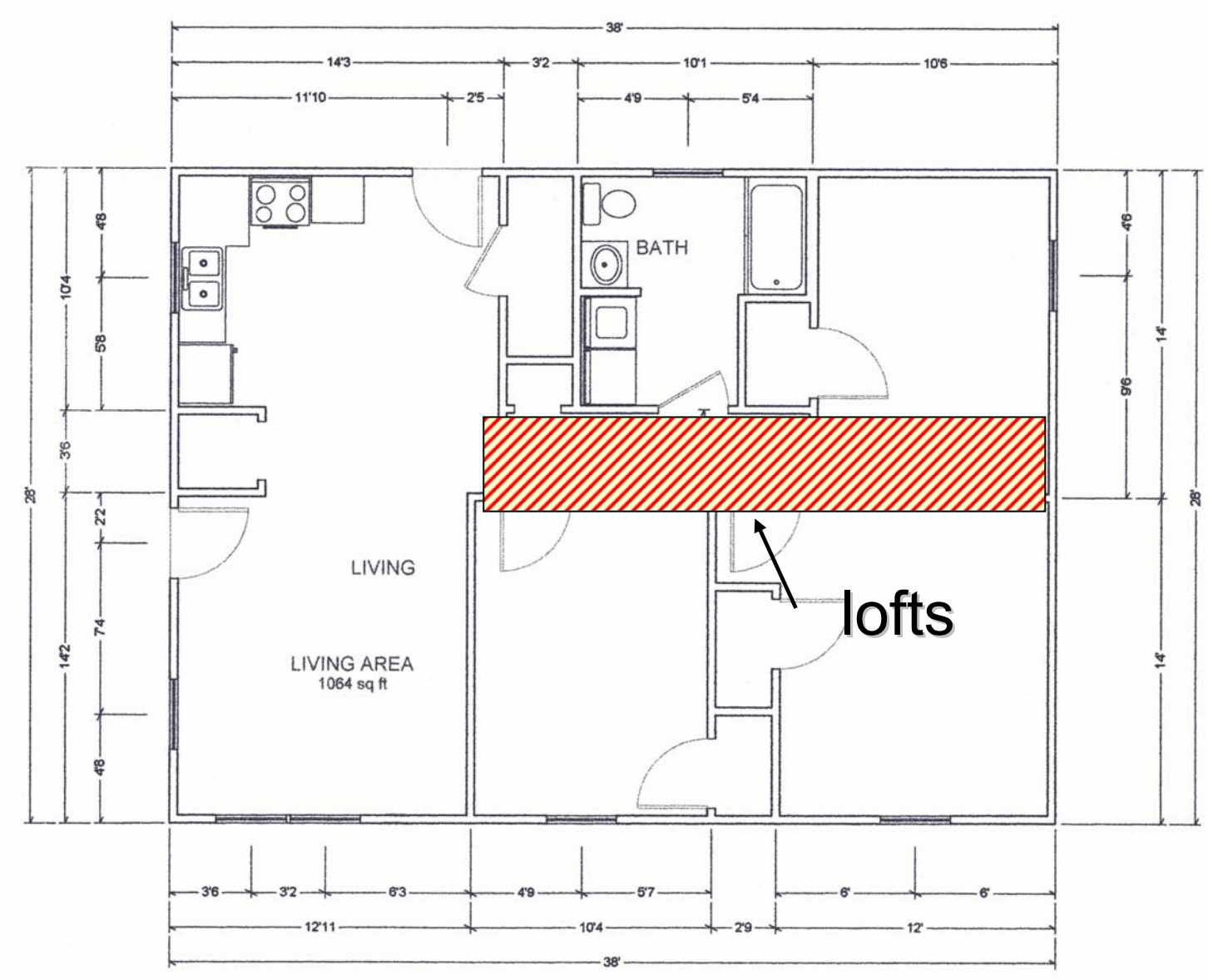
- Solar PV system.
  - Has generated 1330 kWh over first 261 days.
  - Annual production estimated at 2000 kWh.
  - Solar providing.
    - ~17% of load from December through April.
    - 30% of load in March -July
- Average daily total energy bill estimated at $0.80 with TVA green power partner offering $0.15/kWh.
- HERS rating 90.2, 51% energy saver.
- Annual energy cost savings estimated at 60-65%.
- Total first cost value $118 K, $110/ft$^{2.}$
- Solar 2 kWp PV $24K, $12//W$_{p.}$

Lessons learned and future opportunities for attaining net Zero

- Big improvements in HPWH integration
- Cost reductions in PV roof integration
- Bonus Lofts (110 ft^2) reduce $/$FT^2$ about 10%
- Eliminate identified shadow power of inverter, entertainment center and aquariums
- Integrated HPWH can be used for DHW and Space heating
- Mechanical ventilation humidity control in summer months needed, however occupants “are comfortable”
- SIP Floor with white metal laminated on underside a real sleeper.

DOE BA / TVA Living Building Science Laboratory

- Each ZEB house to contain at least one new technology requiring R & D
- Developing 6 prototype houses which will provide incremental steps toward zero energy
  - 1st building America habitat international ZEB, November 2002
  - Building America 60% saver - 2, June 2003
    - Hands on envelope workshop, happening this week
    - Video and best practices documentation
  - High performance 70% saver – 2, June 2004
  - ZEB June 2005
- Our Partners intent on taking fully developed concept to market
  - Across TVA service territory
  - National
  - International
    - Azerbaijan
    - Barbados



Working with Design Basics

Next two ZEB test Houses, working with IBACOS

- HPWH for domestic hot water and space heating with solar tempered crawl space
- Direct Solar DC usage
- Adaptive ventilation using micro cantilever
- Better SIPs, 6in 1lb/ft^3 EPS. 4 in with 2 lb/ft^3 EPS, less wall joints, less dimensional lumber through the foam in roof, better air sealing using seam tape on SIPS, peel and stick seal at ridge
- Cool pigments in raised metal seam roof (forest green)
- Reduce solar installation cost by smaller collector roof foot print (75%), talking with Sharp (Memphis, TN) about 165 watt modules, (Tennessee state energy office to fund)
- DX geothermal heat pump with SEER >20 for space heat and cool, as well as, DHW.
- Novel foam fabricated ducts for supply air and HPWH/ fridge connection

Next two ZEBs

July 28, 2003 13:00

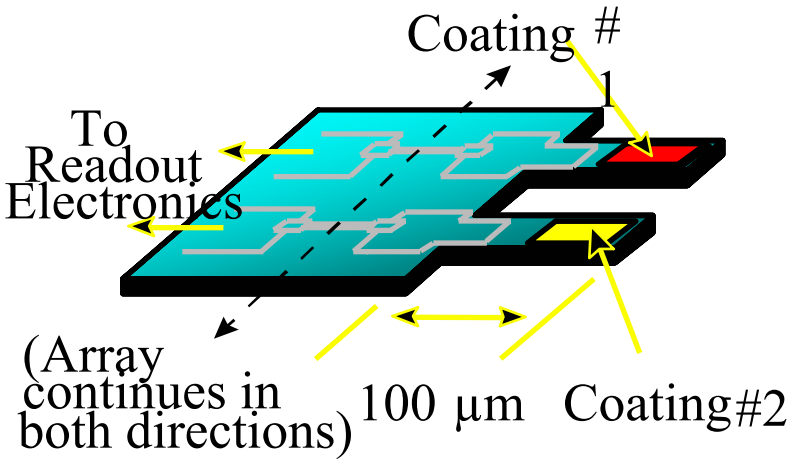
August 1, 2003 8:00

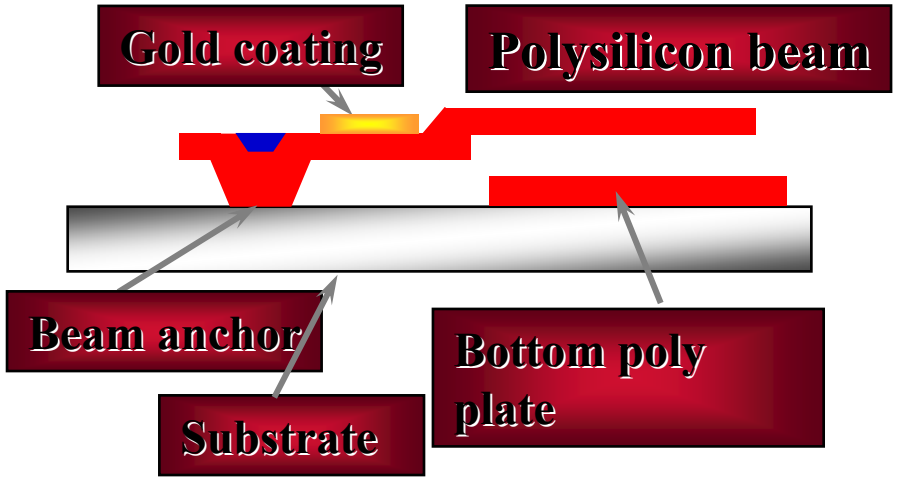
ZEB Sensors and Controls

- Build off micro cantilever
- Low cost
- Zero power
- Integration within the building and the grid is the key
- Adaptive control
  - Lights
  - TV
  - Water heat standby
  - Ventilation

Electrically Readable Microcantilever Arrays - Key to Low-cost, low-power sensing

- **ORNL presently has several patents issued and pending and over a dozen disclosures on the technology**
- **Utilizing *arrays* of microcantilevers on a *single chip* with *customized coatings* to produce application-specific programmable sensors**
- **Test have been conducted on hydrogen, humidity, and mercury**
- **Initiating work on carbon dioxide and room occupancy**





Combined Heat and Power Device Based on Heat Stove with Microturbine Generator .5 – 5 kW. Basic Configuration

1.Filter
2. Compressor
3.Isolated frame
4.Water jacket
5.Wood fuel
6 Ashe
7.Control valve
8. Turbine 1 stage
9. Turbine 2 stage
10.Catalitic reactor
11 Electrogenerator
12.Heatexchanger – Air - gas
13.Heatexchanger Gas-water
14.Furnace

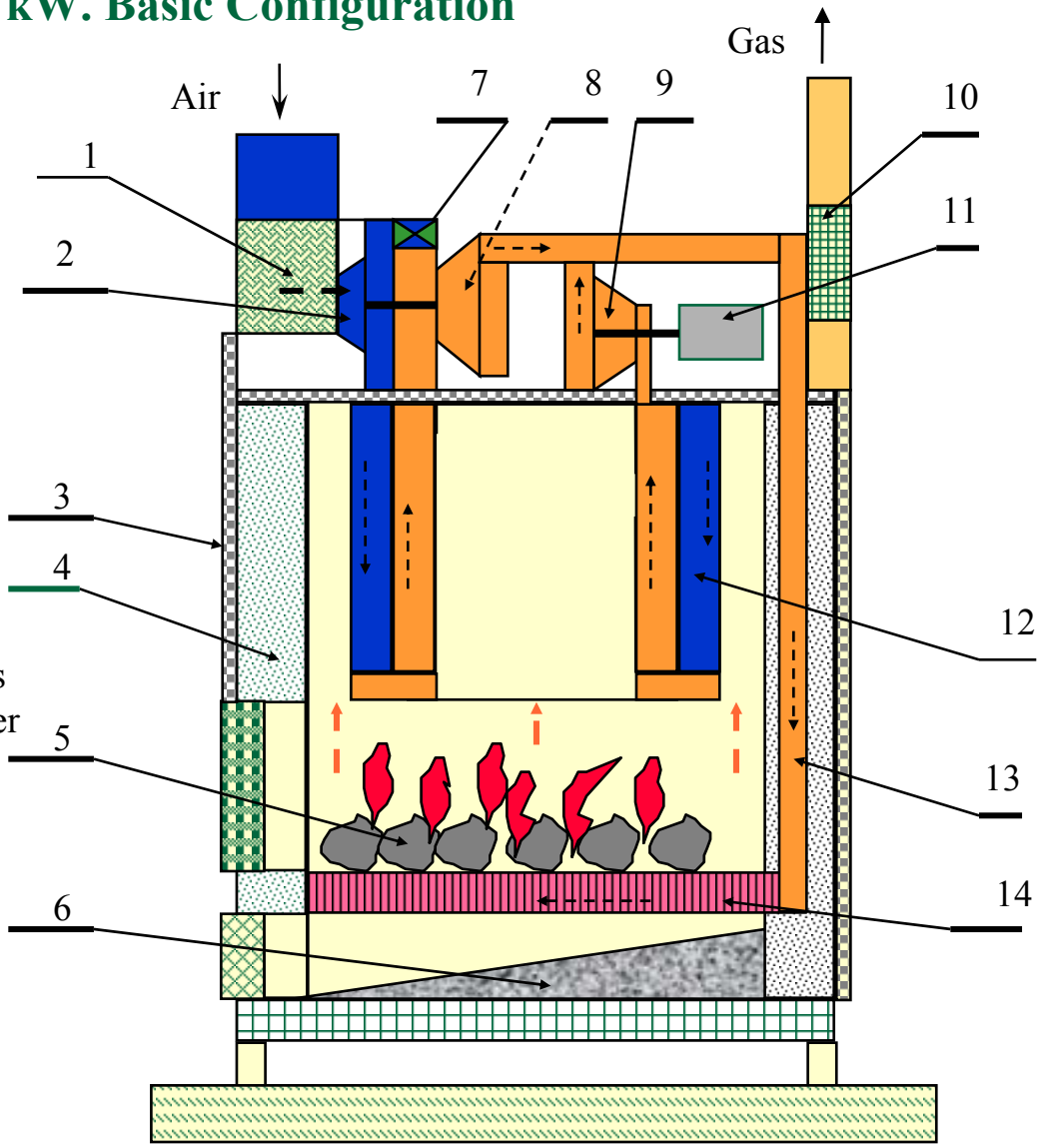
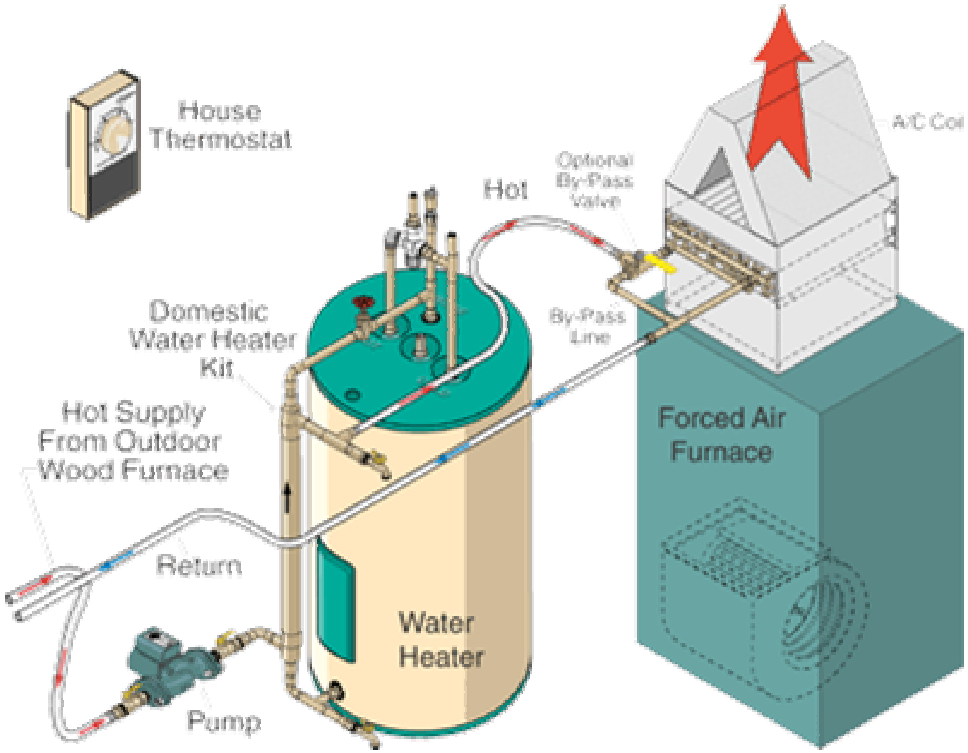


Fig. 1

Awarded U.S. Patent July 2003

Future ZEB option will be Biomass stove with microturbine

Forced Air System



Net Zero will be reached

2005