U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

Building AMERICA
U.S. Department of Energy

TVA/DOE Building America Retrofit Research Houses with Transforming Impacts

Utility Focused Research

November 16, 2010

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Oak Ridge National Laboratory

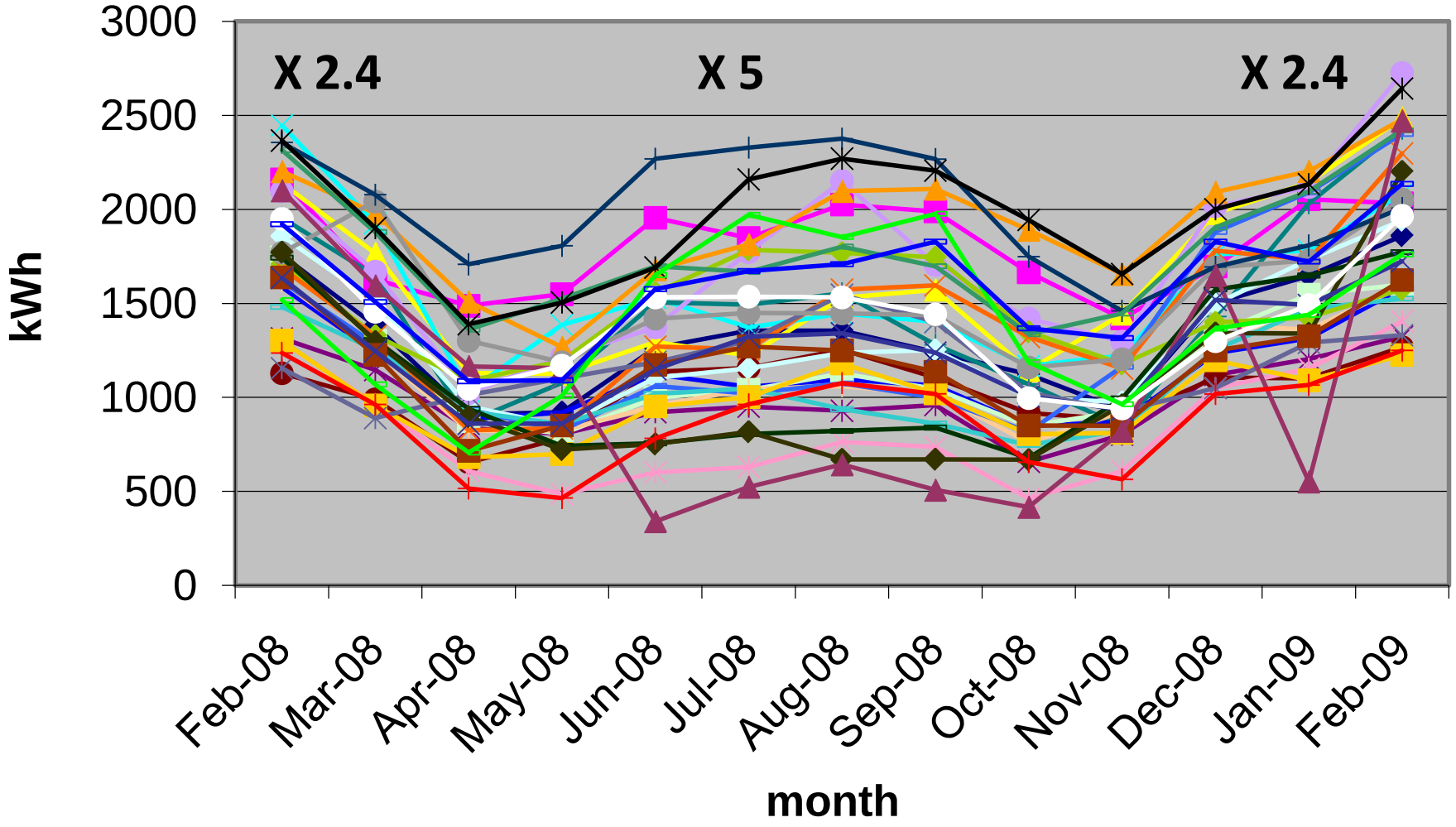
Target

1. Inform TVA's residential retrofit incentive program to help attain 1400 MW of peak power savings by 2012
2. Accelerate Coal Plant Layups, 4730 MW by 2015
3. Delay need for new Nukes, 2018 to 2022

TVA directed residential research collaboration with ORNL

- Past: 10 Habitat for Humanity research homes
  - 3 months to 1 year unoccupied
  - 1-3 years occupied
- Present:
  - Three TVA simulated occupancy Campbell Creek research homes
    - Builder Spec
    - Retrofit
    - High Performance
  - 10 Deep occupied retrofits
- Future: 50% occupied retrofits

Monthly kWh demand of Conventional Habitat occupied houses



Which House used $5/day and which <$1/day?

CC1

CC3

$1800/year

$300/year, $0.82/day

TVA Campbell Creek Research Houses

- Builder house, 2400 ft^2, HERS 101
- Retrofit house, 2400 ft^2, HERS 68
- Maximum affordable, 2500 ft^2, HERS 34
- TVA pays
  - Rent, 2009-2012
  - All utilities
  - Monthly house cleaning
  - Grounds keeping
  - Identical furnishings in all three (internal thermal Mass)
  - Maintenance
  - Annual retrofits

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Year Dashboard

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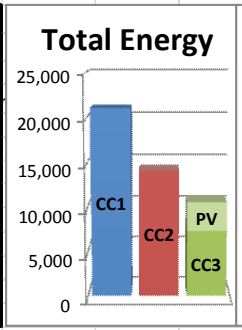
Dashboard Report

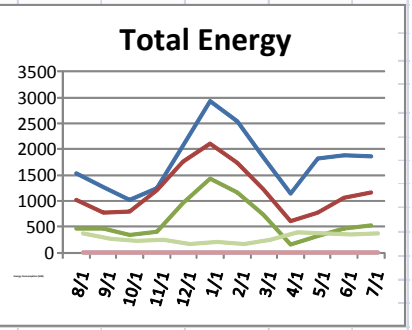
08/01/09 to 7/31/10

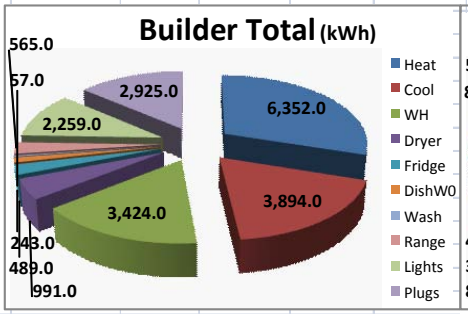
House Name	Total[1]	PV[1]	Net[1]	Cost[2]	PeakHr[1]	Average[1]	Ld Factor
CC1	21,199	0.00	21,199	$1,796.00	14.65	2.42	0.17
CC2	14,274	0.00	14,274	$1,233.00	9.88	1.63	0.16
CC3	10,750	3,292.00	7,458	$285.00	7.42	1.23	0.17

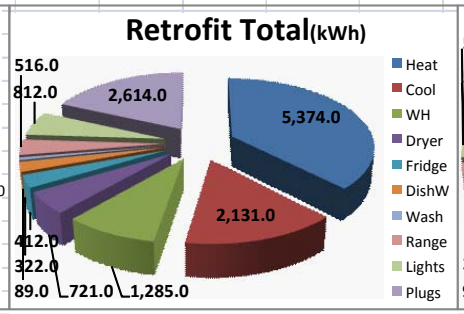
House Name	Total	PeakHr	Net	Cost	Peak Day	Peak Hour
CC1	100.00%	100.00%	100.00%	100.00%	1/4/2010	1/4 9:00
CC2	67.33%	67.44%	67.33%	68.65%	1/9	1/9 7:00
CC3	50.71%	50.65%	35.18%	15.87%	1/8	1/8 8:00

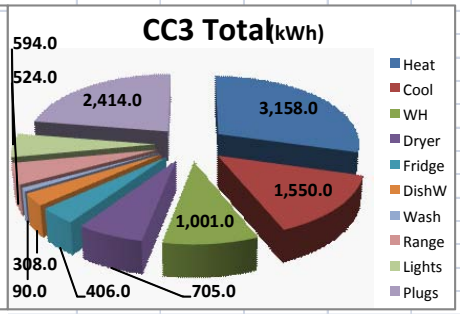
[1] Energy in kWh throughout unless otherwise noted

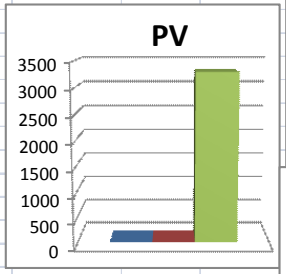


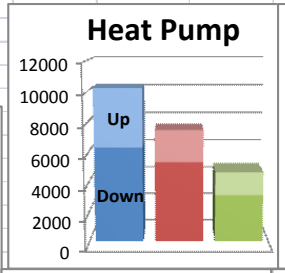


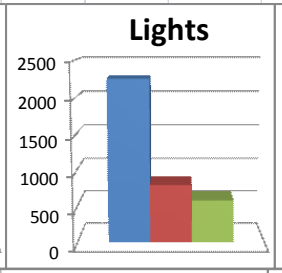


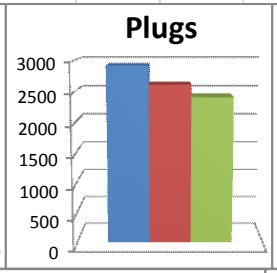


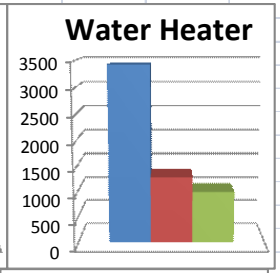


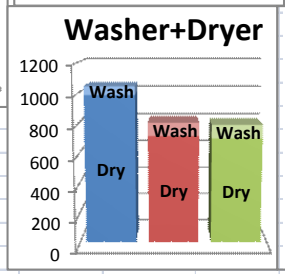


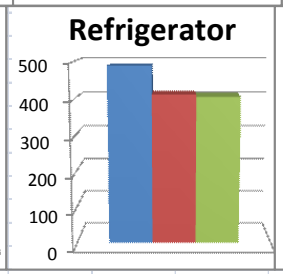


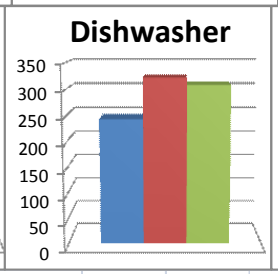


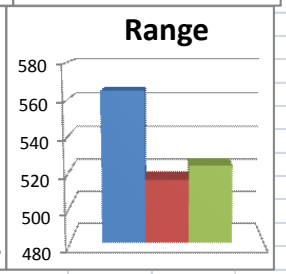












First year; sealed and insulated attic with single stage two zoned heat pump system

- Major retrofit expense Spray foam
- Major gap is optimum lowest cost insulation combination that controls moisture for each climate

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Foamed attic only 7°F warmer than thermostat

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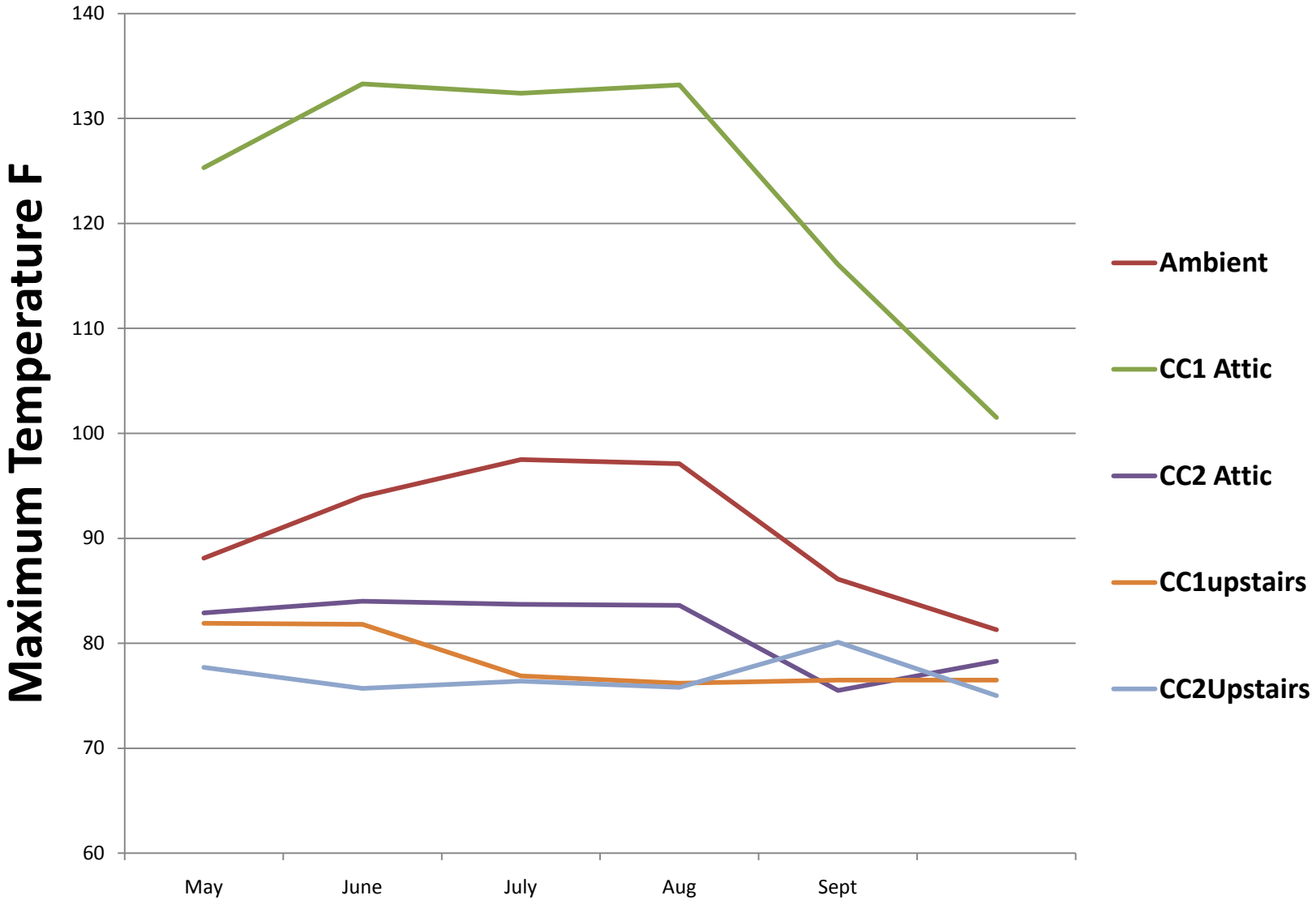
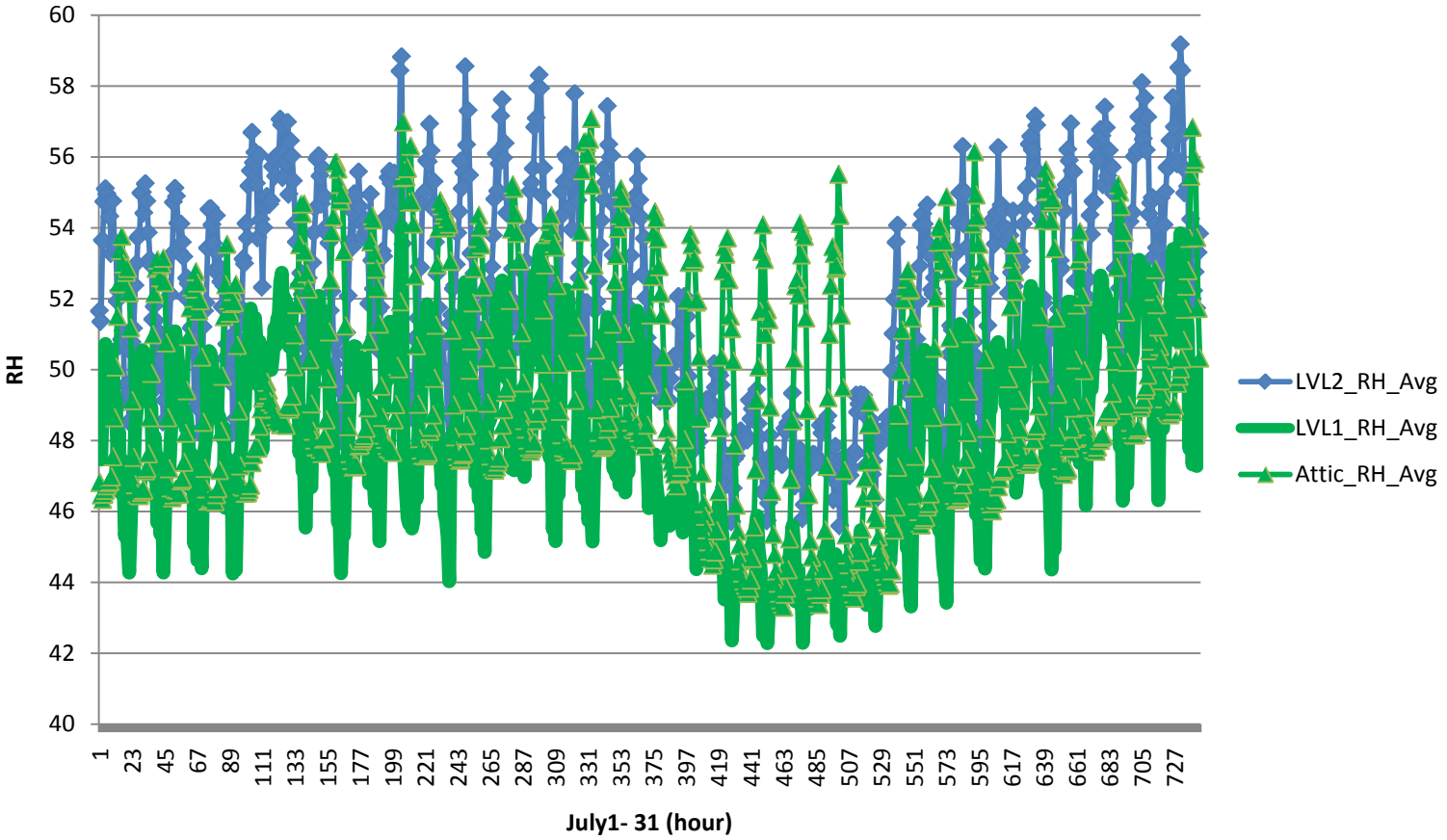


July hourly average RH in the retrofit house



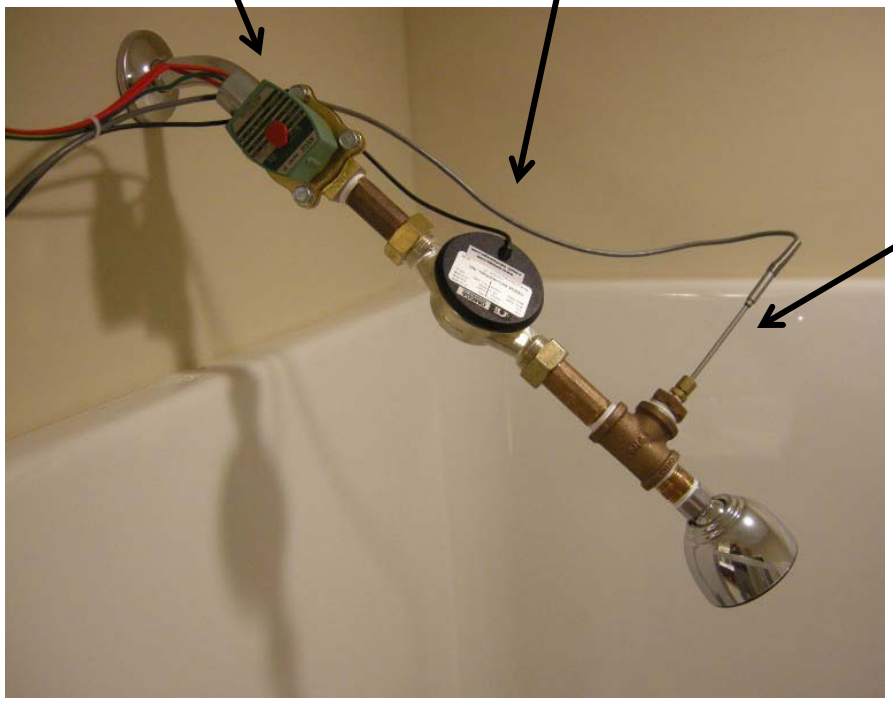
TVA three research houses; 1.5 yrs of detailed measurements collected

- Builder house
  - Standard framing package R-13 walls, R-30 Ceiling
  - 2 Heat Pumps, SEER 13, HSPF 7.7, totaling 4.5 tons
- Retrofit house
  - Sealed insulated attic
  - One 3 ton single stage heat pump, HSPF= 9.5, SEER 16, two zone control
  - Multi-splits to be retrofitted September 2010 (pipes left exposed in unoccupied research house)
  - 100% CFL
  - Energy star appliances, demanded enabled appliances 09/10
  - Single-hung LowE, gas filled windows
  - Heat pump water heater in the garage
  - Measured 42% whole house savings compared to the Builder house, positive cash flow using 10 year, 6% loan, ACEEE 2010 summer study paper

Shower Control

RedHat Solenoid

Omega 4605 Flowmeter



Omega OL-703
Thermister Probe

Refrigerators

Laundry Control

Dryer Mister

Minimize dryer duct run in these very air tight Structures (dryer performance as function of house air tightness)

Relay Rack

Example of appliance control board interface.

Dishwashers run daily

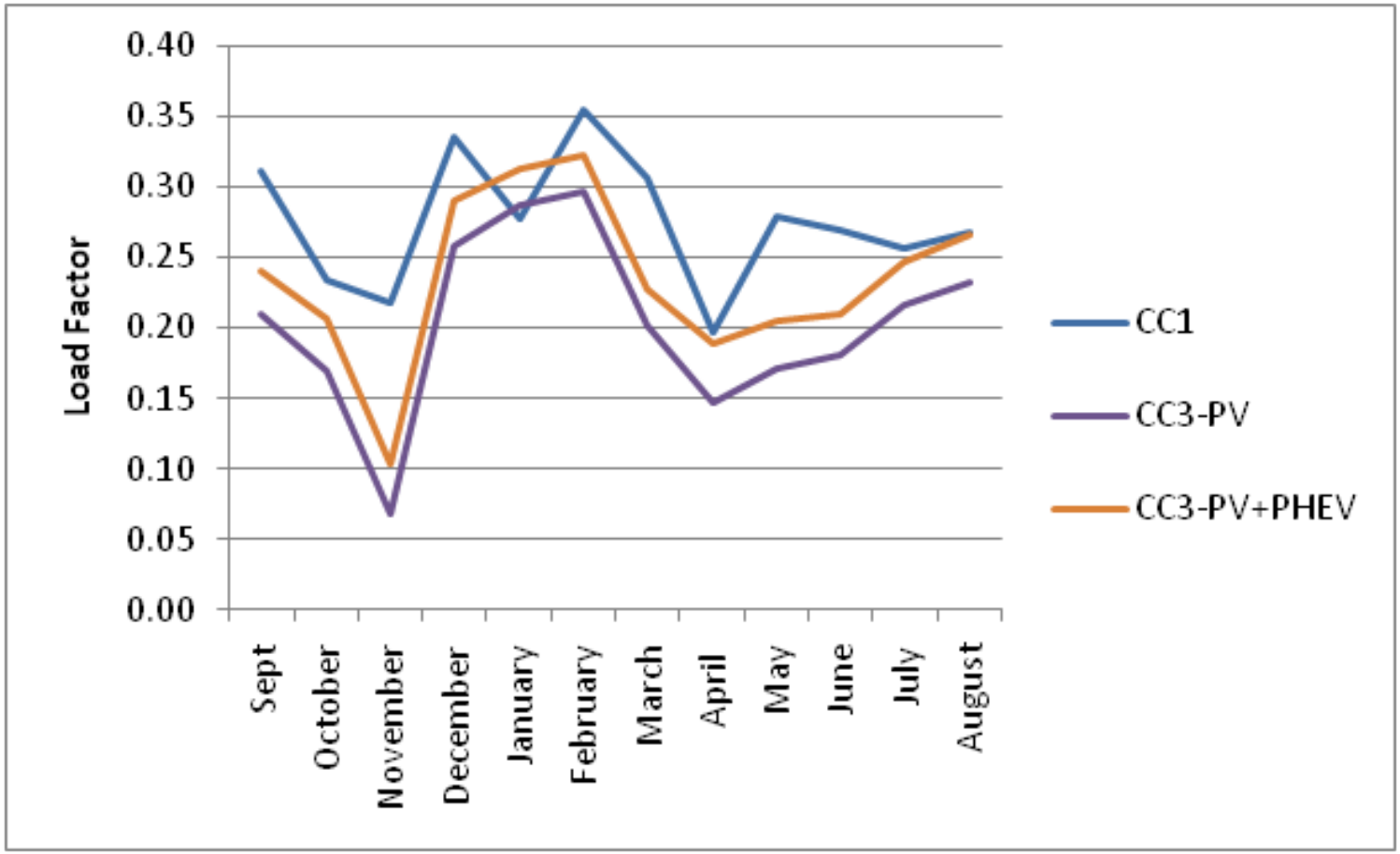
"Builder House"

- One HVAC unit per floor
- Ducts and the indoor coil not in conditioned space
- 4.0 tons for 2400 ft^2
- TVA selected after housing market study

Electric Utilities pay very close attention to load factor

- In January and-March 2010
- Commuting 5-days/wk, 16 miles one way between $1/day Campbell Creek Research House and ORNL Building 2518 with 50 kW Solar inverter
- 102 MPG
- 1000 Miles on One Tank of Gas
- Smart charging only between 11:00 PM- 4:00 AM next morning.
- Makes high performance homes load factor very attractive to electric utilities

Save energy, Save peak, Utility saves $



Select Findings

- House uses 42% less energy than the builder, ORNL 161 page report and ACEEE 2010 Summer Study paper available
- Costs $3.76/day compared to the builder house at $6.46 day.
- $10K incremental cost meets neutral cash flow criteria assuming 10yr@6% home equity loan
- In the cooling season the upstairs heat pump in the builders' house, uses 70% of the cooling energy for the whole house. This is the unit that is located in the hot attic, which results in much poorer performance than the unit located in the garage with most of the supply ducts in between floors within the conditioned space. (tstat set at 76 F in summer)
- The GE HPWH (~$1.5K) and lower hot water demand from the energy star cloths and dish washers saves 71% compared to the standard electric water heater in the builder house with standard appliances.

Lessons on Retrofit Research House to inform 10 house retrofits

- Sealing the attic reduces the whole house on a slab air leakage by 40%.
- The single unit 2- zoned HP distribution systems in Retro maintains uniform temperature in this two story house.
- The peak loads in these houses in the summer have been dominated by the electric dryer.
- The Retro mechanical ventilation CFM is a function of the amount of time the HP is providing heating or cooling. The more load the larger the ventilation air coming into the Retro. May call for seasonal manual damper adjustments to hit the target ventilation flow.
- The dashboards created for this project in a glance have proven to be very insightful, design driven by TVA.

Next Step, Utility stimulated residential retrofit energy savings

- DOE/TVA 40% whole house retrofits
- Targeting Knoxville area surrounding research houses
- 10 deep retrofitted occupied homes 17-72 years old have been selected and detailed preretrofit site evaluations completed
- Energy savings with neutral cash flow
- Inform TVA's in-house energy retrofit program
- Local government electronic tool box to encourage citizen retrofits

DOE funding American Economic Recovery Residential Retrofit Research at ORNL started March 2010 runs until September 2011

- Out growth of the 3-TVA Campbell Creek research homes
- House 2 is the “retrofit house” proposed to engage the surrounding community in the research
- TVA statisticians selected the house size, type, features to be representative of what people want in a Tennessee home and representative of a dominate fraction of similar “middle class” housing
- Build upon TVA’s new residential retrofit program to identify “deep retrofits” (save 40-50% whole house energy savings)

Interest in Extreme Retrofit

- DOE/ORNL/TVA press release in March 2010
- Would consider an extreme retrofit in the next 3 months,
- Requested complete energy records for 3 years
- Prepared for estimated cost of $10/ft^2 – floor area
- Must first complete TVA In-home energy audit
- Would permit 12 months of detailed energy monitoring of home after completion of retrofit, aggregated use of results and publication of pictures.

TVAs "In-home Evaluation "pilot"

- Initiated February 2009
  - $150 reimbursable audit fee
  - $500 after spending $1000 of retrofits
- Two models
  - CSG direct (working better)
  - TVA distributor
- 75 distributors signed up for the pilot
- CSG has more auditors, 20 (total in TN 70)
- Cue per auditor 6 weeks
- Positive action taken on 40-50%
- All 156 on program October 1, 2010 (this project has helped accelerate bring two distributors on board)

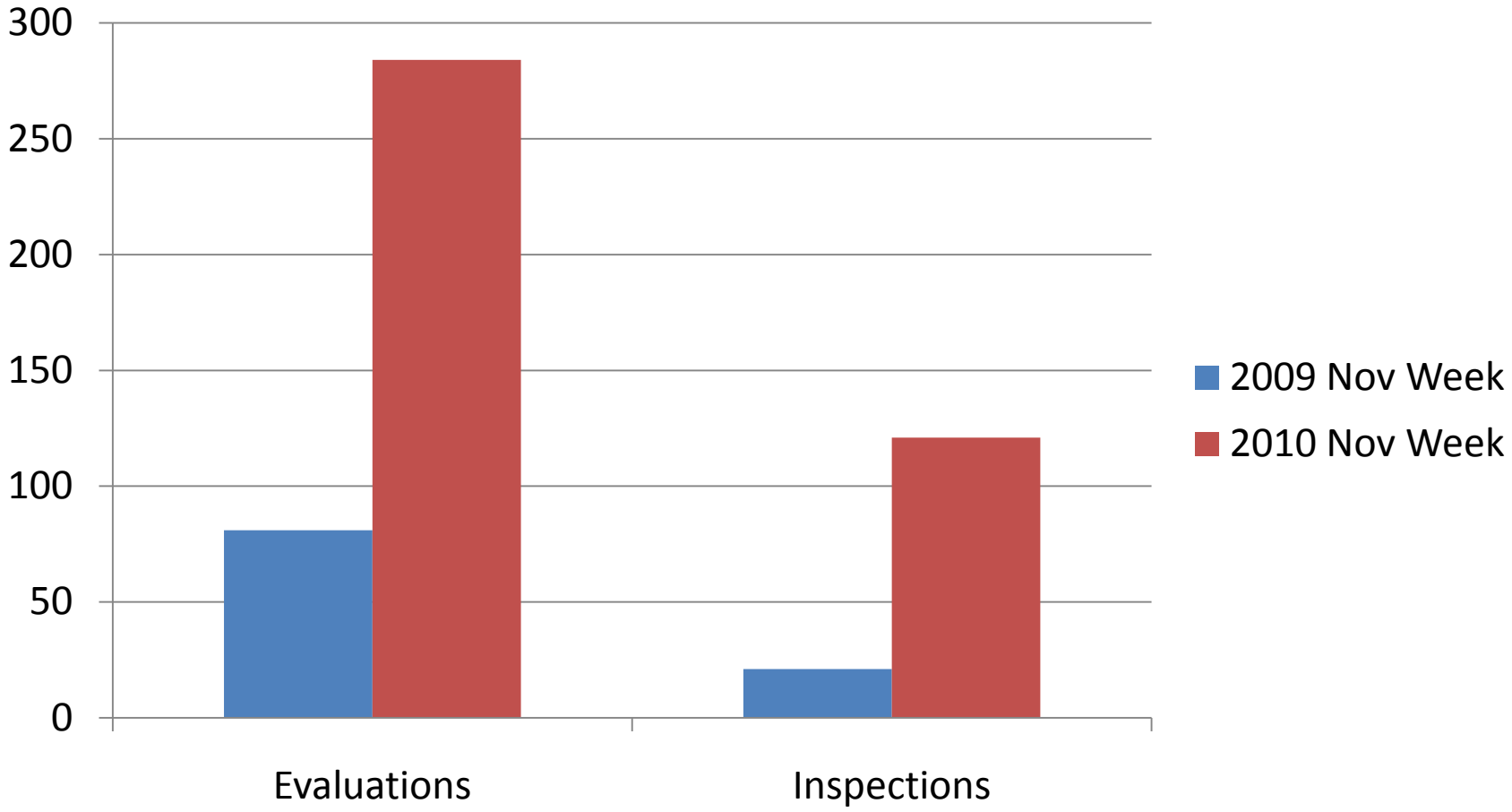
TVA's pilot

- Goals different than California or New York, (more focus on peak load reduction)
- Maintains "quality contractor list"
- Auditor inspects work before distributing the incentive and can have contractor culled from the list if quality installation not met
- No Blower door, duct blaster or IR survey only pre and post walk through inspection.
- Evaluators required to take one week BPI like course and heat pump installation inspection class (taught by CSG in-house instructor), shadow inspector for three weeks and pass test

CSG in TN

- 10,000 "walk through" evaluations completed as of August 2010; ~50% participation rate
- Future direction is more towards low interest loans with monthly payments on electricity bill
- Focus is currently attic, crawlspace and duct air tightness along with attic insulation to R-38.
- Too many window retrofits happening

Evaluations up 350%
Inspections up 580%



TVA/DOE/ARRA retrofit initiative

- TVA cost sharing $500K with ARRA funds
- Incremental retrofit model goes from fruit on the ground, to low hanging but very little elevated harvesting
- FY11 goal is 40% energy savings from current state as measured with 3 years of monthly pre energy bills.
- FY12 goal 50% whole house energy savings

Deliverables

- 10 heavily instrumented houses
  - With l partners; TVA, City of Knoxville, City of Farragut, East TN Quality Growth Council, GE, Diekin, Carrier, Emerson, Lennox, Owens Corning, Contractors (Schaad, John Kerr), Weatherization and HVAC contractors (Triangle, Biobased, Beyer, Icynene, Spray Foam Manufacturers Association, develop selection criteria
  - Selected 13 houses for site evaluations, Completed June 2010
  - Oversee incremental Retrofit, 1. Weatherization, 2. test, 3. HVAC
- Monitor for one year post retrofit (75-100 sensors)
- Place monthly dashboards on Website compared to TVA/DOE research houses with simulated occupancy
- Create TVA in home evaluation customer focused “case study fact sheet” at close out meeting between the auditor and homeowner, Local Government Electronic Tool Box

Compare TVA research houses to extreme retrofits

House 5; 18 year old occupied retrofit, 2438 ft^2

TVA retrofit simulated occupancy research house, 2400 ft^2

House 1, Oak Ridge

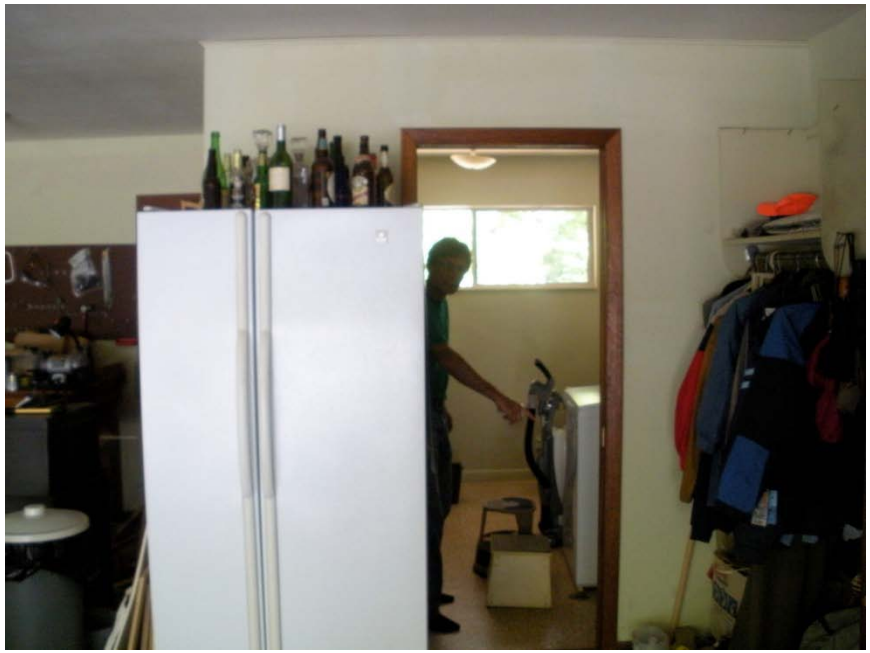
- First House Tested and Measured for HERS Rating
- Blower Door; 28 ACH@50 Pa
- Duct Blaster; Leakage from ducts, 3 PA is maximum pressure
- Results indicate a higher than average envelope leakage, recommendations include extensive envelope air tightening particularly the rim joists, 2nd blower door study, replace the HP unit and install a GE HPWH

Methods of Evaluation

Software using the measurements we make at each house

- REM Rate
- Energy Gauge
- Owens Corning Energy Bill Analysiser
- HESPro
- HERS =135, to use MMBtu/yr/#bedrooms
- Recommendations in post retrofit model suggest 40% whole house savings

Preliminary prediction after retrofit; HERS = 80, ~40% energy savings



Laundry looks like it is in the garage

- But it is really in the house

Knoxville 1982 Worlds Fair House retrofit

Insulated and sealed the attic

- Knox Heritage design team did not want spray foam in walls
- Design called for
  - house wrapped walls
  - foamed rim joist between basement and main and main and upper level
  - R-38 open cell foamed attic
  - Closed soffits and gable rakes filled with foam, encasing top edge of wall house wrap, needed follow up spot sealing with help of blower door

Compare Carrier SEER 18 Air Source Heat Pump to SEER 18 Multi Split

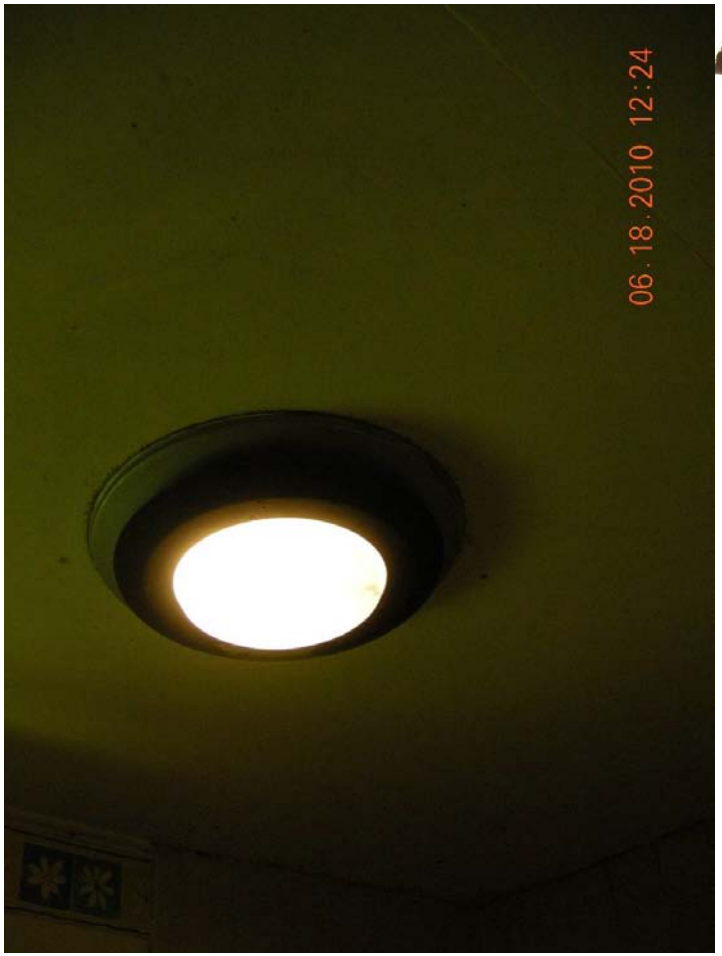
72 year old gut rehab in downtown Knoxville

No insulation in the walls or in walkout basement and very little in attic

Smoky Mountain National Park "Mission 66" Oasis House

http://www.youtube.com/watch?v=VWqkTKolJeI

Bath Fan moisture dumped directly into the attic



Attic/Crawl-by pass

A place to not install the water heater

Each Retrofit House to have a major research element

1. Spray foam rim joist between two finished floors
2. Solar integrated heat pump case study to expand TVA's generation partner hook up criteria
3. Horizontal Geothermal HP retrofit
4. Window and siding replacement cut heat pump capacity in half, preretrofit has 2-2.5 ton HP, after retrofit need only one
5. Perfect comparison to TVA retrofit research house
6. Historic preservation mixed with 40% retrofit on 72 yr old
7. Insulated sealed crawl space on moisture troubled site
8. Cost effective R-5 window retrofit, huge national education opportunity

Each retrofit house to have major research element

9. Gut rehab, low cost attic, wall and basement spray foam, cost effective R-5 windows
10. Pull all HVAC into the conditioned envelope, horizontal coil geothermal HP, single pane window replacement, insulated and sealed crawl space, two to one zoned HP
11. SIP addition and SIP nail base, double floor area with no increase in HP capacity
12. Siding replacement/wall sheathing addition to solve moisture problem on good average energy performing 24 yr old house
13. Run at 2010 zero energy house retrofit of 1982 Worlds Fair "Energy House", enormous educational and historic preservation opportunity.

Gaps and Barriers

- "need to clearly demonstrate to US homeowners that Energy Efficiency residential retrofit is a good investment" Secretary Chu
- Variable Refrigerant Flow Heat Pumps vs central forced air
- Lower cost methods to insulate and seal
  - Attics
  - Crawlspaces
  - Basements
  - and ducts
- Guidelines for home and homeowner life stage retrofit optimization
- High performance home interface with smart grid must team with electric utilities with a heart or guts, preferably both
  - Inverters
  - Heat pumps
  - Appliance controllers
  - Whole house energy managers