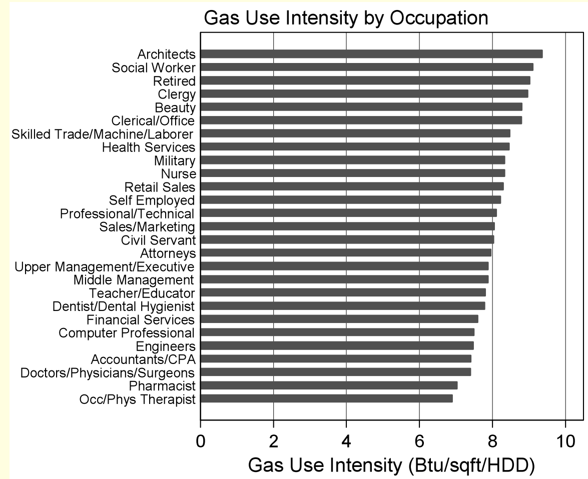
Lies, Damned Lies and Modeling

Seventeenth Annual Westford Symposium on Building Science

August 5, 2013 8:30 AM – 12:00 PM

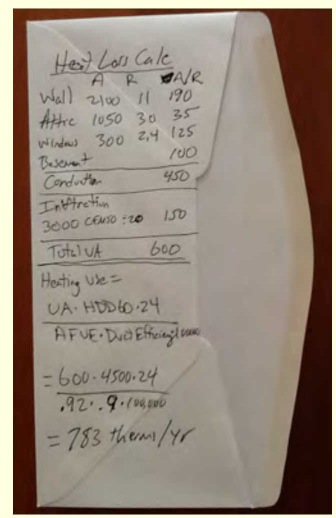
Presented by Michael Blasnik
mb@michaelblasnik.com



All models are wrong, but some are useful

G. P. Box

Energy Modeling "Classic"



Energy Model Accuracy

- How does modeled energy use compare to actual?
- How much can we blame the occupants?
- How about the auditors / field people?
- Do differences between models and actual energy use vary systematic?
- Are there certain features that are hard to model?
- Are the models revised based on measured data?
- Why/when should we model building energy use?

Energy Model "Testing"

BESTEST criteria (from DOE2, BLAST, SERIRES)

- Official software test allows for wide ranges of projected usage
  - Base case heating passes with 50-80 MMBtu/yr
    - Even though inputs clearly defined, simplified house with constant infiltration and int. gains
  - Doesn't test using CFM50, many real issues
  - Does test bizarre buildings to assess physics calcs

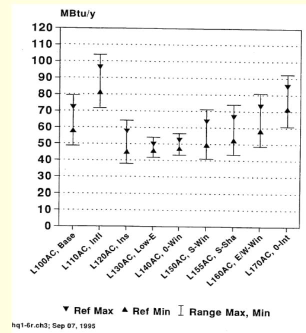


Figure 4-1. HERS BESTEST Tier 1 example range setting—annual heating load (L100AC through L170AC) for Colorado Springs, CO

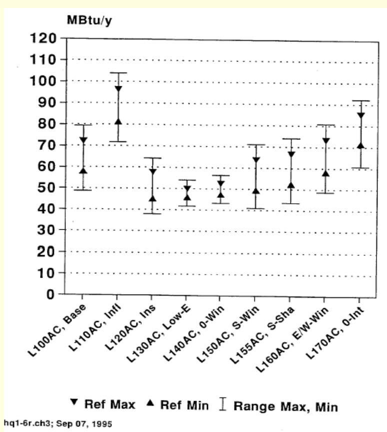
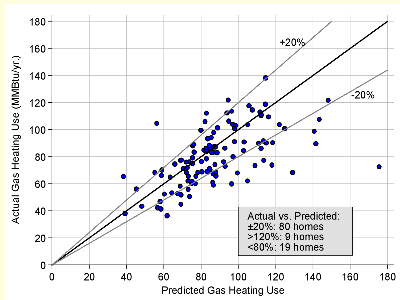


Figure 4-1. HERS BESTEST Tier 1 example range setting—annual heating load (L100AC through L170AC) for Colorado Springs, CO

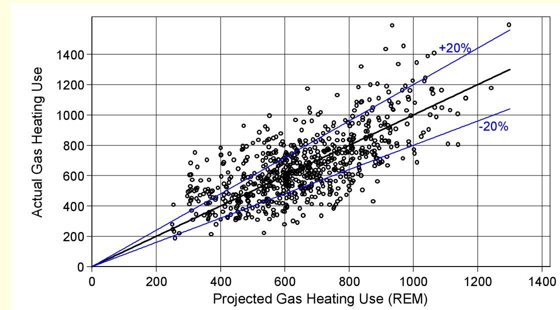
CASE #/ Test Tier	SUBFLOOR	INFILTR (ACH)	R-VALUE (h ft² F/Btu) WALLS, (Note 2) CEILING	FLOOR	WINDOW DATA TYPE	AREA (ft²) (Note 3)	ORIENT	SHADE	COMMENTS (Note 1)
L100A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Base building. Simple construction with typical glazings and insulation. Represents average of US building stock.
L110A/ T1	VC	1.5	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests infiltration.
L120A/ T1	VC	0.67	24,60	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests wall and ceiling R-value together.
L130A/ T1	VC	0.67	12,21	14	DLEW	Gross: 270 Net: 197	AVG DIST	NO	Tests glazing physical properties together.
L140A/ T1	VC	0.67	12,21	14	None	0	N/A	NO	Tests glazing area.
L150A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	1.0 S	NO	Tests glazing orientation.
L155A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	1.0 S	H	Tests South opaque overhang.
L160A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	0.5E,0.5W	NO	Tests E/W glazing orientation.
L165A/ T2	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	0.5E,0.5W	HV	Tests E/W shading.
L170A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Internal loads = 0. Tests internal loads.
L200A/ T1	VC	1.5	5,12	4	SATB	Gross: 270 Net: 197	AVG DIST	NO	Lumped sensitivity low efficiency. Tests HERS ability to cover wide range of construction.
L202A/ T1	VC	1.5	5,12	4	SATB	Gross: 270 Net: 197	AVG DIST	NO	Exterior Solar Absorptance = 0.2. Tests low exterior solar absorptance.
L302A/ T1	SLAB	0.67	12,21	UNINS	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with uninsulated slab using ASHRAE perimeter method.
L304A/ T1	SLAB	0.67	12,21	EDGE INS	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests perimeter insulated slab using ASHRAE perimeter method.
L322A/ T1	BASE-MENT	0.67	12,21 (Note 4)	UNINS	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with uninsulated full basement using ASHRAE method.
L324A/ T1	BASE-MENT	0.67	12,21 (Note 4)	UNINS	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with insulated full basement using ASHRAE method.
P100A/ T2	VC	0.67	24,60	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NY ES New Homes
Actual vs. Projected Gas Heating Usage

- REM-Projected Usage 10% too high avg.
  - 1190 vs. 1069 actual
  - Heat: 881 vs. 804
  - Base: 309 vs. 265
- Typical error= 17%
- Correlation pretty good, but house size drives relationship



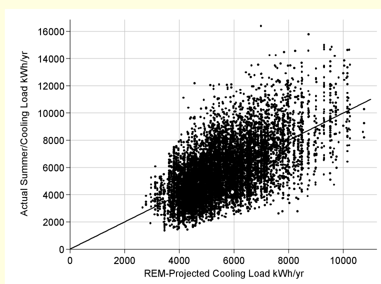
720 Energy Star New Homes in Midwest
Actual vs. Projected Gas Heating Usage



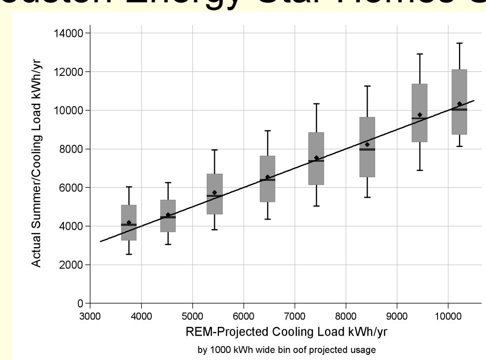
- REM-projected avg. heating use 656 vs. 662 actual
- Typical (median) discrepancy= 16%
- Correlation good (0.70), but floor area better (0.74)?

Houston Energy Star Homes Study

- actual vs. predicted cooling
  - 10,258 homes
  - Lots of scatter
  - Averages close
    - REM= 5,506
    - Actual= 5,677
  - 17% Median diff
  - “actual” = billing data, includes seasonal loads
  - Models based on floor plan and max CFM50, CFM25
  - Model run with default occupancy



Houston Energy Star Homes Study



Combined projected loads into 1,000 kWh bins – agreement looks good

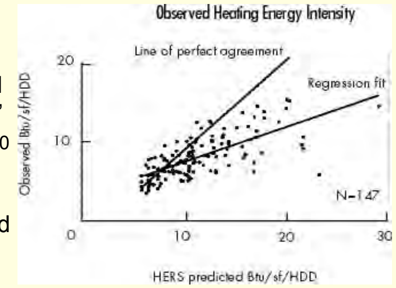
Modeling of Older Homes

There is nothing so horrible in nature as to see a beautiful theory murdered by an ugly gang of facts
- B. Franklin

Modeling Existing Homes
Wisconsin HERS Study

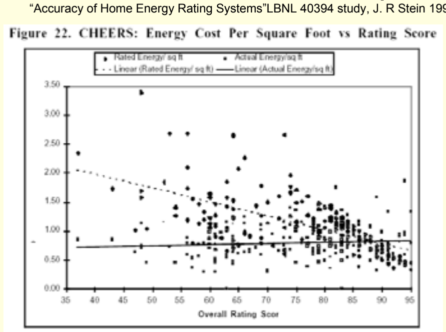
"A Rating Tale", S. Pigg, Home Energy Magazine Jan/Feb 2001

- Projected use 22% high on average
- "badly overestimated for inefficient homes"
  - Low scores too low: 50 should be 70!
  - High scores too high
- 90% of homes should have scored 74-84



California CHEERS (1997)

"Accuracy of Home Energy Rating Systems"LBNL 40394 study, J. R Stein 1997



No relationship to actual energy usage intensity !?

Existing Homes: Earth Advantage EPS Pilot

"Energy Performance Score 2008 Pilot", for Energy Trust of Oregon, 2009

- Energy Labeling of Homes
  - Looking for simpler MPG-type rating for homes
- Tested 3 software tools on ~300 existing homes
  - REM/Rate
    - Full HERS Rating (~100 inputs)
  - Home Energy Saver (DOE - LBNL)
    - tested 2 variations: 24 data inputs, 185 data inputs
  - "SIMPLE" spreadsheet audit (32 inputs)
    - quickly designed to see if simpler tool could work OK
    - only building dimension asked is conditioned floor area
- Compared projections to actual energy bills

Progress is made by lazy men looking for easier ways to do things.

Robert A. Heinlein

Oregon Pilot Findings

Total Energy Use

	REM/Rate	SIMPLE	HES-Mid	HES-Full
Mean Actual Use	101	101	101	101
Mean Predicted Use	133	84	157	119
Mean Error	32	-17	48	18
Mean Absolute Error	37	27	75	28
Median Absolute Error	31	21	66	23
Mean Absolute Percent Error	43.7%	25.1%	96.6%	33.4%
Median Absolute Percent Error	31.1%	24.0%	73.8%	21.8%
Percent of Homes with Accurate Prediction (less than +/- 25%)	43.2%	51.6%	19.5%	53.7%
Percent of Homes w/ Large Error in Prediction (larger than +/- 50%)	31.6%	7.9%	60.5%	21.6%

Table 3.5 Total Energy (MBtu) for 190-Home Sample

Oregon Pilot Findings

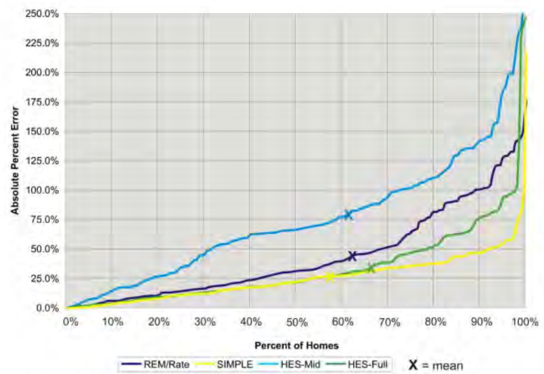


Figure 3.2 Comparison of Accuracy for Total Energy (MBtu) for 190-Home Sample

Oregon Pilot Findings

Gas Use in Older Homes

	REM/Rate	SIMPLE	HES-Mid	HES-Full
Mean Actual Use	617	617	617	617
Mean Predicted Use	1089	643	1152	869
Mean Error	473	27	402	252
Mean Absolute Error	494	210	643	284
Median Absolute Error	430	182	578	198
Mean Absolute Percent Error	91.1%	35.8%	133.1%	52.3%
Median Absolute Percent Error	84.6%	30.9%	100.0%	41.2%
Percent of Homes with Accurate Prediction (less than +/- 25%)	22.0%	44.0%	13.2%	42.9%
Percent of Homes w/ Large Error in Prediction (larger than +/- 50%)	67.0%	23.1%	74.7%	42.9%

Table 3.9 Total Therms for Homes built before 1960 (86 Homes)

Oregon Pilot Conclusions

- None of the tools were very accurate
  - REM and HES over-estimated gas use by a lot in older homes
  - SIMPLE performed better in inefficient homes
    - smallest average error, far fewer large errors
    - even without asking for window area or wall area or other details
- Major errors in standard software for estimating heating use in inefficient homes
  - Need to fix large biases – get the big stuff right
  - Collecting detailed data on some things and using complex models can give worse answers than making reasonable default assumptions and simpler models

Existing Homes: New Study from Minneapolis

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

BUILDING TECHNOLOGIES OFFICE

Field Assessment of Energy Audit Tools for Retrofit Programs

J. Edwards, D. Bohac, C. Nelson, and I. Smith

NorthernSTAR Building America Partnership

July 2013

Minneapolis Study Overview

- Field test of DOE Home Energy Score
  - Simplified model for developing mpg-type rating of existing homes
- 143 home pilot
- Also used REM/Rate and SIMPLE
- Compared models to actual bills
- Many other study objectives

Table 1. Building Performance Models Used in Pilot

	Home Energy Score	SIMPLE	REM/Rate
Number of Inputs	36–67	22–43	Approx. 100
Estimated Length of Home Visit	60–90 minutes	45–60 minutes	3–4 hours
Data Entry and Processing Time	20–30 minutes	15 minutes	1–2 hours
Tool Access	Online (public)	Spreadsheet (proprietary)	Software (proprietary)
Scope	Asset-only	Can include operational information	Can include operational information; asset-only for HERS report

Table 4. Summary of Energy Output From Three Models Compared to Utility Data

	Home Energy Score	SIMPLE			REM/Rate
		v. 1	v. 2	v. 3	
NATURAL GAS					
Number of Homes	*143*	*143*	*143*	*53*	*51*
Utility Mean (therms/yr)	1,166	1,166	1,166	1,150	1,150
Mean Annual Use (therms)	1,769	1,296	1,310	1,256	1,807
Mean of Differences:					
therms	+603	+130	+144	+106	+657
percent	+55%	+16%	+18%	+13%	+63%
st dev (therms)	673	353	360	351	558
Median of Differences:					
therms	+473	+193	+200	+137	+685
percent	+52%	+20%	+22%	+15%	+73%
Abs. Mean of Differences:					
therms	666	288	302	264	725
R-squared	0.42	0.50	0.48	0.55	0.52
Percent of homes within ± 25%	26%	59%	52%	62%	12%
Percent of homes within ± 50%	46%	90%	87%	96%	33%

"SIMPLE" audit inputs

What's Missing?

- Window area
- Wall area
- Attic area
- Detailed R value inputs
- Shell Leakage CFM50
- Duct leakage CFM25
- Window orientation
- Baseload Details: plug, lighting, other end uses
- Thermal mass, dynamic effects, schedules

(note – most of these can be input into the model, but they are not required)

House Characteristic	Current Home	Proposed Home
Finished floor area (sq.ft.)	2000	2000
Stories	2	2
Occupants	3	3
Heating Setpoint (°F)	68	68
Heating System Type	Std Gas 80%	**Condensing Gas**
Wall Insulation	Std Ins	Std Ins
Attic Insulation	Some Ins	**Std 10 inch**
Windows	Dbl/Sgl&Storm	Dbl/Sgl&Storm
Air Tightness	Average	Average
Foundation Type	Basement	Basement
Foundation Insulation	None	None
Heating is not forced air (0-1)	0	0
Ducts: % in Attic	0%	0%
Ducts: % in Basement	75%	75%
Duct Leakiness	Average	Average
Duct Insulation	None	None
Cooling Info		
AC SEER (none=0)	12	12
Cooling Setpoint	78	78
Window Shading	Typical	Typical
Cool Roof / Rad. Barrier rafters	Std Color	Std Color
Water Heating Info		
Water heater Type	Std Gas	Std Gas
Showering Use (flow, time)	Average	Average
Laundry	Average	**Low**
Other Hot Water	Average	Average
All Else Info		
Lighting Usage Intensity	Average	**Low**
Primary refrigerator	Average	Average
Extra Refrigerators / Freezers	None	None
Entertainment (TVs & PCs)	Average	Average
# Other Large Uses (500 kWh)	1	1
Plug & Other Loads	Average	Average
Clothes Dryer	Gas Avg Use	**Gas Low Use**
Cooking	Gas Avg Use	Gas Avg Use

The SIMPLE Model

- Shell Conduction
  - Assume wall, attic, window, foundation areas based on floor area
  - Effective R values based on approximate levels, high defaults if un-insulated, tweak attic for solar gain
- Air leakage
  - climate N factors pre-calculated using adjusted LBL model + latent
- Solar and Internal Gain
  - Solar : climate, adjust for window type, shading, assume orientation
  - Internal: lighting/plug estimates + some of DHW
  - Gains used for heating balance point and as cooling load
- HVAC efficiency
  - Approximate heating AFUE, cooling SEER adjusted for climate
  - Duct efficiency based on location, approximate leakage, R, regain
- Hot Water
  - Estimate gal/day from occupancy, approximate end use efficiency
  - Model water heater standby and recovery separately
- Behavior
  - Optional: t- settings, light/plug/dhw use intensity (low/med/high, etc..)

More Results from Existing Homes

Retrofit Savings Predictions

- Measured savings
  - Many evaluations based on actual bills have found savings= 50%-70% of projections in good programs
  - Some recent studies have found much worse over-prediction for some tools
- Some very poor predictions
  - Save 125% of your usage!
  - Basement duct insulation= 20% savings?

Prediction is very difficult, especially about the future.
Niels Bohr

Why Are Savings Overestimated?

- Are The Actual Savings Too Low?
  - Take Back Effect?
    - Easy scapegoat, but little evidence
    - No significant changes in indoor temperatures found
    - Occupants affect plug loads, showerheads, CFLs, etc.
  - Poor Work Quality?
    - Probably for some retrofits: insulation, air/duct sealing

Heating Take-Back Effect?

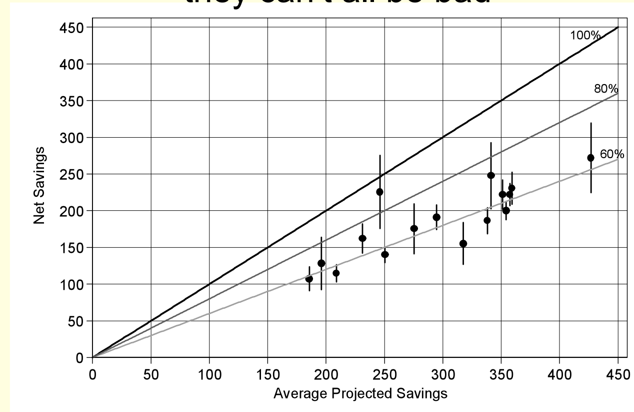
National WAP evaluation findings presented at BECC 2011

Pre & Post-weatherization Indoor Temperature Measurements

Degrees F	Treatment (n=292)	Control (n=168)
Mean Pre weatherization	70.2	70.7
Mean Post weatherization	70.3	70.6
Mean Change	+0.14 ± 0.17	-0.13 ± 0.17
Minimum Change	-6.6	-5.7
Maximum Change	+5.9	+5.2

Excludes days with outdoor temperature > 55F
Results are normalized to Dec-Feb average outdoor temperature

Work Quality: Savings by Contractor they can't all be bad



Why Are Savings Overestimated?

- Are Savings Projections Too High?
  - Error almost entirely in pre-retrofit usage estimate
    - Post retrofit usage is more accurate
  - Poor Projections indicated by patterns in the errors
    - Certain features modeled poorly
    - Inefficient homes have very large over-estimation of usage
  - Model Assumption/Default Problems
    - Effective R values, AFUE, SEER, etc.
  - Algorithms Problems
    - Infiltration and duct models
  - Data Collection / Auditing Problems
    - Bias toward finding problems, doing retrofits
    - Some data are hard to collect

Projections Too High?
Recent Findings: Energy Upgrade CA

Table A-2: PART1 Pre-Retrofit Electric & Gas Energy Use Adjustment Factors derived from 68 PG&E + 29 SMUD EUC Advanced Path sites

	Electric Energy & Demand		Natural Gas Energy	
Home Type	Estimated divided by Actual	Adj. Factor	Estimated divided by Actual	Adj. Factor
Heated & Cooled	3.5	0.30	2.3	0.40
Heated Only	1.7	0.60	3.0	0.30

- Electric HVAC use overestimated 350%, Gas >200%
- Projected electric HVAC savings averaged 159% of annual electric HVAC usage

Why Do Models Overestimate Heating Energy Use of Inefficient Homes by so much?

- Some Hypotheses
  - Heating System Efficiency
  - Duct Efficiency
  - Infiltration: leakage rates, interactions
  - R values: air films, uninsulated components
  - Indoor temperature uniformity?
  - Occupant Behavior?

What's the AFUE of an old Gas Furnace?

- Evaluation results
  - Low Income Programs: 8%-11% measured heating savings from 82% replacements
    - Implies average existing AFUE = 73% - 75%
  - Colorado LI did both 92% and 82% units
    - Saved 18.9% and 8.5%, respectively
    - Both imply original AFUE = 75%
      - (92%-75%)/92% = 18.5%
      - (82%-75%)/82% = 8.5%
  - Multiple studies: No savings from gas furnace tune-ups
- 75% should be low end of estimated AFUE
- Many models assume <75% + degradation factor

How Efficient are Leaky, Uninsulated Basement Ducts?

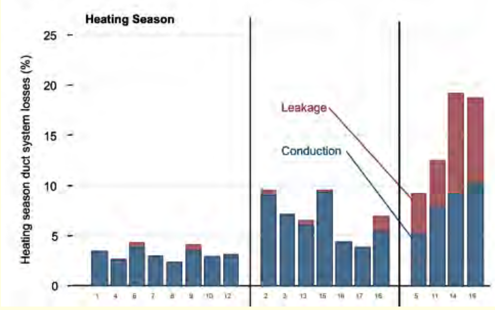
- Evaluation results
  - Multiple studies in 90s found 1% - 3% savings from intensive duct sealing in basements (OH, PA, IA, ORNL)
  - WI study of mostly basement ducts
    - 95+% duct efficiency when ducts in basements and walls
- Basement are Inside!*
  - Even if unintentionally conditioned, semi-conditioned
    - Sealing leaks in basement could increase dP across inaccessible leaks that really go to outside
  - Model should not ask ambiguous basement conditioning question – just report observable conditions

* Basements may be considered outside if people are afraid to go into them

WI Duct Study

Pigg & Francisco, ECW 2008

FIGURE 2, ESTIMATED DUCT SYSTEM LOSSES (BASED ON ASHRAE 152).



Basement Duct Modeling

- Home Energy Saver (LBL free online tool)
- Scenario: Older house in Boston
  - Built 1910, 2000 sq.ft. , dense packed walls, R-38 attic
  - Uninsulated ducts in uninsulated basement
  - No supply registers in unfinished basement
- Specify unconditioned basement
  - Insulated Ducts: save 24% of heating use
  - Seal Ducts: save 11%
  - Insulate floor: save 11%
  - Do all 3: save 41% ($654/year)
  - No basis in any empirical data

Infiltration: What's a CFM50 worth?

- Billing Data Analysis Findings
  - Modeled Savings= 10-15 therms / 100 CFM50
  - Measured savings= 5-8 therms per 100 CFM50 reduction in ~6000 HDD climate
  - 40% less than standard modeled
  - But CFM50 is the strongest predictor of heating use in cold climate homes
    - More important than heated area!

Infiltration: Why the Shortfall?

- Palmiter tracer research on LBNL/SG model:
  - Model overpredicts impact of wind
    - Proposed a correction, 10%-20%+ reduction
  - Stack height should be average, not maximum
    - ~10% difference
  - Houses better shielded than common default
    - ~10%+ difference
  - In most homes, these corrections will be <40%
- Divide by 20 works pretty well for infiltration
  - Raw CFM50 better correlated to heating use than modeled CFM natural from most software

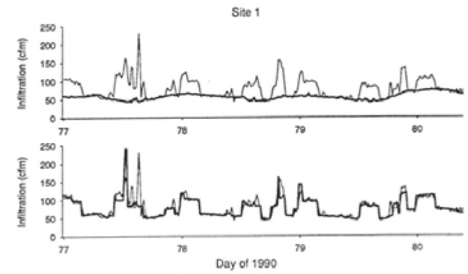
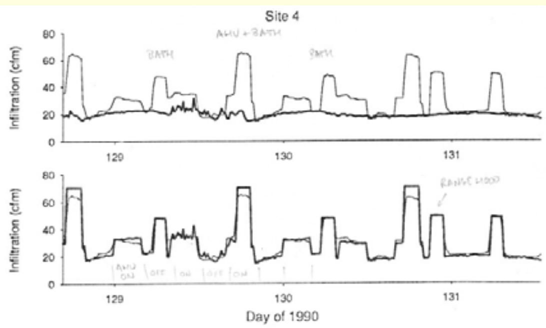


Figure 2. Measured and modeled infiltration at Site 1. The bold line in the upper graph is the adjusted natural infiltration prediction; in the lower graph it is the adjusted infiltration combined with the fan model.



Infiltration: More Issues?

- Infiltration and conduction interact: combined losses are less than sum of the two
  - Heat is picked up by infiltrating air brought into home
  - Heat is dropped off by exfiltrating air leaving home
  - Happens within walls, insulation
    - a.k.a. dynamic wall effect
  - Happens in buffer zones
    - Infiltration into basement/crawl, picks up conductive losses and duct losses and regains them to house
    - Exfiltration through attic warms up attic, reducing dT
- House = low efficiency HRV
  - Maybe 10%-25%?

Attic Bypass Leakage

- Air Leakage house to attic – what does it do?
  - Bypass leakage hurts insulation performance and is the major cause of attic moisture problems – fix the leaks and solve both problems. Really?
- Heat loss is a little more complex
  - Bypass leakage warms the attic, meaning LESS heat loss through insulation due to smaller dT
    - Can be considered heat recovery of exfiltration losses
  - Less heat loss = less savings from adding more insulation
  - So bypass leakage improves existing insulation performance while reducing savings from added insulation

R-Values

- What's the R-Value of a single pane window?
  - R-1? if there's a 15 mph wind non-stop
  - Maybe add R-0.4 or R-0.5 for more typical conditions

Window U-Values

- NFRC test conditions
  - 70ºF inside, 0ºF outside, 15 mph wind

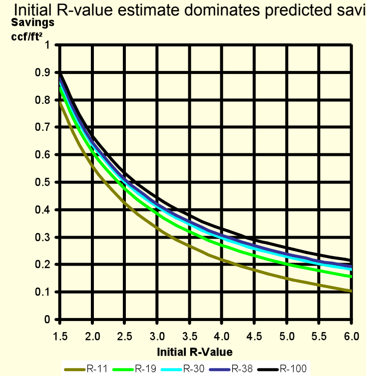
Maybe add R-0.5 to estimate typical performance?

R Values

- What's the R value of an uninsulated wall and associated retrofit savings?
  - R-3: savings = 290 therms (1000 ft²)
  - R-4: savings = 190 therms
  - R-5: savings = 130 therms
- Actual energy use data imply R-5.5+
- Everything is R-5 or better, except windows

Predicted Insulation Savings & R- Value

Initial R-value estimate dominates predicted savings



calculations based on 4500 HDD, 79% heater efficiency

It's easy to over-predict…

Pre-Weatherization Home			
Component	A	R	A/R
Walls	2100	4.5	467
Attic	1050	19	55
Windows	300	2.0	150
Basement	140	1.0	140
Infiltration	3000	16	188
UA total			999
Furnace			72%
Ducts			80%
HDD(60)			4500
Heating Use			**1874**

Post Weatherization			
Component	A	R	A/R
Walls	2100	11	191
Attic	1050	34	31
Windows	300	2.0	150
Basement	140	1.0	140
Infiltration	2000	16	125
UA total			637
Furnace			92%
Ducts			80%
HDD(60)			4500
Heating Use			**934**
Savings (th/yr)			**940**

Change Some Assumptions

and projected savings are cut in half

Pre-Wx - alternate assumptions			
Component	A	R	A/R
Walls	2100	5.5	382
Attic	1050	19	55
Windows	300	2.4	125
Basement	140	1.4	100
Infiltration	3000	20	150
UA total			812
Furnace			78%
Ducts			92%
HDD(60)			4500
Heating Use			**1222**

Post Wx - alt assumptions			
Component	A	R	A/R
Walls	2100	10	210
Attic	1050	30	35
Windows	300	2.4	125
Basement	140	1.4	100
Infiltration	2000	20	100
UA total			570
Furnace			92%
Ducts			92%
HDD(60)			4500
Heating Use			**727**
Savings (th/yr)			**495**

Why Are Savings Overestimated?

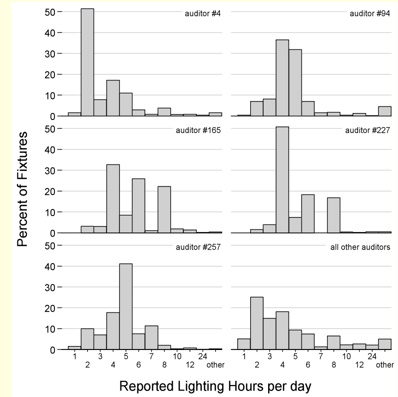
- Or, Are Savings Projections Too High?
  - Poor Projections indicated by patterns in the errors
    - Certain features modeled poorly
    - Inefficient homes have very large over-estimation of usage
  - Model Assumption/Default Problems
    - Effective R values, AFUE, SEER, etc.
  - Algorithms Problems
    - Infiltration and duct models
  - Data Collection / Auditing Problems
    - Bias toward finding problems, doing retrofits
    - Some data are hard to collect

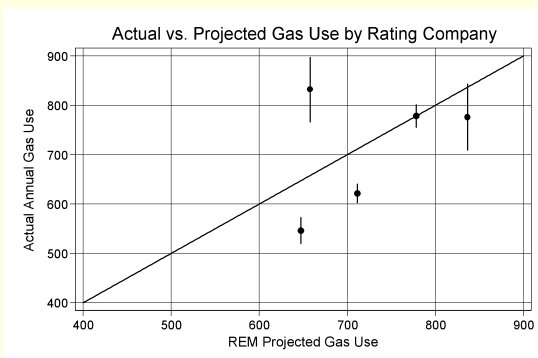
Data Collection Accuracy

- Data collection can be less accurate than defaults
  - Hard to measure
    - window shading, wind exposure, soil conditions
  - Open to Interpretation?
    - Basements: conditioned? unconditioned? semi-conditioned? unintentionally semi-unconditioned???
  - Technician Bias
    - Effective attic R-value estimates: pessimistic to get savings?
    - House set-up: blower door test, duct test (basements)
  - Occupant Behavior
    - Hard to know: e.g., lighting hours
    - Bias toward "good" behavior: TV watching, thermostat settings?

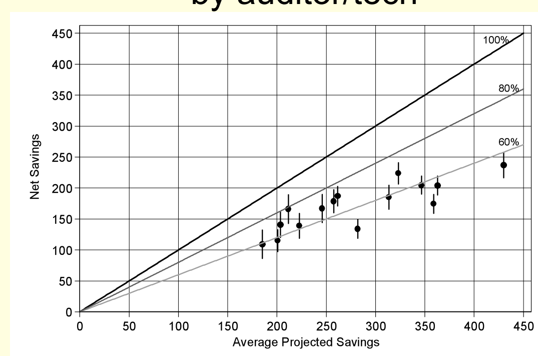
Lighting Hours of Use: reported values by auditor

- Reported hours varied by auditor
  - some liked 2 hours
  - some liked even numbers
  - some liked odd





Actual vs. Projected Retrofit Savings by auditor/tech



OK, Now Can We Blame The Occupants?

- Some say actual energy use has little to do with house efficiency because occupancy effects are so large
  - asset rating vs. operational rating
  - Mostly rely on misleading statistics, outliers, and anecdote to defend bad models
    - 3 to 1 ratio of highest to lowest use actually implies range of +/-50%
- Occupancy has bigger impacts on
  - lighting, appliance, and plug loads
  - Heating loads in warm climates, Cooling loads in cold climates
  - Heating and Cooling loads in very efficient homes
- Hard to measure occupancy impact, but we can begin to bracket it

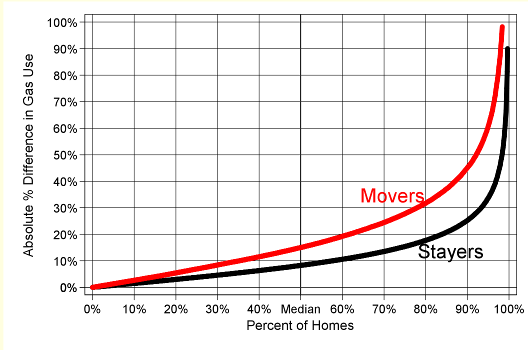
Assessing Occupancy Impacts

- How accurately can we predict the energy use of a home based on the prior occupants' energy use?
- Would an energy model give a better prediction of energy use than using the prior occupants' usage?

Assessing Occupancy Impacts

- Analysis of Midwestern gas utility customers
  - Weather-adjusted gas use in 2012 vs. 2009
  - Owner-occupied single family homes
  - Results for 79,805 movers and 545,136 stayers
  - Observed changes in usage are due to
    - Occupancy effects PLUS
    - Actual changes in building over time
      - renovations, retrofits, replacements
    - Weather normalization errors
      - solar, wind, seasonal baseload uses

Gas Use: Movers vs. Stayers



- Median Abs. Change in Gas Use: Movers=15%, Stayers=8%
- Within ±25% of prior use: Movers=71%, Stayers=90%

How do modeling errors compare?

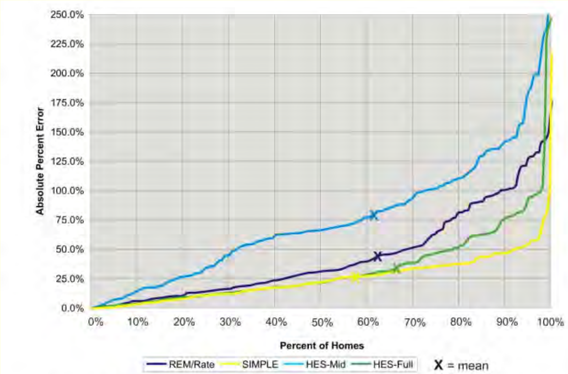


Figure 3.2 Comparison of Accuracy for Total Energy (MBtu) for 190-Home Sample

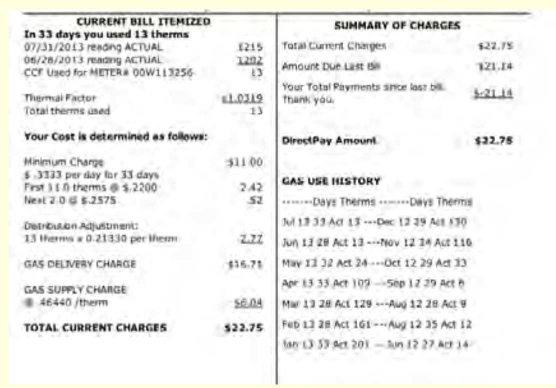
Predicting Gas Use: a recap

		Error		
			OK	Useless
Method	**Project**	**Mean**	**±25%**	**>50% err**
Use 3 yrs old	MW gas - stayers	12%	90%	2%
Use 3 yrs old	MW gas - movers	21%	71%	8%
SIMPLE	MN Pilot	25%	59%	10%
SIMPLE	OR- old gas	36%	44%	23%
HES-Full	OR- old gas	52%	43%	43%
HE Score	MN Pilot	57%	26%	46%
REM/Rate	MN Pilot	63%	12%	67%
REM/Rate	OR- old gas	91%	22%	67%

Another Look at Occupant Effects Electric Use in Hot Climate

- Phoenix Energy Star New Homes Study
  - Total and summer/cooling use in 2000 vs. 2004 for 1289 movers and 1384 stayers
    - Median % difference in electric use was 14% for stayers and 21% for movers
    - More movers experienced large changes in usage compared to stayers
      - 1 in 4 movers showed a usage change of 40% or more, but only 1 in 10 stayers showed that large a change

Best Predictor of Future Bills?



CURRENT BILL ITEMIZED

In 33 days you used 13 therms

07/31/2013 reading ACTUAL	1215
06/28/2013 reading ACTUAL	1202
CCF Used for METER# 00W113256	13
Thermal Factor	x1.0319
Total therms used	13
Your Cost is determined as follows:	
Minimum Charge	$11.00
$ .3333 per day for 33 days	
First 11.0 therms @ $.2200	2.42
Next 2.0 @ $.2575	.52
Distribution Adjustment:	
13 therms x 0.21330 per therm	2.77
GAS DELIVERY CHARGE	$16.71
GAS SUPPLY CHARGE	
@ .46440 /therm	$6.04
TOTAL CURRENT CHARGES	**$22.75**

SUMMARY OF CHARGES

Total Current Charges	$22.75
Amount Due Last Bill	$21.14
Your Total Payments since last bill. Thank you.	$-21.14
DirectPay Amount	**$22.75**

GAS USE HISTORY

--------Days Therms --------Days Therms
Jul 13 33 Act 13 ---Dec 12 29 Act 130
Jun 13 28 Act 13 ---Nov 12 34 Act 116
May 13 32 Act 24 ---Oct 12 29 Act 33
Apr 13 33 Act 109 ---Sep 12 29 Act 8
Mar 13 28 Act 129 ---Aug 12 28 Act 9
Feb 13 28 Act 161 ---Aug 12 35 Act 12
Jan 13 33 Act 201 ---Jun 12 27 Act 14

Modeling Issues for Retrofits

- If you get the big stuff wrong, it doesn't matter how well you model the small details
- Is detailed modeling cost-effective?
  - How do the time/effort/cost of collecting detailed data and using complicated models compare to the benefits?
  - Does it distract from other tasks?
  - Is it just fun work for nerds?

Should we insulate the uninsulated wall?

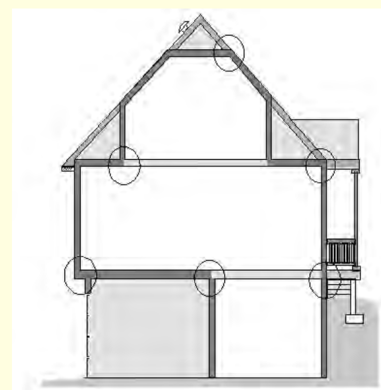
I don't know --let's do some hourly simulations…

What About More Efficient Homes?

- More efficient homes
  - Many problems described matter less – big bias evaporates
    - R-1 error is small for R-19 wall
  - But flaws can have bigger impact on remaining losses
    - Thermal boundary problems, thermal bridges
    - Induced pressures – door closure, unbalanced duct leakage
  - Comparisons of measured and modeled shows
    - many remaining biases
    - but they can cancel out or aren't that large

Key Thermal Defect Junctures:

how do I model this in the software?



What about Super Efficient Homes?

- Why bother?
  - Heating dominated by hard-to-model factors
    - internal gains (and their utilization)
      - appliances, lighting, plug loads
      - DHW recovery
      - Occupants, pets?
    - solar gains/utilization
      - site shading
      - internal shading (and use by occupants)
      - how clean are the windows?
    - envelope flaws – as built
    - occupant behavior
      - thermostat setting, tolerance of swings/imbalances
- But, don't worry – heating use is small
  - DHW and lighting, plug, appliance loads can dominate

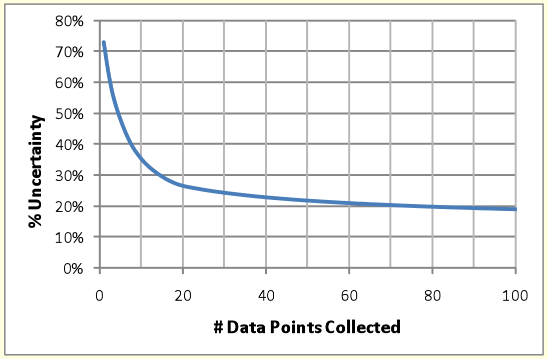
Fundamental Modeling Problems

- Things that are hard to model well
  - Foundation heat loss
    - soil conductivity / ground temperature, waste heat regain
  - Infiltration
    - model errors unfixed, wind?, leak locations?, regain? – houses are HRVs
  - Wall and Attic Heat Loss
    - framing factors, edge effects, installation quality, air leakage interactions
  - Window Loss/Gain
    - Exterior and interior shading, screens, old storms, air film
  - HVAC Performance
    - duct efficiency and regain, AC charge and air flow impacts

The good news…

- Not every home needs to be a science project
  - Especially for retrofits assessed for cost-effectiveness
    - Don't need hourly simulation with 125 inputs to tell you to insulate and air seal your home
  - Modeling new construction? benefits unclear
    - Can detailed models lead to better design trade-offs?
      - If you need a model to make decision, maybe other factors (cost, contractor experience/familiarity, etc) will be more important
      - Even when modeling is needed, is it needed every home?
- Science Projects
  - passive solar
  - unique envelope/HVAC

Value of data / limits of accuracy



Everything should be made as simple as possible, but no simpler
Albert Einstein (paraphrased)

10 Simple Things That Don't Do Enough

Free Energy Advice...Overpriced?

- Major National Energy Group (technical)
  - "Seal air leaks... around exterior windows and doors"
  - "get the most "bang for the buck" by hiring a professional to tune up their furnace, repairing ductwork, and investing in a high-efficiency furnace fan. " (before such a retrofit was sold)
  - "right-sized heating equipment"

Free Energy Advice...Overpriced?

- Major National Green Buildings Group
  - When ... at home, keep the thermostat at ... 62°F or lower in the winter.
  - Common leaks occur around windows, doors, and other wall penetrations. Plugging those leaks with weather stripping and caulk can be a simple task for anyone! Savings: Reduce your energy bill by $100 per year or more!
  - Tune Up Your Heating and Cooling (HVAC) System: Have a checkup for your HVAC system every 2 years to make sure it is running efficiently. Be sure to clean the filter monthly during times of peak usage; a dirty filter can significantly reduce the efficiency of your HVAC. Savings: Reduce your energy bill by $100 per year or more!
    - Air Filters (costing about $30 a year) could save you about $100 a year if you change them every three months, according to the XXXXX (found in national new org. web site -- expertise spreads)
  - No mention of Insulation in their list for greening your home

More Free Advice...

- Utility Companies
  - professional "tune-up" of your heating system should be part of your household's annual check list.
  - especially important to caulk windows and weatherstrip around door frames.
  - Seal leaks in air ducts : save between $116 - $194 per year.
  - Install low-flow showerheads : save between $60 -$100 per year
- Other energy savers touted:
  - Tankless water heaters
  - Cool Roofs
  - Energy Star Window Replacement
  - Behavior changes: refrigerator coils, lids on pots, close fridge door
  - Ceramic paint (Parade Magazine Sep 15, 2007)

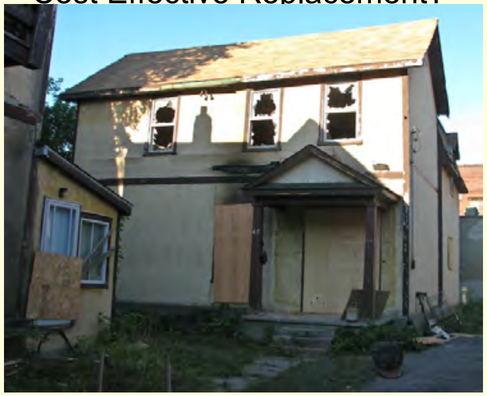
10 Simple Things that …?

1. Window replacements
2. HVAC Tune-ups
3. HVAC “Right-Sizing”
4. Basement Duct Sealing
5. Tankless Gas Water Heaters?
6. ECM air handler fans
7. Floor Insulation
8. Cool Roofs/ Radiant Barriers
9. ASHRAE 62.2 in Weatherization?
10. Small Actions: filters, fridge coils, fridge door

Window Replacements

- Savings ~3 th/yr per window (2%-7%)
  - 100-300 year payback
  - Save a little more if windows really bad
  - Save double if R-5 new window?
- Issues
  - R values are ~0.5 higher Solar gain loss offsets some savings
- Storm windows may be better option?

Really Leaky Windows
Cost Effective Replacement?



Some Furnaces Need A Tune-up...

But significant savings seem to be rare

Furnace "Right-Sizing"

- Modern Furnaces show little part load degradation
  - Oversizing gives quicker recovery from setback
  - But right-sizing may alleviate duct design problems
  - But right sizing increases duct energy losses

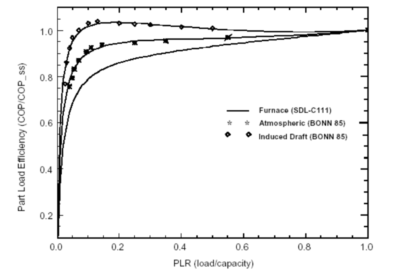


Figure 6: Recommended Curves for Furnaces and Boilers

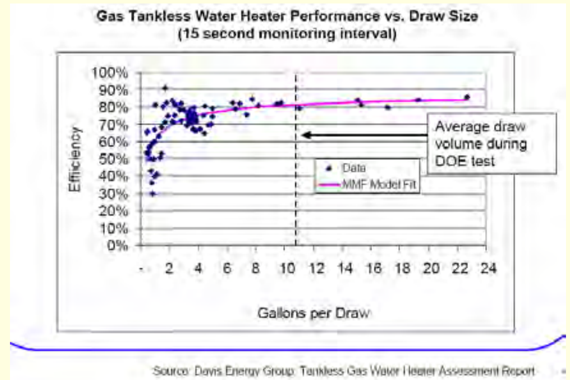
ECW and FSEC studies found no real benefits from right sizing central A/C

Oversized AC?

Tankless Water Heaters

- Tankless gas water heater retrofit
  - Measured Savings pretty good = 65 th/yr
    - EF test over-estimates efficiency, but also for tank units
  - But avg. $2500 cost gives 30 year payback
  - Also - potential issues with maintenance, minimum activation flow, quality of hot water delivery, potential “endless” showers

Tankless Performance

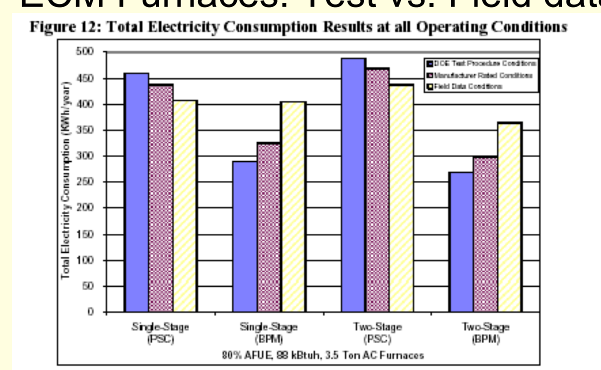


from “Advanced Storage Gas Water Heating Technologies” Marshall Hunt, ACEEE Emerging Technologies Summit, 2006.

ECM Furnace Fan Motors

- Savings depend on operating conditions
  - High static dP: lower PSC watts, higher ECM watts
  - Waste heat is useful in winter, harmful in summer
  - Typical real world: higher dP, lower savings
- Contractors encourage fan “ON” with ECM, reducing and even negating savings
  - Survey in WI found ~20% of buyers switched to fan “ON” with ECM
  - If Fan ON really required, then ECM savings are huge (3000 kWh)

ECM Furnaces: Test vs. Field data



source: “BPM Motors in Residential Gas Furnaces: What are the Savings?”, J. Lutz, V. Franco, A. Lekov, G. Wong-Parodi,. LBNL-59866, 2006.

Floor Insulation

- Measured savings disappointing
    - therms/yr: 0 (OH), 6 (IA), 21 (NJ), 39 (CO, OR)
    - ducts and thermal regain effects
  - Basement ceiling
    - 0 savings in many homes
    - quality / effectiveness questionable
  - Crawlspace ceiling
    - Save 5 th/yr per 100 ft^2/yr
    - But must fix ducts

Cool Roofs / Radiant Barriers

- Reduces cooling if attic poorly insulated or ducts in attic
  - Measured 180 kWh/yr from radiant barrier sheathing in new ES homes in Houston
  - But if ducts are in attic, then may save ~15% of cooling load (if not well insulated)

ASHRAE 62.2 in Weatherization

- Add fan to not very tight home
  - Increases gas use 30 th/yr + electric use
  - Double air leakage control costs
  - Cut air sealing savings in half
  - Makes 5 year payback measure take 20 years
    - Renders air sealing no longer cost-effective in many homes – unless you value the presumed IAQ impact

Small Behavior Changes

- Change furnace filters monthly
- Clean fridge coils
- Close fridge quickly
- Add jugs of water to fridge/freezer
- Ceiling fans in winter?
- Close registers to unused rooms?
- Energy Feedback Displays

- Instead – just unplug 2nd fridge

Furnace Filters

- Replacing furnace filters frequently?
  - System air flow not very affected until filter very dirty
  - Reduced air flow reduces fan kWh if standard motor
    - PSC fans don't really "work harder", but ECMs do
  - Reduced air flow usually has small impacts on system efficiency unless very low flow (pre-existing flow problem, very dirty filter)
    - Gas furnace impacts maybe 1% for 25% air flow change
    - Air conditioner maybe 2% EER reduction for 20% flow reduction
      - recent study found many small ACs (2 ton) have too much air flow so reducing flow improves efficiency
  - Dirty filter works better at cleaning air (MERV increases)
  - **Very** dirty filter can cause cycling on limit