
Energy Simulation and Optimized Retrofit Practices Applied to a Real Dwelling

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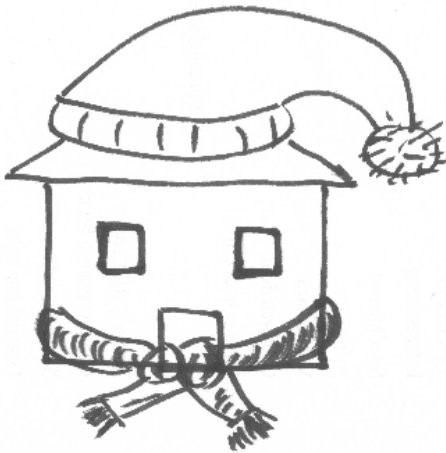
Importance of Retrofit Practices



- Residential Housing account for 22% of the total primary energy usage in US
- The average age of a single family home in the US is 34 years
- Around 130 million existing homes in US, new construction accounts for about 1 million per year.



Importance of Retrofit Practices





Test House

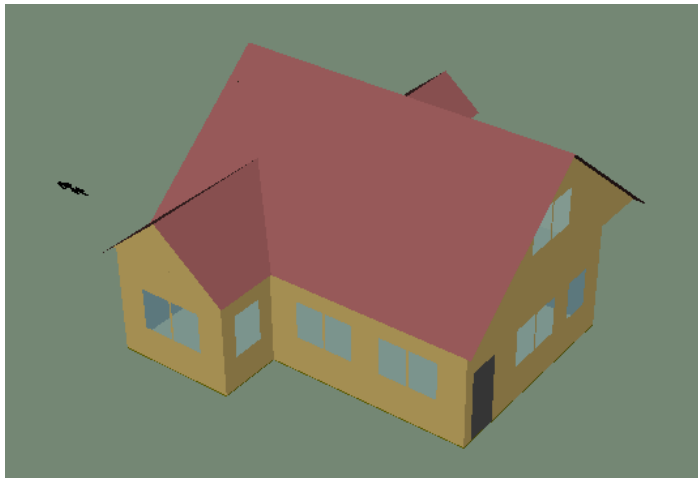




Test House



3D Model

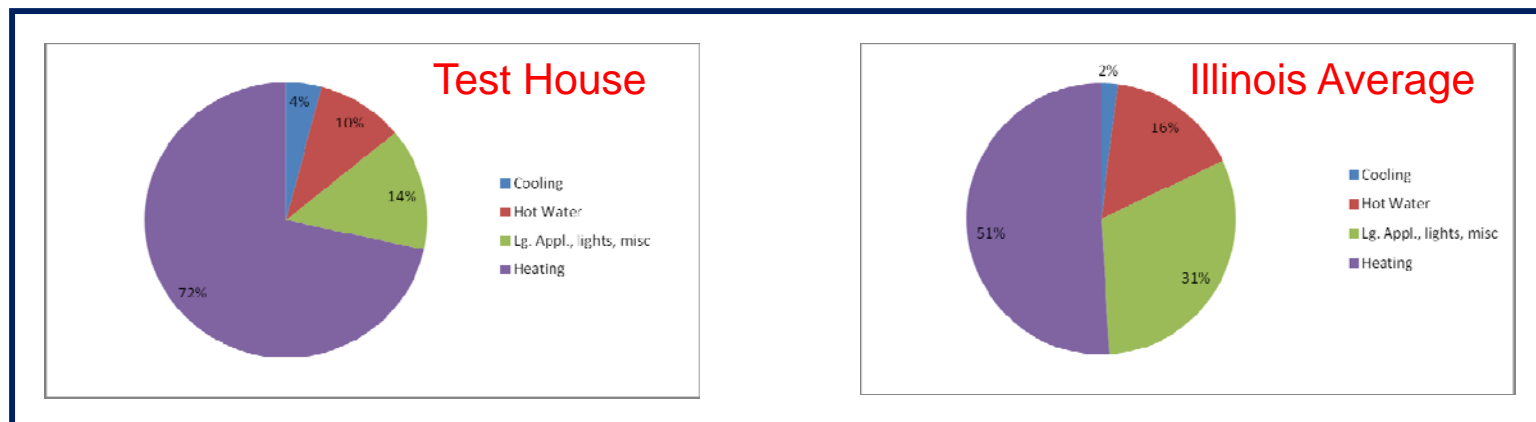
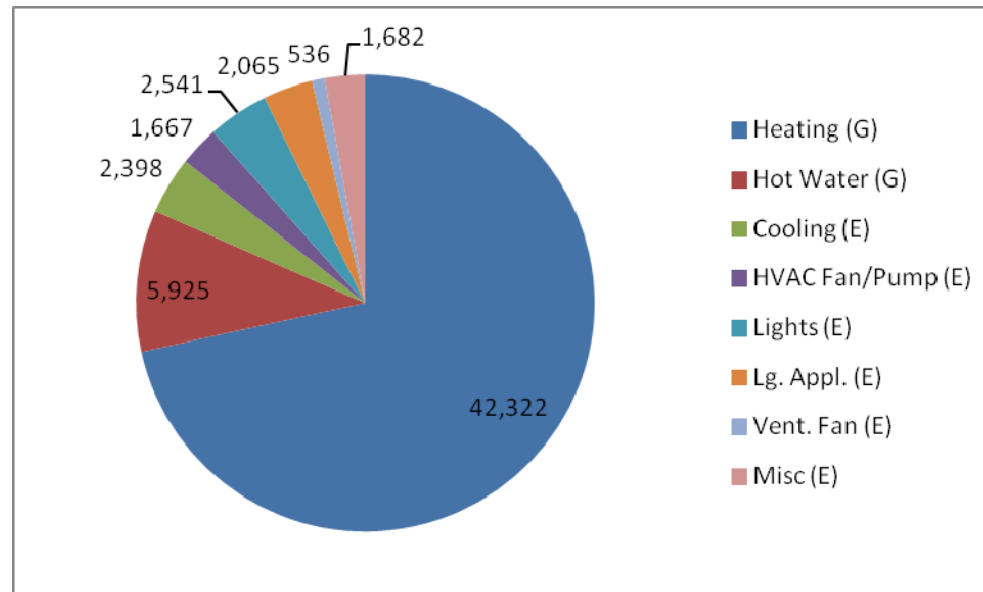


Main Characteristics

- Location: West Lafayette, Indiana, USA
- Square footage: 266 m²
- Age: 86 years
- Envelope: Uninsulated
- Air Leakage: 10 ACH50
- Heating System: natural gas furnace



Baseline Energy Consumption

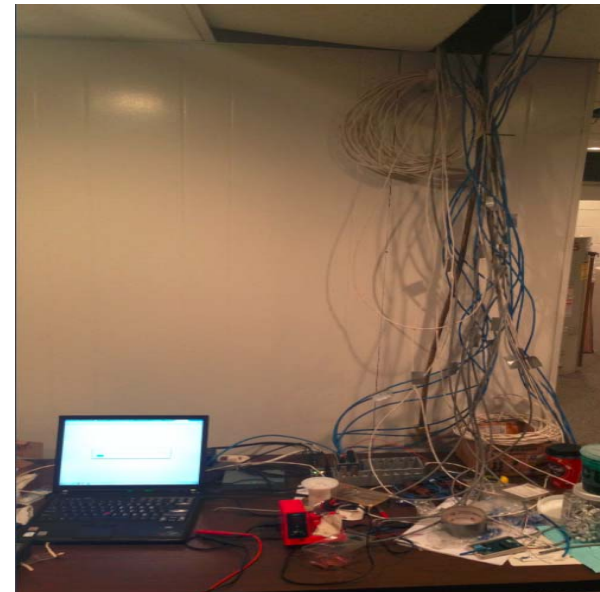




Instrumentation System



- Electricity consumption of each circuit
- Gas consumption (furnace and water boiler)
- Sub-metered Water Consumption
- Temperature and Relative Humidity in each room





Baseline Simulation and Real Data



- The DOE Building America Simulation Protocol is used in the software to reflect the average American family behavior
- The same schedule was replicated in the test house for a week and the data were recorded.

Load	Simulated (kWh)	Measured Data (kWh)	% difference
Heating	42,322	45,455	7.1%
HVAC fan	1667	1538	8.0%
Lights + miscellaneous	4223	4076	3.5%
Appliances	2065	1862	10.3%



Optimization Parameters



Building Shell



Appliances



Lighting



Costs from National Residential Efficiency Measures Database



Simulation Program Parameter Input



BEoptE+ 1.2 - Thesis_Austin

File Screen Case Run Graphs Reports Tools Help

Input: Output:

Type: Retrofit Analysis: [D] Design Ref Bldg: Existing Building Cost Selection: Thesis Data Input

Cases: [D] Austin Base Case [D] Phase 1 HVAC Sizing [D] Phase 1 - Envelope & Sealing [D] Phase 2 - Lighting & HVAC [D] Phase 2 - Lighting & HVAC (Original HVAC Size) [D] Phase 3 - DHW & Appliances Combined Graphs

Designs: 1 - Baseline

- Building
 - Operation
 - Walls
 - Ceilings/Roofs
 - Unfinished Attic: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
 - Roofing Material: 1 2 3 4 5 6 7 8 9 10 11 12 13
 - Radiant Barrier: 1 2
 - Foundation/Floors
 - Slab: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
 - Exposed Floor: 1 2 3 4 5 6
 - Thermal Mass
 - Windows & Shading
 - Window Areas: 1 2 3 4 5 6 7 8 9
 - Window Type: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
 - Interior Shading: 1 2 3 4 5
 - Eaves: 1 2 3 4
 - Overhangs: 1 2 3 4 5 6 7
 - Airflow
 - Major Appliances
 - Lighting
 - Space Conditioning
 - Air Conditioner: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
 - Furnace: 1 2 3 4 5 6 7 8 9 10 11 12
 - Hydronic Heating: 1 2 3 4 5 6 7 8 9 10 11 12
 - Heat Pump: 1 2 3 4 5 6 7 8 9 10 11 12 13 14
 - Ground Source HP: 1 2 3 4 5 6 7 8 9 10 11 12 13
 - Ducts: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
 - Ceiling Fans: 1 2 3 4 5 6 7 8 9 10 11
 - Dehumidifier: 1 2 3 4 5 6 7 8 9 10 11
 - Water Heating
 - Power Generation

Existing: Ceiling R11 Cellulose Blown-In, Vented

Post-Retrofit Unfinished Attic options	Ceiling Nominal R Assembly	Roof R Assembly	RoofTaperFactor @Eaves 0,1,2ft	Lifetime [years]
1) Uninsulated, Vented	1.9	2.0	-	99
2) Ceiling R11 Cellulose Blown-In, Vented	11.9	2.0	1.00,1.00,1.00	99
3) Ceiling R19 Cellulose Blown-In, Vented	19.9	2.0	1.00,1.00,1.00	99
4) Ceiling R30 Cellulose Blown-In, Vented	31.2	2.0	0.99,1.00,1.00	99
5) Ceiling R38 Cellulose Blown-In, Vented	39.2	2.0	0.98,1.00,1.00	99
6) Ceiling R49 Cellulose Blown-In, Vented	50.3	2.0	0.95,0.99,1.00	99
7) Ceiling R60 Cellulose Blown-In, Vented	61.3	2.0	0.91,0.98,1.00	99
8) Ceiling R11 Fiberglass Blown-In, Vented	12.6	2.0	1.00,1.00,1.00	99
9) Ceiling R19 Fiberglass Blown-In, Vented	20.5	2.0	0.99,1.00,1.00	99
10) Ceiling R30 Fiberglass Blown-In, Vented	31.5	2.0	0.97,1.00,1.00	99
11) Ceiling R38 Fiberglass Blown-In, Vented	39.5	2.0	0.94,0.99,1.00	99
12) Ceiling R49 Fiberglass Blown-In, Vented	50.5	2.0	0.90,0.98,1.00	99
13) Ceiling R60 Fiberglass Blown-In, Vented	61.5	2.0	0.86,0.95,0.99	99
14) Ceiling R30 Fiberglass Batts, Vented	31.2	2.0	0.99,1.00,1.00	99
15) Ceiling R38 Fiberglass Batts, Vented	39.3	2.0	0.97,1.00,1.00	99
16) Ceiling R49 Fiberglass Batts (R19 + R30), Vented	50.3	2.0	0.94,0.99,1.00	99
17) Roof R19 Fiberglass Batts	1.9	18.9	-	99
18) Roof R30 Fiberglass Batts	1.9	26.2	-	99
19) Roof R38 Fiberglass Batts	1.9	30.8	-	99
20) Roof R38 Fiberglass + 3.5" Rigid Ins	1.9	60.5	-	99
21) Roof R27.5 SIPs	1.9	29.3	-	99
22) Roof R37.5 SIPs	1.9	39.3	-	99
23) Roof R47.5 SIPs	1.9	49.3	-	99
24) Thesis R38 Cellulose	39.2	2.0	0.98,1.00,1.00	99
25) Thesis R49 Cellulose	50.3	2.0	0.95,0.99,1.00	99
26) Thesis R30 Cellulose	31.2	2.0	0.99,1.00,1.00	99

Attic space that is not directly conditioned. Insulation can be on the attic floor (the ceiling of the space below) or at the roof plane. Options can also specify whether the attic is vented or not.

Roof Taper Factor @Eaves 0,1,2 ft displays the de-rating of ceiling insulation R-value caused by the roof perimeter tapering effect at eaves depth of 0, 1 and 2 feet, calculated based on geometry screen inputs, accounting for the non-linear increase in U-value with reduced insulation thickness. For example, with an original ceiling insulation R-value of 61.3 and a displayed Roof Taper Factor value of 0.85, a de-rated (effective, overall) ceiling insulation R-value of 0.85*61.3 will be used in simulations.

NOTE: Displayed assembly R-values include inside and outside air films and 1/2 in. of drywall.

Previous runtime: 1m (1 simulations)



Optimization Results

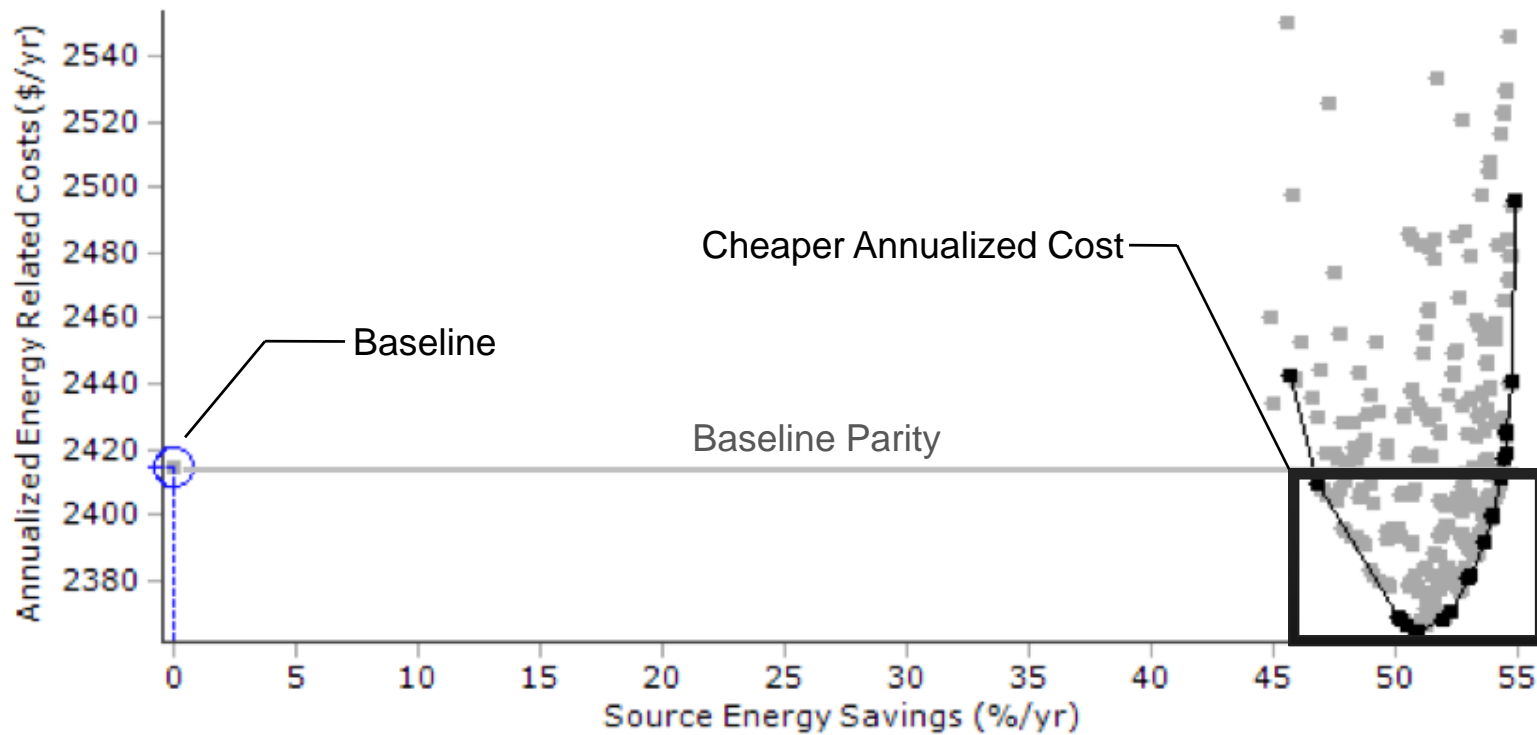


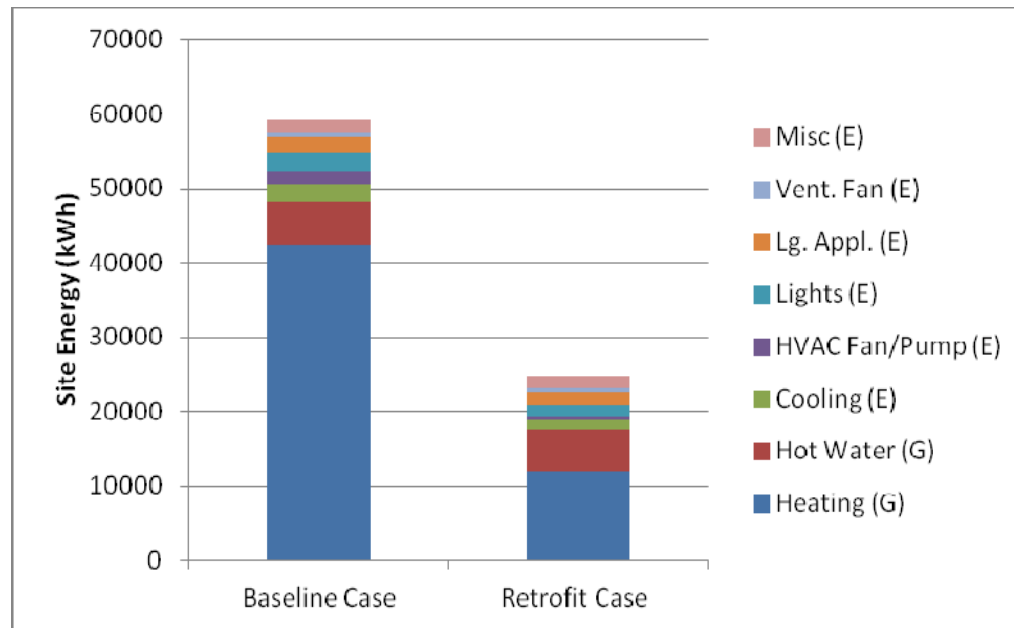
Figure 5: Cost/Energy Savings Optimization Curve

Equivalent annualized energy costs can be achieved using ~46 to 54% less source energy



Optimum Solution

- Total Energy Consumption:
59,136 kWh/year → 24,855 kWh/year
- Heating Demand:
42,322 kWh/year → 11,966 kWh/year

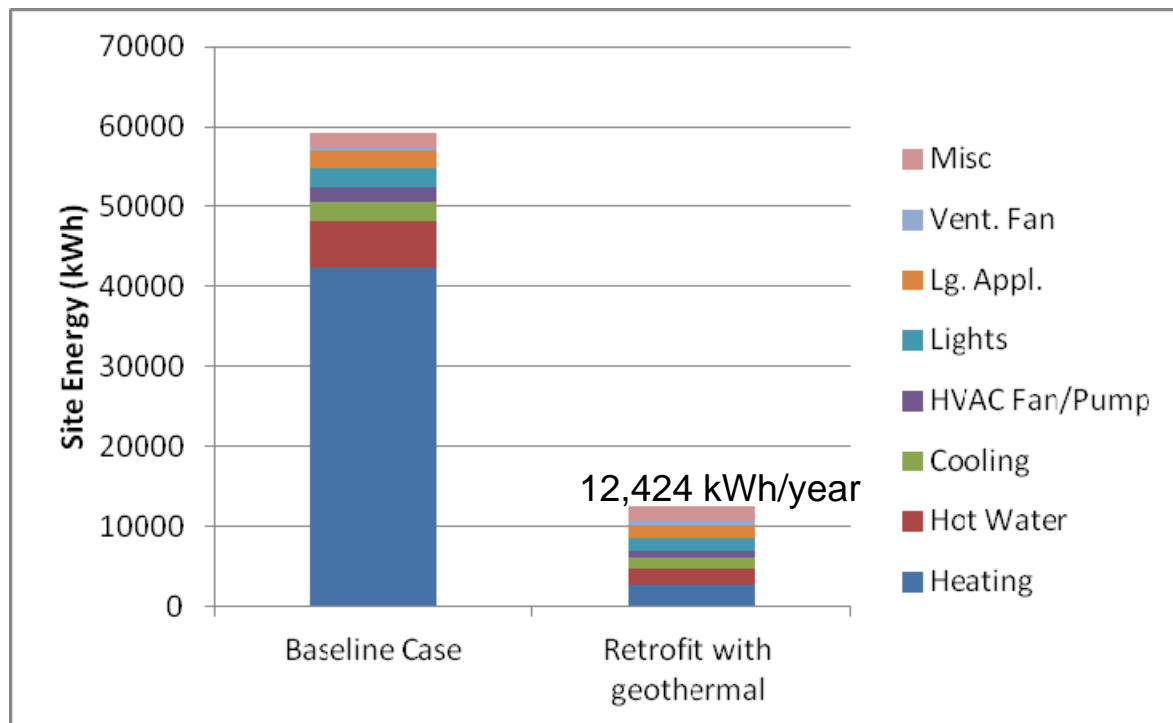




Path to Net-Zero Energy



- HVAC system: geothermal heat pump;
- Water Heater: heat pump water heater;
- Electricity generation: Solar Photovoltaic



11.3 kWp
photovoltaic
system will
produce 12,313
kWh/year



Work In Progress



Thank you!





Back-up Slide

Objective is to minimize Annualized Energy Related Costs while maximizing energy efficiency

Energy Related Costs are comprised of 4 separate cash flows

Utility Bills: Equivalent Yearly Electric & Natural Gas Costs (Home Operating Costs)

Loan Costs: Equivalent Yearly Principle & Interest Payments for Retrofit Work

Replacement Costs: Equivalent Yearly Cost to Replace Equipment at End of Life

Residual Value: Equivalent Yearly Receipt for the Salvage Value of all Equipment

Annualizing the energy related costs is a process of translating these four yearly costs to a single cost at the start of the analysis period, which is 30 years long.