The Robo Retrofit House: 2400 ft^2 that Has 42% Energy Savings Compared to Next Door Robo Builder House

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ABSTRACT

This paper describes a house, called the Retrofit House, which uses 42% less energy than the identical Builder standard; in a side-by-side measured and modeled comparison. This three-bedroom, 2 ½ -bath, 2400-ft^2 house has a Home Energy Rating System (HERS) index of 68 (a HERS of 0 is a zero-energy house, a conventional new house would have a HERS rating of ~100). The identical Builder house right next door has a HERS of 102. The house type, size and dominate features were selected after a demographic housing study in the TVA service territory to determine typical house market demanded in the 2000-2008 time frame.

The Retrofit house has 2x4 nominal wood stud construction with an unvented conventional attic having trusses at 24 inches on center with an insulated- airtight envelope (3.43 air changes per hour at 50 Pascal), supply mechanical ventilation, ducts inside the conditioned space, single hung low-e gas-filled windows, energy star appliances, and a single (SEER 16, HSPF 9.5) heat pump instead of two (SEER 13, HSPF 7.7) heat pumps in the Builder House. The detailed specifications for the envelope and the equipment used in Retrofit House compared to the Builder House are listed in Tables 1 and 2.

Detailed data measured at 15 minute intervals for a year was used to generate a computer simulation of the all-electric Retrofit and Builder Houses with typical three person occupancy patterns and energy services. Energy for the Retrofit house is predicted to cost $3.76/day. By contrast, the Builder house would require $6.46/day. These energy costs are based on average 2009 local residential rates of $0.093/kWh. The Retrofit House uses, on average, 40 kWh/day.

The costs to construct the Retrofit House were calculated utilizing the actual Builder cost invoices including 15% overhead and profit, totaling $253,800 or $105/ft^2. The detailed actual cost data base for the Retrofit House and the Builder House is used to determine the incremental cost of the retrofit package and to conduct a neutral cash flow analysis.

Introduction

Background

This paper documents a 2400 ft^2, house energy efficiency retrofit (Figure 1) that will achieve at least a whole-house energy savings of 40% using a commercially available technology package in the mixed-humid U.S climate region. Invoice level construction costs were used along with measured energy consumption to predicted energy consumption and cost analysis using typical weather year and average United States residential internal energy services.

The lessons learned are presented from designing, building, retrofitting, and monitoring these side-by- side houses through a collaboration of the Tennessee Valley Authority (TVA) and U.S. Department of Energy (DOE). The retrofit was conducted on a very popular housing type found in the TVA service territory.

Figure 1. South Elevation of the Retrofit House

The 42% Energy Saving Retrofit House

The Retrofit house was instrumented with 92 sensors to record 15-minute electric sub-metered usage, temperature and relative humidity (ambient and indoor), hot and cold water usage, heat pump operation, and other data. The data were analyzed to determine component performance and energy consumption and to validate computer models. The models predicted and the measurements support that this house would consume total off-site energy with an average cost of $3.76/day. This includes the current hook-up charges of $0.24/day. The local average 2009 residential rate of $0.093/kWh was used to evaluate costs. The total construction cost of the Retrofit House was $254,000.

Technologies

Tables 1 and 2 list building envelope and mechanical features used in the Retrofit House, compared to the Builder house.

Walls — typical 2x4 construction. The Retrofit and Builder Houses are constructed with conventional 2x4 framing. The exterior walls are insulated with R-13 batt insulation with a framing factor of 0.23. The blower door identified excessive leakage around the patio and kitchen doors, which were tightened up resulting in a June 9, 2009 test result of 3.43 air changes per hour (ACH) at 50 Pascal. The Builder Houses have a 5.7 ACH@50 Pa.

Windows. The only retrofit to the vertical envelope on the Retrofit House was the windows. The windows were fitted with U-factor = 0.35 and SHGC = 0.34. The windows were installed according to best practices. Both caulking and expanding foam was used appropriately.

Sealed and insulated attic. The Retrofit House roof includes sealing off the attic as a cathedralized, conditioned space as seen in Figure 2. The attic is sealed with 2” XPS blocking along the soffits and the entire attic envelope is insulated with spray foam topped with 2 in of sprayed fiberglass to an R-30 value. The HVAC unit is a 3-ton SEER 16 with a dual zone control system with supply mechanical ventilation with a run time set to deliver an average of 30 CFM, located in the sealed, conditioned attic.

Figure 2. Three Ton HVAC Unit in the Conditioned, Sealed Attic

Table 1. Envelope Technology Package in Retrofit House Compared to the Builder House

	Builder House	**Retrofit**
Stories	2	2
Floor ft^2	2400	2400
Conditioned volume ft^3	22262	22262
Foundation	Slab Insulated with 1 inch XPS, 24in horizontal; R-5 except side adjacent to garage	Slab Insulated with 1 inch XPS, 24in horizontal; R-5 except side adjacent to garage
Walls	2 x 4 frame, Ins R-value 13, framing factor of 0.23, vinyl siding with solar absorptance of 0.5	2 x 4 frame, Ins R-value 13, framing factor of 0.23, vinyl siding with solar absorptance of 0.5
Windows	294.5ft^2 Total; 106.8ft^2 window area on south, 8ft^2 on east, 15 ft^2 on west, 165.6 ft^2 on north, U-factor 0.5 and SHGC of 0.58, no overhangs	294.5ft^2 Total; 106.8ft^2 window area on south, 8ft^2 on east, 15 ft^2 on west, 165.6 ft^2 on north, U-factor 0.35 and SHGC 0.34
Doors	3-doors, one solid insulated to garage and front door with small window, U-value=0.4.	3-doors, one solid insulated to garage and front door with small window, U-value=0.4.
Roof	Attic floor (R-30), framing fraction of 0.1	Cathedralized, sealed attic with no ventilation, R-30 with flash and spider
Roofing	0.75 solar absorptance, composition shingles on OSB , attic ventilation ratio 1 to 300	0.75 solar absorptance, composition shingles on OSB with foam/spider , no ventilation in attic
Infiltration	SLA = 0.00034, ACH(50)= 5.7	SLA=.00020, ACH(50)= 3.43

Space conditioning equipment. Heating and cooling design loads were calculated using Manual J (Rutkowski 2004). The total cooling load is 22,000 Btu/h. The heating design load is 33,000 Btu/h. The SEER 16, 2-speed compressor HVAC serves both floors with a zone control air side system. It has an indoor ECM circulating fan. It has a total cooling capacity of 36 kBtu/hr and a Heating Season Performance Factor (HSPF) of 9.5. The HVAC subcontractor selected a 3 ton system which he felt compensated for insulation and air tightness quality typically delivered on his job site. The calculated airflow is 1080 CFM with 2 centrally located return registers: one on each floor. The ducts are all internally located except for two supply run outs in the garage ceiling leading to the bonus room above the garage.

The mechanical fresh air system is a 6 inch duct running form a vent on the north facing roof slope. A motorized damper is controlled with an “Air-cycler” so that on average 30 CFM is pulled into the return side of the heat pump indoor coil.

Water heating. The 50 gallon Hybrid Electric Water Heater is estimated to have an annual COP field performance of 2.1 exceeding the EPA Energy Star guidelines for water heaters (2.0). It is located in the unconditioned garage, which utilizes the heat in surrounding air to heat water. A pre-commercial unit installed in the retrofit house for more than a year performed closer to a measured COP of 2.2.

Appliances. Both houses are furnished with appliances running under simulated occupancy where the refrigerator and freezer door open on a timed schedule, the oven, dishwasher, washer, and dryer run on timed cycles based upon the day of the week. The scheduling of all these appliances is based upon occupancy profiles established by Building America (Hendron 2010). Energy Star® refrigerator, clothes washer, and dishwasher are part of the retrofit Package.

Floor Plans

Floor plans for both houses are available in (Christian, Blazer 2010). The first level has an open floor plan. The 2-car garage is attached and unconditioned with a conditioned space above the garage. The walls adjacent to the garage, the exterior walls of the garage and the floor of the bonus room above the garage are insulated. However the insulation between the garage and the bonus room is done poorly. No blocking of likely uncontrolled air flow anywhere and a 12 inch air gap left between the floor of the bonus and the top of the insulation installed above the garage drywall in this 18 inch floor truss area.

The second level consists of three bedrooms with 2 full baths. The framing for the tray ceiling in the master bedroom provides a potential insulation problem with extra measures necessary to ensure even coverage in the builder house. In the retrofit house this is not an issue because the insulation layer is up under the roof sheathing not on the attic floor.

Table 2. Equipment Technology Packages in Retrofit House Compared to the Builder House

House	Builder House	Retrofit
Heating and cooling	Two heat pumps 2.5 and 2.0 ton HPs, SEER 13, SHR= 0.75,cooling capacity = 54 kBtu/hr, heating capacity 54.0 kBtu/hr, 1620 CFM, HSPF=7.7,	SEER 16 HP, 3 tons in attic, servicing both floors with a zone control air side system, SHR=0.75, total cooling capacity= 36 kBtu/hr, HSPF=9.5
Thermostat settings	76 °F in summer, 71 °F in winter	76 °F in summer, 71 °F in winter
Mechanical Ventilation	30 CFM continuous exhaust from Master bath fan.	Supply to return side of coil, bath fan exhaust, fixed run time of 33%, supply ventilation rate = 30 CFM, exhaust ventilation = 30 CFM controlled by Air Cycler
Duct location	Outside conditioned space, R-5, supply area 460 ft^2, return area 85 ft^2, duct air leakage=209 CFM@25 PA, 183 CFM to outside	All ducts inside, duct air leakage= 80 CFM, zero leakage to outside R-6, supply area 470 ft^2, return area 188.08 ft^2
Air handler location	Attic and garage	Interior, conditioned attic
Water heater	Electric, 50 gal capacity, EF=0.91, usage= 66 gal/day, set temp=125°F	Hybrid Electric Heat Pump Water Heater, 50gal, EF =0.92, set temp = 125F, usage=53 gal/day
Lighting	100% incandescence, 2318 kWh/yr	100% fluorescent, 695 kWh/yr
Refrigerator	501 kWh	421 kWh
Washer and Dryer	105 kWh and 891 kWh, using hot water	101 and 774 using 13 gal/day less than Builder of hot water
Solar PV system	None	None

Notes for tables 1 and 2: ECM = electronically commuted motor; EF = energy factor; HP = heat pump; HPWH = heat pump water heater; HSPF = heating seasonal performance factor; OSB = oriented strand board; SEER = seasonal energy efficiency rating; SHGC = solar heat gain coefficient.

Energy Cost

Costs per day. The average local electricity rate in 2009 for the area was $0.093 per kWh. The national average during this time period was $0.12 / kWh. Energy cost savings would be greater in regions with higher electricity costs. The Retrofit House had an average daily electricity cost of $3.76/day. The Builder house of the same size, orientation and architectural features as the Retrofit would be expected to average $6.46 per day for electricity an annual savings of about $1000/yr.

Measured data. Figure 3 shows the ambient and floor surface temperatures of the attics of the Retrofit house and the Builder house on one of the hottest days observed in 2009. The Builder house's ambient attic temperature shows a greater fluctuation in temperatures because of the vented construction typical in the mixed-humid climate region. The sealed, conditioned attic of the Retrofit house clearly reflects little fluctuation from the attic floor temperatures where the interior ambient air temperature in both houses is set at 76 degrees. The lower attic temperatures in the Retrofit house provide more ideal conditions for having an HVAC unit in the attic space rather than placing it in harsher conditions of a vented attic and an unconditioned garage. The insulated and sealed attic maximum hourly average temperature in the Retrofit house in the summer of 2009 was 82 F, 6 F higher than the thermostat set point. The Builder house attic maximum hourly attic temperature was 131 F. There is no dedicated conditioned HVAC supply or return serving the attic space.

In January the coldest month of the heating season the Retrofit House attic minimum temperature was 69.5 F. This is only 1.5 F below the thermostat set point for the house. The average attic air temperature in January was 72.6 F that is 1.5 F higher than the thermostat set point serving the upper level. This is compared to the conventional ventilated attic in the builder house which had a minimum attic temperature of 21 F and an average attic temperature of 45 F.

Figure 3. Attic Temperature Comparisons of the Retrofit versus Builder House

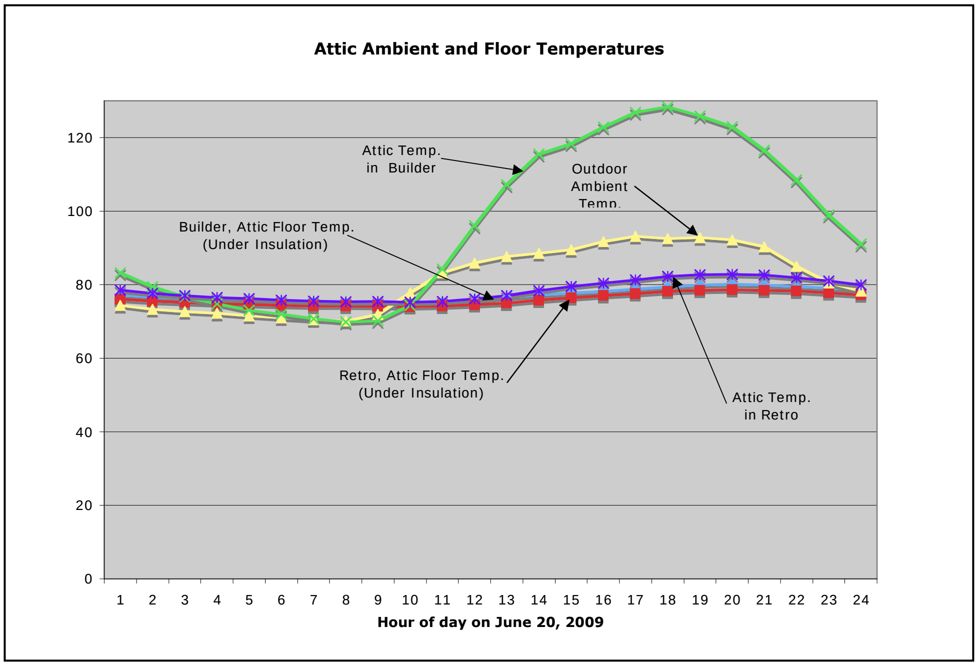

Figure 4 reflects the energy usage of the water heaters throughout the day on June 20, 2009. The Retrofit's house heat pump water heater clearly uses less energy to recover from little to no standby heat losses throughout the day, while the peaks in energy usage of the Builder's house electric water heater usage indicate large energy usage right after showers as well as recovery from standby heat losses throughout the day. The heat pump water heater in the retrofit house provides substantial savings versus the standard resistance electrical water heater of the builder house.

Table 3 shows the energy measured and predicted by the model for water heating in the Builder and Retrofit houses. The model of the builder house water heater over predicts usage by about 8% and the model of the Retrofit House heat pump water heater over predicts water heating energy by 27%. The EF (energy factor) of the standard electric water heater in the Builder House is 0.91 and the COP of the heat pump water heater in the Retrofit house assumed was 2.1. The hot water demand is generated in both houses with simulated occupancy water usage. The average daily demand for hot water in the Retrofit House is 52 gallons compared to the Builder house of 66 gallons due to the more efficient cloths and dishwasher in the retrofit house.

Figure 4. Water Heater Usage on June 20, 2009

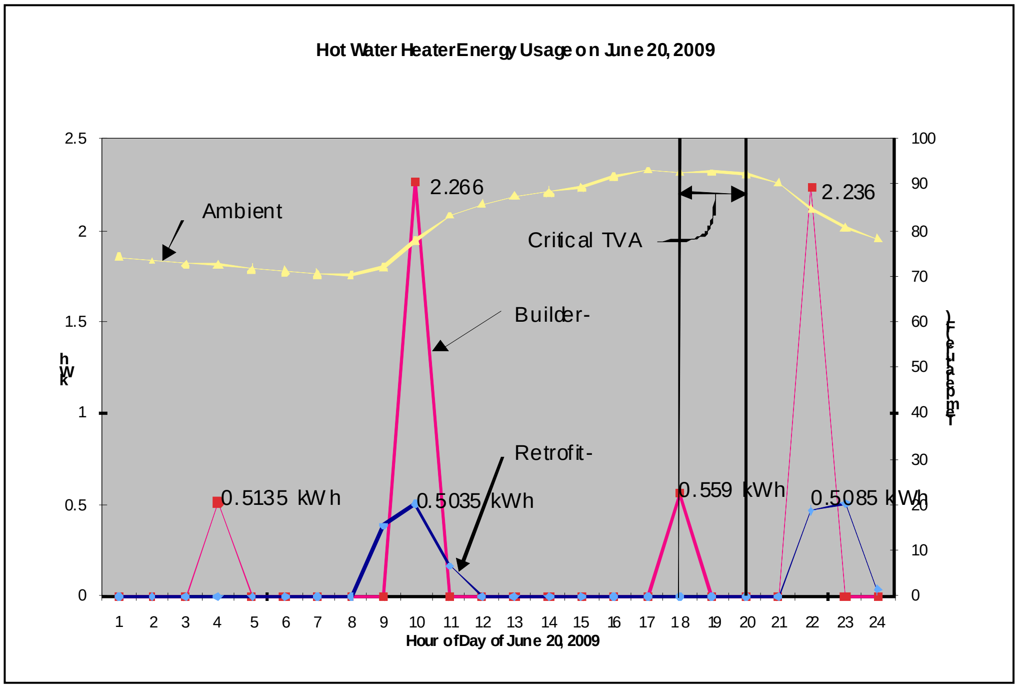

Table 3. Model vs. Measured Energy Hot Water Demand in Both Houses

Month	Builder model Hot water (kWh)	Builder measurement Hot water (kWh)	Retrofit model Hot water (kWh)	Retrofit measurement Hot water (kWh)
Jan 2010	369	334	201	236
Feb 2010	335	331	178	120
March	354	391	162	129
April	317	324	136	94
May	294	307	118	85
June	255		92	
July 2009	243	211	82	67
August 2009	239	207	84	57
Sept 2009	244	200	93	58
Oct 2009	280	238	122	76
Nov 2009	303	252	140	93
Dec 2009	346	286	179	161
Sum	3579		1587	
Partial sum	3324	3081	1495	1176
	8%		27%	
Model vs. Measurement difference	243		319	

Energy Savings Comparison Between the Retrofit and the Builder House

The monthly energy consumption values in Table 4 are based on a combination of measurements and modeling. Since the houses have simulated occupancy from July 1, 2009 until February 2010, the loads shown in Table 4 were estimated using the Building America Benchmark modeling procedure (Hendron 2010). Table 4 outlines the monthly space heating and cooling, hot water as well as other loads for the model prediction of the Retrofit House and compares the data to the totals for the Builder House. The simulated data predicts a 50% savings over the Builder model during the heating season and a 38% savings during the cooling season. The effect of installing 100% CFLs results in a 21% energy savings compared to the Builder house with 95% incandescent bulbs and 5% fluorescent bulbs. Consequently; the Retrofit house would use 2/3 of the energy of the Builder House using the profile in (Hendron 2010). The Retrofit House was modeled with the Energy Gauge software (FSEC 2009) using TMY3 for Knoxville, Tennessee.

Table 4. Retrofit Predicted Energy Use Compared to Builder House

Month	Space heat Modeled	Space heat measured	space cool modeled	Space cool measured	Hot Water	Other	Total Modeled	Total measured
	(kWh)	*(kWh)*	*(kWh)*	*(kWh)*	*kWh*	*(kWh)*	*(kWh)*	*(kWh)*
Jan	1405	1486	0		201	508	2118	2280
Feb	1131	1216	0		178	450	1763	1880
Mar	604	630	0		162	508	1269	
April	358	84	36		136	492	1022	
May			206	233	118	508	828	
June			384		92	492	978	
July			504	420	82	508	1097	1134
August			478	479	84	508	1065	1144
Sept	0		234	241	93	492	839	901
Oct	287	205	25		122	508	925	906
Nov	530	NA	0		140	492	1172	NA
Dec	1062	1136	0		179	508	1753	1835
Retrofit	5377		1867		1587	5974	14828	
Builder House	10687		3023		3579	7724	25430	
Retrofit vs. Builder	50% Savings		38% Savings		56% Savings	23% Savings	42% Savings	

Tables 1 and 2 highlight the technologies used within the building envelopes and equipment in the Builder and Retrofit test houses. The individual technology energy savings can be found in Table 5 for the Retrofit house compared to the Builder House. With all the features and equipment, Energy Gauge (FSEC) predicts a savings of $986/yr, shown in Table 5 column labeled “Package Savings”. The greatest savings based upon individual technologies is placing the ducts in the conditioned space, followed by the higher efficiency heat pump, than CFLs followed by the hybrid water heater and then the tighter envelope resulting from sealing the attic. In reality these features are all integrated and cannot be cleanly isolated. This demonstrates the criticality of locating the HVAC system in conditioned space.

Table 5 Neutral Cash Flow Analysis Results

Increment	Site Energy (kWh)	Builder (Local Costs) ($/yr)	Measure Value ($/yr) ($/yr)	Package Savings ($/yr)	Energy Savings technology kWh	Incremental Cost ($)	Amortized cost ($/yr)	Annual cost ($/yr)
Builder House (BH)	25359	$2,358						
BH + CFL	24016	$2,233	$125	$125	1343	$883	$118	-$7
BH + Energy Star Fridge	23946	$2,227	$7	$131	70	$132	$18	$11
BH ++ Energy Star Wash&Dryer	23129	$2,151	$76	$207	817	$700	$93	$17
BH ++ water heater trap	23090	$2,147	$4	$211	39	$30	$4	$0
BSP +Hybrid water heater	21787	$2,026	$121	$332	1303	$1,221	$163	$41
BSP ++ Windows double pane low E, gas-filled	21105	$1,963	$63	$396	682	$250	$33	-$30
BSP ++ SEER 16 heat pump	19060	$1,773	$190	$586	2045	$0	$0	-$190
BSP ++ Ducts inside conditioned space	15139	$1,408	$365	$950	3921	$0	$0	-$365
BSP ++ Improved ACH from 5.8 to 3.43@50	14292	$1,329	$79	$1,029	847	$5,916	$788	$709
BSP ++ mechanical ventilation	14762	$1,373	-$44	$986	-470	$0	$0	$44
total energy efficient investment	14762	$1,373	$986	$986	10597	$9,132.00	$1,217	$231
REBATES / INCENTIVES								
TVA in-home evaluation						$500	$67	
Energy retrofit federal tax incentive						$1,500	$200	
incentive total						$2,000	$266	
Total Incremental Cost Including Incentives						$7,132	$950	-$35

Table 5 above shows the Builder House has a modeled site energy consumption of 25359 kWh/yr. The actual measured energy use after one complete year was 21,000 kWh. However the simulated occupancy was not operational from April 1, 2009 until June 1, 2009. In addition as of January 1, 2010 the builder house ventilation rate was increased to match the mechanical ventilation provided in the Retrofit house, an average of 30 CFM, which is the value used in the model to simulate these houses.

Cost

Total cost. Detailed costs are found in (Christian, Blazer 2010). The detailed invoice level costs data on the Retrofit and Builder House are used to generate the incremental costs shown in Table 5 for each of the energy efficient technologies beyond those found in the Builder House.

Neutral cash flow analysis. The last three columns in Table 5 show the results from a neutral cash flow analysis performed as if the retrofits were done on the Builder House using the incremental cost of the added energy efficiency features in the retrofit house. The incremental costs are obtained with the assumption that the house needs new windows, water heater, and heat pumps. The retrofit package is evaluated assuming the homeowner borrowed money for 10 year term at 6% interest. Overall the entire retrofit incremental cost package is $9,111. After available federal and TVA incentives (available in April 2010) the cost drops to $7111 and has a positive cash flow to the homeowner of $35/yr. To pass the neutral cash flow analysis the summation of the retrofit energy savings must equal or exceed the added amortized cost for the retrofit loan. The added cost of converting all of the lights in the house to CFL is the actual lighting cost differential from the Builder to the Retrofit House. There were a few fixtures that were changed to accommodate the CFLs in an aesthetically acceptable manner to the lighting designer. This CFL conversion cost was $883. The amortized cost is $118 and the energy savings $125/yr, so the neutral cash flow to the homeowner is a savings of $7/year. Another way of looking at the cost effectiveness is that the CFL conversion will have a 7 ½ year simple payback.

Table 5 lists a series of individual retrofits in the order from what would be considered the easiest to the most difficult to perform in an existing house like the Builders. In reality the goal of getting the HVAC equipment into the conditioned space is enabled by more than one of the listed individual measures.

The energy star fridge should clearly have a positive annual cost but GE provided the fridge in both the Builder and Retrofit house. The builder grade fridge was not rated as Energy Star yet was clearly a very good refrigerator since the measured daily energy demand was 1.15 kWh/day compared to the builder fridge usage of 1.83 kWh/day measured over the same eight month per period with identical automated daily door openings.

The hybrid water heater in March 2010 was $1498. The cost of the electric water heater in the Builder house was $277.50. The incremental cost used in the neutral cash flow analysis is the difference in these costs or $1220.50.

The cost of the 294.5 ft^2 of the regular double pane windows on the builder house was $3702.99 the upgraded double pane lowE, gas filled used in the retrofit house was $3952.07. The incremental cost used for these windows is $250 or $0.85/ft^2$. The window retrofit has a positive cash flow of $30 without incentives.

The same contractor and the same Amana heat pump brand were used in both the builder and retrofit houses. The builder house was equipped with a 2.5 Ton SEER 13, 7.7 HSPF in the attic servicing the upper level and a second 2 ton SEER 13, 7.7 HSPF unit with 10 kW of resistance backup located in the unconditioned garage servicing the main level. In the cooling season the attic unit uses 70% of the cooling energy in the builder house for three of the hottest months of the year July 2009, August 2009 and September 2009. The unit that is in the worst environment, a hot attic, is called upon to provide most of the houses cooling. The HVAC contractor was asked to keep very good cost records for these installations. His cost to the builder was $7143.75 for the Builder House.

In the retrofit house the Manual J calculation found that a 2-2.5 ton unit was the right size for the single heat pump to be located in the insulated and sealed attic, as shown in Table 8. The HVAC contractor felt that a 3 ton was more appropriate based on his experience with the quality of construction in the area. The design called for a two zoned system with the single unit located in the attic. The majority of the supply and return duct system layout was very similar in both houses except for a return trunk line that had to run through the master bedroom closet on the upper level to the ceiling of the hallway on the first floor, and a supply trunk to connect the unit in the attic to the supply duct system located between the two levels through 16 in floor trusses. This second large trunk also consumed a corner of the Master Closet. Motorized dampers, zone control board, a 6 inch ventilated air duct connected to the return plenum of the unit are all additional features needed in the Retrofit House. The HVAC contractor found that his expenses were “about” the same between these two systems. The invoiced cost for the retrofit house HVAC is exactly the same as the Builder House, $7143.75. The incremental cost used in Table 6 is zero.

Placing the ducts inside the conditioned space has the largest return on investment, followed by the change from two heat pumps totaling 4.5 tons of capacity located outside the conditioned space in the builder house to a single 3 ton zone controlled unit positioned inside the conditioned space in the Retrofit House. Placing the ducts inside the conditioned space incremental cost also is assumed to be zero under the scenario of cost savings for the whole 3 ton zoned package to the 2 unit 4.5 ton solution used in the Builder House and almost every other house of this type in the surrounding area. The modeling results from Energy Gauge are used to predict that getting the HVAC system from almost completely outside the conditioned space to 100% inside saves 3921 kWh or 37% of the total energy savings of this retrofit package.

Insulating and sealing the attic has the largest first cost. The foam insulation and the two inches of Spider used to cover the foam cost was $4000. The result was that R-30 was installed under the roof sheathing and on the gable walls compared to R-30 of blown in Fiber glass in the conventional vented attic in the Builder House. The original design was to use enough foam to control moisture and air seal the attic and to than cover the 1 to 3 inches of foam with the lower cost spray applied fiberglass. The fiberglass after repeated attempts would not build up to R-30. So the actual installation is 6 inches of foam mostly low density and 2 inches of spray applied fiberglass. The foam needed to have a flame retarding cover and the Fiberglass provides that and in this case adds R-8 to the assembly. The incremental cost used of $5,916 is attained by soliciting several foam quotes for R-30 alone on an attic sheathing and gable area similar to the retrofit house of 1972 ft^2 at a cost of $\$3/ft^2$. This cost includes the cost of sealing the soffit, gable and ridge vents and working in more confined space such as the case in a real retrofit application. In the test house the foam and fiberglass were installed in the attic without the top floor drywall in place. However the HVAC unit had been installed prior to insulation and this presented added labor cost to work around it. In a real retrofit the project this work would be staged to install the insulation prior to setting the replacement HVAC unit and ducts in the attic. The incremental cost of sealing and insulating the attic in this study represents 65% of the total. The elimination of all envelope leaks in the top floor ceiling and enabling placement of the ducts and indoor heat pump unit inside the conditioned envelope result in a reduction of the whole house ACH@50 from 5.8, measured in the builder and the development "Model House", to 3.43 in the Retrofit House. This leads to 45% of the whole house retrofit package savings.

The builder house depends on the bathroom exhaust fans for ventilation. Typically people that live in these houses do not run the bath exhaust fans except during showering and other bathroom usage time. However, in all three research houses the mechanical ventilation is controlled at an average of 30 CFM. This decision is based on the fact that all three of these simulated occupancy houses can be argued have similar indoor air quality. Energy usage is simulated; indoor air pollutant generation is not. The energy penalty for running the bath exhaust fan 24/7 and pulling a measured 30 CFM from the Builder house is 470 kWh/yr.

Summary

This report has described a cost effective retrofit package for a very typical new home that has a predicted 42% energy savings and meets a neutral cash flow analysis based on electric rates of $0.93, 10 year loan @6% interest and available federal and utility incentives in April 2010. This 3 bedroom 2.5 bath 2400 ft^2 house has a HERS index of 68 after retrofit and a 101 before retrofit.

Based on measured data from almost 100 sensors a computer simulation of the Retrofit house with typical occupancy patterns and energy services for three occupants, energy for this all-electric house is predicted to cost only $3.76/day. By contrast, the Builder House would require $6.46/day. Based on seven months of measured data with the houses operated under simulated occupancy the all electric home is predicted to use an average of 40 kWh/day. The $10,000 incremental cost of the retrofit package described in this report, assuming new windows, heat pump and water heater are in need of replacement has a positive cash flow to the homeowner. With the base house being a typical home built in 2005- 2008, and local electric rates more than $0.02/kWh less than the US national average, the 42% whole house savings should be exceeded in most other homes originally constructed prior to 1990.

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