Deep Energy Retrofits: Four Real World Examples and Lessons Learned

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ABSTRACT

The Obama Administration's Economic Stimulus Plan contains billions of dollars for improving the energy efficiency of existing homes. In the California Energy Efficiency Strategic plan the California Public Utilities Commission and California Energy Commission call for reducing energy consumption in existing homes 40% by 2020. How will we get these energy savings out of existing homes?

The Sacramento Municipal Utility District (SMUD) and the National Energy Laboratory (NREL) have partnered on a unique research and development program that works with local builders in dramatically improving the energy performance of existing homes. These "Deep Energy Retrofits" feature advanced construction techniques and energy efficiency measures designed to reduce an existing home's energy use by 50% or more. This paper describes four completed DER projects and their monitoring results to date.

1. BACKGROUND

SMUD is the sixth largest publicly owned electric utility in the country with approximately 590,000 customers, 88 percent of which are residential accounts. Its record peak demand in July 2006 was approximately 3,300 MW. SMUD's Board of Directors set a strategic goal to reduce electricity consumption by 15 percent by 2018.[1] Recently, SMUD received a State Energy Program grant, funded by the American Recovery and Reinvestment Act, to promote and implement its "Whole House Performance" retrofit program, which seeks to improve each participating home's efficiency by at least 20 percent.

SMUD's Energy R&D program partnered with the National Renewable Energy Laboratory (NREL) to develop a new approach to achieving dramatic energy savings in existing homes. Together they worked together to help builders and homeowners design and build "Deep Energy Retrofits" (DER) of existing homes and demonstrate the results.

SMUD and NREL set a simple design goal for the program: reduce an existing home's total energy use – electric and gas, space conditioning, hot water, lighting, appliances, and plug loads – by at least 50 percent. To achieve this goal meant using a whole house (or systems) methodology to remodel/retrofit the home. DER ventures also demand: (1) an interactive team approach to good design and quality construction; and (2) the integration of all household

[1] SMUD Board of Directors Board Policy, Resolution No. 09-11-08, adopted November 19, 2009.

systems that affect energy usage to reduce environmental impacts. Remodeling an existing home also means dealing with existing conditions that might range from room configuration to hazards such as mold, lead and asbestos. To date, four DER demonstration projects have been completed.

2. THE GREENBUILT DER[2]

SMUD collaborated with Greenbuilt Construction on the first SMUD DER project. The 1980s-era, single-story residence presented several challenges to the project team: a pitched roof, deep roof overhangs, large windows with no dividers, and all-electric heating, cooling, and water heating systems. A list of before and after features is found in Table 1 below.

Table 1. Greenbuilt Existing vs. DER Specifications

System	Existing Features	Deep Energy Retrofit Features
Ceilings	R-19	R-42 blown-in cellulose
Roofing	Asphalt Composition	Asphalt Composition w/ Radiant Barrier
Knee Walls	R-11	1" metallic-reflective face Rigid Foam (R-6) over R-15
West Wall	R-11	R-15 blown in cellulose insulation
Infiltration	6830 CFM @ 50 pa; 21.6 ACH @ 50 pa	1080 cfm @ 50 pa; 4.1 ACH @ 50 pa; ACH (nat) =0.21
Windows & Sliding Glass Door	Aluminum Frame, single pane, clear U-Factor: 1.07 SHGC = 0.70	Vinyl Frame, dual pane, low e, argon filled U-Factor: 0.29 to 0.28 SHGC = 0.22 to 0.19
Space Heating	HSPF 7.75	HSPF 9.75
Central A/C	SEER 13/EER 10	SEER 16/EER 13
Ducts	R-2 insulated in un-insulated attic	R-6 insulated , "Tight" tested to 4.5% leakage @ unconditioned attic @ 25 Pa
Thermostat	Manual	Programmable Communicating Thermostat
Whole House Fan	None	Two Speed Whole House Fan
Water Htg	Electric Storage Tank, Est. Energy Factor .97	Electric Storage Tank w/ Heat Pump 2.11 Coefficient of Performance (COP)
Spot Ventilation	None	Energy Start Bathroom Fans with Timer Controls
Lighting & Ceiling Fans	Incandescent	100% hardwired Energy Star Compact Fluorescent & LED Fixtures in master bath
SolarTubes	None	Energy Star rated interior bathrooms only
Refrigerator	Existing	Tier 2 (.25% Federal Standards) Energy Star
Dishwasher	Existing	Tier 2 (EF = .69) Energy Star
Shading on West	None	Retractable Shading w/ wind sensors and timer
HERS Score	181.5	77.9

[2] Additional information on SMUD's Deep Energy Retrofit R&D projects and energy efficient remodeling "guidelines," are available at: http://www.smud.org/en/residential/EERD/

System	Existing Features	Deep Energy Retrofit Features
Controls	None	Control4 Home Area Network with Wireless green Switch and programmable communicating thermostat
Solar Domestic Hot Water	None	40 gallon Integrated Solar Water Collector 50% Solar Fraction
Photovoltaics	None	2,295 w AC PV

NREL compared energy use in the existing home to that of the upgraded home using its energy simulation software, BEopt. The simulation results showed an energy-savings potential of 61 percent (see Figure 1) and up to 80% reduction in peak demand (see Figure 2).

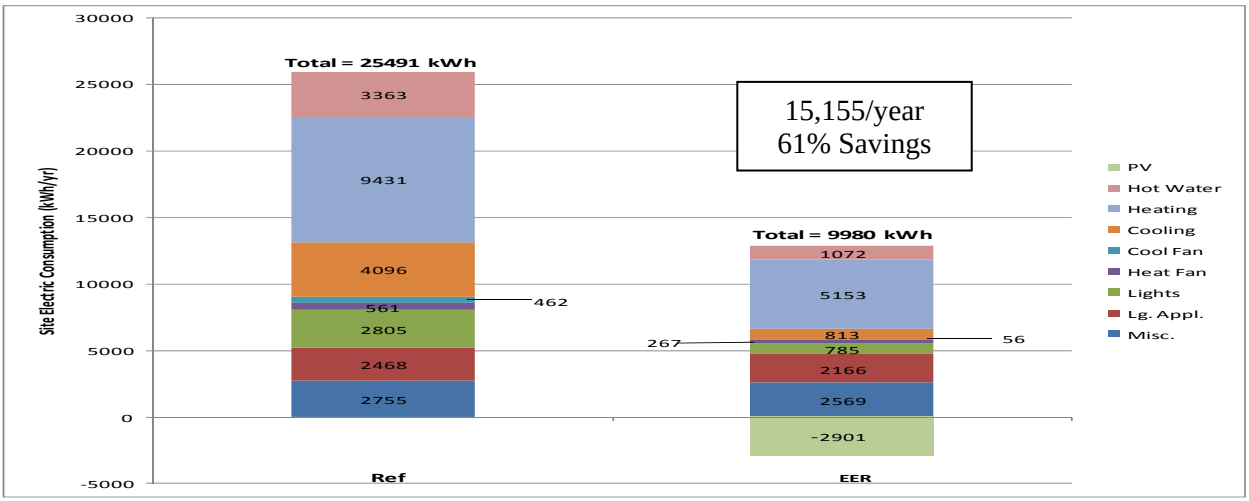

Figure 1. Estimated Electricity Savings for GreenBuilt DER

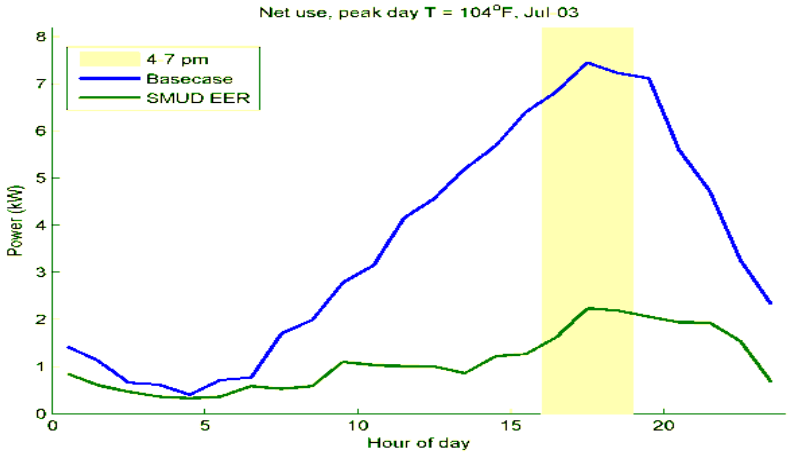

Figure 2. GreenBuilt Estimated Existing vs. EER Peak Demand Savings[3]

[3] SMUD's peak period is July-August weekdays from 4 to 7 pm.

SMUD rented the unoccupied Greenbuilt DER for use as an energy efficiency retrofit showcase and "lab home" until September, 2010. NREL is currently reviewing the data collected and plans to issue a report by the end of 2010.

3. Neighborhood Stabilization Program EERs

SMUD partnered with the Sacramento Housing and Redevelopment Agency (SHRA) to improve energy efficiency of foreclosed and abandoned homes in neighborhoods particularly affected by the recession. Under SHRA's Neighborhood Stabilization Program (NSP) Vacant Properties Program (VPP), qualified single-family developers/builders renovate abandoned homes in low income neighborhoods and sell them to low- and middle-income families. SMUD worked with two NSP contractors, Housing Group Fund (HGF) and Del Paso Solutions.

Under the VPP, HGF bought an abandoned 1950s vintage single-story home with 1,260 square foot, four-bedrooms, two-baths, a two-car garage. The house was built on a concrete slab and required extensive renovation, including a new roof, windows, HVAC system, and water heater. A "package" of energy efficiency measures was installed in the home (see Table 2 below).

Table 2. Mascot Existing Vs. EER Specifications

SYSTEM	EXISTING FEATURES	EER FEATURES
Flat Ceilings	R-19	R-44 blown-in cellulose w/ Radiant Barrier
West Wall	R-11	R-15 blown in cellulose insulation
Infiltration	NA	1121 cfm @ 50 pa; 6.7 ACH
Windows	Aluminum Frame single pane, clear	Energy Star, Vinyl Frame dual pane, low e
	U-Factor: 1.07 SHGC: 0.70	U-Factor: 0.29 to 0.28 SHGC: 0.22 to 0.24
Space Heating	Package Gas .78 AFUE Furnace	Package Gas .80 AFUE France
A/C	SEER 10/EER 8	SEER 16/EER 13
Ducts	R-2 ducts in un-insulated attic	"Tight," R-6 insulated tested to 3.75% leakage @ 25 Pa
Thermostat	Manual	Energy Star Programmable Thermostat
Spot Ventilation	None	Energy Star Bathroom Fans with Timer
Water Heating	50 gal. Gas Storage Tank, 0.52 Energy Factor	Condenensing, Tankless Gas Water Heater 0.98 Energy Factor
Lighting & Ceiling Fans	Incandescent	100% hardwired Energy Star CFLS
Dishwasher	Existing	Tier 2 (EF = .69) Energy Star
HERS Score	241.3	85.76

NREL provided a detailed analysis of the home comparing the existing home's energy use to the upgraded home's energy use using NREL's BEopt energy simulation tool. The

BEopt simulation showed the potential to reduce annual electricity and natural gas use by up to 47% and 59%, respectively and substantial peak demand savings (see figure 3, 4, and 5 below).

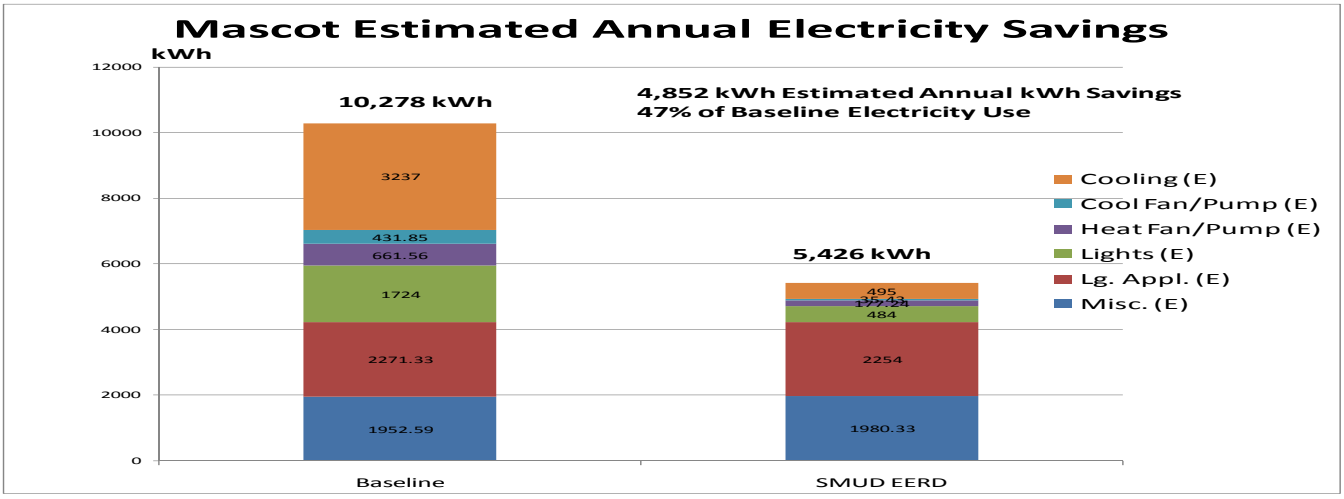

Figure 3. Mascot Estimated Existing vs. DER Electric Use

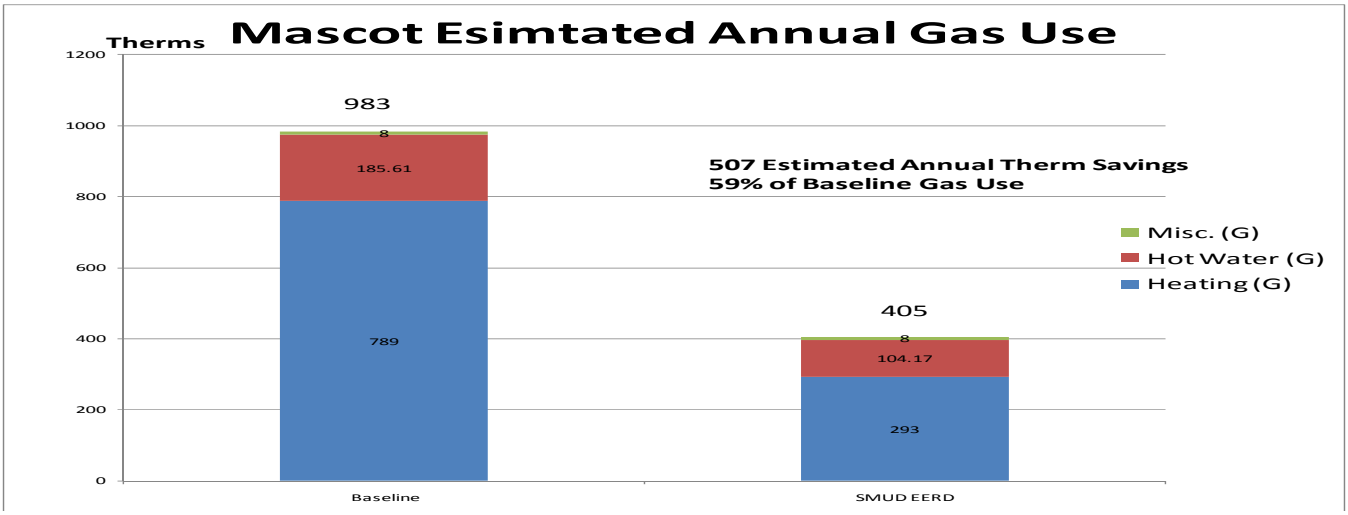

Figure 4. Mascot Estimated Existing vs. DER Gas Use

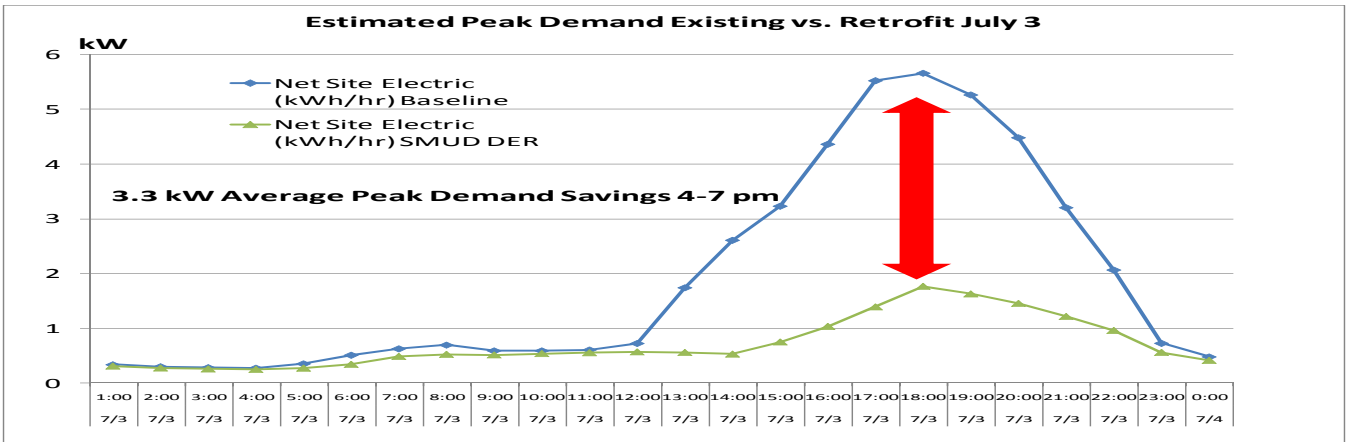

Figure 5. Mascot Estimated Existing vs. DER Peak Demand Savings

HGF completed retrofitting the home in October, 2009 and then sold it to a first-time home-buying family in November 2009. NREL is monitoring the home's performance with a special focus on performance of the condensing tankless gas water heater.

Jean Avenue DER

SMUD worked on a second VPP home with Del Paso Solutions. Under the VPP, Del Paso solutions purchased a 1040 square foot, 3 bedrooms, and 2 bath, abandoned home on Jean Avenue in the Del Paso Heights neighborhood of Sacramento. (See Fig. 8 below). The final list of energy efficiency upgrades is found in Table 3 below.

Table 3. Jean Existing Vs. EER Specifications

BY SYSTEM	**EXISTING**	**ENERGY EFFICIENT REMODEL**
Air Sealing	None	Air Sealed the home
Attic Insulation	R-19	15" blown in cellulose (R-49) attic insulation
Room Addition	NA	2x6, 16" o.c. framing with R-20 cellulose
Infiltration	1880 cfm@ 50 pa	408 cfm @ 50 pa;
	13.6 ACH	2.9 ACH
Windows	Aluminum Frame	Energy Star®, Vinyl Frame
	Dual pane, clear	dual pane, low e
	U-value = .71 est	U-value = 0.32
	SHGC = 0.73 est	SHGC = 0.25
Space Heating	Heat Pump	Tri-Zone Mini-split Heat Pump
	7.0 HSPF	9.0 HSPF
A/C	3 ton Heat Pump	2 ton Ductless, mini-split Heat Pump
	SEER 8	SEER 15
	EER 7	EER 9.2
Ducts	Leaky R-2.1	Ductless
Water Heating	40 gal. Electric	40 gal. Electric Storage Tank
	0.90 Energy Factor	0.98 Energy Factor with 2.5 COP heat pump water
Lighting	Incandescent	100% hardwired Energy Star® CFLs
Ceiling Fans	Incandescent	Energy Star with pin-based CFLs
HERS Rating	194.79	85.54, 56.1% improvement

The Jean Avenue BEopt simulation showed upwards of 60% energy savings and substantial peak demand savings (see Figure 6 and 7 below).

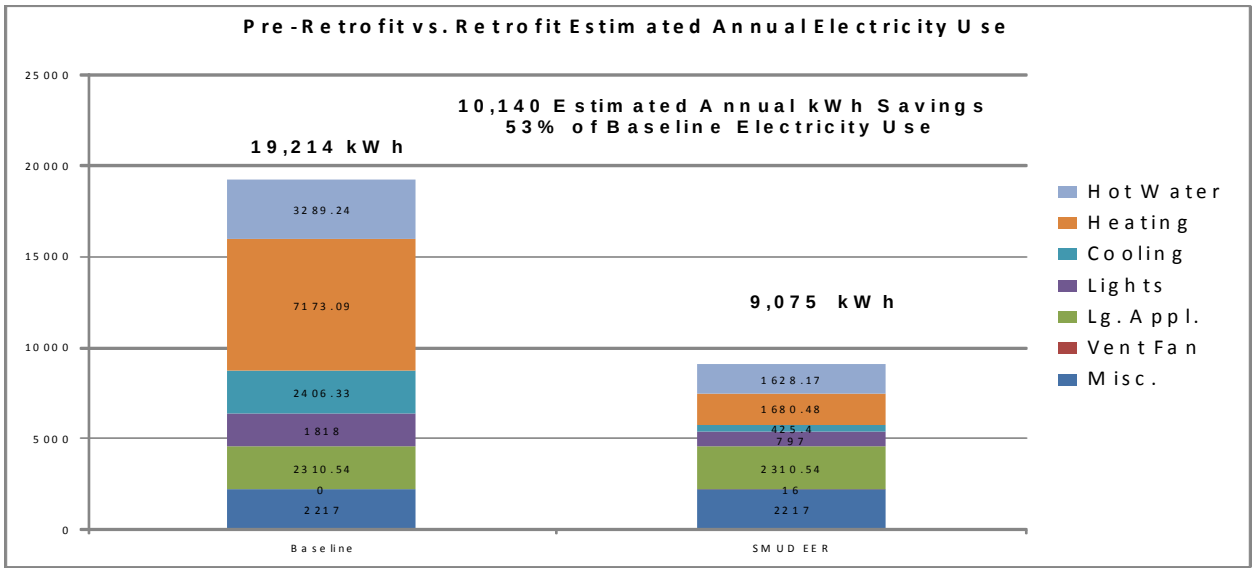

Figure 6. Jean Estimated Existing vs. DER Electric Use

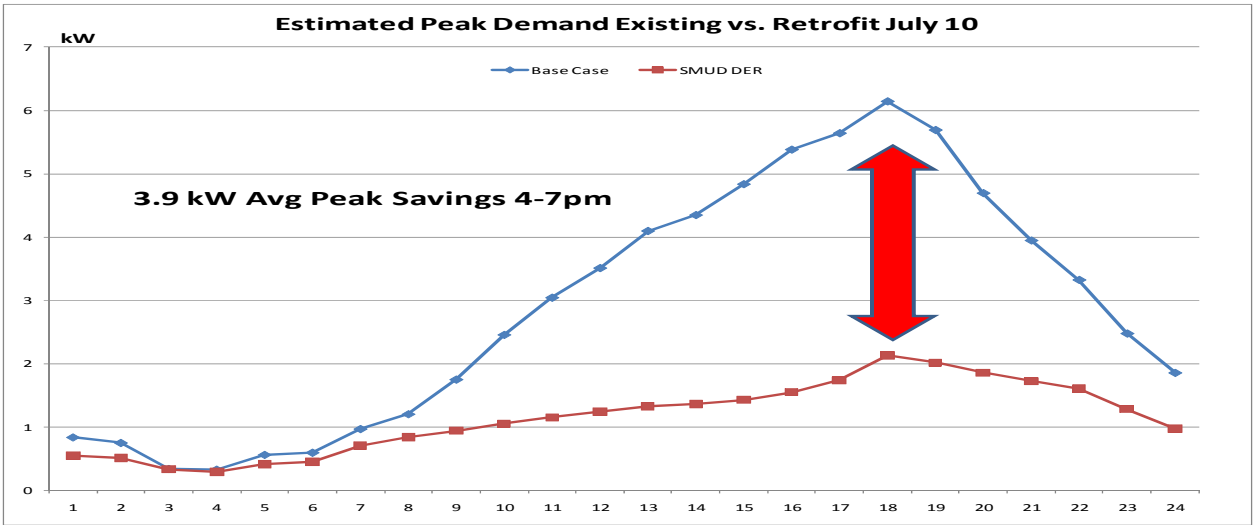

Figure 7. Jean Estimated Existing vs. DER Peak Demand

Work on the home began in August, 2009 and was completed in 2010. Currently the home is unoccupied and for sale.

32nd Avenue DER

The 32nd Avenue project was the second deep energy retrofit SMUD completed with Housing Group Fund (HGF). The 32nd Avenue home was an abandoned 1950s vintage, Eichler style 1,340 square foot, single story four-bedroom, two-bath, 1-car garage tract home built on a concrete slab requiring extensive renovation, including new roof, windows, HVAC system, and water heater. A list of efficiency measures incorporated into the project is found in Table 4 below.

Table 4. 32nd Avenue Existing Vs. DER Specifications

BY SYSTEM	EXISTING	ENERGY EFFICIENT REMODEL
Air Sealing	None	Air Sealed the home
Roof	None	6" exterior rigid foam (R-38)
Wall	None	4" Quadlock exterior rigid foam (R-18)
Infiltration	NA	1100 cfm @ 50 pa; 6.3 ACH @ 50 pa
Windows	Aluminum Frame single pane, clear U-value = 1.07 SHGC = 0.70	Energy Star, Vinyl Frame dual pane, low e U-value = 0.29 SHGC = 0.24
Space Heating	Wall mount .58 AFUE Furnace	.95 AFUE Gas Furnace
A/C	None	SEER 14.5, EER 12
Ducts	None	"Tight," R-6 insulated tested to 3.75% leakage @ 25 Pa in conditioned space
Spot Ventilation	None	Energy Start Bathroom Fans with Timer
Water Heating	50 gal. Gas 0.52 Energy Factor	40 gal. Gas Water Heater 0.62 Energy Factor
Lighting (units)	Incandescent	100% hardwired Energy Star CFLs
Dishwasher	Existing	Tier 2 (EF = .69) Energy Star
HERSII Rating	259	80, a 69% improvement

NREL provided a detailed energy analysis of the home comparing the existing home to the upgraded home's energy use using NREL's BEopt energy simulation tool. The 32nd Avenue BEopt simulation showed upwards of 66% energy savings, including an estimated electric use savings of 68%, an estimated natural gas use savings of 63%, and impressive peak demand savings (Figures 8, 9 and 10 see below).

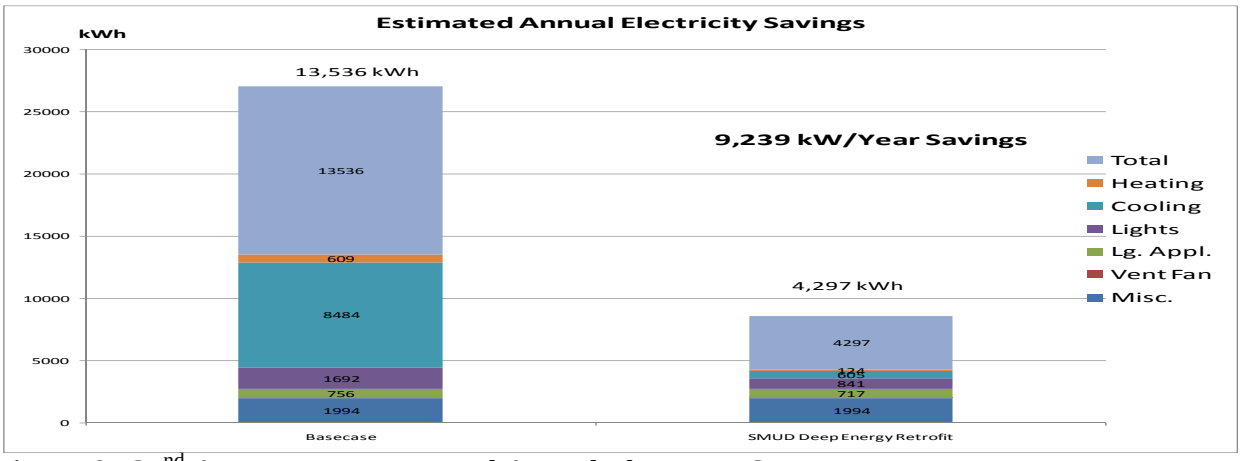

Figure 8. 32nd Avenue EER Estimated Annual Electricity Savings

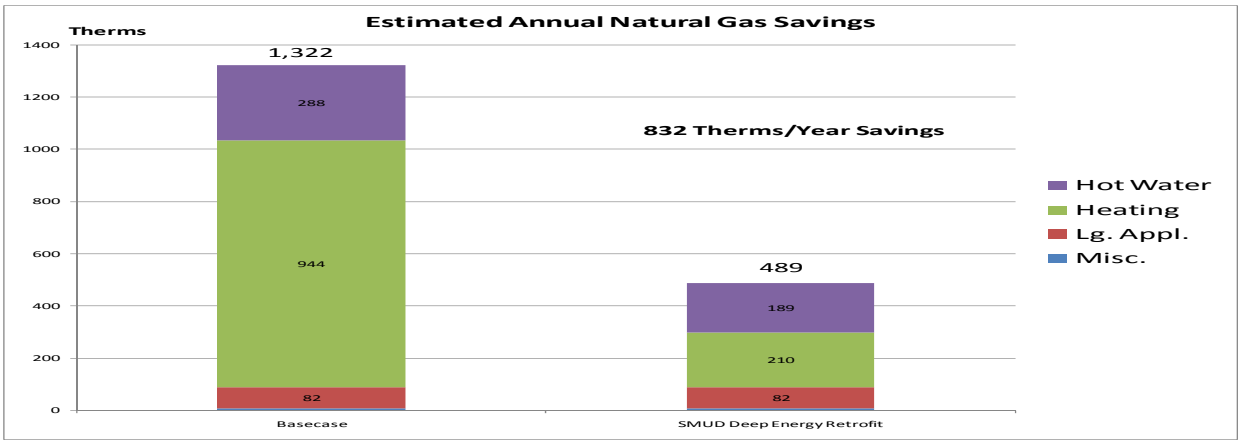

Figure 9. 32 Avenue EER Estimated Annual Natural Gas Savings

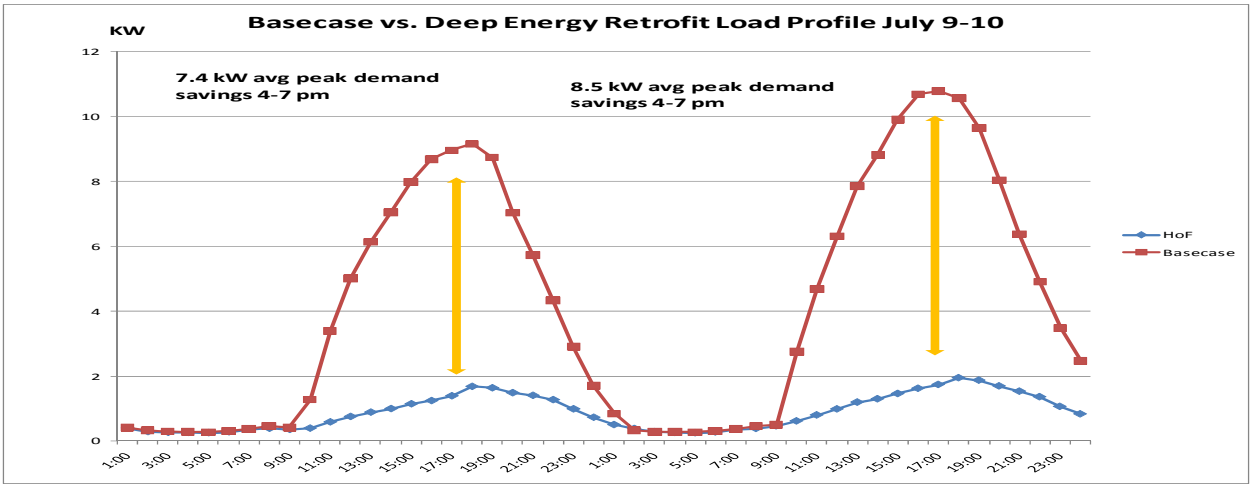

Figure 10. 32 Avenue EER Estimated Peak Demand Savings

The home renovation was completed in March, 2010 and sold to its new owner, a first-time home buyer, in late April, 2010.

5. RESULTS TO DATE

Results to date have been mixed with limited monitored data collected. As mentioned earlier, the Greenbuilt project was operated as a NREL laboratory house and data is still being analyzed (preliminary results will be reported at the ASEP conference in January, 2011). The Jean Avenue project remains unsold and vacant. Only the Mascot and 32nd Avenue projects have occupants and preliminary data is inconclusive. The Mascot project has been occupied for almost a year. To date, Mascot electricity use is more than twice as much as the NREL modeled energy use projections by (see Figure 11 below)

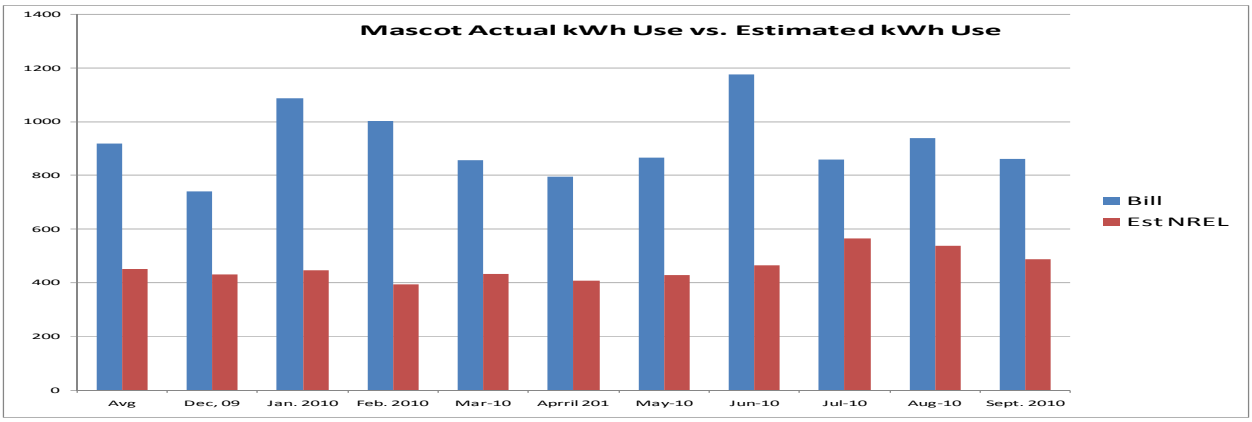

Figure 11. Mascot Actual vs. Estimated Electricity Consumption

However, Mascot's natural gas use is more than third lower than NREL's projection (see Figure 12. below).

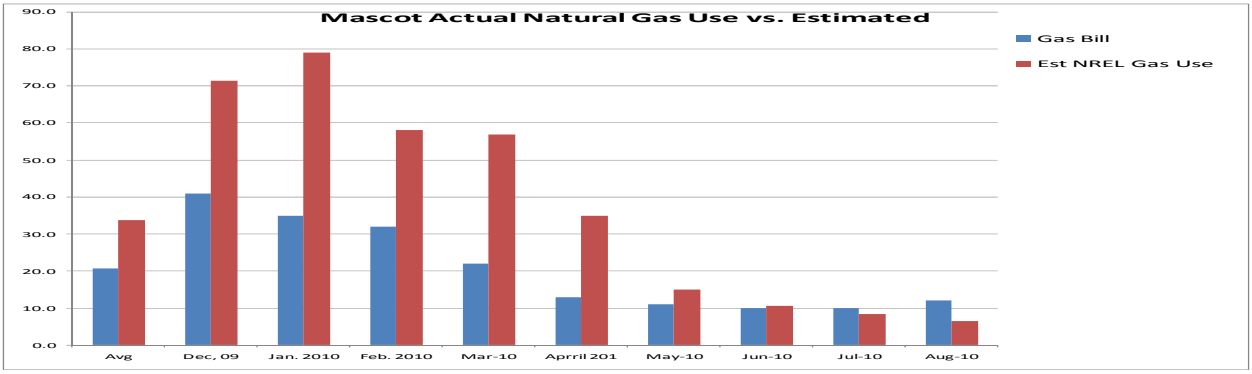

Figure 12. Mascot Actual vs. Estimated Natural Gas Consumption

Similarly, electricity consumption patterns are the same for the 32nd Avenue DER, running about 1.5 times greater than projected (see Figure 13 below).[4]

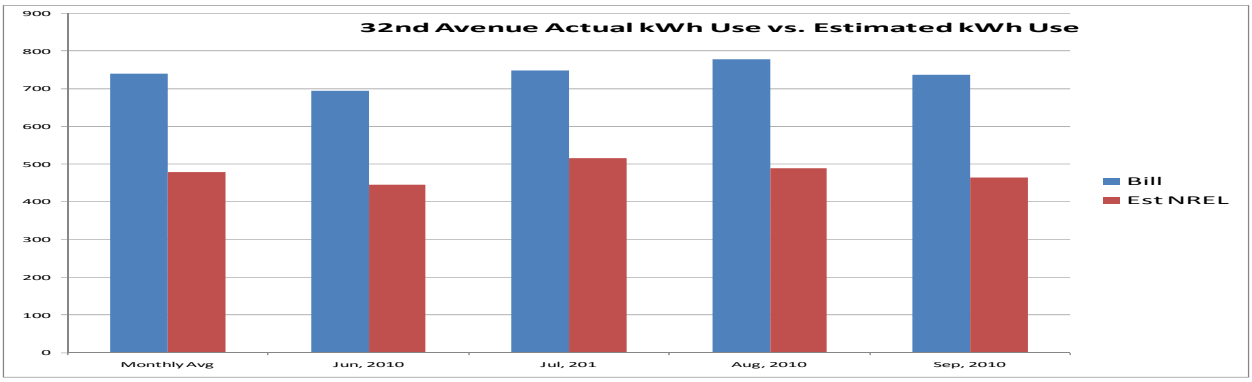

Figure 13. 32nd Avenue Actual vs. Estimated Electricity Consumption

[4] Natural gas consumption for the 32nd Avenue project is not available.

Based on data collected to date, it appears that NREL's estimates of miscellaneous plug loads for the BEopt software need to be re-examined. BEopt uses miscellaneous plug load data collected from the Building America Benchmark House study published in 2005. Since then there has been an explosion of home electronics use. A study prepared by TIAX by the Department of Energy reported that 29% of residential annual energy use and would grow to 38 percent by 2030. [5] All indications are that home electronic use continues to grow with no end in sight.

These results will be updated as data is collected. SMUD and NREL plan to monitor the homes for next two years to determine long-term energy use patterns.

DERS are not inexpensive propositions. Costs for the four DERs ranged from a high of $42,000 to $25,000, not unexpected given the fact that DERS involved major work and equipment replacement. As mentioned, all four of the four SMUD DER projects involved foreclosed homes that required major renovation to make them "market ready," including major structural repair and re-design. For example, all of the projects required extensive interior repairs; three of the projects required a new roof; and so on.

However, the cost of a DER can be minimized if the energy efficiency improvements are undertaken as part of a major renovation of the home, especially when major repairs and equipment replacement is required. The energy efficiency portion of the four DER projects was a fraction of the total cost of the project (see Table 5 below):

Table 5. Total DER Project Costs vs. Energy Efficiency Upgrade Costs

	Total Project Cost	Energy Efficiency Upgrade	% of Total Cost
Greenbuilt	$141,000	$42,000	30%
Mascot	$ 86,050	$25,000	29%
Jean	$120,000	$40,800	34%
32nd Avenue	$ 77,000	$26,769	35%

6. LESSONS LEARNED

Several lessons were learned from these projects. Although a "deep energy retrofit" can be designed and built, occupant behavior can thwart the desired outcome. Nonetheless, good design is essential to in achieving a deep energy retrofit. For example, tight, air sealed homes and increased insulation are critical to improving a home's thermal performance.

The Deep Energy Retrofit (DER) experience suggests increasing the home's thermal performance will be easier to achieve then reducing electricity consumption by the home's "plug loads." For example, data collected to date shows that DERs have an enormous potential to

[5] Residential Miscellaneous Electric Loads: Energy Consumption Charatization and Savings Potential, Roth, Kurt W., et. al., Final Report, TIAX Reference NO, D0370, July 2070.

reduce natural gas consumption in existing homes. Long term monitoring will determine how well the DERs will meet their energy performance goals.

DERs have the potential to dramatically reduce an existing home's energy use and peak demand. In particular, the use of energy efficiency "packages" have the potential of dramatically cutting energy use and a homeowner's bill. Based on the experience of the four SMUD DER projects, especially the Mascot, Jean, and 32nd Avenue projects, a simple package of upgrades could result in up to 60% annual energy savings, especially for Sacramento area homes built before the introduction of the California Title-24 Standards, 1978, and all electric homes. Furthermore, the use of energy efficiency "packages," especially in remodeling projects, could provide predictable energy savings in an easy to understand format for DER contractors to use and homeowners to understand Such a DER package would include:

- Air Sealing the home to a minimum 7.5 Air Changes per Hour (@ 50 pa of pressure)
- R-38 attic insulation
- Energy Star Windows (.30 U-Factor and Solar Heat Gain Coefficient)
- SEER 14 air conditioner, .95 AFUE furnace or 9.5 HSPF Heat Pump with tight (less than 6% leakage), R-8 ducts
- .65 EF Gas Storage Water heater or 2.0 COP Heat Pump Water Heater
- Energy Star Hard Wired CFL Fixtures

The extensive work involved in DERs results in high costs. DER efficiency measure costs can be mitigated if included in major renovation or rehabilitation projects, such as turning abandoned, foreclosed properties into marketable properties. Another promising area for DERS would be major remodeling projects, such as additions, and kitchen and bathroom remodels. Major remodeling projects typically entail extensive structural modifications to the home and often require new equipment, and they are usually very costly. A DER package of energy efficiency upgrades would represent a minor portion of the total remodel cost and potential deliver significant energy and utility bill savings to the homeowner. The homeowner would also gain the non-financial benefits associated with increasing a home's performance, such as increased comfort and reduced maintenance costs.

7. ACKNOWLEDGEMENTS

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