Deep Energy Retrofit Performance Metric Comparison: Eight California Case Studies

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ABSTRACT

In this paper we will present the results of monitored annual energy use data from eight residential Deep Energy Retrofit (DER) case studies using a variety of performance metrics. For each home, the details of the retrofits were analyzed, diagnostic tests to characterize the home were performed and the homes were monitored for total and individual end-use energy consumption for approximately one year. Annual performance in site and source energy, as well as carbon dioxide equivalent (CO_2e) emissions were determined on a per house, per person and per square foot basis to examine the sensitivity to these different metrics. All eight DERs showed consistent success in achieving substantial site energy and CO_2e reductions, but some projects achieved very little, if any source energy reduction. This problem emerged in those homes that switched from natural gas to electricity for heating and hot water, resulting in energy consumption dominated by electricity use. This demonstrates the crucial importance of selecting an appropriate metric to be used in guiding retrofit decisions. Also, due to the dynamic nature of DERs, with changes in occupancy, size, layout, and comfort, several performance metrics might be necessary to understand a project's success.

Introduction

Deep Energy Retrofits (DERs) have become a hot topic in residential energy efficiency in recent years because of their potential to significantly reduce energy consumption in the existing building stock. In response to widespread interest in DERs, numerous national and international efforts have emerged to characterize and improve our understanding of DER performance and methods, as well as to encourage their implementation. These ambitious projects aim to take existing, inefficient homes and to transform them into very energy efficient, comfortable, low-energy homes. Often sustainability, historic preservation and occupant health and safety are intertwined with the energy reduction goals. While the exact definition of a DER is not yet clear, most working in the field consider energy reductions of 50% to 90% to be readily achievable with existing technologies, materials and construction practices (Wigington 2010) (Henderson et al. 2008). The Thousand Home Challenge Level (Thousand Home Challenge 2010) of 75% energy savings is a reasonable DER goal and is used in this study. These drastic energy cuts are typically achieved using a combination of building enclosure air sealing, additional insulation, window replacement, HVAC and domestic hot water system upgrades, lighting and appliance replacement, and sometimes the addition of renewable energy technologies, such as solar PV or solar hot water. These building upgrades are often combined in varying degrees with occupant conservation efforts.

Ten DERs have been extensively monitored and documented in the state of California by the Residential Building Systems group at Lawrence Berkeley National Laboratory (LBNL). Wireless energy monitoring equipment was installed in each case study home, providing one minute data resolution for each electrical and gas end-use. This live data stream was made available to the home occupants via a web application. Each of the homes was retrofitted by the homeowner prior to our involvement, so the research had no influence on the retrofit measures taken. The project goals, strategies used, and results achieved represent actual results of the homeowners', designers' and contractors' approach to a high performance retrofit.

Due to the complexity of the projects and multiple performance metrics, the assessment of DER project performance is not necessarily straightforward. Do we measure energy, carbon or cost savings? Do we consider % savings per house, per person, or per square foot? Do we use site energy or source energy in these comparisons? Is performance based upon a reduction in energy use, a comparison to a reference design or an absolute post-retrofit energy target? Is a DER an asset or operational term? A number of projects in this research did not have pre-retrofit data available. How are these projects to be assessed? Can we honestly compare homes before and after that have different families living in them, different sizes, fuel types, comfort levels, etc? All of these issues are important to consider when judging the effectiveness of a DER, and each can tell a different story. Energy goals and targets that consider all of the above issues are essential to achieving real-world performance in DERs. They guide the design and construction team in their decisions, and they also provide motivation and feedback to the occupants in their pursuit of deep energy reductions. The results presented here will only include the eight out of ten study homes that have a full year of monitored data, and specific end-use breakdowns will not be explored. Further information on the detailed end-use data can be found in Fisher (2011).

DER History

DERs have their origins in the building energy R&D projects of the 1970's, and their technologies and methods have been developed intermittently up to the present. Solar heating of buildings was a popular avenue of research in the late 1970's and early 1980's, but there is a limit to the amount of energy that can be saved using conventional home weatherization techniques and solar heating systems in existing housing (Quivik 1984). This led researchers at Princeton, Danish Technical University, and the University of Saskatchewan to develop retrofits that included adding more depth to the walls and ceilings for added insulation, the addition of airtight vapor barriers, heat recovery ventilators and higher efficiency HVAC equipment.

In 1990, Pacific Gas and Electric's (PG&E) *Advanced Customer Technology Test* (ACT^2) research funded the R&D, design, construction, monitoring and analysis of eight different case studies in northern California, including two residential retrofit projects that achieved 54.2% and 51% weather-normalized energy savings. The project hypothesized that greater energy savings could be achieved through the "synergistic interaction of individual energy efficient measures than would be realized if the measures were implemented individually" (Brohard et al. 1998, 1). The study concluded that energy audits, strict budgets, highly experienced design and construction staff, reliable equipment, performance commissioning and on-going maintenance provisions were required to achieve successful results.

Since 2006, international efforts in DER research have emerged in the European Union. The International Energy Agency's (IEA) Task 37, *Advanced Housing Renovation with Solar and Conservation* (Herkel and Kagerer 2011), has documented and analyzed 60 buildings from Europe and Canada, with pre vs. post source energy savings averaging 74% in single-family homes. Detailed monitoring in a sub-set of German Passive Houses proved that such levels of performance were possible, and that user behavior in both hot water and electricity use proved to be the most challenging variable. Task authors concluded that DERs are only cost-effective in terms of the added incremental costs of high performance components. In England the Technology Strategy Board has funded the "Retrofit For the Future" program, which has seen 86 DERs implemented. The program targets an 80% CO_2 reduction from an average 1990 baseline. Their "Low Energy Buildings Database" is a significant resource for DER case studies (Low Energy Buildings Projects 2011). The Passive House community has also been extensively involved in DERs and recently released the EnerPHit certification (EnerPHit 2012) standard for use in existing buildings that is less stringent than Passive House standards for new construction.

The Canadian Mortgage and Housing Corporation (CMHC) has tested different DER packages in five, 1 ½ story, post World War II homes. Retrofit costs in the five homes ranged from $31,260 to $56,172, PV costs not included. Electrical energy reductions ranged from 17.4% to 42.7%, and gas reductions ranged from 43.2% to 60.1%. The two homes with solar PV are on the path to zero-net annual energy cost (Charron 2011).

In the US, Affordable Comfort Inc. (ACI) launched the "Thousand Home Challenge" (THC) initiative in order to get 1,000 homes across America to save 70-90% of their energy through DERs. (Thousand Home Challenge 2010). Participants either save a minimum of 75% of their total household site energy, or they meet the "Option B Threshold" whole house site energy allowance. The THC website provides numerous resources for DER enthusiasts, including planning tools, 11 documented THC case studies, and recorded webinars on DER topics. The US Green Building Council has also documented numerous sustainable home retrofits as part of its REGREEN program, (USGBC 2011), with numerous design case studies on its website.

Significant DER activity has occurred in the Northeastern US as a result of energy utility activities. In Massachusetts, National Grid has offered nine projects technical assistance and $42K in incentives for DERs, and more funding if meeting the Thousand Home Challenge or Passive House standards. Quality control in design was provided by the Building Science Corporation and during construction through multiple HERS inspections. Incentives provided and costs recorded in this program included only energy upgrades, and did not include siding, finishes, structural or aesthetic upgrades (Neuhauser, 2010). In 2010, the New York State Energy Research and Development Agency (NYSERDA) funded 4 DER case studies, investing around $100,000 each. (NYSERDA - Deep Retrofit 2011). Only air leakage improvements and heating energy reductions are reported; the heating energy was reduced between 47% and 62%.

A substantial number of DERs have also been constructed and documented as part of the US DOE Building America (BA) program. Numerous case studies and research reports can be found on the BA website for projects carried out by BA partners throughout the country. A notable example is the collaboration between ORNL and the Tennessee Valley Authority on 10 occupied DER projects targeting 40-50% energy reductions (Christian et al. 2011). Sacramento Municipal Utility District (SMUD) has partnered with NREL, and they have implemented and are measuring performance in 5 DERs in California's Central Valley. Results are somewhat mixed, with occupant-driven electricity use being 150% and 200% more than predicted in two projects, and electricity savings of 9% and 57% (Keesee 2011).

DER Definitions

Current definitions of DER vary widely; anywhere from 30% to 75% of annual energy use compared with a pre-retrofit baseline (PNNL: Building America Residential Deep Energy Retrofit Research Project 2011) (Thousand Home Challenge 2010). Given advances in minimum building codes and the general DER objective to make significant changes in energy use, the most appropriate DER definition should be on the high end of this scale at the 70% level. Different programs use different energy metrics to measure performance, and they also stipulate the different levels of performance or energy savings that constitute a DER. It is key to remember that the metric used will drive the results obtained, particularly when the metric is used as part of the retrofit design and decision making process. For example, if site energy is the chosen metric, then source energy and CO_2e emissions could increase, despite efficiency improvements.

Several DER definitions assume that pre-retrofit energy use can be determined or modeled, and that these values can be compared with post-retrofit performance. This is not the case in many DERs. A number of our project homes did not have available pre-retrofit energy usage data, and those that did often incorporated significant changes—new occupancy, layout, floor area, window area, fuel type, comfort, etc—that make before and after energy use comparisons impractical or meaningless. Another approach is to use post-retrofit energy use or performance levels as the determining factors of success and for comparison to other projects. Examples include HERS ratings, ‘zero-net energy’ and the Thousand Home Challenge option B Threshold. This method can be used to assess DERs in situations where before and after comparisons are difficult. Allowing both a target savings level of 70% or a target post-retrofit energy use gives us the most flexibility, and we recommend this approach.

Project Descriptions

A significant distinction exists between the project homes of this research and those covered in other studies. Most other DER projects have provided substantial funding and expert design assistance to their participants. This research had zero influence on how retrofits were implemented or paid for. Researchers did not provide design assistance, perform inspections during construction, or provide any financial incentives. Our aim was to study projects that homeowners were willing to finance, and where energy savings and design decisions were based upon occupant needs and interests, rather than external program goals.

There is not room in this paper to sufficiently report the specific details of each DER in this research. More details can be found in Fisher (2011) and Fisher, Less, Walker (2012). The projects were named P1, P2, P3 etc. and are summarized below in a series of tables.

Table 1. Project Summaries

Project ID	Location	Year Built / Year Retrofitted	California Climate Zone	Heating Degree Day (base 65)	Cooling Degree Days (base 80)	Floor Area Pre / Post (sq ft)	Number of Occupants Pre / Post	HERS Index 2006 (Post)
P1	Berkeley, CA	1904 / 2008	3	2909	128	960 / 1630	2 / 4	72
P2	Palo Alto, CA	1936 / 2008	3	2563	486	2780 / 2780	NA / 2	NA
P3	Sonoma, CA	1958 / 2010	2	2844	456	1937 / 2357	NA / 1	25
P4	Petaluma, CA	1940 / 2010	2	2844	456	1540 / 2510	2 / 2	36
P5	Point Reyes Station, CA	1920 / 2010	3	3770	11	800 / 905	NA / 3	86
P7	San Mateo, CA	1910 / 2011	3	3042	108	3136 / 3288	2 / 2	76
P9	Folsom, CA	1998 / 2006	12	2702	1470	3114 / 3114	NA / 4	72
P10	Pacifica, CA	1934 / 2008	3	3770	11	1503 / 1706	2 / 2	25

"NA" is indicated if number of occupants pre-retrofit is unknown, or if HERS Index is not available.

Table 2. Retrofit Features

	P1	P2	P3	P4	P5	P7	P9	P10
Building Enclosure								
Super Insulated (100% > T-24)			X					
Highly Insulated (50% > T-24)	X				X			
Insulated (Meets T-24)				X		X	X	X
All Triple Pane Glazing			X					
All Double Pane Glazing	X	X		X	X		X	X
Passive House Air Leakage Standard <0.6 ACH_{50}			X					
R-2000 Air Leakage Standard <1.5 ACH_{50}	X							
Energy Star V. 3 Air Leakage Standard <5 ACH_{50}					X		X	
HVAC								
Heat/Energy Recovery Ventilation	X	X	X		X			
Electric Resistance Heating	X				X			
Heat pump Heating and Cooling		X	X					
A/C with Evaporative Cooling							X	
Solar Thermal Combisystem			X					X
Night Ventilation Cooling				X			X	
DHW								
Electric Resistance					X			
Heat pump		X						
On Demand Condensing Natural Gas	X			X		X		
Tank Natural Gas							X	
	P1	**P2**	**P3**	**P4**	**P5**	**P7**	**P9**	**P10**
Solar Thermal w/ Condensing Natural Gas Backup			X					X
User Behavior								
Baseload Below 225 Watts	X			X	X	X	X	X
Baseload Above 225 Watts		X	X					
Renewable Energy								
PV		X	X	X				X
Solar Thermal			X					X

Monitored Energy Performance Results

The energy usages of the DERs included in this paper are presented in Tables 3-5 below. The tables show energy performance using several metrics, including site energy, source energy and carbon emissions, normalized by house, by occupant and by square foot of floor area. This has been done for pre-retrofit energy usage (where available), post-retrofit energy usage and percentage reduction in energy use.

Pre-retrofit energy usage was weather normalized for P1, P2, P7 and P9 by calculating the gas consumption per base 65 heating degree day (HDD) in the pre-retrofit period. This value was then multiplied by the base 65 HDD for the post-retrofit reporting period. This adjusted pre-retrofit energy consumption was used to generate energy reductions and percentage reductions for these projects. All source energy values were calculated in accordance with the Building

America Performance Analysis Procedures for Existing Homes, (Hendron 2006) using national site-to-source conversion factors of 3.16 for electricity and 1.02 for natural gas. CO_2e emissions were calculated using the net-site gas and electrical consumptions, and applying current PG&E conversion factors of 0.399 pounds per kWh for natural gas and 0.575 pounds per kWh for electricity (PG&E 2012).

The results in Table 3 are per house and best reflect the energy bill changes (at least for site energy) that an occupant would experience. The high variability in the results reflects the different strategies taken in each case. In particular, site and source energy savings can be dramatically different, such as in P2, where the home went from using natural gas to an all electric home. The percent savings also have a huge range if we look at total source energy; from a savings of 91% to an increase of 6%. However, all the homes ended up being either low carbon or have large carbon savings. The per person results in Table 4 are closest to a true reflection of the societal costs of providing shelter. The biggest difference in savings between Tables 3 and 4 is for P1, whose occupancy doubled post retrofit. Table 5 uses energy normalized by floor area, which is by far the most common metric used in energy analyses and home ratings. This metric has the unfortunate side effect of rewarding larger homes that actually use more energy—the opposite of what a DER is trying to achieve. For example, P5 (a small house with three occupants) has the worst performance in Table 5 despite being a very low energy using home.

Table 3. Energy Use Per House

	Net Site Electricity (kWh)			**Net Site Gas (kWh)**			**Total Net Site Energy (kWh)**			**Net Source Electricity (kWh)**			**Net Source Gas (kWh)**			**Total Net Source Energy (kWh)**			**Total Net Carbon Emissions (lbs CO_2e)**		
	Pre	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**
P1	2,392	5,487	(129)	12,494	4,103	67	14,886	9,590	36	7,559	17,339	(129)	12,744	4,185	67	20,302	21,524	(6)	6,361	4,794	25
P2	6,300	18,333	(191)	41,563		100	47,863	18,333	62	19,908	57,932	(191)	42,395		100	62,303	57,932	7	20,209	10,548	48
P3		4,152			996			5,148			13,120			1,016			14,136			2,786	
P4	2,473	(1,004)	141	8,118	4,543	44	10,591	3,539	67	7,815	(3,173)	141	8,281	4,634	44	16,095	1,461	91	4,662	1,235	74
P5		6,450			201			6,651			20,382			205			20,587			3,791	
P7	6,248	3,131	50	28,693	5,583	81	34,941	8,714	75	19,744	9,894	50	29,267	5,695	81	49,010	15,589	68	15,043	4,029	73
P9	11,987	4,631	61	27,333	13,218	52	39,320	17,849	55	37,879	14,634	61	27,880	13,482	52	65,759	28,116	57	17,803	7,939	55
P10		853			6,038			6,891			2,695			6,159			8,854			2,900	
Avg. CA Home	6,296			10,375			16,671			19,895			10,583			30,478			7,762		

California Average Home is based on 2009 California Residential Appliance Saturation Survey for Single Family homes (CEC 2010).

Table 4. Energy Use Per Person

	Net Site Electricity (kWh)			**Net Site Gas (kWh)**			**Total Net Site Energy (kWh)**			**Net Source Electricity (kWh)**			**Net Source Gas (kWh)**			**Total Net Source Energy (kWh)**			**Total Net Carbon Emissions (lbs CO_2e)**		
	Pre	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**	**Pre**	**Post**	**%**
P1	1,196	1,372	(15)%	6,247	1,026	84%	7,443	2,398	68%	3,779	4,335	(15)%	6,372	1,046	84%	10,151	5,381	47%	3,181	1,199	62%
P2	3,150	9,167	(191)%	20,782		100%	23,932	9,167	62%	9,954	28,966	(191)%	9,954		100%	31,151	28,966	7%	10,104	5,274	48%
P3		2,076			498			2,574			6,560			508			7,068			1,393	
P4	1,237	(502)	141%	4,059	2,272	44%	5,296	1,770	67%	3,907	(1,586)	141%	4,140	2,317	44%	8,048	731	91%	2,331	617	74%
P5		1,613			50			1,663			5,096			51			5,147			1,264	
P7	3,124	1,566	50%	14,346	2,792	81%	17,470	4,357	75%	9,872	4,947	50%	14,633	2,847	81%	24,505	7,794	68%	7,522	2,015	73%
P9		1,158			3,305			4,462			3,658			3,371			7,029			1,985	
P10		427			3,019			3,446			1,348			3,079			4,427			1,450	
Avg. CA Home	2,171			3,578			5,749			6,860			3,649			10,510			2,677		

.

Table 5. Energy Use Per Square Foot Floor Area

	Net Site Electricity (kWh)			**Net Site Gas (kWh)**			**Total Net Site Energy (kWh)**			**Net Source Electricity (kWh)**			**Net Source Gas (kWh)**			**Total Net Source Energy (kWh)**			**Total Net Carbon Emissions (lbs CO_2e)**		
	Pre	Post	%	Pre	Post	%	Pre	Post	%	Pre	Post	%	Pre	Post	%	Pre	Post	%	Pre	Post	%
P1	2.49	3.37	(35)%	13.01	2.52	81%	15.51	5.88	62%	7.87	10.64	(35)%	13.27	2.57	81%	21.15	13.20	38%	6.63	2.94	56%
P2	2.27	6.59	(191)%	14.95		100%	17.22	6.59	62%	7.16	20.84	(191)%	15.25		100%	22.41	20.84	7%	7.27	3.79	48%
P3		1.76			0.42			2.18			5.57			0.43			6.00			1.18	
P4	1.61	(0.40)	125%	5.27	1.81	66%	6.88	1.41	79%	5.07	(1.26)	125%	5.38	1.85	66%	10.45	0.58	94%	3.03	0.49	84%
P5		7.13			0.22			7.35			22.52			0.23			22.75			4.19	
P7	1.99	0.95	52%	9.15	1.70	81%	11.14	2.65	76%	6.30	3.01	52%	9.33	1.73	81%	15.63	4.74	70%	4.80	1.23	74%
P9	3.85	1.49	61%	8.78	4.24	52%	12.63	5.73	55%	12.16	4.70	61%	8.95	4.33	52%	21.12	9.03	57%	5.72	2.55	55%
P10		0.50			3.54			4.04			1.58			3.61			5.19			1.70	
Avg. CA Home	4.05			6.67			10.71			12.79			6.80			19.59			4.99		

Figure 1. Post Retrofit Net-Energy Usage

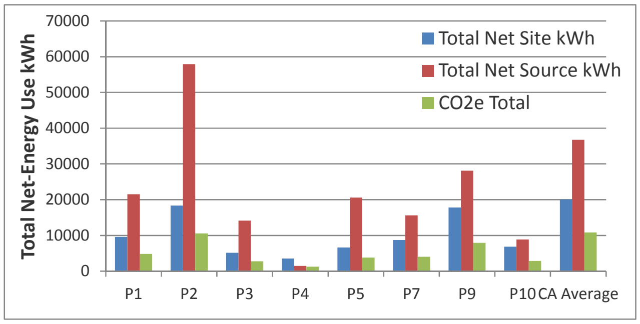


Figure 2. Percentage Reduction in Net-Energy Across Metrics

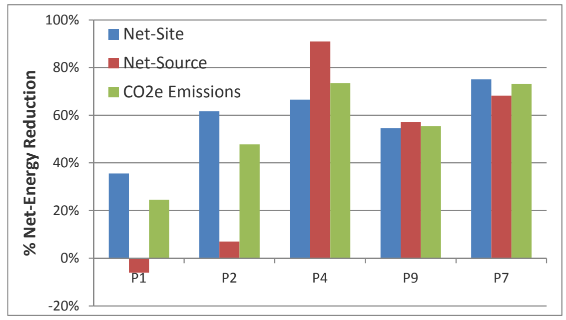


Figure 1 shows that post-retrofit net-site energy usage per house ranged from 3,539 to 18,333 kWh, and net-source energy usage ranged from 1,461 to 57,932 kWh. Figure 2 shows the site energy savings ranging from 36% to 75% for projects with pre-retrofit data, which suggests reasonable levels of success. However, source energy savings tell a different story, ranging from a 6% increase in energy usage to a reduction of 91%. Figure 3 below shows the total net energy reductions (including on-site generation) from pre- to post-retrofit. These reductions varied from 5,296 to 29,530 site energy kWh, and from an increase of 1,222 to a reduction of 37,643 source energy kWh. P9 achieved the highest net-source energy reductions, while still being the second highest consumer of net-site and net-source energy. These findings demonstrate the wide range in net-energy use that can be expected from DERs, and they also illustrate the crucial importance of performance metrics and how they are used to assess projects and inform decision making.

Figure 3. Total Net-Energy Reductions

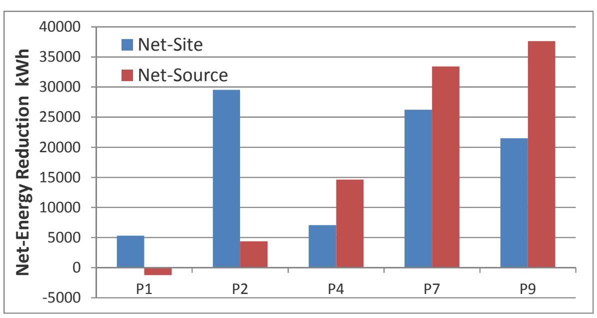
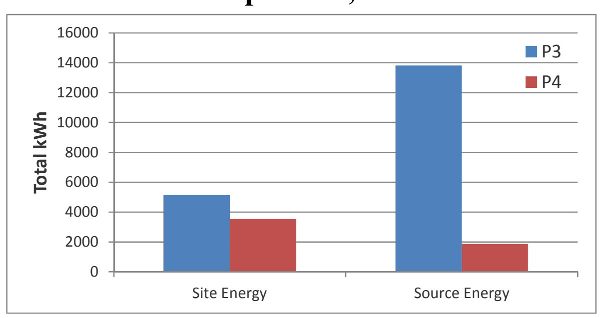


Figure 4. Source Energy and Site Energy Metric Comparison, P3 and P4



The remaining figures further illustrate how these different metrics impact the outcomes of DERs and help explain the shifts in their relative success. In Figure 4 both homes are performing well on a site energy basis (at less than 1/3 the average California home). In terms of net-source energy, P3 uses 7.4 times as much as P4. This is because P4 uses natural gas for space and domestic water heating, whereas P3 uses an electric mini-split heat pump and has higher miscellaneous electrical uses. Both homes have solar PV systems, but P4 is a net-exporter of electricity on an annual basis, providing it a source energy credit. Ultimately, P4 uses very little electricity and the bulk of its total energy use is natural gas for space heating, whereas P3 (a certified Passive House) uses very little heating and cooling electrical energy, and its overall energy use is dominated by other electrical end-uses in the home. The predominance of electrical energy use in P3 and the paucity of it in P4 creates this dramatic divergence in performance.

Figure 5. Percent Savings Site and Source Energy, P2 and P4

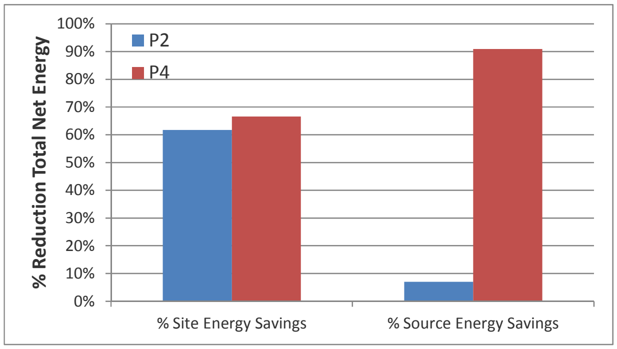
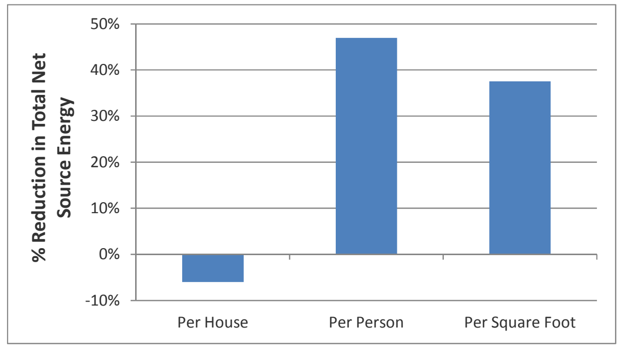


Figure 6. Percent Source Energy Savings Across Metrics, P1



It might be thought that percentage net-energy savings would be an unbiased performance metric in a DER, yet Figure 5 illustrates that fuel mixes and retrofit measures can have a dramatic impact on project performance. When P2 and P4 are compared on percentage net-site energy reduction, they appear to be quite similar performers. However, the conversion to percent net-source energy reduction shows a drastic shift. P4 has achieved 13 times the percentage net-source energy reduction that P2 has, despite their similar percent site energy performance. The reasons for this are that both homes began as users of natural gas for space and water heating, and P2 shifted to an all-electric home, whereas P4 maintained its fuel-types.

DER success can vary significantly depending on normalization by house, person or floor area. Figure 6 above shows the percentage net-source energy reduction for P1 across these three normalization metrics. The home performs poorly on a per house source energy basis, but it fairs significantly better on a per person and per square foot basis, with 47% and 38% reductions respectively. During its retrofit, P1 both increased its floor area from 960 ft^2 to 1,630 ft^2 as well as doubled its occupancy, going from two to four occupants.

So far, we have been picking on the net-source energy usages of P1 and P2, yet when these projects are assessed on CO_2e emissions, they perform at least reasonably well. Table 3 shows the poor net-source energy reductions of P1 and P2, at a 6% increase and 7% decrease respectively. Yet, their CO_2e emissions reductions were 14% and 34%. This illustrates how carbon emissions do not align exactly with source energy conversions, and it is important to keep in mind which value one hopes to reduce. However, California has relatively low-carbon electricity, whereas national carbon conversion factors will negatively affect performance in electricity-dominated projects.

Discussion

The results of this study illustrate how determining 'success' in a DER project can be difficult. Success shifts and slides around depending on how energy use is assessed and how it is normalized. These performance metrics and normalization methods should be carefully considered by program designers, project teams and homeowners alike, so that an appropriate metric can be chosen that will lead them to their desired results.

One of the most distorting elements in DER performance assessment is the fuel chosen to meet different end uses. Fuel choice has a clear impact when comparing between projects, and it is also fundamentally important when a project switches from one fuel source to another during the DER. In all cases described here, such shifts have meant transferring from natural gas usage for space and water heating, to either all electric or electric space heating. The reasons for this switch were different in each case. In P1, electric resistance heat was affordable, and it was assumed that Passive House envelope measures would mean very little need for electric baseboard heaters. In P2, the decision was made believing that all energy would be offset with onsite PV. At P3, a single piece of equipment was desired to meet heating and cooling needs, and a mini-split heat pump was installed as a result. At P5, there was no access to utility natural gas. Other reasons that project teams make the switch to electric include avoidance of combustion pollutants, avoidance of utility connection fees, and the sense that only electric energy can truly be offset by PV production. This has resulted in a number of projects showing poor net-source energy performance. When pursuing a DER, we recommend choosing fuels carefully and doing so only after evaluating energy performance on a source energy basis. Of course, DERs that transfer from using electricity to natural gas for heating end uses receive significant benefits when using the conversion factors used in this report. However, national site-to-source conversion factors may not be accurate depending on the regional electric power fuel mix. For example, areas with predominately hydropower have dramatically different source energy factors, as would California, a state where almost no coal is used in electricity production and non-carbon energy sources account for 45% of the 2010 electricity supply (CEC 2011). Similarly, the controversial issues around the dramatically increased carbon emissions of ‘unconventional’ natural gas raised by Howarth et al. (2011) could significantly alter these results, and a better understanding of natural gas production emissions is necessary.

We have noted the tendency for retrofit programs and homeowners to rely on site energy savings as their measure of success, due to its transparency and ease of use. Yet, this report illustrates how severely distorting such decisions can be. Even a target of greater than 60% site energy reductions cannot guarantee satisfactory source energy and carbon performance, as in P2. Programs like DOE Building America have selected annual source energy as their performance metric, which we believe is a good choice. The Thousand Home Challenge Option B Threshold is another good alternative for homes without pre-retrofit data, as it accounts for the potentially distorting factors of fuel type, occupancy and square footage.

Summary

DERs are at the cutting edge of residential energy efficiency, and they are a key means to curbing climate change. Any DER at this point in time is a demonstration project, whether receiving external funding and support, or not. The methods of achieving deep energy savings are being developed and refined across the country, but the determination of ‘success’ in DERs is yet to be clearly established. We have used a number of monitored projects in Northern California to illustrate how the determination of ‘success’ may not be as clear-cut as previously thought. We recommend following the Building America practice of conversion to source energy use, and to consider the carbon emissions of every DER. Other recommendations include allowing the definition of DER to include significant energy savings (e.g., 70%), as well as target consumption values, and using energy use per house or occupant rather than the traditional normalization by floor area.

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