Deep Energy Retrofits - Source Energy and Carbon Decisions

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The Problem: DERs are projects that create new, valuable assets from aging residences, and part of that process is bringing the home into alignment with the expectations of the 21st century. Some changes we make while upgrading a home can lead to an offsetting of other reductions or even increased electricity use, which can reduce the project's utility bill savings and beneficial environmental impact.

When Is It Important?

1. When switching from gas to electric for heating end-uses, such as space heating, water heating, cooking or clothes drying;
2. When adding energy-using features, such as mechanical cooling, mechanical ventilation, decorative lighting, audio-visual equipment, smart home features or appliances.

The Solutions:

1. In cases highlighted above, carefully assess the impacts of switching from gas to electricity for heating end-uses, using source energy and/or carbon emissions assessments;
2. Only implement those changes in fuel use that can provide a net-environmental benefit;
3. Attempt to include changes in home features (e.g., lighting, smart home features, mechanical cooling, etc.) in your assessments and energy calculations. For example, in BEopt, the user can input a carbon factor for each fuel type specified in the model. If you know the carbon content of your local electricity, use that, otherwise, we recommend the use of local averages, such as those provided on a state-by-state basis in Table 3.
4. Carefully weigh the benefits and consequences of adding features to a home, to ensure they are "worth" the reduction in environmental performance that comes with them. In other words, inspire a conscientious, conservative and aware attitude in the project team and home occupants.

Background and Further Details

The U.S. DOE Building America program already uses source energy as its primary metric in home performance assessment. This is done in order to account for the approximately three-fold increase in primary fuel requirements (e.g., natural gas, coal, oil, hydro, nuclear, etc.) for delivered electricity compared with natural gas (see Table 2). Nevertheless, utility bills (e.g., site energy) are the most familiar to both homeowners and contractors, and they are therefore a useful tool for thinking about deep energy reductions in homes. Yet, site energy does not always reflect the impact of household energy use on natural resources or on carbon emissions. As a society, we have an interest in reducing these negative consequences, and many homeowners engage in the deep energy reduction process in order to specifically reduce their "environmental footprint". When appropriate, using source energy and carbon metrics can ensure that you do not accidently limit the impact of your deep renovation project on these larger, environmental goals.

Energy Type	**Natural Gas**	**Electricity**
Site Energy	1 kWh	1 kWh
Source Energy	1.02 kWh	3.16 kWh
Carbon Emissions	0.399 lbs/kWh	1.32 lbs/kWh

Table 2 Conversion factors between site and source energy, as well as carbon emissions.

You may be thinking that no matter what fuels are used, a deep reduction project will almost certainly still reduce energy use and carbon emissions, but some actual case studies have shown otherwise. The ratio of gas use to electricity use can change even in aggressive deep reductions projects. This can have substantial negative impacts. For example, two DERs in Northern California incurred severe source energy penalties as a result of electricity use increases (Less, Fisher, & Walker, 2012). One project went from site savings of 31% to a source energy increase in usage of 12%, and another went from a 61% net-site reduction to only a 7% net-source reduction. The addition of energy-using features (e.g., cooling, home office, home networking) also contributed to these performance degradations. Similarly, two DERs in eastern Tennessee increased electricity use post-retrofit, and their site savings went from 32% and 61%, down to 8% and 33%, respectively (Boudreaux, Biswas, & Jackson, 2012). In a review of U.S. DERs, seven projects were identified that increased electricity use, and their average site savings went from 52% to 34% for source energy (Less & Walker, 2014). Similarly, in a community of DERs in Massachusetts and Rhode Island the average site savings of 58% was reduced to 41% for source energy (Gates & Neuhauser, 2014).

To illustrate more clearly what can happen, Figure 3 below shows site and source energy before and after an ***imaginary*** deep reduction project. Site energy reductions were 90% for heating, 45% for hot water, 50% for lights and 25% for appliances (an overall 60% savings). But the home’s space and water heating switched to electricity, and mechanical cooling was added, as were some modest plug loads increases. So, a site energy reduction of 60% translates to a 0% source energy reduction! Carbon emissions reductions would be similar, with some variability by location as noted elsewhere in this summary. This is what DER designers and homeowners should try to avoid.

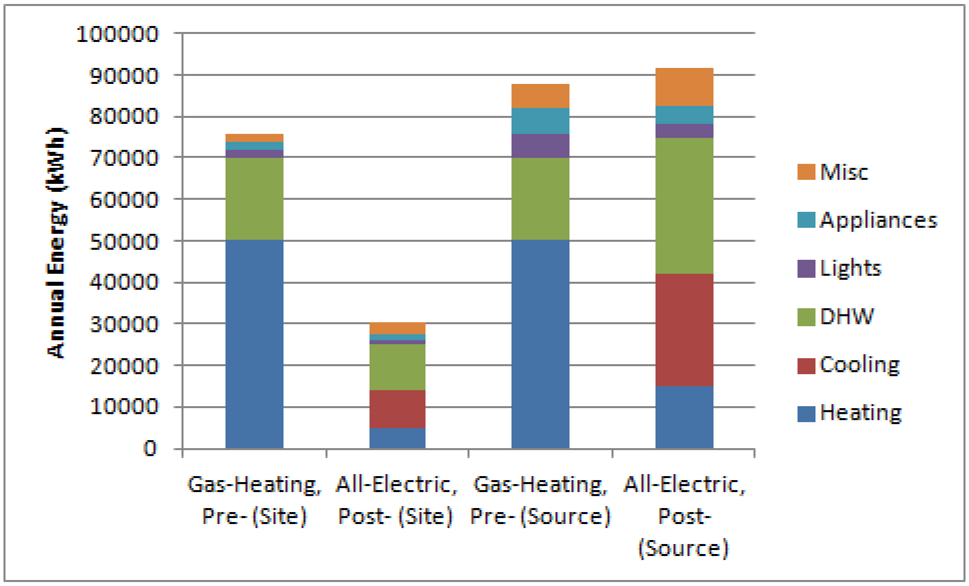

Figure 3 Example energy use of an *imaginary* deep retrofit project whose fuel switching and other choices eliminate all source energy savings and environmental benefit.

So, what leads to electricity increases in deeply retrofitted homes?

1. Switching from gas to electric for heating end-uses, such as space heating, water heating, cooking or clothes drying.
2. Addition of energy-using features, such as mechanical cooling, mechanical ventilation, decorative lighting, audio-visual equipment, smart home features or appliances.

Features added to a home have great value to homeowners, and they may be some of the primary drivers of the decision to do a deep energy retrofit. For example, indoor temperatures and humidity in the summer may be extremely uncomfortable, and the addition of mechanical cooling (along with improvements to the building envelope) are an obvious choice for any homeowner. Other similar improvements are required to modernize any older home that has not had substantial updates. DERs are projects that create new, valuable assets from aging residences, and part of that process is bringing the home into alignment with the expectations of the 21st century.

These additional features will always increase energy usage, unless they are replacing some less-efficient pre-retrofit alternative. A project may still save electricity, but those reductions will be less than they would have been without the added feature(s). As a result, these additional features should be weighed carefully, and in full consideration of their impact of environmental performance.

Some electricity use increases are reflected in common building energy models. For example, switching from a gas furnace to an electric heat pump can be easily modeled, as can changing fuel/system type for water heating (thought these will not be adequately reflected in outputs such as HERS indices). Other elements can be included in a model, but are often not included as part of the typical “asset” performance assessment. For example, lighting density can be modeled, but accurately reflecting the before and after change is not common. The same goes for miscellaneous plug loads, security systems, A/V equipment, etc. The DER designer should be aware that these changes in usage patterns and in-home fuel mix can have a substantial impact on environmental performance. They should:

1. Make a concerted effort to reflect these changes in any building simulation model.
2. In these situations where environmental performance is potentially degraded, designers should assess source energy and carbon reductions, alongside site energy
3. Explain to homeowners that some of their decisions will cut into energy savings they are paying to achieve elsewhere. This will hopefully inspire a conscientious attitude.

Carbon Emissions in U.S. Electricity and Retrofit Decisions

The following is an example of a nuanced carbon emissions/source energy assessment that is based on the variability in the carbon intensity of electricity from state-to-state. Table 3 lists the 2010 carbon emissions per unit of delivered electricity (lbs./kWh) for each state in the U.S. These emissions are compared with those of a 95% efficient, on-site gas heater (gas emissions are 0.399 lbs./kWh) in order to assess the heat pump equipment efficiencies required to break-even with natural gas in terms of carbon emissions. Holding all else constant (e.g., insulation levels, airtightness, ducts), in those states highlighted in green, a high performance air-source heat pump can at least break-even with a 95% efficient gas heater (and often do better). Yellow states require best-in-class heat pumps (such as those listed in the Energy Star Most Efficient list) in order to break-even. In red states, no currently available air-source heat pump can break-even with a 95% efficient gas heater, given federal performance ratings.

These values are not meant to suggest that one should never install a heat pump in a red state nor that one should always install a heat pump in a green state. Rather, these are indicators to **Pay Attention** and assess the impacts in greater detail. There are also other good reasons that one technology is chosen over another, including energy prices, equipment prices, availability of electricity and gas at heating appliance location, performance at part-load, utility service connection fees, etc. Also, think about equipment choice in the context of the house as a system. For example, in a DER, heating loads may be reduced 70-90%, so even a heat pump in a red state would reduce carbon emissions, but emission reductions would be less than they would have been if gas heat were used. This may be acceptable, given the overall environmental benefit; this is for the homeowner and the project team to decide.

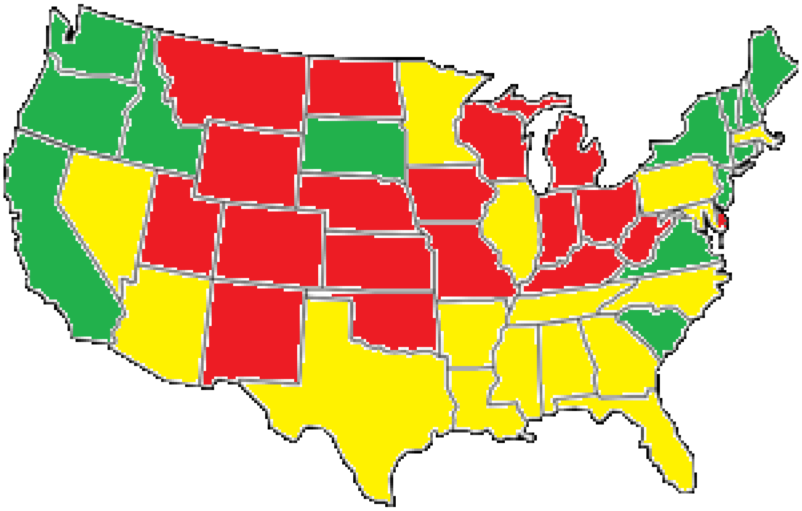

Figure 4 Map of the United States color-coded by carbon emissions for delivered electricity

U.S. State	CO_2e Emission Factor for Delivered Electricity (lb/kWh)	*Break-Even* Heat Pump COP	*Break-Even* Heat Pump HSPF
AK	1.280	3.0	10.4
AL	1.330	3.2	10.8
AR	1.400	3.3	11.4
AZ	1.290	3.1	10.5
CA	0.603	1.4	4.9
CO	2.147	5.1	17.5
CT	0.728	1.7	5.9
DC	2.671	6.4	21.7
DE	1.815	4.3	14.8
FL	1.449	3.5	11.8
GA	1.518	3.6	12.3
HI	1.822	4.3	14.8
IA	1.919	4.6	15.6
ID	0.156	0.4	1.3
IL	1.267	3.0	10.3
IN	2.364	5.6	19.2
KS	1.964	4.7	16.0
KY	2.448	5.8	19.9
LA	1.320	3.1	10.7
MA	1.255	3.0	10.2
MD	1.595	3.8	13.0
ME	0.578	1.4	4.7
MI	1.659	3.9	13.5
MN	1.541	3.7	12.5
MO	2.166	5.2	17.6

MS	1.325	3.2	10.8
MT	1.767	4.2	14.4
NC	1.395	3.3	11.3
ND	2.309	5.5	18.8
NE	1.719	4.1	14.0
NH	0.661	1.6	5.4
NJ	0.728	1.7	5.9
NM	2.136	5.1	17.4
NV	1.243	3.0	10.1
NY	0.745	1.8	6.1
OH	2.083	5.0	16.9
OK	1.744	4.2	14.2
OR	0.476	1.1	3.9
PA	1.385	3.3	11.3
RI	1.071	2.6	8.7
SC	1.034	2.5	8.4
SD	0.916	2.2	7.4
TN	1.350	3.2	11.0
TX	1.501	3.6	12.2
UT	2.162	5.1	17.6
VA	1.227	2.9	10.0
VT	0.008	0.0	0.1
WA	0.355	0.8	2.9
WI	1.841	4.4	15.0
WV	2.325	5.5	18.9
WY	2.468	5.9	20.1
US	1.320	3.2	10.8

Table 3 CO_2e emission factors for delivered electricity in all 50 states, based upon U.S. EPA eGRID 2010 data.

Future Carbon and Electricity

Most long-term carbon reduction scenarios recommend that domestic heating end-uses will need to be converted to electricity. Yet, in many U.S. locations, pursuing this path presently will result in a carbon penalty (as noted above). The expected life-time of HVAC equipment is approximately 15 years, so a choice for gas heating now does not necessarily lock you out of electric heating in the future. But care should be taken to ensure flexibility and maintain the potential for a future switch to electricity in 15-years time. Projects might install a gas forced air heater today, but leave room for future installation of a heat pump heat exchange coil. Or projects could ensure that sufficient electrical service is installed that can meet the demand of future electrical heating appliances (e.g., heating, cooling and hot water).

References

Boudreaux, P., Biswas, K., & Jackson, R. (2012). *Advancing Residential Retrofits in the Mixed-Humid Climate to Achieve Deep Energy Savings: Final Report on Knoxville, TN Homes* (No. ORNL-27 (4-00)). Oak Ridge, TN: Oak Ridge National Laboratory. Retrieved from http://inspire.ornl.gov/Document/View/be3b23ee-a47d-449d-ad62-5bb17299f99a?q=boudreaux

Gates, C., & Neuhauser, K. (2014). *Perforance Results for Massachusetts & Rhode Island DER Pilot Community* (No. Building America Research Report - 1401). Somerville, MA: Building Science Corporation. Retrieved from http://www.buildingscience.com/documents/bareports/ba-1401-performance-results-massachusetts-rhode-island-der-pilot-community

Less, B., Fisher, J., & Walker, I. (2012). *Deep Energy Retrofits-11 California Case Studies* (No. LBNL-6166E). Berkeley, CA: Lawrence Berkeley National Laboratory. Retrieved from http://eetd.lbl.gov/publications/deep-energy-retrofits-eleven-california-case-studies

Less, B., & Walker, I. (2014). *A Meta-Analysis of Single-Family Deep Energy Retrofit Performance in the U.S.* (No. LBNL-6601E). Berkeley, CA: Lawrence Berkeley National Laboratory. Retrieved from http://eetd.lbl.gov/sites/all/files/a_meta-analysis_0.pdf

Less, B. D., & Walker, I. S. (2015). *Deep Energy Retrofit Guidance for the Building America Solutions Center* (No. LBNL-184443). Berkeley, CA: Lawrence Berkeley National Laboratory. Retrieved from https://eetd.lbl.gov/sites/all/files/brennan_less_-_deep_energy_retrofit_guidance_for_the_building_america_solutions_center.pdf