Deep Energy Retrofits - Lessons learned

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Based upon a review of DERs in the U.S., successful projects did the following:

- Had lots of room for improvement
- Were in need of remodeling, repairs and maintenance
- Were high energy users
- Used a skilled design and construction team that planned carefully, involving everyone in decision-making
- Used simple, high-efficiency strategies
- Addressed all energy end-uses
- Employed building science best practices (moisture management, building control layers, ventilation, integrated design, etc.)
- Commissioned and verified work
- Used lower cost alternative strategies wherever possible
- Had engaged occupants
- Provided feedback and education to occupants

Below, we provide more detailed summaries of experiences and lessons learned for specific design approaches and systems.

As long as projects are comprehensive and aggressive, the specifics of the retrofit approach do not have significant impacts on project success. For example, in 36 northeastern DERs, specific retrofit strategies used in basements, attics and walls were associated with increased airtightness, but not with energy performance (Gates & Neuhauser, 2014). In Florida DERs, the most successful projects typically implemented more measures across a variety of end-uses, but with lots of variability in measure packages (McIlvaine, Sutherland, & Martin, 2013). In California DERs, both code-style and superinsulated projects achieved impressive energy performance, using a wide array of technologies and strategies (Walker & Less, 2013). These projects suggest that a flexible but comprehensive approach is acceptable, and that no single technology, material or strategy is required for a successful DER. For example, it is clear that a successful DER can be completed with or without window replacement, at 1.5, 3 or 5 ACH50, with or without use of spray foam, with or without a sealed crawlspace, with or without solar PV, etc. This freedom should liberate project teams to pursue those strategies that are lowest cost and most appropriate for the occupants, the specific conditions encountered in the home, and the experience/skills of local workers.

Do no harm. As is the case with standard remodeling projects, DERs have the potential to expose occupants and workers to hazards from legacy pollutants (e.g. lead paint, asbestos insulation), but free guidance exists to help those involved in remodeling to identify and remediate such issues. Lead or asbestos abatement, radon testing and mitigation, moisture managed construction and other issues should be addressed using the U.S. EPAs [Healthy Indoor Environment Protocols for Home Energy Upgrades]. Also, most DERs include airtightening the building envelope, and this can potentially increase levels of some indoor air pollutants in the home (Emmerich, Howard-Reed, & Gupte, 2005). The average

DER in the U.S. reduced air leakage by 63%, which could have a substantial impact on indoor pollutants. In fact, airtightness in post-retrofit homes was roughly equivalent with that in new, energy efficient construction. Yet, approximately 30% of U.S. DERs failed to install mechanical ventilation, and when broken down by climate zone, installation rates varied from 10% to 90%. Resistance to the installation of mechanical ventilation was particularly apparent in developer projects (Keesee, 2012; McIlvaine et al., 2013). Mechanical ventilation in aggressively airtightened homes should not be seen as optional. At a minimum, we recommend compliance with ASHRAE 62.2-2013, which specifies airflows for continuous fans, as well as bathroom and kitchen exhaust fans. Notably, indoor air pollutants have been measured in deeply retrofitted homes in California, and the pollutant levels were similar to (or better than) those measured in non-retrofitted, existing homes and/or conventional new homes. This was because the projects followed best practices, including continuous and kitchen/bathroom ventilation, commissioning, filtration, occupant education and source control (e.g., eliminate unvented combustion or low-emitting building materials) (Less & Walker, 2013).

Numerous projects reported on performance issues and occupant complaints related to mechanical ventilation systems, namely heat and energy recovery ventilators, which made up 70% of all installed mechanical ventilation systems in DERs (Less & Walker, 2014). Many of these systems could be termed “complex”, meaning they have one or more of the following: independent duct systems, humidity controllers, variable speeds, multiple points of occupant controls, filtration, etc. All of these added complexities add potential points of performance failure and risk of inadequate maintenance; faults were common in these systems (Less & Walker, 2013). This is of great concern in newly airtightened homes packed full of new construction and finish materials. Problematic issues reported by project teams included a lack of knowledgeable suppliers, capable installers and commissioning agents to verify system performance (Berges & Metcalf, 2013). Furthermore, occupants often did not understand the systems or their maintenance requirements. These factors led to comfort complaints, lack of system operation and a lack of required maintenance (Berges & Metcalf, 2013; Gates & Neuhauser, 2014; Less, Fisher, & Walker, 2012). We recommend that DER project teams make systems simpler and less costly (less ducting, simple user-controls), make them easier to commission (easily accessible inlets and outlets), and make their operation and maintenance needs obvious (clear labeling, documentation and discussion with occupants).

Availability is limited of qualified and skilled contractors and design professionals. Many projects reported that finding adequately skilled and trained contractors with building science and energy efficiency experience was difficult, and that the questionable work of subcontractors often reduced project success (Berges & Metcalf, 2013; Phillip Boudreaux, Hendrick, Christian, & Jackson, 2012; Chandra et al., 2012; Gates & Neuhauser, 2014; McIlvaine et al., 2013). Code officials were also noted for lack of awareness and knowledge about energy efficiency upgrades. Issues including frustrations with badly coordinating scheduling, poor cost estimations, problematic building inspections and long lead times for specialty products. It is essential to avoid the low-cost bid mentality, and instead to invest in dedicated and experienced construction professionals. We recommend that a HERS rater or other building science specialist should provide support and guidance to a DER project from its inception until its completion. Also, as recommended elsewhere, choose technologies and strategies that that local suppliers and installers are familiar with.

Simple, high efficiency, off-the-shelf systems are often superior to advanced systems that look great on paper. The realities of complex system design, procurement, installation, commissioning, servicing and repair often means that these technologies cannot be justified. For example, combisystems were used to provide space and water heating in a number of DERs, and these systems often had high costs, with little obvious performance benefit over high efficiency off-the-shelf alternatives (e.g., 95 AFUE condensing gas furnace and heat pump water heater) (Less et al., 2012). The definition of a "complex" system varies by location. For example, DERs in Cleveland noted that ductless heat pumps were not supported by adequate local suppliers and installers (Berges & Metcalf, 2013). And while effective in Florida DERs, two-staged advanced heat pumps were not common for most installers and required extra attention (McIlvaine et al., 2013). We recommend avoidance of any systems that require substantial custom design and engineering services. Complex systems, whether they be mechanical or envelope systems, are most prone to failure, miscommunication and trades person errors. Base your decision on local market conditions and availability of experience professionals. If complex technologies are used, special care is needed to avoid problems, such as detailed training, oversight and inspection on the job site. See our Cost-Effectiveness guidance for more ideas on how to lower DER project costs.

Fuel switching in DERs (going from gas to electric heat) and adding energy using features can reduce or entirely eliminate source energy and carbon emissions reductions. Site energy reported on a utility bill does not always reflect the impact of household energy use on natural resources or on carbon emissions, mostly because a unit of electricity has a roughly three times the environmental impact of a unit of natural gas. Yet, some think that no matter what fuels are used (electricity or gas), a deep reduction project will almost certainly still reduce energy use and carbon emissions. But some actual case studies have shown otherwise (Less et al., 2012), and others have shown how site savings can be dramatically degraded when considering source energy and carbon emissions (Philip Boudreaux, Biswas, & Jackson, 2012; Gates & Neuhauser, 2014; Less & Walker, 2014). We recommend careful source energy and/or carbon assessment in DERs that are considering fuel switching and/or adding energy using features, particularly mechanical cooling. See our Source Energy and Carbon guidance for further details.

Occupants are an essential part of the DER design, construction and operations process. A number of projects reported on how occupant behavior affected retrofit performance. The success of mechanical ventilation systems was often contingent on occupant understanding and maintenance. Occupants were noted to not be familiar with "right-sized" HVAC systems, where pull-down time is long, and aggressive thermostat set-backs can cause problems. Occupants in DERs in Florida were noted to have disabled the smart functions of "smart" thermostats, because their needs were not being met (Parker, Sutherland, Chasar, Montemurno, & Kono, 2014). In a project at PNNL, homeowners were noted as being very finicky, in that they were resistant to actually carrying out retrofits (Chandra et al., 2012). They wanted cheap, silver-bullet solutions that used fancy new technologies, and were minimally disruptive. Careful, continuous support and engagement was required in order to get follow-through in these cases. DERs in Eastern Tennessee noted similar difficulty in engaging owners in this process (Phillip Boudreaux et al., 2012). We recommend broadly that DERs be designed according to the needs and abilities of the occupants (if they are present). But if occupants are not present, then DERs should be designed to be simple, well-documented, clearly labeled and insensitive to occupant behavior (e.g., super insulated, airtight homes have less variability in performance, no matter the thermostat setting). See our Occupant Behavior guidance for more details on this aspect of deep retrofits.

Deep retrofits can be cost-effective when financed improvements are incremental and aligned with other repairs, maintenance and equipment replacement. DERs can be most successful when integrated with remodeling activities that were already needed/desired, or at changes in ownership. Most homeowners who have done DERs in their homes do not focus intensely on cash-flow, and cost-effectiveness does not drive most of their decision making. Rather they are more interested in the numerous other benefits of DERs, including improved comfort, better health, durability, lower maintenance, increased home value, etc. Nevertheless, alignment with remodeling and other improvements reduces disruption and lowers the costs to occupants.

Addressing all end-uses comprehensively is crucial to success, rather than focusing solely on space conditioning. Pool pumps are a great example of huge energy wasters in many Florida homes, which can be cheaply addressed with substantial energy savings (Parker et al., 2014). DERs in California were noted for having highly variable base loads (continuous electricity demand), which contributed substantially to annual energy use (Keesee, 2012; Less et al., 2012). Such energy waste should be addressed intelligently in any DER that is investing heavily in other building elements in order to save energy.

References

Berges, M., & Metcalf, M. (2013). Lessons Learned on Energy-Efficient Affordable Housing: Practical insights on combining deep energy retrofits with affordable housing for 12 Cleveland homes. *Journal of Light Construction*, (February), 55–63.

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

Boudreaux, P., Hendrick, T., Christian, J., & Jackson, R. (2012). *Deep Residential Retrofits in East Tennessee* (No. ORNL/TM-2012/109). Oak Ridge, TN: Oak Ridge National Laboratory. Retrieved from http://inspire.ornl.gov/Document/View/e89694bd-68c0-43fb-a6fa-3a17c6557a97?q=boudreaux

Chandra, S., Widder, S., Parker, G., Sande, S., Blanchard, J., Stroer, D., … Sutherland, K. (2012). *Pilot Residential Deep Energy Retrofits and the PNNL Lab Homes* (No. PNNL-21116). Richland, WA: Pacific Northwest National Laboratory. Retrieved from http://www.pnl.gov/main/publications/external/technical_reports/PNNL-21116.pdf

Emmerich, S. J., Howard-Reed, C., & Gupte, A. (2005). *Modeling the IAQ Impact of HHI Interventions in Inner-city Housing* (No. NISTIR 7212). Gaithersburg, MD: National Institute of Standards and Technology. Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CDcQFjAA&url=http%3A%2F%2Ffire.nist.gov%2Fbfrlpubs%2Fbuild05%2FPDF%2Fb05054.pdf&ei=9itCUdfCGceSyQH4-4GoAw&usg=AFQjCNF46Z_hBEN2IMZ7Do02YSZY2a5y5g&bvm=bv.43287494,d.aWc

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

Keesee, M. (2012). Deep Energy Retrofits: Six Real World Examples and Lessons Learned. In *2012 ACEEE Summer Study for Energy Efficiency in Buildings-Fueling Our Future with Efficiency* (Vol. 1, pp. 141–152). Pacific Grove, CA: American Council for an Energy-Efficient Economy. Retrieved from http://www.aceee.org/files/proceedings/2012/data/papers/0193-000006.pdf

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. (2013). Indoor Air Quality and Ventilation in Residential Deep Energy Retrofits. Presented at the Environmental Health in Low Energy Buildings, Vancouver, Canada: ASHRAE.

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

McIlvaine, J., Sutherland, K., & Martin, E. (2013). *Energy Retrofit Field Study and Best Practices in a Hot-Humid Climate*. Cocoa, FL: BA-PIRC/Florida Solar Energy Center. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/energy_retrofit_study_hothumid.pdf

Parker, D., Sutherland, K., Chasar, D., Montemurno, J., & Kono, J. (2014). *Measured Results of Phased Shallow and Deep Retrofits in Existing Homes* (No. FSEC-PF-463-14). Cocoa, FL: Florida Solar Energy Center. Retrieved from http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-510-14.pdf

Walker, I., & Less, B. (2013). An Assessment of Envelope Measures in Mild Climate Deep Energy Retrofits. Presented at the Thermal Performance of the Exterior Envelopes of Whole Buildings XII International Conference, Clearwater Beach, FL: ASHRAE.