Staged Approaches for Deep Energy Reductions in Existing Homes

Linda Wigington, Affordable Comfort, Inc.

ABSTRACT

It is possible to achieve substantially deeper reductions of energy use in existing homes than was previously assumed practical or possible. However, a comprehensive "all at once" deep energy retrofit may be overwhelming for many homeowners, either in terms of complexity or expense. However well-intended or cost-effective, fragmented improvements have the potential to create barriers to deep reductions as a result of suboptimal levels of investment in efficiency or the need to undo or redo work to achieve a higher level of performance.

This paper addresses the need for and challenge of steering our investments in home improvements and energy investment so that they lay the foundation for substantial reductions in the immediate future. Staging deep retrofits pose opportunities and challenges. This paper will explore bundles of measures that can be deployed in a staged manner to achieve the following objectives: 1) create, rather than block, opportunities and options for further reductions; 2) minimize negative unintended consequences such as indoor air quality or combustion safety problems; and 3) build the knowledge and institutional and human capacity to achieve deeper savings. Bundles of measures that form a defined package have the possibility of simplifying an array of options and making it easier to communicate choices to occupants and owners as well as designers and contractors. This paper will examine potential strategies and implications for energy efficiency initiatives. The confounding issue of uncertainty, particularly related to the cost and performance of emerging technology, will be acknowledged.

The Challenge

It is increasingly clear that we need to achieve substantially deeper reductions of energy use in existing homes than was previously assumed practical or possible (Architecture2030 2010; CPUC 2008; City of Chicago 2008).1 A new framework can redefine the process of evaluating our options and decision-making. The question is not just "What is missing?"; "What needs to be fixed?"; or "What is not working as intended?" but rather, "What combination of measures will maximize the performance of this building?" "How can we create a value proposition that justifies the investment?"; and "How can we avoid well-intentioned investments that sabotage the opportunity to achieve a deep energy retrofit?"

Actions to improve energy performance, particularly those that address the building enclosure and HVAC systems, should not be done in isolation from home repair and improvements that provide indoor air quality, durability, comfort, and safety. The focus of this paper is on the performance of a home's building enclosure, mechanical systems, and installed equipment, not energy reductions due to lifestyle choices. This paper will outline strategies and bundles of measures that could be deployed in a staged manner to achieve the following objectives:

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1 For example, The California CPUC's goal for the existing residential sector is 20% by 2015 and 40% by 2020. The City of Chicago released its plan September 18, 2008 calling for a 25% reduction from their baseline of 1990.

1) Create, rather than block, opportunities and options for further reductions;
2) Minimize negative unintended consequences such as poor indoor air quality or combustion safety problems;
3) Build the knowledge, institutional, and human capacity to achieve deeper savings.

How Deep Is Deep Enough?

In heating dominated climates, a deep energy retrofit is characterized by a substantially higher level of insulation and air tightness than would normally be found in a new home. Here are three examples that address high performance retrofits. Building Science Corp recommends R-60 attic, R-40 walls, R-20 below grade walls, R-10 floor, with R-5 windows as a rule of thumb for a moderate to cold climate. This approach is combined with careful air sealing, effective mechanical ventilation, and efficient appliances as well as high-performance, spill-resistant space and water heating systems (Pettit 2009). To receive Passive House certification (PHI 2010), a building must achieve .6 ACH50 and verify that it meets performance goals. The PHPP software is used by certified Passive House consultants. Passive House Institute recently released a standard that offers more flexibility for existing homes (Feist 2010).2 In addition to energy efficiency, behavioral choices, community solutions, or renewables are usually needed for a home to achieve the 70-90% reduction of measured annual site household energy use targeted by the Thousand Home Challenge (www.1000Homechallenge.org).

For the purpose of this paper, we are not asserting that one of these approaches is preferable to the exclusion of the others. Each one is stimulating new case studies of existing home retrofits that demonstrate that substantial reductions of energy use are possible, and that deep energy retrofits offer significant non-energy benefits.3 If there were a single prescriptive recipe for high performance, it would be easier to clarify which actions are on the path.

Such a comprehensive “all at once” deep energy retrofit effort leaves little untouched – walls, windows, foundation, attic/roof, mechanical systems, and plumbing. Addressing the building enclosure and mechanical systems simultaneously provides the opportunity to design the systems to match the new greatly reduced loads. However, an “all at once” retrofit may be overwhelming for many homeowners either in terms of complexity or expense (Legg 2009).

The cost of the energy portion of a deep energy retrofit in a heating dominated climate can range from $20,000 to $200,000. Labor cost, house size, and material choices are huge variables. In the National Grid Deep Energy Retrofit pilot that provided up to $52,000 per eligible household, lack of access to financing was a significant barrier to broader participation (Legg 2009).

The alternative to “all at once” is a “staged” approach, incorporating clearly defined end points and identifying stages that, taken over a period of years, will achieve a deep energy retrofit. This is not the same as a haphazard approach with no clear goal in sight. “If you do not know where you are going”, the saying goes, “you will end up somewhere else.”

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[2] PHPP (Passive House Planning (Design) Package) is an Excel spreadsheet used as a planning tool and to determine compliance to PH standards.

[3] A deep energy retrofit addresses the building enclosure, mechanical equipment, and in some cases renewables; it is typically reflected through an asset rating of the building which represents the energy efficiency of the building (the asset) under standardized conditions of weather and internal environment. The rating takes into consideration construction, U values of the windows, doors, floors, ventilation levels, lighting systems, etc.

A deep energy reduction addresses the operational performance of a house. This is based on actual energy use. It is a measure of the energy performance of the ‘‘asset’’ when a particular occupant uses it.

The integration that is needed is not limited to energy improvements. Home improvements provide opportunities that can either open the door to achieving higher energy performance or create barriers that make future improvements more difficult.4

Clarify the Value Proposition

In many cases, the value of non-energy impacts outweighs the energy related impact. While the bottom line is "do no harm," many benefits can be attained. Occupant / homeowner benefits include: improvements in comfort, soundproofing, indoor air quality, building hazards, and sustainability; adaptability to changes in operation or weather; resilience in the case of a power outage or disaster. These do not address the obvious – modernized building systems and components, conceivably increasing the home's value and function.

There are many pre-existing problems in homes. One in fifteen homes has elevated radon, resulting in 20,000 lung cancer deaths annually. Sixty-four million homes have lead-based paint somewhere in the building (EPA 2009). It is estimated that 40% of homes with basements or crawlspaces are damp. Damp living spaces are not healthy (Fugler 2007). Many asthma triggers are found in indoor environments. Over 20 million Americans have asthma; in 1990, asthma was the cause of 4,500 deaths annually (EPA 2009). Though not the sole cause, damp living spaces are a factor contributing to the health cost and disability that result from asthma attacks. Millions of homes have attached garages, which can be sources of carbon monoxide and other pollutants.

Pre-existing hazards can be viewed as an overwhelming barrier or as an opportunity to help to create a stronger value proposition for deep energy reductions. Energy conservation initiatives can either help to resolve or exacerbate these problems. Carefully staged, intensive deep energy reductions are more likely to create comprehensive solutions than product-focused or even some home performance interventions that fail to fully address effective and efficient ventilation, attached garages, asthma triggers, or radon.

Recognizing pre-existing hazards is more critical in a staged project than an "all at once," because hazards may not be addressed fully until a later stage. Using a spill alarm on an atmospherically vented hot water tank may be an adequate option in the interim until the water heater is replaced with one that is spill resistant. Devices that also monitor indoor air quality indicators, such as dew point, temperature, CO_2, or radon could help both the contractor and homeowner identify and manage short-term risks.

Indoor air quality, combustion safety, and air tightness are interlinked. Traditional wisdom is to reduce loads through insulation and air sealing prior to replacing the heating or cooling system. If a deep energy retrofit project is staged in order to spread the costs out over several years, how do you sequence the job without creating combustion safety or indoor air quality problems? One option is to install an integrated mechanical system (IMS) that will address space and water heating and mechanical ventilation as an integrated system, and perform well at a full range of loads. With this type of system, the existing loads can be met safely and efficiently, and the system will work well or even better under part-load conditions.

[4] Examples of home improvements that impact energy use include finishing a basement, installing a deck, upgrading plumbing, or the installation of new windows, siding, or roofing.

Embrace Transitional Interventions

Transitional strategies enhance flexibility as an interim solution. Some technologies may end up being the permanent solution, but identifying them as transitional implies that they work particularly well over the course of a staged retrofit. Ideally, transitional strategies also provide information that helps inform future decisions. They offer an alternative to a significant investment that commits a homeowner to a specific system and use of their home.5

For example, a transitional approach could be to initially install one or two efficient room air conditioners in lieu of a central air conditioning system or multi-zoned ductless heat pump. By combining this with an upgrade that reduces solar and internal gains and controls humidity, one could render a central air conditioner unnecessary. Another example would be to install high performance storm windows and use movable window insulation rather than replacing windows. High performance windows are likely to come down in price as demand grows.6

A deployment strategy could be to offer leases for transitional equipment. Components could also be installed with a plan for future re-use. Highly efficient dehumidifiers, room air conditioners, add-on heat-pump water heaters, or sealed combustion space heaters are relatively portable. Their use provides a low risk, and a less expensive way to investigate the performance point source, vs. central heating and cooling systems. For example, an alternative to replacing a heating system that is inefficient, though still functional, would be to install a sealed combustion gas, propane, or oil space heater or fireplace in the primary living space. The use of the primary central heating system would be greatly reduced. In some cases, the occupants would find that it is not needed at all; in other cases, it may be needed only during the most severe weather. Concerns regarding basement temperatures and relative humidity could be investigated. The homeowner could then embark on a several year plan to substantially insulate and air seal the home, and wait until the work is complete to re-evaluate their need for a central heating system.

The transitional approach maintains flexibility rather than making a commitment to an expensive system that may not be necessary. When a basement exists, the central heating system is usually located there. If the basement is fully insulated, this location continues to be a logical choice. However, if basement moisture and IAQ problems cannot easily be addressed, abandoning the basement and isolating it from the house could be a logical short- or long-term choice. However, this is quite difficult to do effectively if the heating system is in the basement.

Evidence from two initiatives that have evaluated the performance of point heat sources suggest this as an option for enhanced comfort, with average heat energy savings exceeding 30%. The Critical Needs Weatherization Project was a pilot project conducted more than twenty years ago in Pennsylvania using direct vent gas space heaters (Brand 1987). The second is an ongoing field study to investigate the performance of a single zone ductless heat pump in electrically heated homes in the Pacific northwest (Storm, Baylon & Larson 2010; Geraghy, Baylon & Davis 2009).

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[5] An example would be that in lieu of installing a ground source heat pump (GSHP) as Stage 1 of a 5-year deep energy retrofit, it would be moved to the last stage. In the interim, a sealed combustion oil space heater could greatly reduce the reliance on the 15-year-old inefficient heating system. The space heater could be sold or given away at the point that it is no longer needed. In the meantime, by evaluating a home’s comfort and performance with a point heat source, the homeowners may decide that a central GSHP is not needed and opt for either a single zone ductless heat pump or decide to just keep the oil space heater.

[6] High performance windows are defined as those with an NFRC U value of .2 or better.

Avoid Suboptimal Investment and Rework

Do each step correctly and comprehensively the first time. The decisions made regarding a home's structure usually last longer than mechanical systems, appliances, or renewables. Marc Rosenbaum suggests a simple maxim: "Invest as much as you can afford to reduce the load, even if it means completing a project in phases" (Rosenbaum 2008).

How is a homeowner or contractor to know the optimal efficiency rating, R-value, or targeted building tightness? The answers are not consistent.7 However, an even bigger problem is the perception that there is a correct answer that is independent of our values and assumptions. In reality, many assumptions are embedded in any determination of optimal economic investment (Hermelink 2009). The answer for a specific project can be answered a number of ways, and this affects the outcome. Who is paying for the project? What are the project goals and objectives? Is this an economic decision? If yes, what are the costs for material, labor, and financing? What is the value of the energy saved, and over what time period? How are non-energy benefits factored in? Are components being viewed as part of an integrated system or as isolated products? Will there be another opportunity for an upgrade in the near future? Are the savings or equipment performance estimates accurate? Clearly, the answers are driven by the project goals. Homeowners seeking expert advice need to convey their goals and make sure the professionals they engage are aware of and responsive to their context. It is ironic that the professionals who are most knowledgeable about residential energy savings could be a liability to a deep energy retrofit project. This is because they fail to recognize that their focus on traditional measure-specific cost-effectiveness creates lost opportunities. If my family's goal is to achieve carbon neutrality in a heating dominated climate and installation costs are not a barrier, concerns for diminishing payback as we move from R-40 to R-80 open blown attic insulation are not an issue (Straube 2009).

When you have the opportunity, it is important to seize it. In many cases, such as with open blown attic insulation, the cost per R value decreases with higher levels of insulation; much of the cost of a job is the fixed transaction cost and job site preparation. Installing drill and fill wall insulation may not be cost effective in a mild climate, but that measure could make a huge impact on the comfort and energy use of the home. Instead of asking the question, "Is this cost-effective?" the question that will yield more significant energy savings is, "How can we affect the value proposition by reducing the cost and clarifying the benefits?"

Components of a Staged Deep Energy Retrofit Effort

Bundles of measures that form a defined package have the possibility of simplifying an array of options and making it easier to communicate choices to occupants and owners as well as designers and contractors. These bundles are critical to the deployment of staged retrofits in a community setting. This could be an alternative to the customized house specific audit with a large array of individual measures. Such packages could build on regional needs and concerns. For example, in areas such as Oklahoma City that have experienced severe storms and frequent basement flooding, the basement packages could address increased resilience to flooding. In areas at risk of wildfires, there are measures such as the elimination of a ventilated attic that reduce the chance of a home catching on fire and also improve a home's thermal performance.

[7] There may be consistency in terms of energy codes; however, this should be viewed as the floor, not the ceiling. The energy code defines the worst performance that you can legally achieve.

By placing the focus on the value, such as security, convenience, comfort, sustainability or adaptability, a specific retrofit package can be marketed more effectively (Wigington 2008b). While many home improvement contractors deliver basement or crawlspace remediation, what we are proposing is the development of technical packages that are more comprehensive in terms of both the energy and non-energy performance. A stamp of approval or certification for approved packages could improve consumer confidence and be linked to financing. An added benefit would result if the home insurance or home financing industries recognized a value in reducing claims and maintaining home value.

We do not have consensus on the "right investment," and the package concept could just as easily create and mobilize what may later be viewed as suboptimal investments. There is a danger of taking a prescriptive package from one climate and applying it to a different one. Field testing the energy and non-energy performance of packages in a variety of settings is essential; ongoing rapid feedback for continual improvement is a critical program design element.

This example demonstrates the potential for confusion, particularly if incentives are driven by the current preoccupation with payback. With the focus and primary goal on cost-effective energy savings, the recommendation for a home with ductwork in the attic may be to seal duct leaks and add insulation to the ducts. Doing so will improve comfort and reduce energy use. In some cases, contractors recommend redesigning the ductwork and installing a new distribution system. If the heating and cooling loads are high enough, and the existing ductwork is bad enough, either option can yield impressive improvement in performance. However, with the larger context of a deep energy retrofit, the focus would not be just on the ductwork, but on the ultimate tightness and performance of the building. Consideration would be given to moving the ductwork inside the home's thermal boundary, moving the thermal boundary to include the ductwork, or possibly eliminating the need for the ductwork altogether.

Below are four components that can be staged as part of a deep energy retrofit effort. They are not identified in a prescriptive manner because of variations in climate, site, and household characteristics. You will see that energy performance is seldom the sole driver; non-energy factors impact the characteristics of a selected retrofit. Ideally, within a community or regional setting, a variety of prescriptive packages could be developed and tested for optimization. It is anticipated that a decision tree would assist a homeowner in selecting an appropriate package. When modeling is used to analyze options for specific vintage housing stock, it is imperative that the uncertainty be identified and field monitoring used to improve our ability to predict performance in high performance homes.8

1) Basement / Crawlspace Remediation

Basements and crawlspaces are often the biggest remaining opportunity for energy savings in homes that are already insulated (Brennan 2008). This is particularly true if they are in a heating dominated climate and are partially above grade. In addition, they are often a source of indoor air quality problems. The World Health Organization is recommending that the radon action level be reduced to 2.7 PC/L from the US current standard of 4 PC/L. Dampness or local flooding is a problem that may only worsen as we experience more intense storms and high levels of precipitation during short periods (IPCC 2007). Solutions that address increased

[8] There are a variety of sources of uncertainty; in addition to energy performance and the value of non-energy benefits, there is uncertainty regarding the cost of energy, products, installation, labor, maintenance, and the cost of financing.

resilience, reduction of asthma triggers and allergens (NAP 2000), and enhanced energy efficiency put basement and crawlspace remediation at the top of my list as a staged component on the path to a deep energy retrofit.

Table 1. Basement / Crawlspace Remediation

<table>
<tr><th>Highest Value Proposition</th><th>Package Elements</th></tr>
<tr><td>1. Major basement problems exist, such as moisture, radon and other soil gases, structural deterioration, or pests.
2. Benefit associated with alteration to space use (either isolation or finishing as living space).
3. Opportunity to integrate with space or water heating system change-out.
4. Benefit to occupants with asthma or allergies.
5. Partially above grade with greater wintertime heat loss.
6. Easier to do at time of sale or immediately after a flood (empty basement).</td><td rowspan="3">1. Address interior and/or exterior moisture and radon problem.
2. Define home’s thermal / pressure boundary to either include or exclude foundation.
3. Air seal / insulate band joist, floor or ground, and walls according to boundary decision, taking into consideration resilience, durability, drying potential, future flooding, pest control, and product flammability.
4. If needed, alter walls to provide for daylight or emergency egress.
5. If clearance is needed, raise house or remove, excavate, insulate, and replace existing concrete floor to increase clearance. Rebuilding the foundation can be the best solution for a dry basement.
6. Provide a floor drain or sump pump to address potential future flooding incident.
7. In planning the home’s ventilation strategy, consider the potential to isolate the basement or crawlspace from the house air.</td></tr>
<tr><th>Barriers</th></tr>
<tr><td>1. Finished basement or installed equipment that blocks access to exterior walls and band joist (stairs, oil tank, hot water tank, furnace, electrical service panel, plumbing, ductwork).
2. Presence of asbestos, mold, or other hazards.
3. Cost and access to address water management from exterior.
4. Interior insulation or finish materials prevent access to exterior walls for inspection.
5. Inadequate head room to insulate basement floor.
6. Contradictory and insufficient information regarding thermal performance of foundation walls and floor. Moisture content of soil, soil type, and proximity of adjacent buildings impact heat transfer.</td></tr>
</table>

Program implications for basement / crawlspace remediation. There is an opportunity for community and efficiency initiatives to demonstrate and communicate a variety of basement remediation opportunities. Partnership opportunities abound. Small incentives could leverage significant homeowner investment, particularly if integrated into: 1) a mortgage at the point of a home sale; 2) building on the opportunity posed after a flooding incident; or 3) as part of a health related effort to address asthma triggers and allergies.

2) Intensive Strategic Air Sealing / Insulation w/Balanced Mechanical Ventilation

Insulation and air sealing are ripe for conflicting standards and claims and missed opportunities due to suboptimal investments. Ironically, at the time a home undergoes a deep energy retrofit from the exterior, previous suboptimal air sealing and insulation can be addressed. The biggest lost opportunity is represented by the millions of homes that are not good candidates for wall thickening.[9] Even experienced contractors using IR, a blower door, and dense pack insulation techniques do not always get two- and three-story homes down to the level where ventilation is recommended. This is due in part to three-dimensional interstitial air leakage between interior and exterior walls and floors.

Table 2. Intensive Strategic Air Sealing / Insulation w/Balanced Mechanical Ventilation

<table>
<tr><th>Highest Value Proposition</th><th>Package Elements</th></tr>
<tr><td>1. Uninsulated walls or attic.
2. Leaky house in heating or cooling climate.
3. Tighter house in heating or cooling climate.
4. Poor indoor air quality.
5. Occupant with health condition affected by IAQ.
6. Remodel, re-siding, or reroofing in progress, providing opportunity to thicken walls, reduce thermal bridging, and improve durability.
7. Integrate wall retrofit with window replacement and possible resizing.</td><td rowspan="3">1. Consider location of thermal boundary (isolate attic or encapsulate it).
2. Decide if, and at what point, wall thickening or encapsulating the attic could be an option. This impacts the first-stage effort. Air sealing targets lower for Stage One if air sealing / insulation will be done in two stages.
3. Achieve significant reduction in air leakage (base target on house vintage demonstrations and work scope; ideally, it should at a minimum meet.3 CFM50 /ft^2 of surface area– 6 sides) by addressing key junctures and breaches in air barrier and, when possible, eliminating them by design as well as sealing cracks and holes (e.g., moving duct to conditioned space).[10]
4. Upgrade conventional attic and wall insulation; insulate to twice the code where possible (Straube 2009).
5. Provide chaseway to attic / roof for future electrical or plumbing upgrades and renewables for future wiring.
6. Install efficient mechanical ventilation.
7. If opportunity for reskinning exists, add continuous air barrier and insulation (+R-20 minimum cold climates) to exterior.
8. If opportunity to thicken to the inside, add insulation to interior.</td></tr>
<tr><th>Barriers</th></tr>
<tr><td>1. Poor uncontrolled indoor air quality is the standard of residential buildings in the US.
2. Most homes are too leaky for mechanical ventilation to work effectively.
3. Standard field practice has not placed a priority on achieving the levels of air sealing or insulation needed to achieve deep energy reductions. This leads to lack of awareness, conflicting goals, and confusion.
4. Adding efficient, balanced, mechanical ventilation is not perceived by professionals or homeowners as a reward of job well-done. Rather, it has typically been viewed as an expense to be avoided.</td></tr>
</table>

[9] This could be due to space constraints, the presence of both interior and exterior skins that are highly durable, location in a mild climate, complex architectural or historic considerations, or lack of homeowner resources.

[10] The potential to reduce air leakage in existing homes varies significantly in response to building complexity, scope of remediation, experience of those conducting the work. As part of staged approaches to deep energy reductions, it is important to clarify CFM50 targets per square foot of surface are for different types of buildings.

Program implications for air sealing and insulation. A unique role that an efficiency initiative could provide would be to focus on common vintage housing stock and develop strategies that successfully achieve substantially larger reductions. This could be done a number of ways, and include competition among contractors posting results by house type, as well as identifying techniques to address the primary missed leakage sites. Once mechanical ventilation is added and indoor air quality issues are addressed, the door is open for further tightening and increased benefits that can arise from it. In a 6,000 degree day climate, a home with 90%+ space and water heating, a superinsulated attic and basement, heat recovery ventilation, and window treatments could perform admirably. If and when the timing and resources are available for re-siding w/window replacements or renewables, the home could be ready. Laying this groundwork greatly reduces the barriers to deep energy retrofits.

3) Point Source, Combi Systems, and / or Integrated Mechanical Systems

A barrier to optimal performance in both new construction and existing homes is the lack of integrated mechanical and water heating systems that can simplify space and water heating, cooling, dehumidification, and mechanical ventilation system installation. When addressed individually, each separate system takes up space and adds to the installed cost. Lowering space and water heating loads after the fact may cause some systems to work less than optimally. In a house with low loads, it can be difficult to justify the cost of highly efficient equipment.[11]

While these issues are recognized as a problem for ultra-low load newly built homes, many existing homes could also benefit from integrated systems. Ideal candidates are smaller homes in mild climates as well as townhouses, row houses, and small and large multis that have individual systems. Even in cold climates. many existing homes may benefit from shifting to "one thermal engine." In many cases when gas heating systems are replaced, the remaining gas hot water system is "orphaned," leaving an oversized and ineffective chimney more subject to spillage, backdrafting, or chimney deterioration (Brand 2010). At the same time, the conventional water heater is still very inefficient (~50% or less) (Hoeschele & Springer 2008, 457). The use of one very efficient combustion appliance to provide both space and water heating at combined efficiencies of over 90% is ideal when supplied as a package by a manufacturer (Gusdorf et al. 2009).[12] If not done as a package, it could require a high level of skill and customization with a contractor or consultant assembling separate components and controls.

11 One might also consider expanding the "box" of the house to include more than one unit (e.g., duplexes, townhouses, and apartments).

12 By efficient, I mean efficient in terms of system performance in a range of partial to full load conditions. High combustion efficiency equipment may have high idle losses (boilers) or fail to condense (DHW equipment and boilers). As a result, some systems that are rated as high efficiency may perform worse than mid-efficiency equipment (Butcher 2007, Evgueniy 2010).

Table 3. Point Source, Combi Systems, and / or Integrated Mechanical Systems

<table>
<tr><th>Highest Value Proposition</th><th>Package Elements / Opportunities</th></tr>
<tr><td>1. Coupled with water heating system replacement as an option.
2. Combustion safety or chimney durability problem that can be fixed with spillage resistant equipment.
3. Equipment at end of useful life.
4. Opportunity to eliminate or fix poorly performing distribution systems.</td><td rowspan="3">1. Reconsider the home’s thermal / pressure boundaries and eliminate breaching new boundaries.
2. Consider fuel switching options.
3. Consider transitional strategies for a lower cost intermediate solution, such as a sealed combustion space heater or room air conditioner.
4. Install systems that are:
a. Spill resistant;
b. Have very low parasitic energy loss;
c. Have high distribution efficiency;
d. Operate efficiently (or whose efficiency improves) as the load is reduced.
5. Consider ductless heat pump or ducted minisplit hybrid in combination with other system (original or space heater) for peak load winter conditions.
6. Consider integrated mechanical system for heating, hot water, cooling, ventilation, and dehumidification.</td></tr>
<tr><th>Barriers</th></tr>
<tr><td>1. We lack testing protocols and standards in the US for combination systems, domestic water heating, and hydronic systems that accurately reflect performance at a variety of load conditions.
2. Our ability to select specific equipment appropriate for high performance homes is limited, particularly as it relates to combination systems, boilers, ductless and ducted minisplits, and integrated mechanical systems (Geraghy, Baylon & Davis 2009; Entchev 2010; Butcher 2007).
3. Lack of verification of field performance.
4. Resistance to and lack of experience by the trades
5. High first cost, due in part to low volume and lack of contractor experience.
6. Inability to incorporate these systems into conventional auditing and modeling tools.</td></tr>
</table>

Achieving Broader Deployment of Combi / IMS (with caution!)

While many aspects of staging deep energy reductions can be deployed at the local or regional level, overcoming the technical and institutional barriers to broader effective use of combination and integrated mechanical systems requires strategic leadership at the federal level. Convening forums to contribute to information exchange among manufacturers, efficiency program managers, policymakers, and trade associations can foster accelerated product development. Accelerated development of testing and standards for determining performance is critical; at a minimum, we need agreement on ways to reflect performance in current rating tools. Let’s tap the technical leaders in weatherization and efficiency programs to embark on accelerated field testing to determine performance and savings across a variety of climates and load conditions. The effectiveness of this effort could be enhanced if managed centrally. An expert process with manufacturers and industry partners could support the design and implementation by identifying best practices, reaching consensus on technical challenges and the design, installation, and commissioning of systems, particularly related to retrofit applications. In order to reduce risk, engage third-party financial underwriting so that consumers, contractors, programs, or manufacturers are not as vulnerable while accelerating the deployment of innovative systems.

4) Water Heating & Plumbing Makeover

Water heating is often the second biggest annual energy load in a home (BEDB 2007 1.2.3). On average, and in mild climates or in low load homes, it may be the largest end-use. Atmospheric gas tank water heaters are the most common type encountered in single family homes, and these are the ones most commonly installed as replacements (Adams 2009). Actual field performance is 50% at best, and significantly worse as hot water use is reduced (Thomas et al. 2009 27; Hoeschele & Springer 2008, 457). Our water-using appliances and fixtures use less hot water now than previously, but the plumbing codes have not been updated to reflect new flow patterns. As a result, plumbing systems do not function effectively when viewed from the perspective of user satisfaction, water use, or energy use (Klein 2010). This is less of an issue in older two-story homes with the utility room, kitchen, and bathrooms stacked horizontally in a compact core; it is more significant in larger homes with longer plumbing runs.

Table 4. Water Heating & Plumbing Makeover

Highest Value Proposition	**Package Elements**
1. Plumbing is out of date or in need of repair, such as slab on grade homes with embedded plumbing. 2. Delay in getting hot water to point of use is an aggravation to occupants. 3. Current hot water use is spread out widely in the home. 4. Water savings or waste water reduction is a high priority. 5. Furnace has been or will be replaced and current water heater is vented into the original chimney (orphan water heater). 6. Due to house tightness or pressure imbalances, the backdrafting water heater is a problem. 7. Other changes to the plumbing system are needed.	1. Replace water heater with one that will perform well at both high and low loads. 2. Consider relocating water heater to a more central location and replumbing with smaller diameter plumbing on hot water side, applying structured plumbing concepts. 3. If combustion appliances are present, consider a combi appliance (one thermal engine) for both space and water heating. 4. If water is heated by electricity, consider a heat pump water heater, particularly if dehumidification is a value. 5. Consider eliminating the hot water line to infrequently used and low-use fixtures and using point source electrically heated water. 6. Incorporate freeze protection or increased freeze resistance. 7. Increase insulation between water heater and uninsulated surfaces during installation. 8. Consider heat recovery (from dehumidifier, attic pre-heat, or drain water heat recovery) if loads are well-matched and space permits. 9. Consider space and plumbing for future solar hot water system.
Barriers	
1. Water heater is relatively new but poor in performance. 2. Systems are installed that do not perform optimally along the entire continuum of full and partial loads. 3. Systems are installed in locations that are not within the home's thermal / pressure boundary (heating climates). 4. High cost of condensing water heaters. 5. Current US test methods and standards do not convey performance over range of expected load conditions.	

Program Implications: Reducing Energy Used for Water Heating

Integrating energy reductions with tap water and waste water conservation provides an opportunity for greater impact than if viewed alone. Water heating energy use varies significantly (Thomas et al. 2009). Segmenting the market by targeting high users (energy and water) could provide an opportunity for greater impact and cost effectiveness, while developing the infrastructure and experience with the Hot Water Makeover. Energy savings are highly variable in response to both hot water usage and the performance of pre-existing water heating systems. Strategies that address both the behavioral as well as the technical components have the potential for the greatest impact.

Integration with Home Improvements

In 2007, over nine million existing homes had a major exterior upgrade to siding roofing, or windows and doors. The total expenditure for these three items alone was over $38 billion. Interestingly, over 19% of the expenditure for siding and windows was spent on do-it-yourselfer installations (JCHS 2009). These upgrades each offer opportunities for affecting the energy performance for years to come. Some of the nine million projects may be able to be converted into comprehensive deep energy retrofits involving upgrades to all six sides and changing out the building systems. There will be less resistance from homeowners and contractors alike to enhancing a single component through a staged approach.

If a home has a dry basement or crawlspace, spill resistant combustion appliances, and an intentional provision for fresh air, it is positioned for major exterior retrofits. There is less risk and complexity for home improvement contractors and DIY homeowners who are working on homes that have already been prepared (staged). Let's create opportunities to learn from initiatives designed to engage home improvement contractors and do-it-yourselfers through case studies and training that demonstrate deep energy retrofit techniques. Mentoring and engaging in community-build projects can support collaboration among design and energy professionals, energy/sustainable initiatives, contractors, and homeowners. Strategically combining professional and volunteer labor can help to overcome cost and knowledge barriers.

Uncertainty

The only thing that appears to be certain regarding energy availability, costs, environmental impact, and the increased need for adaptability is increased uncertainty. It is also likely that there will be a creative response with a vast array of technical solutions affecting energy use and energy supply. Part of staging a deep retrofit is anticipating the unknown future and designing in adaptability. Even more important, perhaps, is the acceptance of uncertainty.

Knowledgeable and motivated energy professionals and occupants are critical resources. The change agents who are embarking on deep energy reduction projects can help to inform and educate, to lead and serve those in their communities. Mobilizing a cadre of individuals who are willing to test emerging technology in their homes could be a valuable resource for accelerating the refinement and deployment of new systems and products. Building the knowledge and human capacity to achieve deep energy reductions at the community level is an investment in accelerated deployment and enhanced community resilience. We have the opportunity to unleash a creative, entrepreneurial, and competitive spirit to tackle the transformation of our housing stock.

Conclusion

Our patterns of energy use have developed during a period of climate stability, low energy prices, and the perception of abundant sources. The awareness of the need and opportunity to reduce residential energy use is now reflected in a range of national and local policies. There are hundreds of thousands of opportunities to begin to stage deep reductions and influence near-term investments. However, if our vision is limited to component substitution or installing measures that are missing or "cost effective," we will create lost opportunities and not meet the goals being set. "If you do not know where you are going, you will end up somewhere else." Fragmented investments in energy efficiency have the potential to make it harder to reach deep reductions. By starting with the end in mind, a staged process can lay the foundation for successful deep energy reductions.

There is an urgent need to develop, demonstrate, measure, and verify the performance of deep energy reduction components in order to build our capacity to transform existing housing stock. This data can inform us of the potential energy reductions, the broader value proposition, and investment needed to ensure that our homes are sources of security for their occupants, owners, community, and our nations.

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