Remodeling Efficiently – Efficiency By The Numbers

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The world of the built environment is littered with single-family houses. This 'American Dream' has presented itself to us in many forms, from single bedroom bungalows, oversized mcmansions, the 20^{th} floor Manhattan condo and finally, prefabricated / mobile homes. In 2009 the US Census Bureau reports that there were 130,159,000 housing units in the United States. We have a domestic infrastructure that averages 2,392 square feet per new residence built and this is down from the high in 2007 of 2,507 square feet (1). Compound the fact that more than half of these residences are over 34 years old (2) and we have ourselves a remodeler's paradise.

Regardless of form, time marches on, along with ever-improving energy standards, leaving behind a wake of aging structures with diminishing performance begging for attention. As a result of the current economic conditions, the adjusted value of the homes now on the ground compounded with the difficulty of the current lending environment and inability for people to sell what they have, we are at an all time low for new construction reaching back over 20 years (Figure 1). With little other option, homeowners are now, more than ever, opting to improve the houses that they currently own. The focus is not only on aesthetic and space but also function and energy performance.

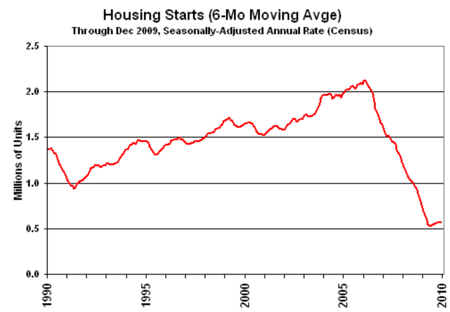

Figure 1: Courtesy Shadow Government Statistics, January 2010

To be sure, there are a myriad of materials, systems, and products that can transform the function of a home but the question remains, what are these tools and how will they pay back? In many cases, the answer is convoluted to the homeowner, architect, designer and remodeler (heretofore also referred to as builder). The manufacturer will give best world scenarios but as it turns out, every home is different, has different needs, and, with different sources of heat gain/loss, is a complex kit of parts affected by a panacea of materials and systems. What may seem to be the most logical change may be secondary in lieu of a more simple and accessible cure. To effectively answer this question and the others that will surely follow we need look at some of the most common issues that older homes face while supplying some simple tools that will allow the builder, architect, and homeowner make an informed decision before executing a design or construction.

Identification:

In my years of home inspection, design and research, I have found that the average home is woefully short on effective energy saving strategies but the highway of options is as long as it is wide. When approaching a remodel project, careful selection of materials, and system improvements based on the opportunities that the project presents is key to maximizing overall value. This means that the most obvious source of inefficiency is not always the most cost effective and therefore may be omitted in favor of more accessible options, that is, one of the mandates are to address most egregious sources of energy loss with less consideration for the budget.

Following from the tenant that budget is the driver for nearly all remodel projects, careful evaluation of the home is primary to discovering what options to incorporate within the scope of the remodel. Using standard calculations and tests we can arrive at a much more educated course of action that will not only yield annual savings in power consumption but also improve general comfort of the spaces to be remodeled.

Visual inspections can easily ascertain the majority of faults within a home. Some of the most common visually identifiable are listed below:

- *Air infiltration around doors & windows (limited visual interpretation)
- *Air infiltration through the structural elements (more difficult to ascertain – see list below)
- Conditioned air loss through aging ductwork
- Substandard insulation or no insulation
- *Poorly insulated windows and doors (identification but requires further calculation)
- Poorly ventilated attic
- Westward facing windows (design flaws)
- Aging HVAC system
- Poor energy practices
- Substandard building materials
- *Substandard installation of building systems
- *Air loss within the duct system to unconditioned spaces

* Indicates that the line item above requires alternative inspection methods to accurately collect data

In terms of of identifying optimum performance and measuring the effects of the systems in place, a more involved method is recommended before making decisions of design and scope. Advanced identification requires 2 additional forms of evaluation, namely, through mathematical interpretation and specialized equipment. With these tools the certainty of apprehending the most problematic culprit amends our above list further.

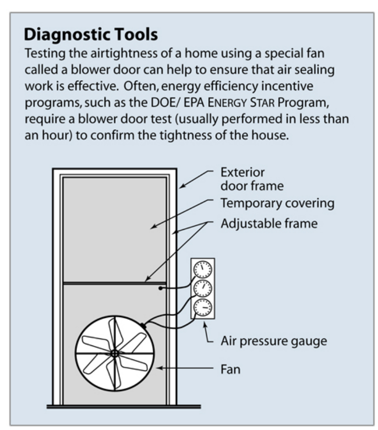

Figure 2: Air Door diagram, courtesy the United States EPA & DOE, 02/09/2011

- Pinpoint air infiltration points
- See heat transfer within walls
- Understand the extent of heat transfer from doors, windows, insulation and other materials
- Consider the entire air infiltration
- Value of mechanical upgrades
- Evaluate the extent of air loss in a ducting system

Advances in equipment technology now allow us to see what was unseen. Simple application of sophisticated devices such as an infrared camera used in tandem with an air door not only identifies the amount of infiltration but the locations. While the combination is powerful, alone, each device offers a host of options for identification of deficiencies. Apart from being a truly fascinating device, the infrared camera or thermal imaging device alone can see missing insulation, (Figure 3) flow of outside air to indoor locations and show temperature variations of different surfaces even through walls, on many new devices, in real time motion. Likewise, the installation of a wind door as shown on Figure 2, can detect the overall air infiltration of a structure. Using either a thermal camera or a smoke stick, the areas of infiltration can be detected and, in most cases remedied. The last critical element to the equipment evaluation should be a duct test. Duct blasting equipment is much like the air door is to the house. This equipment can

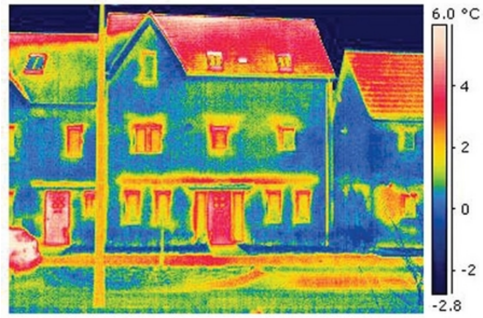

Figure 3: Sample thermal image shows variation in heat loss on overall structure. Note heat loss at third floor attic is indicated by the rather large area of red on the roof.

While owning this equipment is cost prohibitive there are companies and organizations, both locally and nationally, that can perform the above tests with rather accurate results. Cost varies but the average 2500 square foot house can vary between $200 and $500 in today's dollars. In some cases, the cost of the test is waived if the inspection company performs the improvements or by the municipality if the owner makes upgrades.

Aging ductwork comes in many forms. Essentially, however, if the home in question is over 5 years old, there are multiple reasons that air from an HVAC ducting system can loose air. Modern round duct (also known as flex duct) is typically rated at R8 and higher while old flex duct is much less in some cases in past decades, was built of a degradable material that has, in extreme cases, actually rotted away, leaving conditioned air to blow directly into the attic spaces. Likewise, very old square duct often breaks apart at the seams due to constant on/off cycle that changes pressure. This type of duct can be re-sealed but is no match for complete replacement by newer round type duct. Additional tests for ductwork with the duct blaster can serve to accurately measure loss of air and pinpoint accessible leak locations via equipment that pressurizes the system. Once pressurized, a non-toxic fog is injected into the system to locate leaks that are visibly accessible. It is this final test that, combined with the air door test will underscore the home's performance in terms of air leakage and infiltration.

Much like exploratory surgery, the attic is a treasure trove of information. Beginning with the insulation depth and type, this information can readily yield preliminary performance expectations of the building envelope. Application of radiant barrier to the underside of the roof structure is a second item that will provide pertinent data in our overall home efficiency calculation. Experience of this author in attics has yielded a differential of as much as 20 degrees Fahrenheit between attics with and without radiant barriers. In addition to this data, we will also need to look into the attic ventilation. Finally, the visible design of the space should include the ability for the attic to evacuate heat either via the venturi-effect or through a thermostatically controlled attic ventilation fan (not to be confused with a whole home attic fan).

Windows are the eyes, façade and soul of the house but also the highest radiant heat transfer vehicles. Visual inspection can provide our program immediate feedback on the performance of these structures.

In short, we are typically looking at windows that are over 30 years old. This means single pane, poor weather stripping, and thermally un-broken frame materials such as aluminum or wood. In the case of aluminum, these older windows, typically with no thermal break, transmit heat much like a radiator. This simple window material inspection can be plugged into a separate equation provided by the NFRC to yield current performance benchmark with which a comparison to an upgraded window can be conducted.

Our final piece of information will be located both on the interior and exterior HVAC equipment. For this, we are looking for heating capacity, cooling capacity, manufacture date and serial number. Many times this information is included on the labels on the outside of the unit. For cooling capacity, for instance, this number is included in the product number in terms of British Thermal Units per Hour or BTUH of which 12,000 BTUH is equal to one ton of heating or cooling capacity. For sizing purposes, one ton of cooling capacity can condition an average of 600 floor square feet. For example, an exterior condensing unit typically has a serial such as **WOL7321698** number and a model number such as **06092400CU**. These numbers each have meanings, for example, in the serial number above, last four digits are the month and year of manufacture while in the model number above the last 4 indicate the capacity, '24' in this case indicate that it is a 24,000 BTUH or British Thermal Units of capacity (rule of thumb: 12,000 BTUH = 1 ton of cooling capacity) there are other numbers and letters that denote whether the unit is a heat pump or simple condenser. Although it is a rare condition, some manufacturers actually print the date of manufacture and cooling capacity on the tag. All of these numbers provide pertinent information not only on capacity of the unit but also the performance rating or Seasonal Energy Efficiency Rating or SEER. As a rule of thumb, air conditioners that are currently 20-years old or older, pull over twice the electrical current that a new unit of the same cooling capacity that is built within a year of the date of the writing of this article. Without complex calculation, the energy savings and payback of system replacement can be easily calculated. Considering return on investment, replacement of 20-year old split system HVAC units under normal household use, pay back in dollars saved within 3 years and possibly less depending on climate conditions, run time and your local price per kilowatt hour.

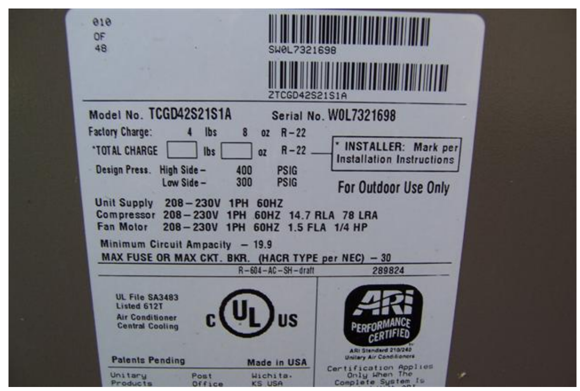

Figure 4: Typical tag on condensing unit. Note Model Number and Serial number. This unit is a 42,000 btuh built in June of 1998. That means that this is a 3 ½ ton unit that should handle a home sized near 2100 square feet.

By The Numbers:

Windows: Now that the house has been evaluated for air infiltration which is one of the chief passive energy saving technique, it will be important to consider the second most influential energy constituent, windows. While serious advances have been made in residential windows over the past 20 years, it has only been within the past decade that we have see local municipalities adopting standards for residential use. Thermally broken frames, double/triple pained glazing, multiple gaskets and low-e coatings have, together revealed a revolution in providing natural light to a home. The problem, again, is age. The majority of the homes built prior to a decade ago likely have windows that allow serious energy loss. How do we calculate for savings of new windows? Traditionally, windows had no standard of measure until the National Fenestration Rating Council required a standardized label to measure resistance to heat loss (U-Factor), Solar heat gain coefficient, visible light transmittance or visible light that can pass through the glass, air leakage around the joints and structure as well as condensation resistance. Each of these measures, with exception of condensation resistance is the first line item needed to calculate the efficiency of a structural envelope. Remember these numbers, as we will return to this section again to calculate the efficiency of a sample home. To pinpoint or compare window performance with existing windows, thermal calculations via the publicly available Window 6.3 software can illustrate the comparisons with currently installed windows with new windows (5). Additionally, with some calculations, we may also take the sun angles on faces of the house such as higher heat gain through south or westward facing windows as opposed to heat loss to north facing windows.

Figure 5: NFRC standard label. Courtesy National Fenestration Rating Council, January 2005.

Attics: Considering numbers, all materials, especially insulation, also have assigned R-values and U-values for calculation of wall efficiency. While rarely used in residential remodel, these numbers will provide a baseline for overall building performance. Typically, when purchasing a home, the inspector will only have the option of inspection of the attic insulation and, as a result of the accessibility of the attic; it is the area we most often see augmented with insulation. In addition to adding insulation, other building materials such as radiant barriers applied to the back side of the roof structure is essential to the envelope calculation for resistance to heat loss & retention. In terms of remodel, the attic area is one of the prime targets to grab additional savings, typically at an economical advantage to other improvement alternatives.

Exterior Walls: There are many ways to build a wall but in all cases we can make an educated guess about the general thermal resistance. While general internal construction of walls may not be visible, reasonable interpretation based on materials on either side, thickness and (if available), photos during construction or old building plans can provide enough information to calculate the overall resistance to heat flow for any given wall composition type. Broken down into it's parts, the thickness of each material yields an R-value which is simply added up for the overall thickness to yield a per-square foot R-value that can be plugged into our equation. If, for example, during a remodel, an exterior sheathing is removed, the application of a simple membrane of radiant barrier covered with a high density / high r-value sheathing such as polyurethane

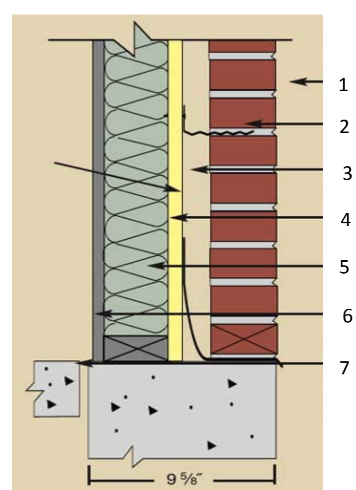

Figure 6: Typical wall section of a wood framed home with masonry exterior and thermal foam sheathing inter-membrane

can be added into the equation for passive efficiency calculations as in item number 4 in figure 6. On the flip side, for instance, if a remodel project dictates that the interior drywall will be removed from the inside of exterior walls containing standard batt insulation, upgrades such as foam insulation can be used to great advantage in the overall building calculation. The addition of any foaming insulation or rigid foam insulation typically provides 2 sources of overall building structural composition performance. It not only doubles the R-value per inch of thickness over standard batt insulation but can also serve as a stop-gap to air infiltration within the exterior walls. As in figure 6, a typical wall section, the R-values are as follows: 1) outside air film is 0.17r, 2) 3-5/8 thick brick is 0.44r, 3) the 1" air space is 0.44r as well, 4) thermal foam sheathing (as discussed above) is R6.5, 5) the 3-1/2" batt insulation is r11, 6) drywall is 0.45r and, finally, the inside air film is considered 0.68r. Simple addition yields a total R-Value for this wall type at R20.21. By calculating the area of this wall and variations to wall types within a structure we begin to paint a thermal efficiency map through area and combined R-value that we can plug in to the final calculations.

Heating and cooling equipment: As above, numbers provided on the manufacturers label or literature will be a critical component in our calculation. Additionally, depending on improvements, we may find in our calculations that the equipment specified for the original house is now oversized for the new efficient configuration, thus, leading to savings not only in purchase of smaller and less expensive HVAC equipment, but also lower power demand combined with lower peak demand providing a double benefit to utility bills and interior comfort. To calculate savings you can use an online calculator at http://www.hvacopcost.com. This will take into account the SEER or Seasonal Energy Efficiency Ratio between the old and new unit. The equation takes into account the upgrade in SEER, the number of hours the unit typically runs during the day and the Kw hour price for your electricity to produce a very accurate savings scenario (5). Typically, stepping up 3 SEER will supply a return on investment within 5 years.

Making sense of it all:

Now that we have covered the essential elements necessary for a detailed home efficiency analysis, it is time to plug in our old & new numbers. While it is possible to do the calculations long hand, for each of the items it is time and knowledge prohibitive for all but the adept engineer or mathematician. For any home our structure for which you collect the above data. The next step is to calculate both the before and after total energy usage and compare this against upgrades. To do this with the most accuracy, the adept engineer, architect or builder will have a computer model into which to plug this data. For our purposes, we are considering the most current version of the highly sophisticated Department of Energy software called EnergyPlus.

EnergyPlus is an actively updated software back-end whole building energy simulation program that engineers, architects, and researchers use to model energy and water use in buildings. Energy Plus can be found at: http://apps1.eere.energy.gov/buildings/energyplus/. While well supported, EnergyPlus is, again, only a back end program, which means that we need a front end or graphic interface to input data and view resultant calculations. There are several powerful interfaces available, all with different objectives and price points. This above page link will also offer the options of plug-in program information that you will need for our application. We recommend using Green Building Studio™ by Auto Desk. This is a subscription based web platform that allows detailed analysis of the building and requires drawings based in AutoCAD™ Architectural Desktop™ and several other types of AutoCAD™ based programs exported to a gbXML file type. This program will return data for both residential and commercial projects but the value is in the time proven accuracy and continuous support.

The power of taking a project already drawn in CAD or a remodel already documented as an as-built drawing and uploading it to the web based client is a powerful tool in understanding the incorporation of value engineering and design aesthetic and providing a strong performing product to the client at a more considerable value. While the hit or miss method of trying a product and hoping for results with varying degrees of success may be appropriate for small singular improvements, for the more savvy client with scopes commensurate with farther reaching improvements and looking for value in addition to visual architectural cues will, in terms of a more educated and well founded proposal, benefit to a far greater degree from this type of analysis.

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Sources:

1) U.S. Census Bureau, 2005-2009 American Community Survey
2) Posted in Real Estate by Creditopia on Jan, 18, 2010, http://www.sabuilding-remodeling.com/articles/9-202RC.php
3) Copyright 2003-2011. Shadow Government Statistics, American Business Analytics & Research LLC.
4) Window 6.3, publicly available thermal window calculation program, NFRC 2011, http://windows.lbl.gov/software/window/window.html
5) 2011 US Airconditioning Distributors, © 2011, www.webhvacopcost.com

6) United States Department of Energy, EnergyPlus Energy Simulation Software, http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename_submenu=energy_simulation