Industrial Revolution

Every home makes compromises among different and often competing goals: comfort, convenience, durability, energy consumption, maintenance, construction costs, appearance, strength, community acceptance, and resale value. Often consumers and developers making the tradeoffs among these goals do so with incomplete information, increasing the risks and slowing the adoption of innovative products and processes. This slow diffusion negatively affects productivity, quality, performance, and value. This department of Cityscape *presents, in graphic form, a few promising technological improvements to the U.S. housing stock. If you have an idea for a future department feature, please send your diagram or photograph, along with a few well-chosen words, to elizabeth.a.cocke@hud.gov.*

The Remodeling Conundrum: When the Order Matters

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Abstract

During the past several decades, too many homebuilders, remodelers, and homeowners tried to make positive change in their houses but ended up with unintended consequences. In fact, many of those consequences could have and should have been predicted. To move our current housing stock forward—whether to make it more energy efficient, healthier, or perhaps more durable—we need to determine how we can increase the potential for success while we reduce the potential for harm. In remodeling and renovation efforts, the changes unfortunately often are implemented out of order; we tighten the enclosure before addressing critical ventilation issues, we upgrade furnaces without ensuring the water heater will continue to operate properly, we add insulation without resolving critical moisture or air leakage problems, and we replace windows without considering potential water management or indoor air-quality effects.

Many of our contemporary new home construction programs (ENERGY STAR, Department of Energy Zero Energy Ready Homes, and many more) have successfully demonstrated a clear pathway and process to achieve high-performance homes that provide superior comfort, efficiency, durability, indoor air quality, and value. It is important to recognize, however, that it took several decades to develop, demonstrate, and deploy

Abstract (continued)

those high-performance solutions that are common in the marketplace today. This article shares a conceptual chronology of what we learned on that journey and how we might use those lessons to develop a repeatable and affordable process for existing houses—which, thus far, has proven to be far more difficult than imagined.

Introduction

Anyone who has remodeled a home knows how challenging and complicated the process can become. The process can be analogous to "boxing with your hands tied behind your back," which requires a person to be nimble, anticipatory, and responsive to remain on his or her feet. Homeowners may know what needs to be done or what they want to do, but they simply encounter too many obstacles or run out of resources. If homeowners add high performance to the list of goals and outcomes, the project takes on even more complexity. This article looks back at the evolution of new construction to analyze options that can move our existing homes forward.

Lessons From the School of Hard Knocks

If we take a trip back to the 1970s, we will encounter a series of energy crises that forced us to rethink our energy consumption in the United States. The message was clear to everyone. We needed to collectively improve the energy efficiency of our housing stock. We needed to build new homes with more efficient standards and retrofit our existing homes, when and where possible, to a higher standard.

Starting With Insulation

Increased insulation seemed like a perfectly logical place to start, but what we did not know became quickly obvious: improper insulation can lead to convective looping, thermal bridging, and air-transported heat and moisture (see exhibit 1). Typical insulation materials in the 1970s and 1980s were vulnerable to airflow within, around, or through them. This effect not only compromised the insulation value, but it could quickly transport moisture to the cooler side of the insulation and potentially lead to condensation and subsequent mold growth or wood decay (see exhibit 2).

Moving to Air Seal

The insulation problem appeared easy enough to fix: contractors should properly install the insulation and provide a continuous air seal. This approach made the building enclosure much more efficient and potentially much more durable as well. When the air sealing was done well, however, the air exchange rate of the house was significantly reduced and existing pollutants and moisture

Exhibit 1

Improper Insulation Can Lead to Convective Looping, Thermal Bridging, and Air-Transported Heat and Moisture

Good intention: Installed high levels of insulation to the attic.
Unintended consequence: Concentrated heat loss due to air leakage around the plumbing stack contributed to snow melt and future ice dams.
Solution: Air-seal all holes before installing the insulation so both transmission losses and air leaks are properly managed.

Source: Patrick H. Huelman, 2000

Exhibit 2

Air-Transported Moisture Can Lead to Condensation and Subsequent Mold Growth or Wood Decay

Good intention: Heavily insulated wall cavities and rim (band) joists.
Unintended consequence: Air-transported moisture (because of elevated interior humidity and indoor pressures) condensed on the cooler sheathing.
Solution: Install a continuous air barrier to prevent exfiltration of moisture air during winter.

Source: Patrick H. Huelman, 1995

loads began to build, resulting in indoor air-quality concerns. Subsequent research showed that poor water management resulted in many of these walls taking on exterior water over time (see exhibit 3). In addition, as these walls were no longer poorly insulated and no longer leaked air, they could not dry out with time. Not enough energy flow was available to convert the water to vapor, and not enough airflow was present to carry the vapor out of the cavity.

Exhibit 3

Over Time, With Poor Water Management, Walls Can Take on Exterior Water

Good intention: Framed wall with good insulation, air barrier, and vapor retarder.
Unintended consequence: Water leaked into a window cavity that had limited drying potential.
Solution: Provide proper exterior water management to limit water infiltration.

Source: Steve Klossner, 1998

Examining Water Management

After professionals recognized that building penetrations (vents, windows, utilities, and so on) also leaked water and put the durability of the wall system at risk, they decided to refocus on exterior water management (see exhibit 4). This decision, in general, had very little kickback. It might have further tightened the building enclosure, however, and further reduced a home's natural air exchange.

Adding Ventilation

Problems began to become evident indoors. Odors lingered, moisture accumulated, and indoor pollutant concentrations began to increase—a result of the overall reduction in air exchange and also a lack of attention to indoor pollutant sources (see exhibit 5). The resolution was pretty straightforward, however—pay attention to interior sources, remove what you can, and provide good ventilation for the remainder. By this time, the mantra "build tight, ventilate right" was widely recognized, although advocates of the "house as a system" frequently suggested that it should be "ventilate right, then build tight." That suggestion really is the inspiration for the entire conversation in this article.

Exhibit 4

Proper Exterior Water Management Can Limit Water Infiltration

Good intention: Constructed 2-x-6 frame walls with good insulation, air barrier, and vapor retarder.
Unintended consequence: Improper stucco cladding added moisture to a cavity that had low drying potential because of reduced heat and airflow.
Solution: Provide proper exterior water management to limit water infiltration and a wall design with improved drying potential.

Source: Richard Stone, 2009

Exhibit 5

When Air Exchange Is Reduced, Indoor Humidity and Window Condensation Increase

Good intention: Weatherized house (added insulation and airtightness).
Unintended consequence: Amount of indoor humidity and window condensation became elevated.
Solution: Control interior moisture sources; add source point and whole-building ventilation.

Source: Joe Nagan, 2004

Addressing Combustion Gases

As houses became tighter and the amount of exhaust increased, the negative pressure working against natural-draft chimneys grew. This condition led to increased combustion spillage, back-drafting, and flow reversal, causing combustion gases to enter homes (see exhibit 6). Because of the potential for nitrogen oxides and carbon monoxide to be added to the indoor environment, construction professionals addressed this concern with new equipment, makeup air, and safety devices.

Exhibit 6

Good Insulation and Air Sealing Can Cause Backdrafting of Combustion Byproducts Into a House

Good intention: Ensured the house was well insulated and air sealed and added exhaust devices.
Unintended consequence: Negative pressure in the combustion zone caused backdrafting of combustion byproducts into the house.
Solution: Reduce the negative pressure with makeup air or switch to sealed or power-vented appliances.

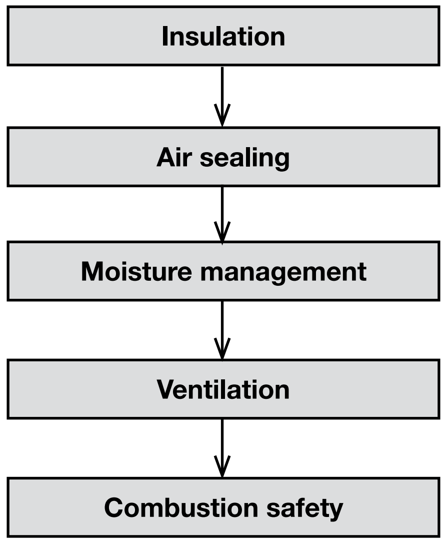
Source: Joe Nagan, 2006

Lessons Learned

Although this story of how new home construction has evolved since the 1970 energy crisis is highly conceptualized, it clearly documents a trail of mistakes and lessons learned (see exhibit 7). The overriding objective is to set the context for how to move forward to improve the energy performance of our existing house stock.

Exhibit 7

The Order Matters—This Order Has Proven To Be Risky for House and Occupants



Will History Be Repeated?

Many current energy upgrade initiatives seem to focus on insulation—some with air sealing and many without. This continued approach suggests that we are setting ourselves up to repeat history. A parallel story to the one discussed previously is based on the experiences of the energy weatherization program throughout the United States. The story unfortunately follows a very similar path with a lag time of one to two decades. Today, most weatherization programs fortunately recognize the system implications and take a much more holistic approach that includes significant testing.

To examine a contemporary approach, we will start with a question. Is it possible to upgrade a home in such a way that the renovation might push it over the cliff? The "cliff" is a metaphor for what might happen if a house is moved too close to the cliff, where it might become unstable and fall. For an energy upgrade, this failure refers to an efficiency, durability, indoor environmental quality or to a health and safety problem. We are using the cliff concept to help people think about where the house is today with respect to the cliff and how much closer or farther away it might be when they make a change.

The effect of any change is twofold. First, homeowners must consider the type of change they are making. If they are simply changing light bulbs, the change is unlikely to significantly affect how the house system is performing. On the other hand—based on the above history lesson—if homeowners add insulation or a large range hood, the change could result in significant consequences. Second, homeowners must consider the robustness of the current house. Some houses are so stable that even large blows to the system will be absorbed. Other houses are much more fragile, however, and small changes can have larger effects and move the house toward the cliff much more quickly.

The critical questions that both contractors and homeowners must address are these—

1. How close is the house to the cliff before the change?
2. What type of change are they proposing?
3. How robust or fragile is the existing house?

The answers to these questions will ultimately determine how the house performs when the changes have been completed. A previous article published in the Industrial Revolution department of *Cityscape*, titled "Reducing Appliance Backdrafting Risks With HVAC-Integrated Makeup Air Systems," provides an excellent example of this concept and approach (Turns, 2013).

Moving Forward With Our Existing Homes

How can we take these lessons and apply them to the decisionmaking process for upgrading our existing housing stock? A good example is the current U.S. Department of Energy Building America program for existing homes, which focuses on reducing energy use by 30 percent by accelerating the adoption of high-performance technologies using a systems engineering and integrated design approach. It is inclusive of a "do no harm" promise to ensure that safety, health, and durability are maintained or improved. The following three overarching strategies that could be employed are built upon the lessons of the past and should mitigate undesirable consequences.

Strategy 1: Follow the Proper Order

The first strategy simply follows the previous new construction order of events, but in reverse (see exhibit 8). Problems are rarely created when using this order. If construction professionals properly address combustion backdrafting and spillage (for example, by installing sealed combustion space and water-heating equipment), subsequent changes in ventilation or airtightness will be accommodated. If they install whole-home ventilation, homeowners will have little concern for future air sealing of the building enclosure. If they properly implement water management and air sealing, adding insulation will be of little risk. The challenge to this order is not so trivial. A significant investment may be needed to prepare the home for the final measures—air sealing and insulation—that can ultimately provide a financial payback to the homeowner.

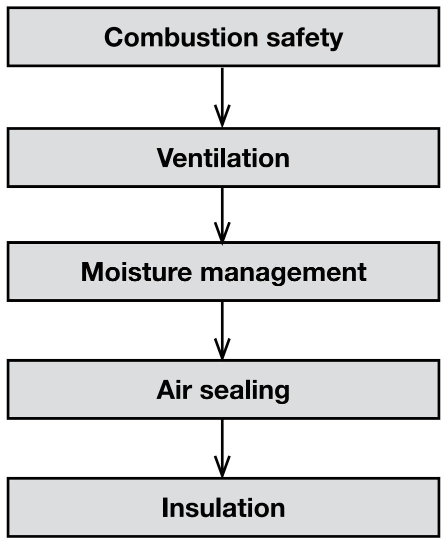
One final and important caveat exists with this new order. For many homes, changing the furnace, water heater, and hearth products from natural-draft to sealed or direct-vented equipment can dramatically reduce the overall air exchange of the home and lower the neutral pressure plane in the home. While both of these outcomes are desirable, they can increase the indoor moisture and pollutant levels and the exfiltration of heat and moisture at the upper sections of the home. By moving to the second strategy—implementing a good ventilation strategy—homeowners can easily mitigate this concern.

Strategy 2: Test In and Test Out

What happens if this order is highly impractical or prohibitively expensive? A second strategy that is widely promoted today uses tests to determine the current condition of the house and how fragile

Exhibit 8

The Order Matters—This Order Minimizes Risk to House and Occupants



it might be. That information can be used to better inform and guide the work being contemplated. After the work is concluded, testing is repeated to ensure proper performance of the house and its systems. This approach should reduce unforeseen consequences using the initial testing and identify any remaining problems through the final testing. Many building professionals, however, argue that this testing—both before and after installation—adds significant costs that could have been used to further enhance the improvements to the home.

Strategy 3: Combined Approach

The last strategy focuses on the type of work being proposed and its probability of negatively affecting the performance of the house. In essence, it is a blend of the first two strategies. If the upgrade is unlikely to cause issues with the current house systems, it is given a green light to move forward without testing. Actions like changing to more efficient light bulbs, upgrading to a more efficient refrigerator, or using a programmable thermostat improve efficiency and can have potential system interactions, yet they are highly unlikely to push a house over the cliff. Other items such as adding insulation, installing a new furnace, or applying whole-house air sealing, however, have large system interactions and have the potential for major changes in house durability, indoor air quality, and combustion safety. These proposed changes would be given a red light to encourage homeowner and contractors to "stop, look, and listen" to see if the house could be pushed over the cliff with any of these changes. Of course, some measures may fall in between the green light and the red light, and perhaps some very robust houses are unlikely to be moved very far. These conditions would get a yellow light, requiring due caution throughout the process and perhaps a quick or abbreviated test at the completion of the work to ensure the home is left in a safe condition. For instance, based on the caveat given above, a furnace changeout might be a yellow light and could necessitate some followup testing to make sure the house has not moved closer to the cliff.

Conclusions

We can, and must, do better this time around. There is simply no reason for the remodeling, renovation, and home improvement industries to repeat the mistakes of the past. Furthermore, homeowners do not need to bear the scars of these past lessons. Although we recognize the clear challenges and limitations with remodeling, retrofitting, and installing energy upgrades, the basic principles and processes still apply. These lessons and their application, however, will need to be brought to the market by a whole new set of contractors. Those who set out to improve the performance of our existing housing stock must incorporate these lessons and solutions into their daily procedures and practices.

Acknowledgments

This article is a reflection on decades of experience, observation, and research by many building scientists and construction professionals. The author acknowledges their contribution and thanks them for sharing their insights and knowledge.

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