Adoption of Innovative Products in the US Housing Industry: Builders' Practices 2000-2010

Residential Building Design and Construction Conference
February 20-21, 2013
Bethlehem, PA

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Abstract

Researchers and policymakers have struggled with the lack of technological innovation in the US housing industry (Koebel 1999). While housing is arguably no different in nature than other industries, several unique factors have been established as causing risk and uncertainty in the context of innovative construction technology (McCoy et al. 2009). Previous intervention strategies borrow from other industries to explain prior adoption and diffusion patterns and do not address the divergence of recent residential construction technologies. Where homebuilding innovation has traditionally experienced slower rates of adoption, some green building technologies exhibit accelerated patterns. In order to understand underlying reasons for resistance, it is important to not only understand uncertainty and risk, but also articulate use of innovation in the residential built environment. Towards this goal, the authors examine and highlight broad patterns of innovation use (adoption) by builder firms within clusters of products (i.e. traditional versus innovative) for six energy efficient (EE) products, across recent years.

Introduction

Definitions of green building remain broad and do not necessarily reflect the needs of the residential construction industry, According to the fifth edition of The Dictionary of Real Estate Appraisal Sustainability (2010), green design and construction is "the practice of developing new structures and renovating existing structures using equipment, materials, and techniques that help achieve long-term balance between extraction and renewal and between environmental inputs and outputs, causing no overall net environmental burden or deficit." In 2007, the United States Energy Independence and Security Act defined a high performance building as one that "integrates and optimizes, on a lifecycle basis, all major high performance attributes, including energy [and water] conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations" (EISA 2007).

In residential construction, High Performance Homes (HPH) can include a variety of proven energy-efficient features that: 1) contribute to improved home quality and comfort, lower energy demand and reduce air pollution; 2) include features such as design strategies and installation methods; and 3) use innovative green products (Lukachko et al. 2011). Such features have been suggested as significant in achieving green, high performance buildings, with green product technology offering solutions that reach across all features of green construction, design and HPH, including the green strategies and categories of accepted certification systems. As a result, HPH green product technologies contain broad implications for the Architecture, Engineering and Construction (AEC) industry.

Despite the increasing worldwide concern for the environmental impact of buildings, the residential construction industry is often seen as a laggard industry or one adopting innovations only after the products or techniques are clearly established (Dibner and Lemer 1992; Laborde and Sanvido 1994). Homebuilding firms are also perceived as laggard and resistant to the benefits of technological innovations (Tatum 1987). Researchers and policymakers have struggled with the lack of technological innovation in the US housing industry (Koebel 1999). While housing is arguably no different in nature than other industries, several unique factors have been established as causing uncertainty and risk in the context of innovative construction technology. Reflecting on the "Laggard industry" assumption, Koebel et al. (2004) identified barriers and impediments to innovation for firms in residential construction. Based on these barriers and others, McCoy et al. (2012) consolidated uncertainty and risk into the following categories: site variability, one-off nature, longevity of warranties, supply chain variability, path dependency and stakeholders.

However, previous studies on innovative practices do not address the divergence of recent residential construction technologies. For example, in place of path dependency and resistance to innovation, numerous industry studies point to a widening awareness and likely use of innovative practices and techniques that support environmental goals (Bodie et al. 2008). Where homebuilding innovation has traditionally experienced slower rates of adoption, some green building technologies exhibit accelerated patterns. In order to understand underlying reasons for resistance, it is important to not only understand risks, but also articulate use of innovation in the residential built environment.

Towards this goal of articulation, the authors examine and highlight broad patterns of innovation use (adoption) by builder firms within clusters of products (i.e. traditional versus innovative) for six energy efficient (EE) products, across years 2000-2010. The paper first reviews literature on uncertainty and risk that might hinder innovation in housing, building construction and green building. Second, we examine data from the National Association of Home Builders' Builders Practices Survey from 2000-2010 and describe the diffusion trajectories of the following six energy efficient, HPH product technologies in residential construction: 1) insulated concrete forms, 2) structural insulated panels, 3) cellulose and spray foam insulation, 4) PEX tubing, 5) programmable thermostats and 6) air infiltration barriers (housewrap). Each product is analyzed within a cluster of their substitute products, and based on the survey questions asked.

Literature Summary and Review

Research shows that innovation in construction in general and in the residential construction industry, specifically, has been slow to be adopted. While relatively few innovation studies are specific to uncertainty and risk in residential construction, researchers have attributed resistance to adoption and diffusion to many factors.

Beginning in the 1990's, researchers investigated innovation broadly, while some recognized the need to focus at the product level. In 1993, Slaughter investigated the product case of "stressed skin panels" and discovered that most of the innovation occurred at the builder level rather than at the manufacturing level. Slaughter later investigated unique elements of the construction industry and how they informed categorical models of innovation (Slaughter 1998). She suggested that theories of innovation should be modified when applied to construction due to the complexity, long lasting facilities. These facilities are created and built by a temporary alliance of disparate organizations within an explicit social and political context (Slaughter 1998). A 2004 survey of builders indicated that national and regional homebuilders, multi-family builders, modular, and custom builders are more likely to adopt innovations than other firms (Koebel et al. 2004). Koebel et al. (2004) also identified innovative firms as likely to: have a technology advocate in the firm, stress creativity, use a technology transfer program (e.g., PATH), and use union labor at least some of the time. These innovative builder firms also recognized the importance of demand for innovative products (from homebuyers) as well as the ability of a manufacturer to stand behind the quality of their product (Koebel et al. 2004).

Koebel et al. (2004) also identified several barriers and impediments to innovation in residential construction for large, production builders: R&D expenditure shortfalls, liability, cyclical market, disaggregation (many small firms), diverse building codes, and financial/insurance concerns that can and do inhibit the adoption of innovation in the construction industry. Larger firms relied on advantage/cost of products, while smaller firms required: high product awareness, an innovation's lower price to its replacement, and a change in the home production process. In addition, firms building in locations where increased awareness of innovative materials existed were more likely to adopt, while areas exhibiting path dependency and resistance to new technology contained limited potential for adoption (Koebel and McCoy 2006; Koebel et al. 2004).

Since the early 2000's, several trends have also emerged that could affect innovation adoption and diffusion for residential construction firms, including: homebuilding firm consolidation and growth of national, publicly traded homebuilding firms, increased industry concentration in high growth metropolitan markets, migration of technical/management talent from outside industries, decreasing supply of developable land for medium density development (increasing restrictions on land development), increasing energy costs, decreasing supply of craft labor, and Systems integration tools for design, modeling, and processing (Koebel and McCoy 2006).

While an understanding of general industry risks for residential construction exist, it is also important to understand uncertainty and risk for areas of the industry prone to adoption. Where homebuilding has traditionally experienced slower rates of innovation adoption, some specific green building technologies exhibit accelerated patterns. General innovation research on green building products has focused on user behavior, termed ecological consumer behavior, while recent work in residential construction focused on the performance characteristics of the product itself (McCoy et al. 2012). Common attributes affecting diffusion of green products in residential construction include (McCoy et al. 2012):

- Timing of Commitment,
- Compatibility/Special resources,
- Supporting Innovation,
- Complexity,
- Simplicity,
- Trialability,
- Observability,
- Relative Advantage/Cost,
- Risks,
- Supervision Competency,
- Consumer Resistance,
- Trade Resistance,
- Regulatory Resistance, and
- Coordination with Project Team.

Energy efficient, HPH construction is gaining acceptance as a sign of excellence in the trade, limiting the options in the market for firms who cannot bring these skills to a building project. Other factors, such as energy prices, regulation, and health or safety concerns, also increase the need for the adoption of energy efficient and 'green' practices in the building construction field. Similar types of evidence for price premiums have been found in certain housing markets and given certain types of green attributes of housing (Aroul and Hansz 2011; Bloom et al. 2011).

Nevertheless, few studies have been able to articulate statistically significant patterns of use for green products. According to a National Association of Homebuilders (NAHB) poll (Hudson 2011), almost 80 percent of respondents mentioned actions and products within the 'green' portfolio. Building industry professionals provide ample testimony that green building is not a trend or a passing phase (McCoy et al. 2012). Instead, energy efficiency and related HPH building practices are becoming the state of the art in the building industry and the ability to deliver these services to clients are increasingly important to maintaining a successful business. This work therefore aims to increase the significance of understanding for levels of firm adoption, and in the innovation literature, through an analysis of use for six EE HPH products (adoption), across builder firms (diffusion) and among substitute products within its cluster over time.

Methodology and Research Steps

This paper utilizes data from the 2000 to 2010 National Association of Homebuilders' Builder Practices Survey (BPS) on the annual use of high performance products (and related substitute products) by builder firms. The BPS survey data includes approximately 2 to 3 thousand firm responses, at FIPS county, state and regional levels, per year and over 1100 total products. Usage data for this paper only reflects a binary level of use and non-use, as opposed to percent use by firm, while percent use is available. To begin, the authors explored the survey, identified EE HPH products and classified them into 20 major innovation clusters (e.g. Engineered Wood, Air Sealing/Cement Board Siding/Insulation, Home Electronics, Insulation, and Plumbing). Some of these clusters had subdivisions, for instance, Engineered Wood Cluster includes types of wood floor framing, types of exterior wood/steel frame walls, and type of roof framing. Based on these clusters, this work draws on 6 high performance products and identifies their usage patterns during the time period of 2000 to 2010. The total use of these EE HPH products, across builder firms and across clusters of products, is plotted by product in the following findings section. Figure 1 describes the process of creating these use plots.

In order to produce the first group of graphs, a summary sheet was extracted which includes the number of firms and their responses to whether or not they have used the product across 10 years from 2000-2010. The relative use of each product within its cluster was determined by calculating the total number of firms using each product in each year and was called n_{ij}, where i represent each product within the cluster and j represents each year from 2000-2010. Then, the total use of all products in each year, n_{tj} was calculated. Finally, index S_{ij} was determined by the following equation:

$$S_{ij} = \frac{n_{ij}}{n_{tj}}$$

The resulted indices (i.e. S_{ij}) were then plotted using JMP software. The plot of each cluster, in the coming findings section, shows the percentage usage of each product relative to other products within that cluster during 2000-2010. Note that plotting years were often due to the availability of data for certain products over time.

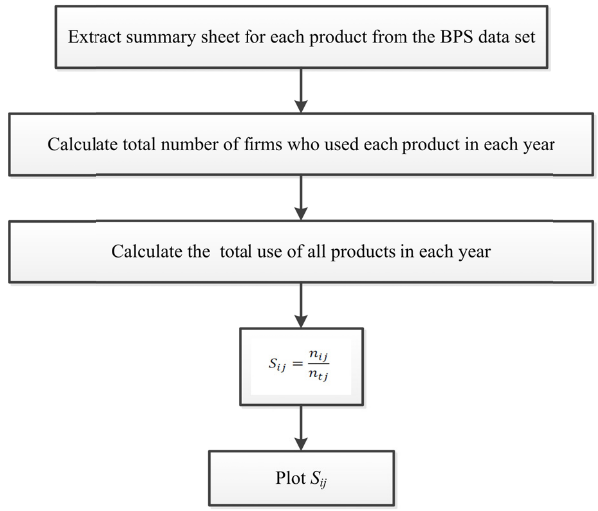

Figure 1. The process of producing graph 2-7.

Findings

Fig. 2 describes materials used by builders in basement or crawlspace walls. Poured concrete and concrete block are the two market leading building materials with block taking market share over the last five years. Interestingly, insulated concrete forms (ICF) has made a very small penetration in the market and appears to be sensitive to market conditions, with a somewhat increasing share in economic expansions and decreasing share in contractions. ICF represents a systems innovation that requires changes in how the house is built, different contactors, and potential disruptions in other contractor, supply chain, and regulatory networks. HPH innovations of this sort will have to overcome the inherent resistance of path dependency and the equilibrium reinforcing effects of networks.

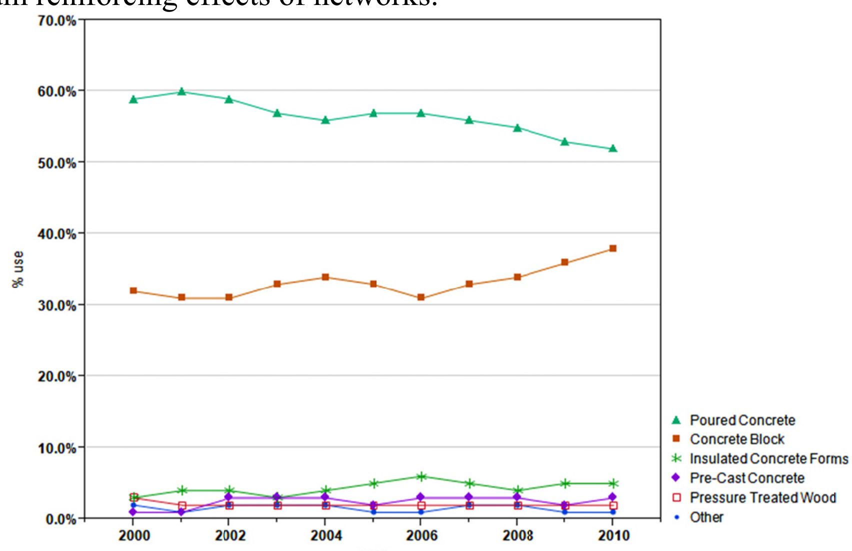

Figure 2. Basement/crawl space wall material vs. year.

Figure 3 depicts the cluster of exterior wood/steel wall products and includes Structural Insulated Panel Systems (SIPs). Site built walls with dimensional (2 x X) lumber dominate the market with nearly 90% use from 2000 to 2010. Panelized light frame systems comprise less than 10% of market share. Similar to findings in McCoy et al. (2012), SIPs walls represent a consistent 2% of the above grade wall market. Similar to ICF, SIPs represents a building systems technology innovation that requires some changes to the home construction process. Most of these changes focus on acquisition via the supply chain and movement/installation strategies due to panel weights. However, unlike ICF, SIPs panels do not represent a significant interruption to the construction process from knowledge, scheduling or tooling standpoint. More research on the obstacles and drivers of SIPs is needed to determine why a technology with significant insulation value occupies so little of the wall market.

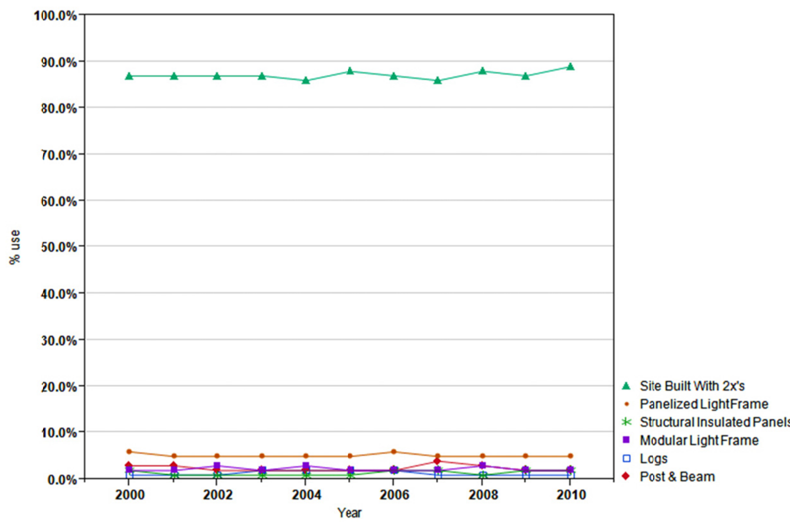

Figure 3. Types of exterior wood & steel walls vs. year.

Figure 4 characterizes wall cavity insulation material use over the study period. Fiberglass batt insulation is the market share leader capturing nearly 60+% of use. However, with it declining in use from 80% to 60%, other insulation technologies have gained share. Blown cellulose and spray foams have grown to capture a combined 20% of the market. Interestingly, spray foam popularity spiked in 2007 indicating potential market displacement of other economic substitutes and will be targeted for further research. Blown cellulose and spray foam insulations represent material innovations but not system innovations. They require very little out of the ordinary for a general contractor in terms of new skills, tools, labor, scheduling, or supply chain knowledge and provide higher levels of building energy performance.

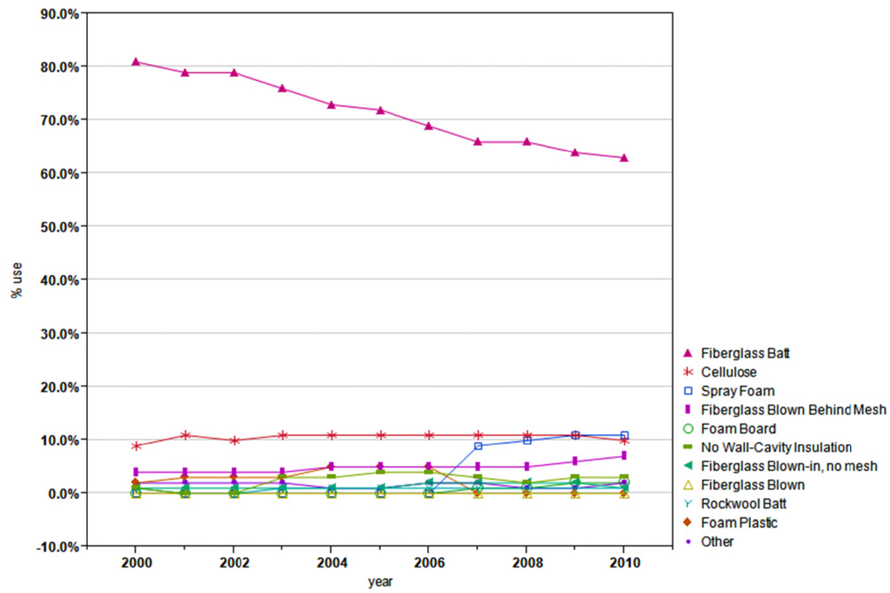

Figure 4. Wall cavity insulation material vs. year.

Figure 5 describes use of various types of water pipes from 2000-2010. Copper pipes dropped from nearly 65% of the market to 30% in 2010. Part of this decline can be explained by the five-fold increase in the retail price of copper/lb during the study period though certainly other factors contributed. Use of PEX piping grew from substantially from 2000 to 2010 when nearly 55% of builders reported use. PEX represents an innovation in piping, as it does not corrode like metal. Further, it is resistant to both scaling and build up and some contractors report reduced installation time due to the product’s flexibility. PEX piping is an energy efficiency innovation in that the plastic does not conduct heat or cold so conductive loss or transfer is minimized when compared to metal substitutes.

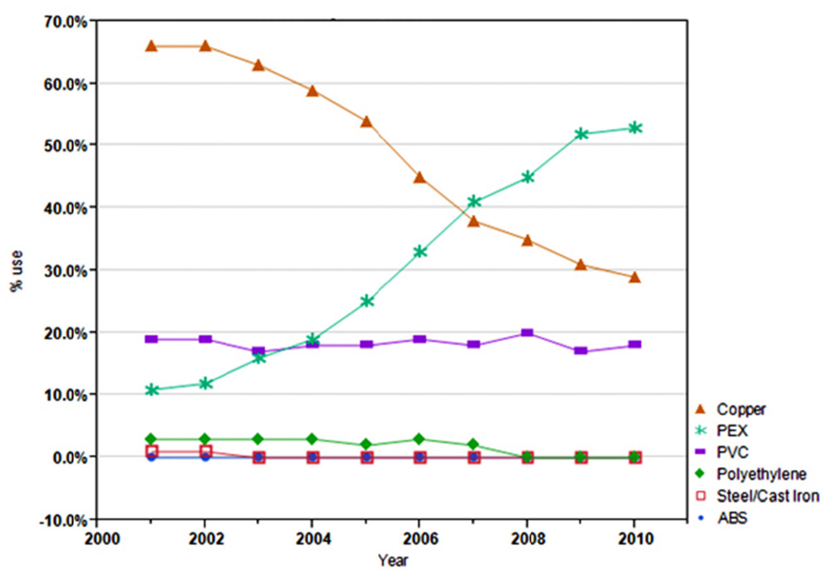

Figure 5. Water pipes vs. year.

Figure 6 shows the use of 13 Home Electronic products during 2000-2010. Programmable thermostats dominate the market with between 65% and 85% use. Easily installable, programmable thermostats allow occupants to more precisely control the interior temperature of their homes. Though occupants have long had either analog or digital control over their HVAC systems, programmable thermostats are a system innovation that allows the occupant to customize temperature settings based on time of day and other factors. Though not included in the survey data, the Nest thermostat represents the next wave of programmable thermostat innovation. Nest is a system that both communicates with smart phone and other mobile technologies but also detects occupant behavior patterns and adjusts temperatures accordingly. While not an energy efficiency technology, it was interesting to observe the decline in multi-line phone systems over the study period. In the context of increased smart phone sales and in mobile only consumers, this decline is not much of a surprise.

Figure 7 represents a slightly different chart type than Figures 1-5. This figure summarizes use of a single technology vs. non-use of the same technology—air in-filtration house wrap. The BPS question structure did not provide a set of economic substitutes for synthetic house wraps. So instead of the use of a product compared to others in its cluster, we show use vs. non-use to provide a second reference line on the chart. Non-use is defined here as the difference between total respondents and respondents indicating use. The pattern of house wrap use is intriguing in that it shows a decline over the study period. Given the increase or at least static nature of use in other energy efficient building technologies, this small decline is somewhat of a surprise. However, where we combined all building types SFD, SFA, and MF to create the graph, there is the potential for some noise as not all SFA and MF buildings require the use of a house wrap (building height, skin, and other design factors contributing).

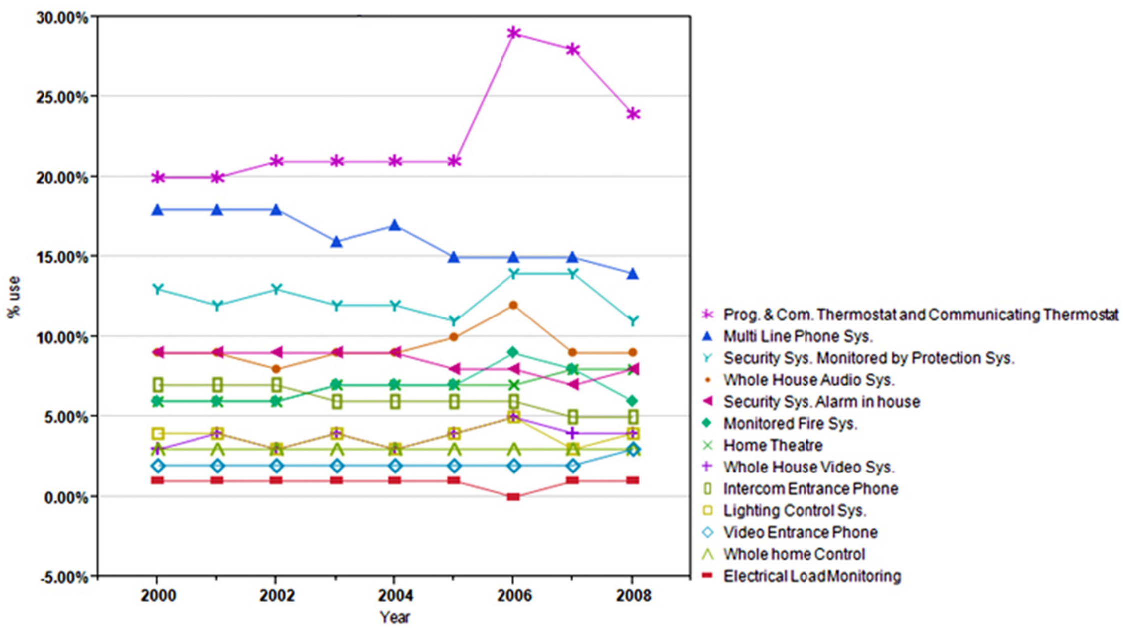

Figure 6. Home electronic systems vs. year.

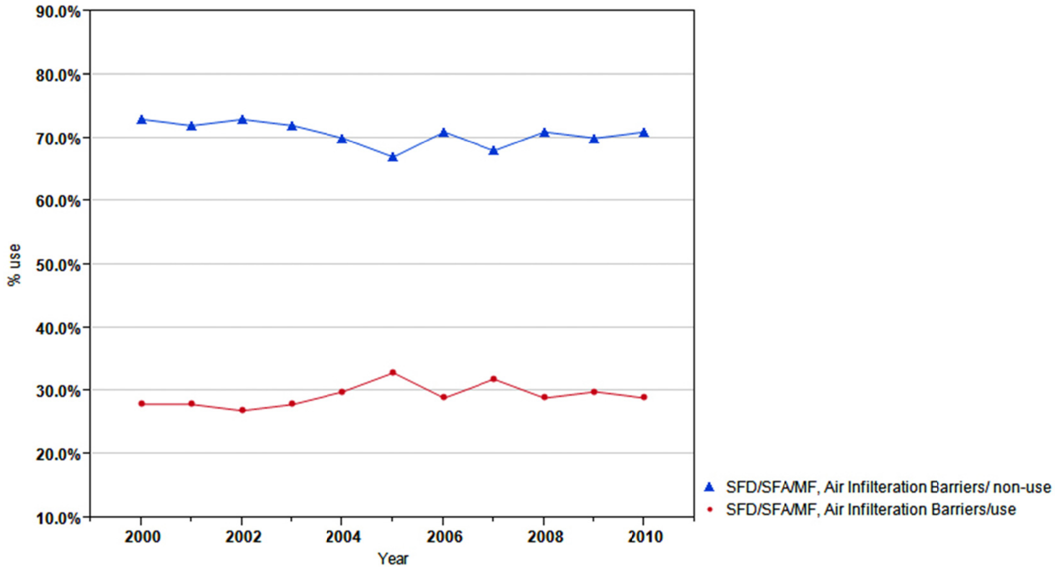

Figure 7. Air infiltration vs. year.

Implications of Patterns

From 1980 to 2009, the number of housing units in the United States grew from 81.6 million to 113.6 million. During the same period, the average consumption of energy per housing unit dropped from approximately 114 million BTUs to 89.6 million BTUs (Energy-Information-Administration, 2010). Similarly, there are now nearly 15,000 LEED certified homes and more than 130,000 homes were certified under the Energy Star rating system in 2011. When combined with the above data suggest that the housing stock is becoming more energy efficient and that there are building technologies and processes used to create or contribute to increased environmental performance. These data appear to confirm preliminary and literature based evidence that energy efficiency and green building are growing trends the residential construction and real estate sectors. But some aspects are puzzling and require further investigation.

Conclusion

To analyze the underlying reasons for resistance, the authors examined and highlighted broad patterns of innovation use (adoption) by builder firms within clusters of products for six energy efficient (EE) products, across recent years. The plots point toward an increase in the adoption of innovations in residential industry over time. Although homebuilding innovation has traditionally experienced slower rates of adoption, some green building technologies such as Programmable Thermostat and PEX piping exhibit accelerated patterns. The plots also indicated that some products such as ICF, SIPS, cellulose and spray foam have to overcome the inherent resistance of path dependency and the equilibrium reinforcing effects of networks.

This study attempts to prepare the ground for further study and exploration of current patterns of adoption in the residential industry. These preliminary explorations of the BPS data helps us to identify potential the underlying reasons for resistance, as well as to identify the risks and uncertainties associated with residential built environment.

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