Cryptic Barriers to Energy Efficiency

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October 2013 revision

Report Number A135

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Contents

Acknowledgments

This research was carried out with funding from the U.S. Environmental Protection Agency to build on observations of cryptic barriers impeding energy efficiency. The concept and research plan was developed by Harvey Sachs; the bulk of the research was carried out by Alice Stover, an ACEEE intern, under the supervision of Amanda Lowenberger and Harvey Sachs. The work was edited by Jennifer Amann and Renee Nida. We are grateful to our external reviewers: Fred Gordon, Energy Trust of Oregon; Scott Pigg, Energy Center of Wisconsin; and Charlie Stephens, Northwest Energy Efficiency Alliance; and our internal reviewers: Steven Nadel and Jennifer Amann. The comments by each of these reviewers enormously improved the logic and contents of the report.

Abstract

Much time and effort has been invested in addressing the market barriers that inhibit greater investment in energy efficiency technologies and practices in the buildings sector. In addition to these common and well-known barriers (e.g., split incentives, asymmetrical information, higher first costs, etc.), there is a class of barriers that has received less attention. These barriers are cryptic in the sense that they are hidden or unrecognized; they do not stem from the same market failures that have been the subject of extensive study and the target of many policy and program interventions. Cryptic barriers reflect several different underlying problems, including regulatory uncertainty, archaic or legacy regulations, and inaccurate ratings and standards. This report is a first effort to characterize and explore cryptic barriers in some detail. We selected cryptic barrier case studies from the results of a broad survey to identify as many cryptic barriers as possible and start a compendium. Drawing on these cases, the objective of this report is to suggest opportunities for policy actions that could improve residential building efficiency and to propose potential tools to eliminate cryptic barriers.

Introduction

Much time and effort has been invested in addressing the market barriers that inhibit greater investment in energy efficiency technologies and practices in the buildings sector. In addition to these common and well-known barriers (e.g., split incentives, asymmetrical information, higher first costs, etc.), there is a class of barriers that have received less attention. These barriers are cryptic in the sense that they are hidden or unrecognized; they do not stem from the same market failures that have been the subject of extensive study and the target of many policy and program interventions. Often these cryptic barriers are aspects of building codes or standards. In this context, "standards" include safety standards, energy efficiency standards, and other standards established to assure common quality or performance metrics.

By definition, cryptic barriers are hidden from most stakeholders, unless they do in-depth "due diligence." Here's an example: Industry compares the efficiency of water heaters with a measure called the "Energy Factor" (EF). Few people keep track of how EF is calculated, but it turns out to be important. The federal rating method for residential water heaters uses a hot water supply temperature of 135°F, with a stipulated 77°F temperature rise from the inlet water temperature. However, manufacturers ship their products with a lower default temperature setting in the range of 120°F to 125°F and consumers have largely adopted this setting as the norm. At the time the rating method was developed, this discrepancy was irrelevant for the product classes on the market because these products all relied on similar heating technologies. Since that time, new water heating technologies have been introduced that make this discrepancy very relevant. Almost all heat pump water heaters[1] require some electric resistance heating boost to provide 135°F water, which reduces the efficiency measured by the EF test. Similarly, the apparent efficiency of condensing gas water heaters, especially in comparison to conventional water heaters, may be reduced by rating at a supply temperature of 135°F if test conditions leave the heat exchanger trying to transfer heat to hot water.

A rational business is unlikely to attempt to change a true cryptic barrier. Both government and voluntary consensus standards are intended to establish performance floors without favoring one firm or another. Thus, they rarely require use of a proprietary technology that is only available from one source. In addition, standards adoptions and changes generally take several years. In practice, this means that a firm that invests in changing a standard to allow for innovation is unlikely to directly benefit since they are investing their funds to open the market for competitors too. Thus, standards, at times, can have the unintended consequence of stifling innovation.

This report is a first effort to characterize and explore cryptic barriers in some detail. We selected cryptic barrier case studies from results of a broad survey to identify as many cryptic barriers as possible and start a compendium (see Appendix A). Drawing on these cases, the objective of this report is to suggest opportunities for policy actions that could improve residential building efficiency and to propose potential tools to eliminate cryptic barriers.

[1] Except those units using carbon dioxide working fluid.

Cryptic barriers reflect several different underlying problems, including regulatory uncertainty, archaic or legacy regulations, and inaccurate ratings and standards. One example of regulatory uncertainty is contractor reluctance to install a technology not yet familiar to code inspectors in his jurisdiction. If challenged, the contractor still has to invest in an uncertain waiver process, which adds additional costs if the project schedule is disrupted. In turn, this makes familiar designs and equipment more attractive.

Archaic or legacy regulations are ones that have not responded to changes in the technology of the products or building techniques that they regulate. These regulations become cryptic barriers when they no longer serve the original purpose for which they were written and instead inhibit innovation and further development. Sometimes these regulations even begin to affect products or techniques they were never intended to regulate.

The water heater ratings example above illustrates how legacy regulations can present a barrier and their impacts. The rating method was introduced when residential "water heater" meant a tank heated by electric resistance or gas using natural draft combustion. It provides reasonable comparisons among products in each of these product classes. As noted above, it is expected that heat pump water heaters would get higher ratings if a realistic test were carried out with 120–125°F supply temperature instead of 135°F, since the former probably would not require invoking auxiliary resistance heat as often. Expectation of lower ratings (and thus, of calculated lower energy savings for incentive program purposes) may have contributed to the reluctance of major manufacturers to invest in the technology.

Indeed, this example also illustrates inaccurate ratings as a cryptic barrier. A rating method *should* be the simplest feasible test that gives reasonable predictions of performance in the field, for all present and anticipated products. However, to a greater or lesser degree (depending on use volumes and patterns, for example), comparisons of conventional storage water heaters to newer tankless water heaters can be uncertain, at best. The issues with the federal water heater efficiency rating method were so pervasive and important to industry that legislation was enacted to require development of a new "uniform descriptor" method; the U.S. Department of Energy (DOE), American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), and Air Conditioning, Heating, and Refrigeration Institute (AHRI) all are developing proposals now.

Cryptic barriers inhibit investments that would provide a public good. When this situation occurs, governments should intervene with policies—or revise existing policies that could be problematic—to ensure that actions that contribute to public interest are not impeded. There may also be a role for energy efficiency stakeholders to pursue interventions to address these barriers. An understanding of the nature of cryptic barriers is needed to guide policy and program interventions.

A Compendium of Cryptic Barriers

Our first step in exploring cryptic barriers was to develop a quick compilation of examples of cryptic barriers (see Table 1) including a brief description of the barrier and the mechanisms that could be used to eliminate it (the full compendium is in Appendix A). By definition, cryptic barriers are difficult to identify. The barriers identified in this report were pulled from personal communications with industry experts, press releases, and technical reports. This compendium suggests the wide variety of institutional barriers that affect emerging technologies in the buildings sector. We have not attempted to estimate the savings potential from eliminating these barriers.

Drawing from this compendium, we selected three cryptic barriers to discuss as in-depth case studies in this report. Others represent opportunities for further research and/or consideration as part of policy initiatives or program activity targeting these technologies or end-uses.

Table 1: List of Cryptic Barriers Identified

Fire rating testing procedures for foam insulation
Rating calculations on heat pumps
Ratings for residential air handlers
Total house electrical load and multiple point-of-use resistance water heaters
Zoning regulations and external insulation
Zoning regulations and alternative energy installations on roofs
Commercial clothes dryers
Implications in code language in regards to lighting
Regulatory uncertainty in standards for equipment venting
Flame and smoke concerns with plastic air distribution ducts
Unrealistic testing procedures for electric water heaters
Electrical sockets not required near water heaters
Regulatory uncertainty for rooftop solar panels

Case Studies

Plastic Residential Ducts

Each of the three conventional materials used in residential ductwork has problems that contribute to making ducts inefficient. Galvanized sheet metal, which is used primarily in plenums and main supply/return ducts, is expensive and needs to be assembled on site; it is also difficult to seal. “Ductboard” and Flexduct are difficult to seal at joints and have rough interior surfaces that increase airflow resistance. Furthermore, rough surfaces are more likely to trap dust and can even support mold growth if there is condensate in the duct. The frictional losses in Flexduct are exacerbated when segments are purposely cut too long and compressed to save time during installation.

Some manufacturers (e.g., KBDuct and Lindab) have lessened the difficulty of sealing joints by creating round sheet metal ducts that snap or clamp together at joints and have elastic seals. These systems reduce the risk of leaky joints by assuring a tight seal and reducing the skill needed for proper installation. However, these ducts are both only intended for commercial applications and cost more than the residential market generally accepts.

Rigid plastic drain pipe could be an attractive model for an easily-assembled tight duct system. It is simple to assemble, with glue and slip fittings—and would not leak much even without glue. Therefore, something like it could drastically reduce the prevalence of leaky joints in residential systems. Because plastic drain pipes are typically used to carry liquids, which create obvious problems when they leak, they have been developed to a high standard with respect to durability and ease of installation. Ductwork can take advantage of the technology already developed for drainpipes to improve efficiency. Drainpipe is relatively inexpensive, has smooth surfaces for low flow restriction, and is available in many sizes, with adapters in many shapes. It's also "semi-flexible," tolerating minor curves to fit as needed.

What is the barrier and why does it exist?

Ducts are the arteries and veins of a building, connecting and circulating air throughout, but in the event of a fire, they can also serve as a conduit for smoke and flames. Flammability concerns have ruled out the use of most plastics in ductwork. An exception to this is ductwork installed under slab foundations, where plastic ducts can be used because flame propagation is unlikely.

The cryptic barrier to the use of plastic piping in residential ductwork is code restrictions that either prohibit above-grade plastic ducts or are ambiguous on the topic. In respect to residential construction, the code is unclear. The 2003 International Residential Code does not explicitly prohibit above-grade plastic ducts, but it only refers to plastic ducts installed below-grade. However, the 2003 International Mechanical Code prohibits above-grade plastic ducts: "Plastic ducts and fittings shall be utilized in underground installations only."

In 2005, a Committee Interpretation was ordered by the International Code Council (ICC) to establish their official position on the question of whether plastic ducts are allowed in residential construction. The outcome of the interpretation was a statement that plastic ducts may be used above-grade in residential construction as long as they are made out of materials that have a Class 0 or Class 1 rating under UL 181.

> *UL 181:*
>
> *1.3 For the purpose of these requirements, air ducts and air connectors are classified as follows:*
>
> *Class 0 - Air ducts and air connectors having surface burning characteristics of zero.*
>
> *Class 1 - Air ducts and air connectors having a flame-spread index of not over 25 without evidence of continued progressive combustion and a smoke-developed index of not over 50.*

The two plastics used in drainpipes do not meet Class 1 requirements. Polyvinyl chloride (PVC) has a low melting point. High-density polyethylene (HDPE) is inert, self-extinguishing, and can withstand temperatures of up to 248°F for short periods but still falls short of the Class 1 requirements. Certain compounds can be added to HDPE that allow it to meet the requirements, but the process makes the manufacturing process more costly, and the presence of the compound in homes raises health and air quality concerns.[2] QADUCT currently manufactures plastic ducts and plenums that meet UL 181 Class 1 requirements using HDPE with a fire and smoke retardant filler.

BHDB (bishydroxydeoxybenzoin),[3] a relatively new polymer, is fire-safe without requiring the addition of fire- and smoke- retardant material. Currently it is being tested for commercial applications in aircraft. Further research is needed to determine if it would be appropriate and cost-effective for use in residential ductwork.

Stakeholders

- Plastics Manufacturers—Individual manufacturers have little incentive to make an investment in addressing this problem because once the barriers to entry into the plastic duct market are reduced, their competitors will also benefit. The manufacturer who initially invests in reducing the barrier is unable to gain a competitive advantage and therefore will be unable to fully capture the financial benefit of the investment.
- Manufacturers of Incumbent technology duct materials—They will be opposed to any changes, whether alternative materials or other ways to distribute energy, that could negatively affect their sales.
- QADUCT—As the sole manufacturer of fire resistant plastic ducts that meet UL 181 guidelines, QADUCT has done well in the high-velocity market. In high-velocity applications, the benefits of the low frictional losses associated with plastic ducts outweigh the added costs. It would seem they have an incentive to reduce the barriers to plastic ducts in order to bring down costs and become competitive in non-high-velocity applications. However, despite being slightly more invested in the technology already, QADUCT is subject to the same problem as other plastic manufacturers: they would have to share the benefits of their investment with any other manufacturer who decides to begin manufacturing plastic ducts.
- Construction Industry—As building energy codes become more stringent, builders will have to invest more to reliably achieve high performance, low-leakage duct systems. Plastic ducts can save time in this regard but are less convenient than Flexduct in tight spaces or where the ductwork needs to make many changes of direction. One voluntary program, ACCA Quality Installation (ACCA 2010), may help raise expectations and establish a better value proposition for customers of high-performance systems: Leading contractors will gravitate to technologies that improve quality (decrease construction errors), reduce call-backs, and reduce labor costs—good installers are hard to find.
- Homeowners—Homeowners would receive several benefits from removing the barriers to the use of plastic ducts. First, ductwork would become more airtight, which would lead to improved distribution of conditioned air within the house and savings on heating and cooling costs. Second, the improved efficiency of the ducts might allow for the size of the heating/cooling system to be decreased, providing further heating and cooling cost savings. Finally, plastic ducts would likely be more durable, resulting in less need for repairs as the system ages.

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[2] According to Charlie Stephens (NEEA), HDPE water piping (PEX) is widely used in homes and is often treated with the same fire and smoke retardant substances.

[3] See http://www.treehugger.com/clean-technology/burn-baby-burn-making-plastic-fire-proof.html.

Potential savings

Residential ductwork improvements have the potential to reduce significant energy losses and save consumers money by reducing leakage of conditioned air into unconditioned spaces and reducing frictional losses. In turn, these improvements often allow for substantial downsizing of heating and cooling equipment.

Reducing leaks. It is estimated that 30% of space conditioning energy is lost to air leaks in ductwork and conductive heat loss in a typical system (Winter 2007). Ducts leak because most processes for sealing joints on-site are difficult, expensive, and/or time-consuming. Consider the difficulties of reaching perimeter ceiling registers *after* the roof is installed, when there is barely clearance for the duct itself, and the installer must crawl through and over attic installation to connect the register boot to the duct, and then try to reach around to seal with mastic.

In addition to direct losses of space conditioning energy, duct leaks can lead to other difficult and expensive repairs. Although it is widely acknowledged that placing ductwork outside the thermal envelope is a bad idea, the practice is still very common. In hot, humid climates, leaks in return ducts can cause condensation to form inside the ducts during the cooling season, when warm, humid air is drawn into the return air stream. This moisture buildup can cause mold, air quality problems, and water damage. Alternatively, leaks into insulation with a water-tight cover can condense and "pond," eventually leaking onto the ceiling insulation and damaging ceiling sheetrock. Similarly, winter leaks in supply ducts in attics can lead to condensation outside the ductwork leading to condensation on roof decking or nails, and potentially rotting the roof. These problems usually take a long time to manifest, thus, the benefits of the laborious sealing process are underappreciated and there have been few incentives for builders to improve performance.[4]

The U.S. Department of Energy has identified leaky ducts as a key element in its effort to meet the goal of reducing annual heating, ventilation and air conditioning (HVAC) energy losses by 50% (Winter 2007). Building codes are moving toward placing limits on maximum leakage, typically around 6% (CEC 2008). Meeting these limits using traditional methods and materials will place a considerable burden on builders. Alternative materials, such as plastic ducts, could gain market acceptance despite slightly higher initial costs, if they save builders time and effort meeting maximum leakage requirements. In the Veridian test house built by Steven Winters Associates, the plastic duct system was installed in half the time it took to install the conventional metal system in the control house. A major contributing factor was the fact that the plastic pipe can be cut with a utility knife.

[4]It should be noted that the risks of condensation buildup vary depending on the climate, so the benefits of better sealed systems are not the same in all regions. In dry climates like the Southwest, small leaks will make air conditioning systems less efficient, but not pose much risk for condensation. Because of this, the balance of costs and benefits for plastic ducts compared to Flexduct may be different depending on the part of the country.

In the long run, plastic ducts will likely be more durable, making them more attractive to home owners who experience the costs of leaky ducts most acutely. Leaky ducts increase heating and cooling costs, and make it difficult to control the temperature in all areas of the house.

Reducing frictional losses. The interior surfaces of plastic ducts are smooth, which decreases the frictional losses associated with Flexduct or ductboard. Flexduct, in particular, performs poorly in terms of frictional losses. The biggest strength of Flexduct is its flexibility, which makes it a popular choice for installing in hard–to-access areas, but when Flexduct is compressed while being installed the wire support structure produces significant drag. In order to install Flexduct correctly, it should be cut to minimum length and stretched. This means that it is much easier to install Flexduct incorrectly as opposed to plastic ductwork, which is harder to install badly. Research should be conducted on the ease of installation between correctly installed Flexduct and plastic ducts. In general, flex duct has about 10x more frictional loss than galvanized steel, for equivalent diameter round ducts. For this reason, good practice precludes use of flex duct except for short (no more than five feet) connectors to better materials (ASHRAE et al. 2008).

Policy or other mechanisms for removing barrier

The main barrier to the acceptance of plastic ductwork is the concern for fire safety, which is reflected in the requirements of the ICC. This barrier can be addressed through technological changes or policy changes. The first of the possible technological solutions is to use fire-safe materials, either by adding fireproofing material to HDPE or by creating a new inexpensive fire-safe polymer. This tactic is being used by QADUCT, but the additional cost of fire-proofing the HDPE drives the price of the ducts too high to take over a significant share of the market. Another technological solution is to look for alternative, less expensive fire-safe polymers, such as BHDB.

From a policy standpoint, the barrier could be removed by modifying the UL 181 requirements so that HDPE would be an acceptable choice of duct material without additives. Winter (2007) suggested that the UL 181 requirements be analyzed to determine if such high standards are justified. This kind of change would be contentious, pitting incumbent industries facing market share loss against potential new product suppliers.

Furthermore, if building codes were changed to allow plastic ductwork, the material would need to gain acceptance by the construction industry and consumers. Measures that reduce the transaction costs of choosing plastic ductwork would help in this regard. Square ducts fit better into typical residential construction, so developing oval or square plastic ducts would reduce the design changes that would need to occur in a building to accommodate plastic ducts.

Strengthening the language in building codes would make the benefits of more leak-proof ducting more tangible to the construction industry. IRC uses subjective language: "…duct systems shall be sufficiently airtight…" without quantifying what is meant by "sufficiently." Requirements like these are not enforceable.

Heat Pumps

Efficiency rating systems balance interests that include accurately describing the performance of a piece of equipment, the burden of developing and implementing rating programs, and the need to provide consumer information that is accessible enough to be useful. Problems arise when rating methods are slow to adapt to technological innovations or when there are significant factors that affect the efficiency of a piece of equipment that don't get accounted for in the rating procedure. Heat pumps provide a good example for exploring the cryptic barriers presented by inaccurate and outdated equipment rating methods.

Testing temperatures for heat pumps

Heat pumps are rated using Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER). HSPF represents the heat pump's efficiency over one heating season by comparing the extrapolated total heating output to the extrapolated total energy consumed. SEER measures the heat pump's efficiency over one cooling season by comparing the total cooling provided to the total energy consumed. Both HSPF and SEER measure heating or cooling loads in Btu and electricity consumption in watt-hours, based on the testing methods laid out in AHRI 210/240 (Kavanaugh 2002) and federal code (10 CFR 430.3, Appendix M).

Several studies have shown limitations of the AHRI 210/240 testing protocol and the federal method based on it.[5] The first problem stems from the temperatures at which heat pump efficiency is rated. Thermostats are almost always set to a higher temperature during the summer than during the winter, meaning that there is a certain range of temperatures at which the heating or cooling system will not operate. This should be reflected in the rating system for heat pumps, but in fact the minimum temperature at which SEER calculates a cooling load is 5 degrees lower that the maximum value at which HSPF calculates a heating load. Instead of this overlap, a more accurate rating system would have a no-load gap between HSPF and SEER rating "temperature bins," perhaps as large as 10 degrees. This would account for the range of temperature at which both heating and cooling systems are off (Energy Information Services 2012).

Although it may appear that this flaw simply underestimates the efficiency of a heat pump by doubling the load for a certain range of temperatures (i.e., calculating both heating and cooling loads for the 62° to 67°F range), it is important to consider that heat pumps work most efficiently in moderate temperatures. That means that the rating system over-emphasizes the fraction of time the heat-pump will spend operating in the most ideal conditions compared to the time it might spend operating at more extreme temperatures (at extreme temperatures it may even use back-up electric resistance heat) (Energy Information Services 2012). The efficiency rating of heat pumps is also distorted when comparing performance in different climatic regions. The HSPF and SEER ratings assigned to a heat pump under AHRI 210/240 are based on Climate Region IV. It was not the original

[5] For a few examples, see Fairey et al 2004; Kavanaugh 2002; Sachs et al. 2007.

intent to have the data from one average region applied as a reference across all regions, but for the sake of simplicity Region IV data became the default.[6]

Why are there ratings barriers?

Accurate rating systems provide consumers with the information they need to make informed decisions about which equipment to purchase. In turn, if purchasing decisions are based on accurate information, then manufacturers will have the incentive to invest in increasing efficiency. Designing the ideal rating system depends on finding a balance among the many trade-offs involved. For one, there is the trade-off between providing thorough and complete information that paints an accurate picture of the efficiency of each piece of equipment and providing concise and easy-to-understand information that is meaningful to the average consumer. There is also a trade-off between using a rating system that is tailored to a specific piece of technology for the sake of accuracy and making rating systems broad enough to allow for simple comparisons across a range of technologies.

The results of these cryptic barriers affect both consumers and manufacturers (and other market players). If ratings aren't accurate they can misdirect purchases and investments, and manufacturers won't be motivated to make more efficient products. On the other hand, rating systems that are too complicated or extensive won't be consumer-friendly either. In order to be useful to consumers a rating system needs to be concise and clearly summarize large amounts of information.

Stakeholders

- Manufacturers—Manufacturers are reluctant to support an effort to change rating methodology because more accurate ratings may require expensive redesigns to optimize for new criteria. There is also a "headroom" issue. When a manufacturer decides to offer a higher efficiency product, the difference between the rated performance of this higher-end piece of equipment and the minimum-standard-rated performance is colloquially called headroom. The greater the headroom the more justification manufacturers will have for the higher price of the more efficient equipment. Although headroom is for the most part dependent on the stringency of standards, the rating process can also have an effect. Rating methodology determines which efficiency aspects of a product factor into its rating. If a particular efficiency feature is not well measured in the rating process, a manufacturer will be unable to establish headroom with that feature.
- Other market participants—The relatively small changes in efficiency from revising the test procedure would not concern distributors and contractors—if the label efficiency did not change. Bad ratings can also present real problems for utilities and other public benefit programs. While test procedure revisions can make it harder to calculate savings, ratings that don't accurately reflect real-world performance are a bigger issue. If anticipated program

[6] One exception to this is a table titled "Heating Cost Factor" in the AHRI directory of Certified Unitary Air-Source Heat Pumps. It provides data on approximate cost of heating in six different climate zones. However, even this table does a poor job of accurately reflecting costs in severely cold weather and tends to underestimate heating costs in most regions (Fairey et al. 2004).

savings based on ratings are not borne out when the program is evaluated, public benefits programs may fail to meet their goals and face financial penalties or other consequences.

- Homeowners—More accurate ratings will help homeowners choose appliances and equipment that are most efficient in their home and that save them money. However, most homeowners don't plan ahead of major home equipment replacements. Instead, new equipment is bought when old equipment fails, and most consumers are more concerned with getting a replacement quickly rather than obtaining high-quality or efficient equipment. Because homeowners don't have the time to research ratings, the minimum standard becomes the more important number, ensuring that the cheapest and quickest replacement option meets a basic level of efficiency.
- The U.S. Department of Energy—DOE operates under a statutory requirement that states that "test procedures must be reasonably designed to produce test results that reflect energy efficiency, energy use, and estimated operating costs during a representative average use cycle…" and not be unduly burdensome to conduct (42 USC 6314(a)(2)). In the practice of establishing efficiency standards and test methods, DOE must also conform to specific criteria laid out to evaluate the cost and benefits of any actions it may take to alter standards and ratings including the economic impact on manufacturers and consumers, total energy savings, impacts on product utility or performance, and other considerations. While their mission should lead to interest in the most effective possible rating systems, the complex of objectives complicates their interests.

Potential energy savings

The more accurately ratings reflect the actual efficiency of appliances in the specific conditions in which they will be used, the more incentive manufacturers will have to improve overall efficiency and the more likely consumers will be to purchase equipment that most efficiently meets their needs. Savings will be realized not only as more appropriate equipment is installed, but also as the manufacturers respond to the incentive to improve efficiency effectively raising the baseline standards.

Policy or other mechanisms for removing barrier

Cryptic barriers can be a combination of a market failure and government failure. Market failures are situations in which market operations result in inefficient distribution of goods and services, and require increased government regulation to correct. Government failures, on the other hand, are a problem of regulation creating a more inefficient allocation of goods and services than would occur in a natural market and are remedied by an adjustment of existing policies (Weimer and Vining 2004).

The market failure that ratings and standards are meant to deal with is the asymmetric information problem that occurs when homeowners or builders try to compare the efficiency of various pieces of equipment. The policies that establish ratings procedures and minimum standards can lead to a government failure if they fail to provide complete or accurate information.

In order to fix this problem, policy tools need to be established to evaluate the kind of information being provided by ratings. There needs to be a balance struck between clear, simple ratings and the inclusion of all relevant information in product labels administered by the Federal Trade Commission.

Furthermore, DOE needs to take a fresh look at the test procedures for major energy-using products. Many of these tests are decades old and, while the tests may have been tweaked over the years, larger changes may be warranted. If a new test with significant changes is adopted, it can be phased in with the next standard revision—this worked well with the revised clothes washer test procedure adopted in 2000 that took effect with standards in 2004. Once a satisfactory system of ratings and standards is established there needs to be a periodic review to ensure that it stays relevant to changing technology.

Venting for Condensing Gas Water Heaters

Condensing gas water heaters achieve over 90% thermal efficiency (Amann, Wilson, & Ackerly 2012). This high level is achieved by capturing much of the heat that would otherwise be lost up the flue and by capturing the "latent heat" from condensing water vapor (a combustion product) to liquid water. The relatively cool exhaust (<150°F) can be vented through the side wall of a building instead of up through an exhaust stack on the roof, leading to significant savings in the cost of installing an efficient condensing gas water heater, at least in new construction.

Although condensing gas furnaces are common, at least in Northern states, condensing water heaters are novel. Furnaces are typically installed by HVAC contractors, while gas water heaters generally are installed by plumbers. Plumbers generally have much less experience with condensing equipment. This means that installing a condensing water heater means learning new methods and learning new ways to sell the more expensive equipment. This is particularly important since the vast majority of water heater sales are replacements (as opposed to new construction), generally installed because the old water heater failed. Thus, the plumber risks losing a sale if he tries to upsell to a more expensive condensing water heater instead of a low-cost atmospheric one. He may also need to carry the condensing water heater in his stock, if his suppliers don't maintain local supplies. Thus, the major barriers are market-related. However, there are related cryptic barriers as discussed below.

What are the barriers and why do they exist?

Building code provisions can restrict use of sidewall vents, and thus installation of condensing water heaters. Vents cannot be installed over sidewalks or other pedestrian areas because dripping condensation could cause ice to build up in winter. It is important to ensure that they are installed above the snow line so that they don't become blocked in the winter. Another concern is that sidewall vents need to be located far enough away from windows that exhaust is not drawn back into the house (Beers 1994). Finally, the water heater's "inducer fan" has limited power, which imposes trade-offs of vent diameter vs. vent length and number of bends. Long runs or more elbows typically require 3" PVC instead of 2", and the 3" is both somewhat more expensive and more awkward to install.

The above barriers reflect real tradeoffs between safety, cost, and efficiency, so are not intrinsically cryptic barriers. However, aspects of the code in these areas may appear ambiguous to plumbers, or ask them to treat different situations differently. Plumbers prefer a "stock" approach and may not read the details in the code. Furthermore, if the plumber feels that the code is ambiguous (either because it is, because the plumber didn't read it, or because he fears that the inspector didn't read it), he may feel that there are risks from inspectors with restrictive or overly generalized interpretations. Thus, the plumber may choose to over-interpret the restrictions in the code without even consulting the inspector. Or inspectors may apply restrictions everywhere because the inspector doesn't trust the contractor to do otherwise and needs to make the most of "teachable moments." Contractors are then vulnerable to the individual decision of the inspector as to whether or not their installation will be approved and will tend to shy away from adopting the technology.

Stakeholders

- Contractors —Contractors need to take on additional risk in order to overcome this barrier, but the benefits of installing the more efficient equipment are mostly passed on to the owners.
- Building Owners—As the party responsible for utility bills, building owners stand to gain the most from eliminating the regulatory uncertainty surrounding sidewall venting for condensing gas heaters. However, they are less involved in the design and approval process and therefore less likely to be aware of the option of sidewall venting to reduce the cost of efficient heaters and the problems that are caused by regulatory uncertainty.
- Inspectors—While they have the final say to approve an installation, they have limited time to master ever more complex regulations, which frustrates them and their clients, the contractors and plumbers.

Potential energy savings

Condensing gas heaters save energy used to heat water. Condensing residential gas water heaters would have Energy Factors of about 0.80 or higher compared to the 0.59 [0.58] EF for a standard 40 [50] gallon water heater. According to ENERGY STAR, a condensing gas water heater can save the average U.S. household around 30% of their water heating costs, or about $170 per year for a family of four (EPA 2013).

Policy or other mechanisms for removing barrier

Standards for sidewall venting of gas-condensing heaters should be written into the code in jurisdictions where they are absent. Inspectors and plumbers require training, which need not be extensive. Perhaps the most difficult barrier is the nature of interaction between plumbers and inspectors given the limited opportunities for interaction. The nature and quality of enforcement vary by jurisdiction. Training would help, but there may be a further need from managers to create an expectation that installations and inspections will be site-specific, not based on broad application of narrow provisions.

Discussion

A few categories emerge when looking at an overview of cryptic barriers. Each category represents a group of cryptic barriers that are caused by similar problems and can be resolved using similar strategies. The three categories that arose in this study are archaic regulations, inadequate rating methods and standards, and regulatory uncertainty.

Archaic Regulations

Archaic or legacy regulations are specific pieces of code that at one point served a purpose but are no longer relevant to their original purpose. Building technology develops and improves constantly, but in most jurisdictions codes do not adapt as quickly. Without a systematic review process, a regulation can remain in place past the point when advancing technology makes it obsolete and it can continue to have repercussions, sometimes negative, on issues and technology it was never originally meant to affect.

One clear example of an archaic regulation is the case of cooling standards for data centers that don't evolve as quickly as server technology does. The issue of flammability of plastic ducts could also be considered an archaic regulation, but only if the flammability concerns are found to be unnecessarily high.

One strategy for eliminating archaic regulations can be found in Texas's legislation. The state sunsets all legislation so that after a set period of time all regulations are reviewed to assess continued relevancy. While this can help edit out unnecessary legislation on a state level, there are still jurisdictional issues that can complicate the editing process. Regulations exist on many levels (federal, state, county, local) and the interactions among these levels of regulations make actions taken on just one level (state, in the case of Texas) less effective.

A second strategy involves drafting legislation so it is less likely to become obsolete. This can be achieved by focusing on performance-based objectives instead of prescriptive standards. Prescriptive standards can quickly become outdated as new technology evolves, while performance-based standards leave room for innovation. Furthermore, prescriptive standards effectively serve as both a lower and upper efficiency limit by disallowing more efficient technology from being adopted as it is developed. Performance-based standards avoid this trap by serving only as a minimum-efficiency requirement.

Regulatory Uncertainty

Regulatory uncertainty arises when a certain aspect of a technology or product is not explicitly dealt with in the building code. The uncertainty means that inspectors must use judgment instead of rules when making permitting decisions. Contractors are not likely to embrace any technology that leaves them vulnerable to personal interpretation by inspectors. Condensing gas water heaters and rooftop solar installations are both technologies that would benefit from a more thorough treatment in codes to reduce the regulatory uncertainty that discourages their use.

One solution to the problem of regulatory uncertainty can be seen in the actions taken by the New York City Council. The Council commissioned a thorough review of the city's building codes and zoning regulations in order to find opportunities to change the code to promote more sustainable practices. In doing such a thorough review, several instances of regulatory uncertainty were uncovered along with other cryptic barriers. However, a comprehensive review is a big undertaking, one that other cities may not have the funding or political will to carry out. Furthermore, the study uncovered 111 recommendations for change, which might be overwhelming to a city with fewer resources than NYC.

The panel that reviewed the codes in New York City was made up of experts from a wide range of areas, attempting to uncover all potential amendments to the code that could increase the sustainability of the city's building practices. The scope could be pared down to focus on uncovering areas of regulatory uncertainty related to new energy-efficient technology The process could be made less daunting by creating a panel of emerging technology experts and industry representatives who could identify technologies that are not thoroughly dealt with in building code.

Inaccurate Ratings and Standards

Rating systems need to strike a balance between accurately describing the performance of a piece of equipment and providing information that is concise enough to be useful to the average consumer. Problems arise when the ratings are slow to adapt to technological innovations or when there are significant factors that affect the efficiency of a piece of equipment that don't get accounted for in the rating procedure.

There are many examples of inaccurate rating systems. In fact, it is impossible to get a completely accurate rating system, so the important question becomes: "To what degree is this rating system inaccurate and what effects does that inaccuracy have on innovation and purchasing decisions?" In instances where ratings significantly skew the incentives that manufacturers have to be innovative in energy efficiency by obscuring certain information from consumers, the ratings should be evaluated to make them more representative of actual performance.

What Makes Cryptic Barriers so "Sticky"?

A defining characteristic of cryptic barriers is the split incentive for the innovation in question. In other words, no particular individual can capture enough of the benefits of eliminating the barrier to justify rational investment, which is precisely what makes it so persistent. Commonalities emerge from the stakeholder analyses that explain the obstacles that each group faces in acting to remove the barrier.

Trade associations are often unwilling to support any cryptic barrier removal that leads to what could be considered commodification of their members' products. Manufacturers want to be able to differentiate their products in as many ways as possible to avoid having to compete on price alone. One way that manufacturers can distinguish and therefore justify the higher cost for a high-end product is by making it more energy efficient. The greater the difference between the efficiency of a high-end product and the minimum efficiency standard (the "headroom"), the more justification the manufacturer will have to charge more for the high-end product. As the headroom decreases, products become more homogenized and manufacturers are forced to compete on price. This headroom effect makes trade associations unlikely to take a leadership role in improving efficiency standards.

Federal law is interpreted to limit DOE efficiency standards to no more than one performance metric, although disclosure of additional metrics (such as first hour rating for water heaters) can be required. Many features that would improve efficiency would require adding a metric (such as Energy Efficiency Ratio for air conditioners). This adds to the testing burden because these numbers must be certified (with penalties for failure) and is thus resisted by trade associations and most manufacturers.

Homeowners usually have the most to gain by eliminating cryptic barriers, but also the fewest tools available with which to do so. Homeowners also act individually and tend to be more concerned with the efficiency options available to them personally as opposed to being motivated to change the market as a whole. Homeowners don't have the political power that manufacturers have due to the scale of their involvement in the industry .

Contractors, on one hand, may be in a position to benefit from the removal of cryptic barriers, since many barriers increase the price of efficient equipment. On the other hand, greater headroom makes selling efficient equipment easier and more profitable.

The Importance of Studying Cryptic Barriers

Lying just outside the focus of many stakeholders, cryptic barriers can persist because they are not given much consideration. Identifying and cataloging these barriers is essential to making the appropriate stakeholders aware of the barriers. There is great potential for improving efficiency by removing cryptic barriers, but the challenge is finding the right spokesperson to initiate the change. These barriers are cryptic because in the course of business as usual they will continue to be outside the focus of stakeholders who could work towards eliminating them.

By categorizing cryptic barriers that on the surface have little in common, such as standards for cooling equipment for data centers and fire code restrictions on plastic ducts, into groups determined by root problems like archaic regulations, solutions such as sun-setting legislation can be applied where appropriate.

Conclusion

Cryptic barriers are a unique category of regulations whose intended purpose has been eclipsed by the stifling effects they have on innovation in energy efficiency. Identifying these barriers is not the only challenge to their removal. The advantages in efficiency that are gained when a barrier is removed are public goods shared by society as a whole. Without a mechanism for capitalizing on this benefit, no individual, group, or business has much motivation to invest in breaking down a barrier.

The recommendations drawn from this study are a combination of fixes to correct existing barriers and guidelines for writing codes, standards, and rating methods that will reduce the number of cryptic barriers created in the future. The first of these recommendations is that codes and standards be reviewed and evaluated regularly. As technology changes, the standards and regulations applied to the technology need to adapt. The link between a particular aspect of the code and its negative effect on energy efficiency may not be obvious, hence the name “cryptic” barriers. Because of this, the process of reviewing code has to be proactive, not just reactionary when a particular problem arises. Standards should be performance-based instead of prescriptive because prescriptive standards become obsolete more quickly.

On the other end of the spectrum from obsolete or archaic regulations is the situation in which a lack of regulation causes a barrier. Regulations provide assurances to contractors that as long as established procedures are followed, projects will be approved. The uncertainty that arises when particular equipment or technology is unregulated can be enough to drive contractors or homeowners away from using them. Finally, rating procedures that are not carefully designed to accurately reflect installed conditions can misalign incentives in a way that inhibits innovation in energy efficiency.

Once the question of how to eliminate cryptic barriers is answered, there is still the question of who will undertake the effort. One reason that the problem of cryptic barriers is so difficult to solve is that their removal creates positive externalities that businesses or individual are unable to capitalize on.

A broad survey of cryptic barriers as is presented in this report reveals useful similarities in both the root causes of the barriers as well as the solutions that could be applied. There is also value in maintaining a running survey of cryptic barriers as a resource for future initiatives to remove barriers. Further research should be done to continue to catalogue existing barriers.

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Appendix: A Compendium of Cryptic Barriers

This appendix compiles 12 prospective cryptic barriers identified early in this study. The case studies in this report were taken from these examples, which are presented for possible future study. No priority of importance or urgency should be assumed from the sequence in this listing.

1. Fire rating testing procedures for foam insulation

"Tunnel" testing procedures for fire rating, in which the fire resistance of spray-on foam insulation is determined by testing its ability to be ignited in a tunnel-shaped channel, limit the thickness of foam insulation to 2 inches in conventional facilities. For greater test sample thicknesses, larger tunnels would be required, but apparently are not available. Greater foam thicknesses could be tested using other procedures (such as test walls in fire-proof chambers), but those procedures are more expensive.

Policy or other mechanisms for removing barrier: A cheaper method of testing thicker layers of spray-on foam insulation should be developed so that there is no concern on behalf of the builder that a project using more than 2 inches of insulation won't be approved.

2. Rating calculations on heat pumps

Current heat pumps perform much more efficiently in moderate climates than in very cold climates, since in very cold temperatures conventional designs require the use of back-up resistance heat. If the moderate climate ratings are used to make comparisons between different types of heaters for use in a cold climate, the results may be skewed in favor of the heat pump. Conversely, the benefits of a "cold climate" heat pump designed to work better at low temperatures than conventional units will be obscured by the rating method. This makes it much harder to market these "northern" designs.

Policy or other mechanisms for removing barrier: Rating systems should be reviewed to determine if the additional effort required to tailor the testing procedures to cold climates will be recaptured by society when consumers make more educated purchases.

3. Ratings for residential air handlers

Anytime an energy-consuming component of equipment uses is excluded from rating procedures there is a disincentive for manufacturers to invest in efficiency for that particular use. Residential air handler ratings include information on the electricity consumed by the fan, but not in a way that reveals fan inefficiency. Thus, manufacturers gain no advantage over other manufacturers by providing efficient fans.

Policy or other mechanisms for removing barrier: Rating systems should be reviewed regularly to ensure they are accounting for all energy consumption. DOE has released a *Notice of Proposed Rule-Making* for furnace fans (DOE 2012), but it restricts its concern to the actual fan, shroud, and motor, ignoring aerodynamics of the cabinet.

4. Total house electrical load and multiple point-of-use resistance water heaters

For purposes of sizing the total electricity supply capacity required by a house, the possible load contribution of the first point-of-use resistance water heater in a house is reduced by 40%, but each subsequent heater needs to be calculated at the full rated load to satisfy the National Electric Code. That is, capacity of the electric service panel (and circuit breaker box) must be adequate to meet 60% of the maximum load of one point-of-use water heater, but the full load of each additional water heater is added where there are multiple water heaters. This adds to the cost of installing multiple point-of-use resistance heaters and discourages their use.

Policy or other mechanisms for removing barrier: Safety provisions in the electrical code should be evaluated to ensure they are not unfairly punishing equipment that would improve efficiency—if that is the case.

5. Zoning regulations and external insulation

External insulation is a relatively easy way to improve the efficiency of a building. It has some advantages over internal insulation, such as installation with minimal disruptions to occupants; avoiding cold bridges at fixtures; ceiling junctions, etc.; protecting wall structure from exposure to the elements; and potentially improving the external appearance of a building. However, if a building is built up to the minimum distance allowed from the property line, also known as the setback, zoning laws prohibit adding anything to the exterior of the building that would increase its depth or width. In some cases, historic preservation or other local ordinances also can prohibit any exterior appearance changes.

Policy or other mechanisms for removing barrier: Where feasible, zoning regulations should include exceptions for certain actions that may contribute to the greater good, such as exterior insulation on existing buildings built up to the setback.

6. Zoning regulations and alternative energy installations on roofs

Rooftop mechanical equipment is allowed to exceed the height limit established by zoning regulations in many situations, but alternative or distributed energy systems are not given the same exemption as a "permitted obstruction."

Policy or other mechanisms for removing barrier: Zoning regulations already make exceptions to height restrictions for certain mechanical roof top equipment. Alternative energy systems should be given "permitted obstruction" status as well.

7. Implications in code language in regards to lighting

Some building codes make reference to incandescent lighting, implying that it is the standard choice. Furthermore, many codes don't explicitly allow for occupancy sensors in public areas as an energy-efficient alternative to 24 hour illumination.

Policy or other mechanisms for removing barrier: Building codes should be reviewed regularly to ensure that they include the most up to date technology. Alternatively, and perhaps preferably, codes should not mention any specific technology and only specify performance requirements.

8. Regulatory uncertainty in standards for equipment venting

Condensing boilers produce exhaust that is relatively cool and non-noxious, allowing exhaust to be safely vented through a sidewall instead of a rooftop stack. This brings down the cost of more efficient equipment making it more competitive. However, because certain concerns, such as the risk of condensation creating ice on sidewalks, are not addressed in the code, some inspectors are refusing to permit sidewall vents. This situation creates uncertainty that discourages contractors from incorporating sidewall vents.

Policy or other mechanisms for removing barrier: Sidewall vents need to be explicitly allowed in building code as long as specific concerns such as ice on sidewalks are taken into consideration. If they are not explicitly allowed they will continue to be underutilized because of the potential problems caused by regulatory uncertainty.

9. Flame and smoke concerns with plastic air distribution ducts

Traditionally constructed ductwork is infamously leaky, which leads to inefficiencies and air quality problems. Plastic ducts could be more leak-proof and easier to install, but fire code may prevent plastic from being used as a duct material because of concerns about its flammability.

Policy or other mechanisms for removing barrier: The two technical solutions to this barrier are adding fireproofing material to existing plastics, and creating a new inexpensive fire-safe polymer. From a policy standpoint, the UL 181 requirements should be examined to determine if such restrictive standards are justified.

10. Unrealistic testing procedures for electric water heaters

Test procedures for electric water heaters require that the water heater sit on a wood base during testing. In reality, most water heaters are installed on concrete. The substitution of wood for concrete acts like an additional layer of insulation, and can result in ratings that overstate the efficiency of the heaters.

Policy or other mechanisms for removing barrier: All testing procedures should be reviewed to ensure that they replicate as closely as possible the conditions in which the equipment is most likely to be installed.

11. Electrical sockets not required near water heaters

Not all kinds of gas water heaters require electricity, but the most efficient models commonly do. If a water heater that doesn't consume electricity is installed in a new construction, there are no codes requiring that an outlet be installed nearby. Furthermore, because longer power cords increase the risk of electrical fire, there seems to be a six or 10 foot limit on how far 120 volt electricity can be run in power cords. This creates a situation where the options for replacing water heaters with efficient models are limited. In order to replace a water heater, costly renovations or creative engineering is needed to run electricity to the heater so that a more efficient electricity-consuming heater can be installed.

Policy or other mechanisms for removing barrier: New homes could be required have an outlet adjacent to the water heater, whether or not the heater being installed initially requires electricity. This would facilitate the replacement of the first water heater with a more efficient one when the time comes to replace it.

12. Regulatory uncertainty for rooftop solar panels

Building codes have not caught up to advances in technology. Although there are standards for how to install most other kinds of rooftop equipment, we did not find codified regulations for how to install solar panels. This uncertainty tends to discourage designers away who fear uncertain treatment by code officials.

Policy or other mechanisms for removing barrier: New installation standards should be drafted for rooftop solar panels, as well as for all other new efficient technology. A regular review of the existing building codes by emerging technology experts could help assure that standards and codes keep up with technological developments and therefore minimize the regulatory uncertainty associated with new technologies.