Ratings for Standards, A Quarter Century at a Time

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ABSTRACT

Appliance and equipment efficiency rating methods are laboratory tests based on *models* of how we think equipment operates in the field. Rating methods determine compliance with efficiency standards, and underlie incentive programs. Product efficiency claims in the US must be based on the federal standards, so manufacturers design to maximize test performance. "What you measure is what you get." But, most rating methods date back decades. Technologies have changed, and many rating methods are obsolete. For example, the water heater rating method, developed to compare relative performance of tank water heaters, gives misleading results when used to compare tank to tankless units. The air conditioner rating method uses values for duct resistance and fan power that are much too low, discouraging air handler efficiency investments and distorting humidity control capability. The commercial boiler rating overstates applied efficiency of non-condensing boilers, and drastically underestimates the savings from condensing systems at part load.

These shortcomings have profound real-world implications. Federal tax credits were based on incorrect assumptions about tankless water heater savings. Air conditioner rating methods discouraged differentiated regional products that could cost-effectively save energy (and inadequately policed some simulation-certified equipment). As important now, using federal ratings as the basis for efficiency programs may lead to reduced savings from equipment that tests better than it works in the field.

We need a national commitment to expanded field studies of how buildings and equipment work and interact, and substantial collaborative work to revise our rating methods to be better models of performance and innovation. As part of the process overhaul, more stringent certification programs are required, and can improve quality as well as performance.

Introduction

Mandatory efficiency standards for appliances and equipment are based on laboratory tests run according to prescribed protocols called rating or test methods. Early metrics, standardized by industry trade associations, were typically based on steady-state maximum output. These were relatively easy to measure in standard ways, and gave pretty good comparisons of "like" equipment. As an example, the ratio of the steady-state heat delivered to the system (Btu/hr) to the rate of fuel use under those conditions (Btu/hr) is a decent descriptor of a boiler with a single-stage burner. This is the meaning of a "COP" (Coefficient of Performance). Similarly, it's relatively easy to measure how much water is removed by a dehumidifier (liter/hr) relative to the electricity used (watts) under standard conditions in a humid chamber.

When energy efficiency became important in public policy, more "consumer-friendly" measures were developed to estimate seasonal or annual performance, to better approximate the combination of part-load and full-load performance that typifies use. In general, these metrics involve measurements under more than one operating condition, and calculation of a derived figure of merit from the calculations. SEER (seasonal energy efficiency ratio, Btu/watt-hr) for central air conditioners is one example, based on measurements at two different operating conditions for single-stage equipment.

As equipment becomes more sophisticated, even these approaches have limitations. In some cases, such as commercial roof-top units, the refrigeration cycle efficiency may not even be the largest of its contributions to efficient energy use: its control of an economizer cycle and how it handles building ventilation requirements also matter greatly. The household refrigerator has multiple energy-using functions (including control of door-edge condensation), which opens additional opportunities for advanced software control. Indeed, a *major limitation of efficiency standards is that efficiency measures that do not affect the rating results will not be valued in the market.*

Two examples from water heaters illustrate this point well. Because the water heater test is done on a relatively insulated platform, there is little incentive to insulate the bottom of an electric water heater. Unfortunately, we believe that most electric water heaters are installed on concrete floors, and would use less energy if the bottoms were insulated. Similarly, adaptive controls that take advantage of tank stratification and "learned" use patterns could save energy that is not reflected on the test, so manufacturers cannot advertise in-use expected savings from these features. This may discourage investment.

The key is remembering that rating methods are *models* of how we think equipment operates in the field. Also, most rating methods date back decades (although there have been "tweaks" over time). Technologies have changed, and many rating methods are obsolete. For example, the water heater rating method, developed to compare tank water heaters, gives misleading results when used to compare tank to tankless units. The air conditioner rating method uses values for duct resistance and fan power that are much too low, discouraging air handler efficiency investments and distorting humidity control capability. The commercial boiler rating overstates applied efficiency of non-condensing boilers, and drastically underestimates the savings from condensing systems at part load. The clothes dryer rating gives a fixed energy savings credit for temperature and moisture sensors despite the fact that sensor performance varies widely, discouraging efforts to improve sensor performance. Rating methods determine compliance with efficiency standards, and underlie incentive programs. Product efficiency claims in the US must be based on the federal standards, so manufacturers design to maximize test performance. "What you measure is what you get."

In this context, the goals of this paper are to reflect on how much has been accomplished by standards, note the limitations of our current processes for progress, and begin the conversations on ways to foster innovation, provide the right information, limit testing burdens, and generally make progress for the next quarter century, building on what we learned from the past quarter century.

A Brief Introduction to Appliance Efficiency Standards

We start with test or rating methods, because they underlie all standards, including efficiency standards. Efficiency standards set legal minimum performance based on a specific rating method for the product. As is the case for all engineering problems, the "perfect" rating method would have a bundle of incompatible attributes, so compromise is necessary:

1. *Easy to measure.* Yet the rating method should not require disproportionate equipment investments.
2. *Quick.* For a manufacturer, the time that a product must occupy a test cell is a cost driver, so short term tests are preferred.
3. *Easy to understand.* "KWh/yr" is easier to grasp than "EER," a simple ratio but one that mixes Btu with kWh. In turn, "SEER," is a simple ratio, but really hard to grasp in all its perturbations and formulas (it requires sixty dense pages in the Federal Register) (DOE 2005).
4. *Unbiased.* It should have the same level of applicability across all technologies rated. For example, available data indicates that the water heater rating method, developed to compare tank water heaters, gives artificially high ratings for tankless water heaters when compared to expected use in the field.
5. *Easy to use.* Consumers, intermediaries such as contractors, and marketers should be able to rely on the output of the standard (a rating) to quantitatively compare alternative products. For example, SEER 13 is arguably 23%, not 30%, more efficient than SEER 10, but the definition obscures this. Ideally, the rating method would allow easy estimation of energy use (and cost) for the customer's own application.
6. *Helps assure quality.* This has multiple attributes, none fully realized. It could refer to degradation and low-voltage testing (done now). It could include protocols for selecting test samples that encourage manufacturers to minimize manufacturing variability.

Since rating methods originated with manufacturers more concerned about unfair competition than attributes further down the list, they started out simply. The energy price shocks of the 1970s made efficiency a matter of public policy. Early state standards in California and elsewhere led manufacturers to accept national standards instead of the threat of a patchwork of local efficiency standards, setting the basis for our current system administered by the Department of Energy (Nadel 2002). The same drive to meet perceived consumer needs led to the development of annual standards like SEER for air conditioners, annual fuel utilization efficiency (AFUE) for furnaces and boilers, and energy factor (EF) for water heaters. Compromises were accepted for consumer products like refrigerators and clothes washers, and new rating methods developed for a wide range of regulated products (DOE 2010).

The process of setting a federal efficiency standard starts with Congress, which can direct the Department of Energy (DOE) to set a standard, or to determine if one is needed. To begin the ensuing multi-step process, DOE has to either adopt an industry rating method or develop an alternative. In either case, public input is sought through a well-established and ritualized process. The Department's process generally includes analyses of the market and technology, leading to publication of a *Framework* and a *Technical Support Document* that underlie the rule-making.

Historically, DOE rulemakings have been contentious, featuring arcane analyses by dueling experts representing manufacturers, advocacy groups, and utilities. Tension is built into the process, which stipulates that standards be set "to achieve the maximum improvement in energy efficiency…which the Secretary [of Energy] determines is technologically feasible and economically justified" (42 U.S.C. 6295(o)(2)(A)). In addition, the Department has to satisfy a list of criteria in its *Process Rule,* dealing with impacts on manufacturers, consumers, utilities, and competition. More recent changes encourage the development of consensus agreements among stakeholders and seek to make the process less contentious, but deficiencies in the analytical framework persist.

The DOE engineering analysis is one basis for the process. Historically, it has used narrow criteria of availability, eliminating some efficiency features that are in use internationally but not in the US, or for other products but not the one being considered. This compounds uncertainties in the analysis of the cost of efficiency, where DOE has frequently over-estimated the mature market prices after regulations are implemented. In turn, this underlies elaborate but unconvincing life cycle cost studies. In many cases, ACEEE has shown that life cycle cost differences among alternatives evaluated are very small relative to the uncertainties inherent in the analyses. At different times, both advocates and manufacturers have felt that the Department's analysis has been far more detailed than our understanding of the underlying systems, and that the conclusions have been more precise than accurate.

At a deeper level, for many covered products, energy efficiency has been a feature used to help differentiate premium products in a crowded "commodity" market. Sales of premium products may be much more profitable than the base products, and these profits pay for future innovation. To the extent that more stringent standards reduce the performance "headroom" for premium products, making it more difficult to show value to consumers, manufacturers will resist change. This carries over to the influence of market incentives by utilities and others: if the performance of the best electric resistance water heater is only a few percent better than the legal minimum, savings are too small to warrant the costs of an incentive program.

In addition, in the quarter century of mandatory efficiency standards use, there have been important changes that may not be reflected in today's standards:

- New technologies such as tankless water heaters were not anticipated when the rating methods were developed, and are not well characterized by them.
- The US has not invested enough in field research to actually understand how products are used in the field. The national rating method for water heaters assumes that the average unit, of any capacity, produces 64.3 gallons of hot water per day, while available data now suggest that average use may be about 43 - 45 gallons per day (gpd) (DOE 2009). Similarly, we understand far too little about field degradation from improper installation or maintenance – or inherent attributes of products (insulation breakdown might be an example).
- Improvements in associated products that reduce energy consumption have not been reflected with updates in the rating methods. The clothes dryer rating method assumes the dryer receives wet laundry loads with 70 to 100% remaining moisture content, substantially higher than the current average and much higher than the average for models meeting new minimum efficiency standards.
- National standards for climate-sensitive products limit the ability of manufacturers to respond to opportunities for regional optimization.
- Firms have introduced energy-saving and performance-boosting technologies whose contributions are not "seen" by the rating method, so there is little encouragement for adoption. Improved outdoor reset or purge boiler controls are an example that has been legislatively mandated because DOE would not include them as prescriptive product features (see the residential boiler discussion below).

As a result, the well-understood ritual of standards adoption has been unsatisfying to all parties. After discussing some specific cases, we turn to alternative vehicles that broaden the focus from standards to combined approaches.

Cases and Issues

Residential Boilers

Issue: STRINGENCY misses big savings opportunity from controls. Like furnaces, residential boilers are rated by AFUE. Increasing stringency would reduce the ability of manufacturers to market premium products on the basis of their large energy savings. Beyond this, it is widely understood that certain control features can save energy that is not reflected in the rating method. "Outdoor reset" strategies reduce the temperature of the water circulating to the radiators to the lowest feasible level at all times, which reduces standby and distribution losses. Similar gains are offered by "purge" systems that turn off the boiler but continue circulating water through it until the boiler is near ambient temperature and all the heat has been transferred to the building zones. Together, manufacturers and advocates reached a consensus in 2006, proposing to DOE that it adopt a standard for AFUE that also required elimination of standing pilot lights and an advanced control system for all gas boilers. DOE rejected this proposal, arguing that it could not require *both* a prescriptive standard (controls) and a performance standard (AFUE) for the same product.

Fix for now: add prescriptive requirement through legislation. Advocates and industry worked together for a legislative provision that sets the standard at AFUE 82 and requires advanced controls, to take effect in 2012 (DOE 2008). This modest step showed that effective collaboration could meet the needs of all parties.

Residential Furnaces, Air Conditioners, and Heat Pumps

Issue: national ratings hide need for regional differences in efficiency. When implemented in 1992, DOE's SEER (annual efficiency) rating metric was considered a pro-consumer advance that would give good relative comparisons of energy efficiency across the country. Experience since then has shown that regional climate needs are not well served by the combination of advanced technologies and national ratings (Amrane 2010).

Fix: consensus agreement that includes other issues, like building codes. In 2007, the Energy Independence and Security Act (EISA) instructed DOE to examine whether regional standards for residential furnaces, air conditioners, and heat pumps should be adopted. With that stimulus, manufacturers and advocates negotiated a consensus agreement announced in October 2009. If accepted, this agreement will lead to different AFUE levels and SEER levels in northern vs. southern states, with additional requirements for high-temperature air conditioner performance in four southwest states (Amrane 2010).

What's interesting for present purposes is that the consensus agreement achieves more savings than could be gained through standards alone. It does this by including provisions for residential building codes to include more stringent options for new construction, which will require legislative action that all sides will support. Another provision requires manufacturers to provide EER data for each temperature bin, which will help software developers provide better design tools and choices for contractors. Finally, the result of regional standards will be to shift responsibility for enforcement from the manufacturers to state and local code officials, and to distributors and contractors.

Residential Water Heaters

Issue: rating method biased and unreliable. As noted above, the current "EF" rating method has several major problems. First, its inherent structure, based on 6 equal draws of about 10.7 gallons each, favors tankless water heaters. Limited available data suggest that when challenged with use patterns more like those in real installations, they would have EF values about 9 points lower (DEG 2006). In addition, the rating method requires storage tank temperatures about 135F – 140F, although manufacturers ship their units with the thermostats set in the range of 120F – 125F, to avoid scalding. The temperature at rating matters for heat pump water heaters, whose HFC refrigerants work poorly at high temperatures. Thus they use resistive backup as a booster, reducing efficiency relative to expectations at realistic temperatures. Finally, the EF test is considered poorly reproducible at today's efficiencies.

Fix: consensus legislation. AHRI and ACEEE have together proposed to Congress that the Department of Energy be instructed to quickly fix the rating method (U.S. Congress 2009). This legislation may adopt the commercial rating method, or some other one, in a process led by NIST and advised by ASHRAE[1] and other stakeholders (manufacturers, advocates, utilities).

Lighting

Issue: rating fails to account for efficacy of desired service in specific applications to be regulated. In response to a directive in the Energy Policy Act of 1992, the "luminaire efficacy ratio" (LER) was developed as a metric to evaluate the efficiency of the whole light fixture, including lamp, ballast, optics and other design features. LER is defined as the ratio of total rated lamp lumens to input watts, with adjustments for ballast factor and a "fixture efficiency" (FE) factor, which is total luminous flux emitted from the fixture compared to total rated lumens. A major shortcoming of the LER metric is the creation of unintended advantages for some fixtures that rate well (e.g., they allow a lot of light out of the fixture) but offer poor light distribution. In outdoor lighting applications, this issue is exacerbated since light that leaves the fixture, but is not directed toward the target area or surface yields light pollution impacting neighboring occupants and communities, astronomers, wildlife, and others.

Fix: use improved rating methods and product categorization to gauge performance in defined applications. To address this issue, the National Electrical Manufacturers Association (NEMA) first published a revised metric for light fixture efficiency called the "target efficiency rating" (TER) which accounts for the amount of light hitting the work plane or "target" rather than total light output from the fixture. The TER metric can be used for interior and exterior lighting applications. Following adoption of TER, a new luminaire categorization system to address backlight, uplight and glare (BUG rating) was developed. In negotiations of a consensus agreement on minimum efficiency standards for outdoor lighting fixtures, minimum efficacy

[1] SPC 118.2, which is responsible for the rating method.

requirements vary based on the luminaire BUG ratings with products with the highest ratings receiving an allowance in the form of a reduced TER requirement to account for their superior performance in delivering light to the target area with minimal light trespass or pollution. The consensus agreement incorporates other performance metrics (lumen maintenance and power factor) and prescriptive requirements (controls) for some covered products. If adopted, this will represent the first federal standards covering whole fixture performance.

Appliances

Issue: refrigerators "learn" to optimize performance for test conditions. The federal test procedure for residential refrigerators sets specific laboratory test conditions that are very different from ambient field conditions. Ambient room temperature for the test is 90°F—which may reflect summer temperatures for the growing number of second refrigerators found in garages, but not the typical American kitchen—in large part to make up for the lack of door openings during the test cycle. The test is also conducted with an empty refrigerator. Without any food or beverages to introduce moisture, newer refrigerators will not enter a defrost cycle. Sensors and controls in modern refrigerators readily recognize these test conditions and some manufacturers have developed "test cycles" that recognize when the refrigerator is operating under the test conditions and shut down certain functions or make other adjustments to minimize energy consumption.

Fix: establish test procedures that are more difficult to game. Ambient conditions and usage patterns have a large impact on in-field refrigerator energy consumption making it very difficult to establish rating methods that meet the needs for consistency, repeatability, and cost-effectiveness while providing a realistic estimate of typical in-field use. Improvements to the refrigerator test method should emphasize changes in test conditions so that they are a more realistic reflection of potential in-field operating conditions making it harder for manufacturers to game the test. A new test should also rate the energy performance of the refrigerator including features and functions utilizing sensors and controls rather than simply providing a set deduction in tested performance when sensors and controls are present. This would provide an incentive to optimize the performance of these components and differentiate between high- and low-performing controls and sensors.

Televisions

Issue: distorted ratings from artificial test conditions. The federal rating for television sets, initially adopted in the late-1970s, required measurement of television power consumption while the unit displayed two static images. First, power consumption was measured using a white test pattern with all consumer image controls (e.g., brightness) turned to the level corresponding to maximum power consumption. Then, power was measured using a black test pattern with all consumer controls turned to the level of minimum energy consumption. In both instances, the volume control was turned to the lowest position. The measured values were averaged to determine active mode television power use. Not only did this method fail to yield an accurate representation of actual television energy use, it also minimized the differences in real-world performance between television models and failed to provide realistic information on the energy savings opportunities from minimum efficiency standards for televisions.

Fix: new rating method. DOE rescinded the federal TV rating method in late 2009. While DOE has yet to adopt a new federal test method, ongoing efforts in this area will allow DOE to adopt a widely accepted rating method as soon as they act on their stated intention to do so. The California Energy Commission has adopted a method for televisions in conjunction with recently established state minimum efficiency standards building on a new IEC test method. A similar method is used by the EPA ENERGY STAR program. The new rating uses a standard test clip to more accurately recreate typical television viewing conditions with variations in color, image movement, and sound.

Discussion

Lessons Learned in a Quarter Century

Many of today's efficiency standards are built on obsolete rating methods that can't capture the energy-saving benefits of new technologies (including advanced software). Indeed, it's almost an oxymoron that high performance equipment requires – and warrants – comparably sophisticated ways to measure performance potential. At the same time, letting the testing burden grow indefinitely will divert resources from innovation, so there must be balance – or a new approach.

We've also learned some things about differences between the assumptions made about how appliances are used versus their actual use patterns, knowledge that often warrants changes to the rating methods. For some products, such as water heaters, field data suggests that use patterns are lower than anticipated, which may make advanced energy-saving technologies *less* cost effective than had been assumed. But mostly we have learned that a robust field research program is required to support efficiency standards. Only with such research can we better calibrate our rating method "models" to real use.

A good field research program will also help settle some open questions about long-term performance in the field. If efficiency drops over time because of condenser coil fouling, compressor lubricant coating of the coils, or scale accumulation in water heaters, we need to understand it. Doing so would help to justify the stimulus and efficiency gains of early replacement programs, and help establish a value proposition for self-diagnostic capabilities in equipment.

Some Ideas Going Forward

It's probably time to consider explicitly separating certified measurements from consumer information. As an example, two or more groups are developing a new rating method for water heaters, because that system works so poorly across technologies and at high efficiency levels. Today, manufacturers certify a calculated result, EF, based on the energy required to carry out a specific set of hot water draws. One alternative being considered would adopt the system used for commercial equipment, in which steady state efficiency and idle loss are separately measured. This reduces the burden on the labs, but the information is not user-friendly. What if manufacturers certified these parameters instead of EF, and we allow a range of open-source programs to be used for estimating energy use by the specific water heater for different customer classes? This approach could give much more useful information than the present "yellow label" or EF rating, without increasing the testing burden. It could also allow a process for including the benefits of other parameters that manufacturers might choose to certify, such as an advanced control.

For some equipment classes, this strategy offers major advantages for efficiency. Consider the case of the central air conditioner. It is rated as a product, but it is part of a system, and the efficiency of the system depends on its interaction with the other parts, from ductwork to house size and location. If manufacturers are only certifying two parameters, it reduces the risk of releasing supplemental information, such as EER for each temperature bin. But this "performance map" is exactly the information required by software developers who support contractors who want to offer informed choices ("good-better-best) to their customers. In this case, all of the choices could be efficient, but differentiated by other features that consumers value.

We also must recognize the challenges of rating software-controlled appliances. We have already seen evidence of refrigerators "smart" enough to recognize and adapt to specific test conditions to falsely improve rated performance – an effect that has been documented for some vehicle emission requirements, too. We can see no way to counteract this except to limit the numbers of parameters certified, and carry out random sensitivity tests with variations of the ambient test conditions. This approach will not be feasible unless the number of certified parameters is small.

In this conjunction, we emphasize the importance of third party certification. Indeed, third party certification of randomly chosen units could drive improved efficiency and quality with a simple protocol change: At present, the rating method requires the laboratory to assure that the unit being tested meets the manufacturers' specifications, such as refrigerant charge. Although we might wish the contrary, it is unlikely that installers carry out the same tests. Therefore, we propose that random units be tested, in the condition received from the warehouse.

Issues

Separating certification from label information, and mapping the former into the latter with open algorithms, may be a good path forward. But it's not without its own challenges. For example, it still will be hard to show the efficiency gains from adaptive technologies that just don't show up in the stipulated tests. Today, manufacturers are limited in efficiency claims to use of the federal descriptors. We must think about whether these features remain "outside the fence," or get provable default benefits that can be recognized.

The other major issue is how to do a transition from the present system to an alternative one. On the one hand, the burden of recertifying existing products would be high, but there would be confusion if multiple methods of rating products coexist in the market. One proposal is to delay implementation of the new system until a date certain. Existing products today would have to be recertified to continue being sold. New products would have been rated both ways, so it's just a question of a new label after the date certain.

Public Policy Imperatives as We See Them

First, the US needs a vigorous research program that supports standards and certification. Technologies change over time, as do applications, and someone must assure that ratings are relevant, by tracking how ratings map into field performance. In addition, our present certification is based on new equipment. We need to study changes in performance through time, so we differentiate technologies and products that maintain performance over time. This even extends to features like automatic diagnostics that can track equipment performance and call for energy-saving maintenance when required. There is simply too little incentive for individual firms to carry out this work.

Foster Innovation, Don't Retard It

It is imperative that standards not only assure performance today, but that the standards environment fosters innovation for greater energy savings. Because standards are built on simplified “models” of applications, they cannot capture all features that save energy. Thus, a balance needs to be found that keeps the playing field level, but still acknowledges the need for manufacturers to show savings from advanced features. A blanket prohibition on any reference to energy efficiency other than the rating hinders investments in advanced approaches.

Industrial Policy and Efficiency Standards

Whether we like it or not, energy efficiency is a piece of industrial policy. There is evidence that some national competitors have used bogus certifications to protect their domestic industries, but that's just not a competitiveness strategy for the US in the future. Our standards need to give full value in the marketplace to solutions that work better for customers. Certification should reward quality by testing truly random product samples. Finally, the standards regime must foster innovation for efficiency and customer satisfaction, rather than protecting stagnation.

Summary

Appliance and equipment efficiency rating methods are laboratory tests based on *models* of how we think equipment operates in the field. They are very important, being used for everything from showing compliance with federal standards to eligibility for incentives and tax credits. Because product efficiency claims in the US must be based on the federal standards, manufacturers must design to maximize test performance. Unfortunately, many test methods are obsolete. First, new technologies often have features that are poorly reflected by the old tests, and the old tests were never designed to compare disparate technologies (such as tank v. tankless water heaters, and possibly also ducted v. ductless air conditioners and heat pumps).

A national commitment is needed to better understand how equipment and appliances are used in the field, so we can develop much better rating methods that balance robustness and simplicity, and that do not stifle innovation. As a corollary, as part of the process overhaul, more stringent certification programs are required, and can improve quality as well as performance.

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