Long and Winding Road to Higher Efficiency—The RTU Story

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ABSTRACT

Rooftop units (RTUs) and other packaged heating, ventilating, and air-conditioning (HVAC) equipment consume more than four quads of energy annually while conditioning more than 50% of the commercial building floor area in the United States. Historically, these systems have low operating efficiencies and receive infrequent maintenance. In addition, the market has a low first cost, run-to-failure, like-for-like replacement mentality and has been slow to adopt change. This paper explores the broad market transformation that has resulted in higher efficiencies and tremendous energy savings. Although there are many factors in this market transformation, this paper highlights:

- Research behind advancements in components and controls
- Adoption of an operational efficiency metric
- Raising the bar for high efficiency with the RTU Challenge
- Market barriers overcome through the Advanced RTU Campaign
- Upstream and midstream incentive programs and HVAC distribution networks
- Alignment of the market efficiency drivers of ASHRAE Standard 90.1, federal minimum efficiency standards, the ENERGY STAR® program, and the Consortium for Energy Efficiency's (CEE's) efficiency tiers.

Measures of the market transformation include more than 50% increase in RTU efficiencies, more than 1 billion kWh saved and 160,000 RTUs upgraded with high-efficiency measures by the Advanced RTU Campaign partners, large increases of high-efficiency RTUs purchased through incentive programs, and the largest energy savings from any federal minimum standards action. Although these results are impressive, the market transformation is just beginning, and there remain exciting opportunities for improvements in equipment efficiencies and improved operating performance with advanced controls and fault detection and diagnostics.

Introduction

Packaged HVAC units, including RTUs, serve the conditioning needs for more than 50% of the U.S. commercial building floor space (DOE 2011) and consume nearly 4 quads of primary energy (electricity and gas). RTUs are the work horses of space conditioning for one- and two-story commercial buildings. These factory-built units have become commodity items in a market dominated by lowest first cost, which discourages technology advancements (Shugars et al. 2000, Lowinger et al. 2002, ACEEE 2019). Figure 1 displays an estimated number of commercial air-conditioning units shipped per year by cooling capacity (refrigeration tons) in the United States since 1996 (AHRI 2019). There are no public data on division of residential and commercial systems. For this graph, all systems above 5.4 tons, 5% of the units between 2.75 to 3.24 tons, and 20% of units between 3.25 and 5.4 tons are assumed to be for commercial applications.

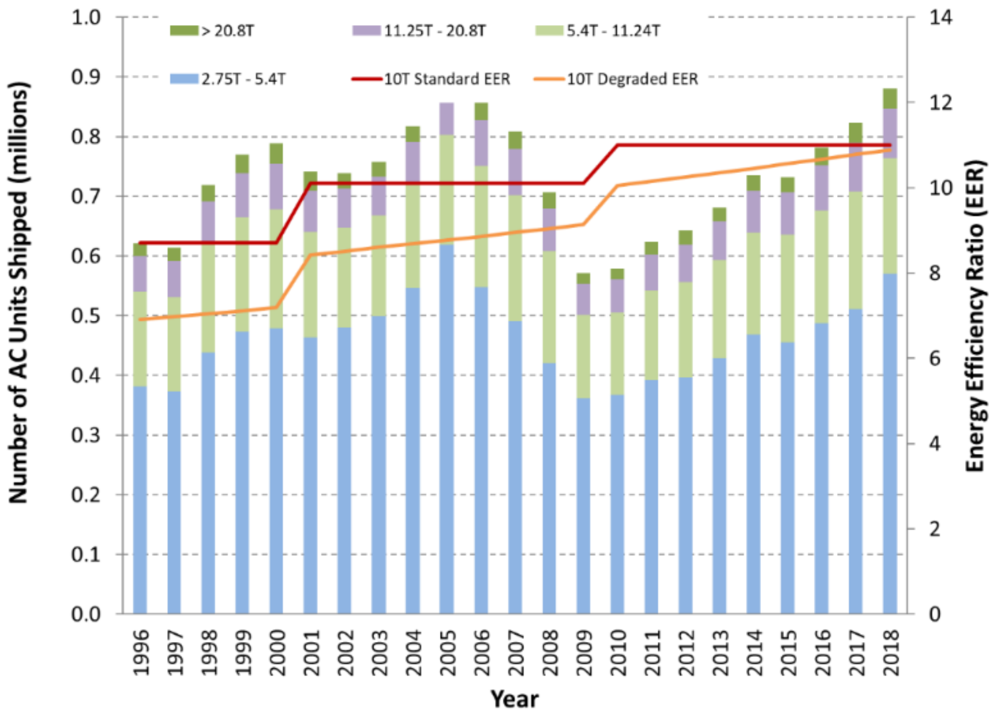


Figure 1. Number of light commercial air-conditioning units shipped per year by cooling capacity (tons)

The line graphs show the minimum standard efficiency levels and operating efficiency levels assuming a 1% degradation per year. The typical RTU lifespan is 15 to 20 years, but they can last more than 30 years or fail in fewer than 10 years in harsh environments. Poor maintenance can lead to performance degradation and lower efficiency over time. There are no data on the number of installed RTUs; however, based on this shipment data, there are approximately 15 million RTUs on commercial buildings in the United States. The low performance and large distribution show that there are great opportunities for improving energy, cost, and space-conditioning performance. This paper outlines the main challenges facing the market for high-performance RTUs as well as some of the strategies that have proved successful in achieving higher efficiencies and lasting energy savings associated with packaged HVAC equipment.

Market Barriers

The light commercial HVAC market is complex, with many actors and intertwined layers. Understanding these actors and the interactions between them allows us to appreciate the market barriers to increasing efficiency and developing possible solutions. The major actors that play a role in the RTU market and their main interactions with building owners are shown in Figure 2. There are significant interrelationships between all actors involved, some of which are not included in the figure.

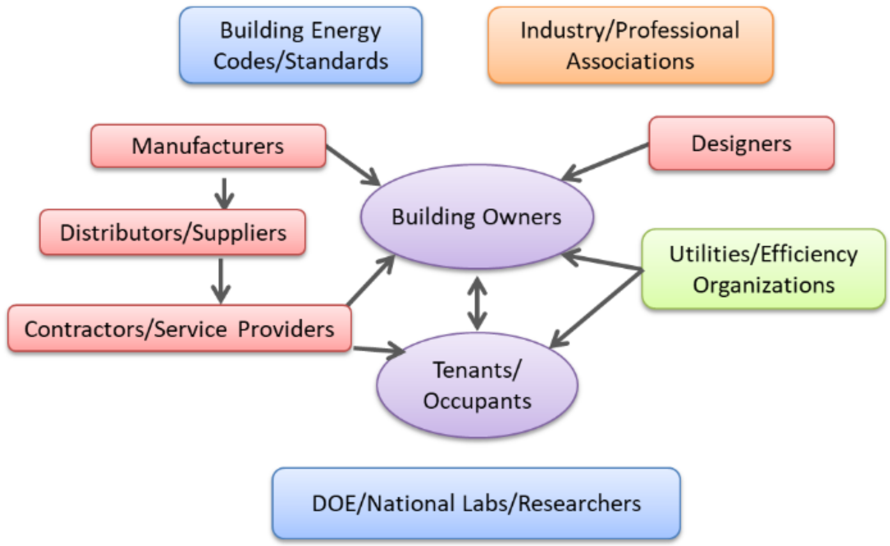


Figure 2. Market actors and interactions for light commercial HVAC

There are multiple barriers for implementing higher performance measures in the commercial HVAC market. Because of the complex nature of the market, the barriers are often multifaceted and not easily addressed with a single solution. A summary of the main barriers and recommended solutions is presented in Table 1. The solutions presented here are simplified and overlap across barriers. A comprehensive solution set covering all (or most) of the barriers will be the most effective for transforming the market.

Table 1. Market barriers for high-efficiency RTUs

Barrier	Description	Recommended solutions
High first cost	Primary barrier	Promote life-cycle cost practices and develop consistent incentive programs
Unawareness of the benefits of high-efficiency units	Non-energy benefits are often not included in cost analyses	Characterize non-energy benefits and provide full life-cycle cost analysis examples
Split incentives	Buyers do not pay energy bills and want lowest first cost	Develop energy-aligned leases and promote non-energy benefits
Complicated/ inconsistent financial incentives	Incentives, rebates, and tax breaks are often difficult to use, variable, or inconsistent	Provide clear and comprehensive guidance on incentives and financial opportunities; encourage consistent programs and midstream incentives
Low-cost market does not support efficiency innovations	No incentive for manufacturers to add new features or innovate new technologies	Educate owners, research optimal performance solutions, challenge manufacturers to raise performance, and raise minimum standard levels
Uncertainty/mistrust about savings claims	Owners and utilities may not trust energy and cost savings for high-efficiency units	Compile third-party demonstrations and case studies and promote life-cycle cost planning

Barrier	Description	Recommended solutions
Long life of RTUs (15–20+ years)	The long turnover time for RTUs creates slow market uptake of new technology	Promote early retirement and adoption of high-efficiency options
Multiple efficiency metrics and recommended efficiency levels	Confusion around multiple metrics; misalignment of federal standards, 90.1, ENERGY STAR, and CEE	Educate owners and contractors about metrics and performance; align market performance levels
Lack of expertise for specifying high-efficiency units	Designers, contractors, and owners tend to go with what they know and are hesitant to ask for higher performance	Educate actors on the values of higher-performance units and provide standard specifications and load calculations for proper sizing
Size and connections not compatible with existing systems	High-efficiency RTUs may be larger and heavier, may not align with existing systems, and may require adaptors and roof support	Evaluate replacement requirements and downsize if possible
New maintenance procedure requirements	Innovative technologies sometimes come with additional maintenance requirements	Original equipment manufacturers can simplify maintenance requirements, provide training and user support, and design intuitive interfaces with actionable feedback

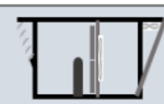
Many of the barriers are interrelated, illustrating the intricate nature of these challenges. For example, the first five barriers are connected to first cost, which is the primary barrier most often cited by buyers. One interpretation of this result is that there is no way to make a significant impact because it is overly complicated, and another is that there are multiple options for addressing the high first-cost barrier. This paper shows how multiple solutions have been able to support market transformation toward higher-efficiency RTUs.

The small- to medium-size commercial building market is very cost conscious, and this is especially true with HVAC systems. As reported by Shugars et al. (2000), this obsession with first cost of RTUs for new and replacement systems is prevalent throughout all levels in the decision-making process. Despite the significant cost implications over the long life of RTUs, first cost is the primary decision point for the purchase of new equipment. A major reason for the low first-cost driver is that the decision makers for purchasing RTUs are often not the ones paying the operating costs, and naturally the RTU buyers want to minimize their costs (Shugars et al. 2000). Financial incentive programs are one method to reduce first costs of high-performance equipment; however, they also do not work well in a split incentive market. Incentives require substantial effort (real and perceived), are often complicated, inconsistent across utilities, and short-lived. In addition, as much as 65% of the commercial HVAC market are for replacement upon failure, in which case there is less time to work through an incentive process (Cornejo 2013). Each of these challenges reduce the likelihood of taking advantage of incentives to purchase higher-efficiency RTUs.

Manufacturers respond to the strong first-cost market pressure by producing what the market will support, which is the lowest-cost units. In this competitive race to the bottom, manufacturers trim nonessential features from units in order to gain more market share. One effective method of raising overall efficiency levels is to increase the minimum standard efficiency levels. However, national minimum efficiency levels for commercial HVAC systems have been slow to advance. The Energy Policy Act (EPAct) of 1992 established the first national minimum efficiency standards for commercial HVAC between 5.5 and 20 tons, and these minimum efficiency levels were raised in 2003 and 2011.

The multiple performance metrics used for rating packaged air-conditioning equipment (see Table 2) also contribute to the slow market adoption of high-efficiency solutions. Energy efficiency ratio (EER) is a single point performance metric that measures the net rate of cooling divided by the electrical power input. Rated EER performance is determined at conditions that represent full load performance and is used for all packaged HVAC equipment. Part load performance of small HVAC equipment under 65,000 BTU/h (5.4 tons) is rated by the seasonal energy efficiency ratio (SEER), which was developed for residential applications. Commercial buildings also use a significant number of units in this size range, but SEER is not a good indicator for commercial building operations because of operational differences compared to residential buildings. Part load performance of packaged HVAC with cooling capacities greater than or equal to 65,000 BTU/h (5.4 tons) was historically rated by the integrated part load value. However, the integrated part load value does not set consistent part load capacities and does not accurately represent efficiencies across all units. In response, the HVAC industry developed the integrated energy efficiency ratio (IEER), which is a weighted sum of the EERs measured at four operating conditions that represent 25%, 50%, 75%, and 100% loading. IEER is a reasonable representation of performance and is easy to understand; however, market adoption of IEER has been slow. Because EER was the key performance indicator for large equipment for many years, manufacturers focused on the lowest-cost approach to meeting the minimum EER levels and did not add features to improve part load performance. However, RTUs spend most of their time operating at or below 50% capacity, and focusing on EER has resulted in significant lost energy saving opportunities.

Table 2. RTU performance rating efficiency metrics

Performance Metric		**Units**	 **< 5.4 Tons**	 **≥ 5.4 Tons**
Single Point Perf.	Energy efficiency ratio (EER)	BTU/h/W	EER	EER
Part Load Perf.	Seasonal energy efficiency ratio (SEER)	BTU/W	SEER	
	Integrated energy efficiency ratio (IEER)	BTU/h/W		IEER

Having multiple performance metrics for small and large equipment introduced confusion and further slowed the adoption of higher-efficiency technologies. A clear example of this market confusion is the impact on replacement practices for small commercial building developers and owners who are very busy and tend to go with the easiest and lowest-cost solutions. A common practice in small commercial buildings is to do a like-for-like replacement, which represents a tremendous missed opportunity for energy savings and locks the owner or tenant in for another 15–20 years of higher energy costs. Even in new construction, engineers and contractors tend to go with what they know, which is usually standard efficiency equipment. Another barrier of the highest efficiency equipment is a potential requirement for additional specification language and special installation and commissioning requirements. Units with complicated controls are sometimes not commissioned correctly, and the savings are lost.

Another common challenge with high-efficiency equipment is their larger and heavier size. High-efficiency replacements sometimes require curb adaptors to allow for their size or different orientation of the ducting connections. The curb adaptors add further costs, height, and weight to the installed system. Height can be a problem for locations that require screening to hide the RTUs. Additional weight may exceed the loading capacity of the roof and necessitate structural support, which can be expensive and exceed energy savings from high-efficiency equipment.

The light commercial HVAC market is diverse and complex, with multiple and interrelated barriers that make it difficult to gain market adoption of new technologies. The barriers listed, although not comprehensive, show why this market has been more challenging and slower to change than other technology areas like lighting and appliances. Instituting substantial change requires understanding the interrelated barriers and a comprehensive approach with multiple solutions.

Technical and Market Solutions

Finding effective solutions to overcome multiple barriers requires an understanding of the market and market drivers. There have been significant efforts to advance the market over the years. These solutions can be grouped into three major areas, as shown in Table 3 along with some of the most impactful solutions.

Table 3. Summary of technical and market solutions

Solution area	Solutions	Examples
Research and development	Advanced technologies	Compressors, heat exchangers, fans, controls
	Performance validation	Field validation studies, case studies
	Technical resources	Modeling tools, calculators, decision tree
	Market resources	Proactive RTU management models, leasing language, case studies
Market push	Market challenge	RTU Challenge, prizes
	Performance rating metrics	EER, SEER, IEER
	Product labeling	ENERGY STAR, CEE performance tiers
	Performance standards	Federal minimum standards, ASHRAE Standard 90.1
Market pull	Market leaders	Better Buildings, large portfolio owners
	National or regional campaigns	Advanced RTU Campaign
	Innovative business models	Midstream/upstream incentive programs, Comfort (energy) as a service

Research and development of technologies to improve the performance of packaged air-conditioning equipment has been a slow and steady process. Incremental improvements to compressor efficiency, heat exchanger performance, refrigeration circuit control, and fan and motor efficiencies progressed continuously; however, market entry for these advancements was slow due to market aversion to higher costs. Modest advancements in performance were made in the early to mid-2000s as large portfolio owners (such as national retailers) started looking at the life-cycle cost of RTUs and asked manufacturers for higher-performance RTUs. Inclusion of IEER in ASHRAE Standard 90.1-2010 provided a signal to manufacturers to develop and add features that affect part load performance. However, making significant improvements through optimal integration of all the advances required a major redesign of the RTUs, which is a significant undertaking for manufacturers, and they were unwilling to take on this risk without a promise of a large market adoption.

DOE realized there was large gap between the technical potential and available RTU efficiency options, so in partnership with several national labs, the RTU Challenge was developed to encourage manufacturers to produce high-efficiency RTUs (DOE 2012). The RTU Challenge launched in 2011 as a challenge to manufacturers to produce and market a 10-ton RTU with an efficiency of 18 IEER along with several advanced control features. In addition, DOE and the national labs worked with Better Buildings Alliance[1] partners, who are market leading customers, to generate interest in high-efficiency RTUs to develop a potential market demand for these high-efficiency units. A benefit of working with potential customers is that they provided input to the RTU Challenge specifications and voiced concerns over potential barriers, such as the higher weight of high-efficiency RTUs. When the RTU Challenge was issued, there was one RTU that exceeded 15 IEER and very few that exceeded 13 IEER. Five manufacturers signed up to participate in the RTU Challenge, and two of them met the challenge by the deadline in 2013.

Around the same time, there was significant development in effective retrofit solutions for improving energy performance of RTUs. In 2011, the Pacific Northwest National Laboratory released a study on the energy performance improvement of an advanced RTU control retrofit package that included a variable frequency drive for the supply fan, demand controlled ventilation, and other advanced control features (Wang et al. 2011). They reported an average 38% energy savings over standard RTU performance through energy simulations of four building types in 16 locations. A follow-up report in 2013 showed an average 57% energy savings over the operating performance from a field validation study of 66 RTU retrofits (Wang et al. 2013).

By 2012, high-efficiency solutions for retrofits, replacements, and new installations existed; however, much of the market continued in a business-as-usual mode with the minimum standard efficiencies. Analysis of RTUs over 5.4 tons shipped in 2011 showed that 68% met the minimum standard efficiencies and another 31% met one step up from the minimum standard efficiencies (DOE 2015a). This situation represented a large market inefficiency and wasted energy. DOE and the Better Building Alliance partners identified this market disfunction and determined there was a need for an intervention to educate and motivate the market to make changes. The Advanced RTU Campaign was born out of these discussions; it launched in May 2013 by DOE and NREL and operated through 2019 (DOE 2020). The Advanced RTU Campaign was a partnership between DOE and the private sector with the mission of shifting the

[1] The DOE Better Buildings Alliance brings together commercial building leaders to develop and share innovative and cost-effective solutions to advance energy efficiency. Alliance members partner with DOE technical experts to identify gaps and work needed to accelerate the adoption of greater energy efficiency practices. https://betterbuildingssolutioncenter.energy.gov/alliance/about

market toward adoption of high-efficiency RTU best practices. The Campaign was well received with more than 300 partners and included all major RTU manufacturers, several distributors, utilities, efficiency organizations, industry associations, contractors, and building owners. Campaign organizers worked with the partners to understand the market and technical barriers and developed a series of resources and activities to overcome these barriers, including 15 technical resources, more than 30 webinars and presentations, and a dozen case studies. One of the most effective activities was an annual national award ceremony to recognize the leaders in high efficiency, which helped create excitement and motivate others to act.

One of the most successful practices for energy and cost savings from the Advanced RTU Campaign partners was proactive RTU management. Proactive RTU management starts with an inventory of RTUs, assessing their health and developing a management plan for improvement. This task can be daunting for facility managers, who are not HVAC experts and have many responsibilities. The Advanced RTU Campaign developed a series of decision-maker tool kits, including the decision tree shown in Figure 3 (DOE 2019), and Campaign partners developed resources such as a mobile app to help field technicians quickly assess the health of RTUs (DOE 2017). One Campaign partner developed a proactive RTU management program that resulted in higher efficiency RTUs at a 15% capital cost savings over a run-to-failure practice by avoiding extra costs from overtime pay, expedited permitting and ordering, higher per unit cost, lost opportunity for rebates, and failure to address the potential for down-sizing (DOE 2015b). Another Campaign partner achieved 50% HVAC savings by taking advantage of other efficiency upgrades such as lighting retrofits and re-engineering the HVAC system at time of replacement to optimize the ventilation and sizing (DOE 2015c).

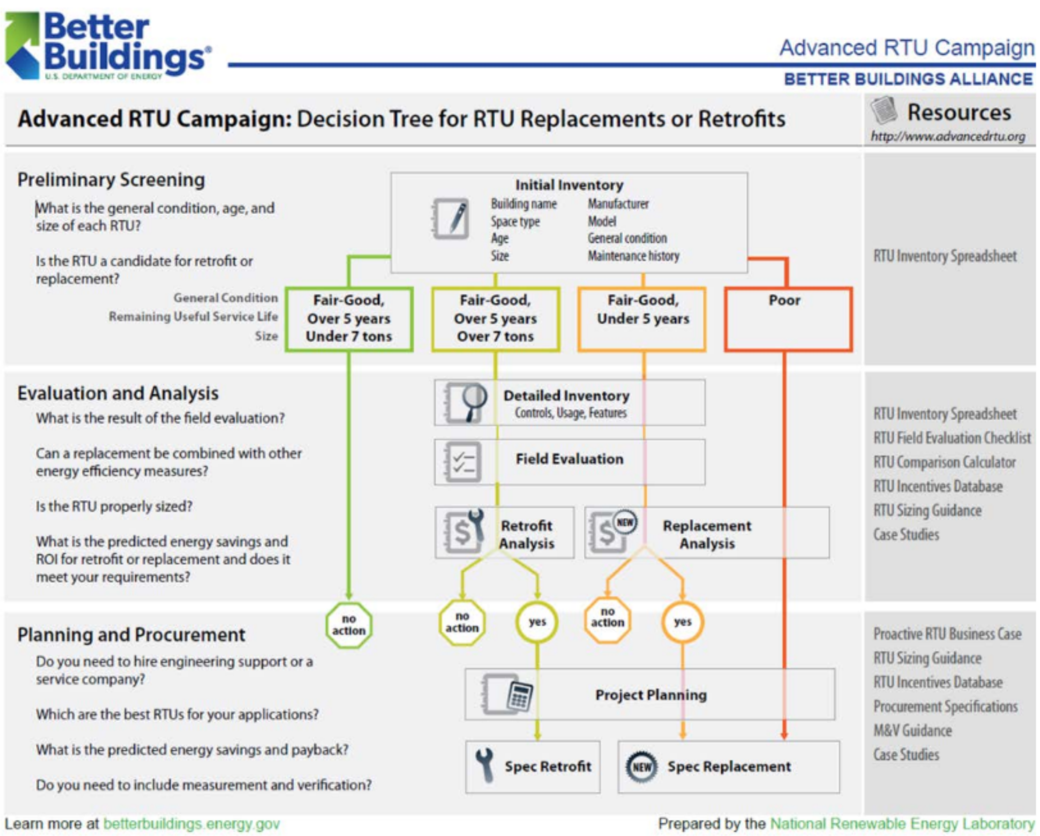


Figure 3. Proactive RTU management decision tree

Utility incentive programs can be powerful tools to advance market adoption of efficient technologies, and the Advanced RTU Campaign worked with several utilities and tracked their incentive programs. A typical downstream incentive program provides a rebate to the final customer on a per ton basis for efficiency levels equal to or above ENERGY STAR or CEE Tier 1 or 2 efficiency levels. However, participation for light commercial HVAC is often low and burdened with high implementation costs for the utilities. Consumers are often not aware of the incentives or perceive that the programs are too complicated and not worth the effort. A review of Colorado demand-side management programs showed that only 10% of businesses participated in downstream programs over a five-year period (Quaid and Geller 2014).

Upstream and midstream incentive programs that target manufacturers and distributors have been shown to be very effective in some applications compared to downstream programs (Wemple 2015). The first HVAC midstream incentive program started in 1998 with PG&E, but broader adoption was limited until recently. A 2018 study found 26 HVAC midstream and upstream incentive programs, more than any other technology category (Daughton 2019). These programs achieve deeper market penetration compared to downstream programs, as shown by increases in participation in nonresidential HVAC programs of 900%, 86%, and 600% over downstream programs in California, Massachusetts, and Colorado (Wemple 2015 and Xcel 2019). The largest market transformational impact of these midstream and upstream programs may be that the distributors stock higher-efficiency RTUs, which are then readily available to contractors for emergency replacements. In some cases, distributors will not even stock minimum-efficiency RTUs. Finally, manufacturers support upstream and midstream programs and would like to see an expansion of these programs (Lord 2017).

Another approach for helping consumers understand complex technologies is product labeling, which can be used as a trusted source of information to help consumers sort through competing marketing claims. ENERGY STAR is broadly recognized as an effective efficiency labeling platform for residential appliances. While it is used by some utilities and the federal government for light commercial HVAC, its use in commercial applications is not as well established. CEE works with utilities to establish efficiency tiers for light commercial HVAC systems for use in incentive programs; however, they are not recognized nor used directly by consumers. Unfortunately, these two market signals were not aligned for several years (see Figure 4), which created market confusion and made it difficult for manufacturers to align their product lines with the different efficiency levels. This situation generated inefficiencies in the market, which slowed advancement of RTU efficiency and adoption of higher-efficiency RTUs. In 2016, DOE announced new minimum efficiency standards for RTUs starting in 2018 with an increase in 2023. These efficiency changes were announced as the largest impact on energy consumption of any federal minimum performance standard issued by DOE (DOE 2016). By itself, this was a huge win for energy efficiency, but this was not the whole story. ENERGY STAR for light commercial HVAC was revised in 2017 to align with the 2023 federal minimum performance levels, and CEE revised Tier 1 to align with the federal 2023 performance levels, Tier 2 as slightly above this level, and a new Advanced Tier slightly below the RTU Challenge. It is too early to measure the impact on the market, but there is evidence to suggest the coordination of market drivers will be very positive. Utility programs can now point to ENERGY STAR and CEE without confusing consumers. Manufacturers can focus their product development toward these efficiency levels with confidence about current and future market signals. One manufacturer released two new product lines at the end of 2019 that focused on CEE Tier 1 and Tier 2 with confidence that they are aligned with future efficiency levels.

Impacts

Some impacts of individual efforts have been described in the previous section, but several of the larger impacts are worth calling out as well. The first impact is a view of the various efficiency metrics and market efficiency targets. Figure 4 shows historical EER and IEER federal minimum and market values for a 10-ton RTU. EER has a longer history starting in 1989 and increased from 8.7 to 12.4 (43% increase), while IEER changed from 11.2 to 17.8 (59% increase). These market signal efficiency levels do not tell us about the efficiency of units sold, but there has been a tremendous expansion of the number of higher-efficiency RTUs available. The highest-efficiency RTU when the RTU challenge was issued was just over 15 IEER (offered by one manufacturer in 2011), and at the time of writing this paper there are 14 brands that exceed the 18 IEER performance level, and the highest performance exceeds 23 IEER. Sales by efficiency level are not public data, but the number of models is a good indicator that there is a market for higher efficiency. Most of the light commercial HVAC market is for replacements, and most of these replacements are unplanned and go with the lowest-cost units available. Upstream and midstream incentive programs are changing the stocking practices of some distributers, making higher-efficiency RTUs available for the replacement market.

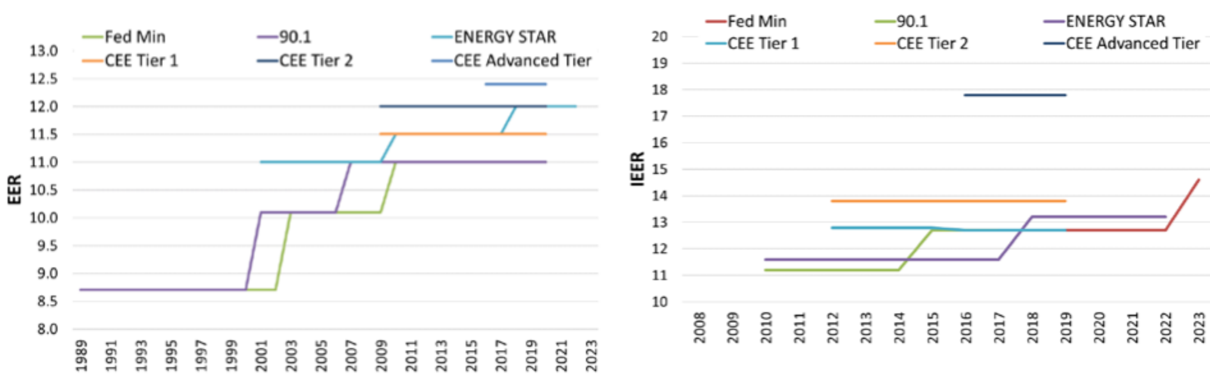


Figure 4. Historical federal minimum and market EER and IEER levels for a 10-ton RTU

The Advanced RTU Campaign tracked high-efficiency RTU installations and advanced RTU control retrofits of its partners. The Advanced RTU Campaign did not track the IEER values of installed RTUs, but all RTUs were required to meet or exceed CEE Tier 2 efficiency levels to be counted. From 2013 through 2018, the Campaign partners installed nearly 108,000 high-efficiency RTUs and retrofitted 54,000 RTUs with advanced controls. These installations saved the partners more than 1 billion kWh, $110 million, and 1.4 billion lb of CO_2 annually.

Conclusions

Building efficiency markets are complex, diverse, and notoriously slow to change, and this is especially true of the light commercial HVAC market. Market change is a continuous process, and accelerating or directing this change requires a range of efforts and a variety of change actors. There have been numerous efforts to change the light commercial HVAC market, and this paper highlights a few of the more significant efforts. These efforts form a pattern that can be replicated for other technology areas and can be summarized as follows:

- *Maintain continuous R&D* with market connections to ensure market viable solutions
- *Challenge the status quo* through market interventions and specific challenges
- *Engage and motivate* the entire market to make changes, starting with market leaders
- *Reduce market barriers* through resources, education, labeling, and innovative business models
- *Institute permanent change* through policy, codes, and standards
- *Align market drivers* to reduce market confusion and provide consistent market signals
- *Think long term* by maintaining market and R&D connections and planning for the future.

Although there have been significant changes in the light commercial HVAC market, it is just a beginning, and there is more work to be done and many more opportunities to improve energy and environmental performance. Most of the installed inventory of RTUs is still constant-speed, low-efficiency units with minimal maintenance, and it is important to continue finding market inefficiencies and determining how and when it makes economic sense to install and maintain higher efficiency.

One of the biggest challenges with operating RTUs is that there is typically no insight to how well a unit is performing in real time. Intelligent control systems with monitoring and automated fault detection and diagnostic capabilities can track performance real time and provide feedback on faults and performance trends. Adoption of these systems is limited but growing. As more systems are developed and the market demand increases, hopefully there will be further improvements to the energy and economic performance of these systems.

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