The Advanced Cooling Market Tracker:

Monitoring deployment of climate-friendly cooling technology worldwide

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Abstract

In 2016, the Clean Energy Ministerial launched the Advanced Cooling (AC) Challenge, which challenges governments, companies, and other stakeholders to make, sell, promote, or install super-efficient space cooling and refrigeration solutions that are smart, climate-friendly, and affordable. To aid Challenge participants in meeting these goals, the AC Challenge is developing the AC Market Tracker, which aggregates data on product models sold online in participant nations and other nations of interest, focusing initially on small residential air conditioners, which are expected to be a high-growth area in emerging markets in the near term. Automated software gathers public information on the air conditioner models sold in each nation, cross-references the data against government energy efficiency certification databases, and presents the resulting data to users via interactive data visualization tools. The primary objectives of the database are to support (1) determination of market baselines, (2) benchmarking and cross-market comparison, (3) procurement of efficient cooling equipment, and (4) tracking of market progress toward a more climate-friendly cooling future. In this paper, we describe the framework and functionality of the market tracker, as well as the data collected to date, and we present example data visualizations and other tools that support the primary database objectives. We discuss key insights that can be drawn from the current database.

Introduction

In the coming decade, space cooling is expected to be among the fastest-growing electrical end-uses globally, as improved electrical service and rising incomes drive rapid adoption of air conditioning in the developing world [1]. Over the same period, a major transition will occur in the manufacture of space-cooling and refrigeration equipment, as countries begin to implement the Kigali Amendment to the Montreal Protocol, phasing down hydrofluorocarbon (HFC) refrigerants, which are the most common non-ozone-depleting refrigerants today but which have a high global warming potential (GWP), in favor of non-ozone-depleting replacements that have lower GWP [2].

At present, the global air conditioning market contains a wide variety of products spanning a broad range in energy efficiency (EE). Top-performing products that utilize variable-speed compressor technology can consume less than half as much energy on average than their fixed-speed counterparts at the same cooling capacity. EE thus presents an important opportunity to mitigate the impacts of growth in the global space-cooling and refrigeration markets. Implementing a transition to efficient cooling technologies in parallel with the Kigali HFC phasedown could roughly double the GHG impacts of the Kigali process alone [3], while also dramatically reducing the challenges of space-cooling and refrigeration demand growth for local electricity generation and power grid infrastructure.

The Clean Energy Ministerial (CEM) [4] is an international forum that brings together energy ministers from major world economies in an effort to accelerate the global transition to clean energy. At its seventh meeting, in 2016, CEM launched the AC Challenge [5], which accepts voluntary commitments from governments, manufacturers, and other participants, to help drive adoption of energy-saving and climate-friendly cooling technology around the world. Government participants, for instance, may pledge to implement more stringent EE standards and labeling (S&L) policies for cooling technologies, while manufacturer participants may pledge to upgrade production lines to produce more efficient cooling products, and other private-sector participants might adopt space-cooling or refrigeration procurement guidelines that give preference to efficient products. In addition to these commitments from individual participants, the AC Challenge will also undertake certain joint initiatives that support the broader goals of the Challenge, under the guidance of a steering committee of the participating governments (currently comprising Canada, Chile, China, Mexico, India, Saudi Arabia, and the United States).

The first initiative of the AC Challenge is the AC Market Tracker (ACMT), a set of tools for data collection and visualization which collects, aggregates and presents data on global air conditioner markets to monitor progress toward the Challenge's goals. At present, the ACMT focuses specifically on small residential room air conditioners—specifically ductless mini-split units—since this is the market segment poised for the most significant growth globally in the near future. On a regular basis, automated software collects public information on room air conditioner models offered for sale in markets of interest, from a variety of different sources including online retailers, manufacturer websites, and public-facing government efficiency databases. It collates and compiles the information from these diverse sources, presenting the resulting data in an interactive visualization tool that paints a coherent picture of the status of each monitored market for policymakers, industry members, EE advocates, and other stakeholders in the process of cooling EE deployment.

The public version of the ACMT is now available on the website of the International Energy Agency (IEA) [9], having been formally launched at the CEM 8 meeting in Beijing, China, in June 2017. In this paper (which was composed prior to the development of the IEA-hosted tool), we give a conceptual introduction to the ACMT and present visualizations and insights from an earlier prototype of the data visualization tool. In the next section, we describe example uses for model-level market data on advanced cooling technologies collected across different international markets. Next we describe the data-collection toolkit that provides data for the ACMT, and we summarize the collection strategy and the data currently being collected. We then present example data visualizations using the data collected so far, describe interactive elements that allow user exploration of the dataset, and discuss early insights that can be drawn from the prototype visualizations. Finally, we describe future visualizations and applications of the ACMT dataset and the challenges expected in their development.

Example use cases for the Advanced Cooling Market Tracker

The ACMT aims to compile a comprehensive database of residential room air conditioner models on the market in particular countries, with regular updates over time. Such a data set can be utilized in several different ways in the context of monitoring adoption of advanced cooling technologies across the globe. In the following, we summarize the primary use cases of the ACMT.

Market baseline determination. In order to set goals for the adoption of efficient cooling technology in a given market, it will be important for policymakers to have an up-to-date snapshot of the market, to set a baseline against which to measure progress and to identify opportunities for improvement. To support this use case, the ACMT will include a basic single-country snapshot view that displays statistics and distributions (weighted by the number of models available on the internet market) that can yield a basic understanding of the country's air-conditioning market. These statistics and distributions include the following.

- The distribution of models on the market by cooling capacity.
- The distribution of models by EE.
- The distribution of models among the EE labeling categories established by the national S&L program.
- The fraction of models on the market that use variable-speed compressor technology.
- The fraction of models using particular types of refrigerant.
- The fraction of models that are reversible (i.e., that can be operated as heat pumps as well as air conditioners).
- Simple price statistics (e.g., median price, typical price range) for models categorized by cooling capacity, EE, or other features of interest.

To enable a more detailed understanding of the market, filtering tools will allow the user to view these same statistics for a particular segment of the market—for example, one might wish to view the efficiency distribution and price statistics for air conditioners within a narrow range of cooling capacity.

Benchmarking and cross-market comparison. Researchers and policymakers may also wish to compare different countries' AC markets against each other and against top-performing global markets. Such comparisons can help to identify high-priority targets for market transformation, or to track the inter-market impacts of advances in policy or technology, via diffusion through trade. To facilitate such comparisons, the completed ACMT will allow users to select countries of interest and compare them against each other and against global top-performing markets using certain indicators of efficiency performance or AC technology adoption in each country. Relevant technological indicators might include the fraction of the market utilizing variable-speed technology or the fraction of the market using low-GWP refrigerants. Relevant EE indicators might include the fraction of the market exceeding some benchmark EE threshold, or the EE of the most efficient product available on each market. A complication arises with these EE indicators, however, because standard EE metrics for space cooling equipment can have a strong dependence on local climate and therefore may not be directly comparable across markets. Thus the cross-market comparison functionality will require development of a normalized global EE indicator, or an algorithm for conversion between climates, to allow different countries' EE performance to be compared (see the "challenges and future work" section below).

Tracking market trends. As discussed in the next section, the data collection process underlying the ACMT allows the tracker to be updated regularly with freshly collected market data. Over time, it will become possible to track trends and progress in each individual market, allowing policymakers and grantmaking organizations to observe the real-time impacts of market transformation efforts. For example, it will be possible to gauge progress in the availability of super-efficient technology or low-GWP refrigerants by examining trends in the indicators used for cross-market comparison, compared to the values in a top-performing economy.

Facilitating AC procurement. The ACMT can help to support the procurement of efficient cooling technologies by large scale purchasers such as governments or hotel chains. On a simple level, the information on efficiency and price available in the market snapshot tool can help to guide the development of EE targets that can be met at a reasonable cost. In addition, because the ACMT rests on an underlying database of individual air conditioner models currently sold in each market of interest, the ACMT could also serve as a tool allowing buyers to identify particular products to consider for purchase. This more detailed use case is not part of the current implementation of the ACMT, but it could be added in the future to support AC Challenge participants in putting their commitments into practice.

Data sources, collection, and management

The data inputs for the ACMT include detailed information on the air conditioner models offered for sale in each country of interest, including product specifications and features, retail price information within each country's market, and EE metrics measured according to the test procedures specified by each country's EE S&L program. A data set incorporating all of this information has historically been difficult to assemble, since the different components have typically been scattered across various disjoint data sources. Prices and certain product features are housed at retailers, detailed product specifications reside with manufacturers, and certified EE information is held by the relevant government agency. Drawing these various data sources together to paint a coherent picture of the state of product EE in a market has been very challenging historically.

To improve this situation, Lawrence Berkeley National Laboratory has constructed the International Database of Efficient Appliances (IDEA) [6,7,8], a suite of software tools for collecting, collating, and organizing data on the EE, features, and price of appliances being sold on markets around the world. Using web crawling and other automated methods, IDEA collects data on appliances of interest from online retailers, manufacturer websites, and government certification databases. In addition to the automated collection from internet sources, IDEA can also ingest data provided directly by governments, manufacturers, or other market actors, when available.

The IDEA data integration process then identifies unique models across the different sources, and combines the information from the various data streams into a single comprehensive record for each unique appliance model found offered for sale in a market of interest. Crucially, the IDEA integration process identifies product features that are presented in different data sources using different names and maps them to a canonical naming convention, allowing a common set of analyses to be applied to data from diverse countries and data sources. IDEA is the first fully functional implementation of a data-access framework for appliance EE that was developed under CEM's Super-efficient Equipment and Appliance Deployment (SEAD) initiative [10]. Figure 1 shows a simplified schematic of the IDEA data collection and integration process.

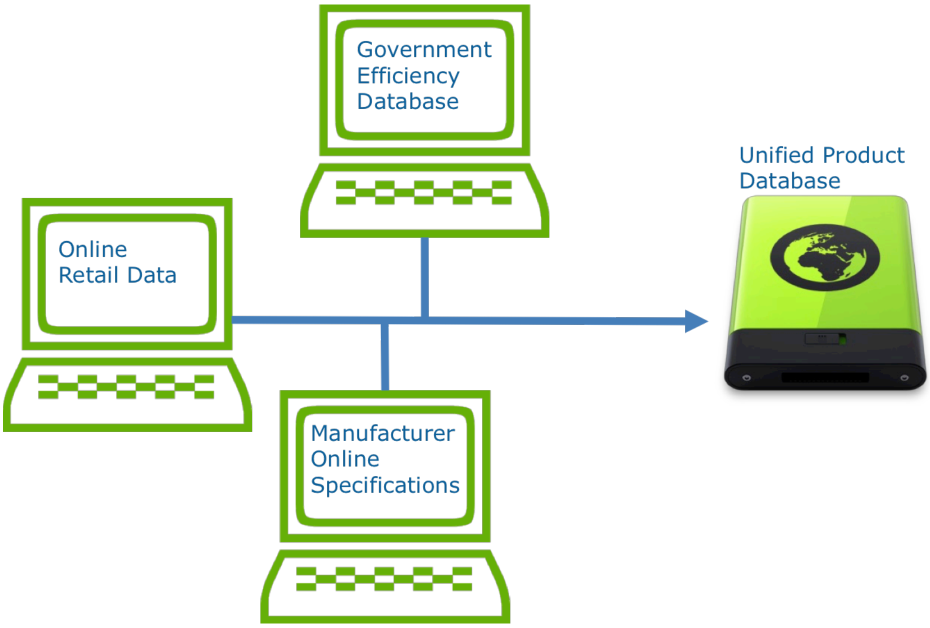

Figure 1. Schematic diagram of the data collection and aggregation for IDEA.

To support the ACMT, IDEA is currently collecting data on ductless mini-split, window, and portable air conditioners in several participant countries of the AC Challenge, namely, Canada, China, India, Saudi Arabia, and the United States. Automated data collection is underway using web crawling for several retailers in each country, and the resulting data are cross-referenced against the public EE certification databases that each government makes available as part of its S&L program. Quarterly data collection has been underway in each of these countries since late 2016.

The final data set in each country comprises all models found offered for sale online, with retail prices and consumer-relevant features drawn from online sellers and EE metrics and energy-related technical specifications (e.g., cooling capacity) drawn from the government certification database. As a result, all market distributions shown in the ACMT are model-weighted distributions of products offered for sale on the internet market in each country. It is worth keeping in mind that such distributions may differ from the distributions of products sold in physical stores, for example if internet retailers focus on a higher-end clientele in countries with limited online commerce. However, a separate paper in the current session of this conference [11] compares data collected by web-crawling and by physical store surveys in Indonesia and finds relatively small differences in the product distributions by cooling capacity or EE. Moreover, one might expect that the internet market would cover both products with mass-market appeal, as might be found at physical retailers, as well as niche products, meaning that a data set gathered via web crawling would arguably yield the more comprehensive view of the overall market. Additionally, a recent study of retail prices [12] finds that there is little difference between the prices of products sold online and at physical stores, across a broad range of products and markets, suggesting that price trends observed online can be taken to be generally representative of the market at large.

Market snapshot visualization tools

Each round of data collection for a given market yields a snapshot of the state of EE and advanced technology options in the relevant segments of the space cooling market, which can be explored using the snapshot data visualization tools in the ACMT. Figure 2 shows an early prototype of these tools for a snapshot of the Chinese market for ductless mini-split air conditioners in late 2016.

In the top row, annulus plots show the breakdown of the observed mini-split models by EE label and technology. At left is a diagram showing the distribution of models among the EE levels specified by the China Energy Label program, in which Level 1 represents the most efficient products and Level 3 the least efficient. As shown, the market is dominated by relatively low-efficiency products, with approximately two thirds of all models being rated at Level 3. Next is a plot showing the market breakdown by refrigerant fraction, showing that the market has largely, but not entirely, transitioned away from the ozone-depleting refrigerant R22, in favor of the common replacement R410A, which has a high GWP. The lower-GWP, non-ozone-depleting refrigerant R32 had a very low penetration in the Chinese market during the period shown here. The next plot shows that the majority of mini-splits on the Chinese market use variable-speed compressor technology, which creates the potential for significant EE gains over fixed-speed technologies. The final plot shows that nearly all Chinese mini-split models can be run in reverse to provide heating as well as cooling service.

The second row shows the distribution of models by cooling capacity and by EE metric. At left, the cooling capacity distribution appears tightly clustered into four narrow ranges. These peaks correspond approximately to standard cooling capacity levels measured in refrigeration tons, namely, 0.75, 1.0, 1.5, and 2.0 tons. At right is shown the distribution of models by efficiency, where the relevant EE metric is the energy efficiency ratio (EER) for fixed-speed units and the seasonal energy efficiency ratio (SEER) for variable-speed units. Both metrics indicate the watts of cooling capacity that a given unit delivers per watt of electrical power consumed, with the difference that variable-speed units can achieve much higher efficiency levels because they can operate at lower speeds, where they are more efficient, when the cooling load is smaller than their maximum capacity. The SEER metric, roughly speaking, represents the expected average energy efficiency achieved over the cooling season in a typical weather year in the country specifying the metric. As shown in the plot, variable-speed units in China can achieve efficiencies up to 75% higher than typical fixed-speed units, corresponding to energy savings greater than 40%. This demonstrates the substantial energy savings potential of transforming a space-cooling market like China's from fixed-speed to variable speed technology.

Figure 2. A data-visualization snapshot of the overall distribution of ductless mini-split air conditioners in China, as observed in the autumn of 2016. The various data visualizations shown are described in more detail in the text.

At the bottom right of Figure 2 a plot shows the range of retail prices observed for mini-splits on the Chinese market, subdivided into quintiles of EE, as well as the mean and median prices in each quintile. There is little clear relation between price and EE apparent in the plot; however, as we discuss in the next section, the correlation between price and cooling capacity can obscure the price-efficiency relation when considering the entire market. At the bottom left of the figure is a set of filtering tools that allow the user to select subsets of the data for more detailed exploration, or to select different countries for consideration. In the next section we present some example insights that can be gleaned using these tools.

Example insights from early data

Figure 3 shows the same snapshot of China's mini-split market as is shown in Figure 2, except that the cooling capacity filter has been applied to limit the displayed data to units having a cooling capacity of approximately 1.0 tons. The cooling capacity and EE distribution plots (middle row) show the distributions for the selected subset as shaded bars, as well as the underlying total-market distributions as open bars for comparison. The annulus plots (top row) show that the 1-ton market segment is largely similar to the market as a whole, with the exception that the low-GWP refrigerant R32 has not yet achieved any penetration in this segment.

The price-efficiency plot at bottom right, however, shows a much clearer relation between price and efficiency than was apparent in Figure 2. For 1-ton units, the price means, medians, and overall ranges rise steadily as efficiency increases, indicating that a clear trade-off exists for the consumer between long-term energy savings and up-front purchase price. Establishing a price-efficiency relation like the one shown here is the first step in a more complete cost-benefit analysis of potential EE upgrades for a consumer or potential updates to S&L policy. It is worth noting that the price-efficiency relation captured by the market tracker may be different from the relationship between manufacturing

Figure 3. A visualization of the Chinese mini-split market, for the same era as shown in Figure 2, but with a filter applied to show only units having cooling capacity of approximately 1 refrigeration ton. A much clearer relation between price and EE is apparent when the confounding factor of cooling capacity is controlled for.

cost and EE, since it includes effects such as the bundling of EE with other premium features and other pricing strategies.

The appearance of a clear price-efficiency relation in the 1-ton segment, when no such relation was apparent in the full market, can be explained by looking in more detail at the EE distribution (middle right), where one can see that the lowest efficiency portions of the distribution are completely depopulated in the 1-ton market segment. Examination of the 0.75-ton segment shows a similar effect, suggesting that the least efficient models on the market have relatively large cooling capacities. Since larger-capacity models are also more expensive, their overabundance at the lower end of the EE range serves to confound the price-efficiency relation visible in Figure 3. This demonstrates the importance of controlling for other features that may be correlated with price when using market data to determine the price-efficiency relation. Without fully considering such confounding effects, one risks misestimating the costs associated with a particular level of energy savings, which might lead to non-optimal purchase or policy decisions.

Figure 4 shows a comparison of the annulus diagrams from the snapshot visualization for the Chinese market, filtered to show only data for fixed-speed (top) or variable speed (bottom) models. The two market segments have markedly different distributions of EE and technology. Whereas the fixed-speed market has more than three quarters of its models in the lowest EE labeling category, more than half of the variable-speed market falls in the upper two EE levels. In making this comparison, it is important to note that the definitions of the EE labeling categories are different for fixed-speed and variable-speed models, since the EE metrics are different for the two technologies. Variable speed units labeled at a given EE level are generally much more efficient than fixed-speed units bearing the same label, meaning that the variable-speed market segment is overwhelmingly more efficient than the fixed-speed segment, given the different labeling distributions.

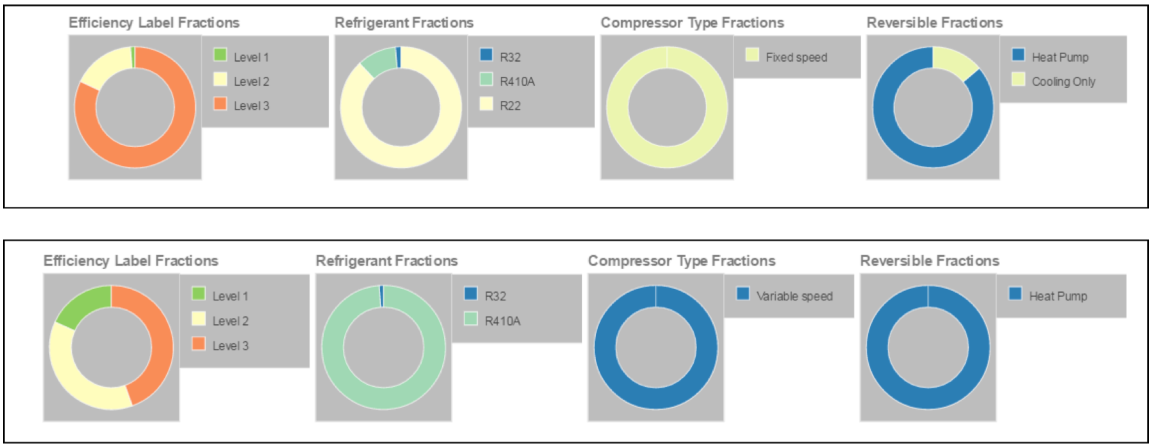

Figure 4. A comparison of the market-breakdown diagrams for Chinese mini-split units utilizing fixed-speed (top) and variable-speed (bottom) compressor technologies. Substantially different refrigerant utilization is apparent in the two market segments. Note that the EE values associated with the efficiency labels are different for fixed and variable speed products.

It is also interesting to note that the fixed-speed market segment is dominated by the ozone-depleting refrigerant R22, while this refrigerant has been fully phased out in the variable-speed market segment, in favor of the non-ozone-depleting R410A (with a small contribution from the low-GWP R32). In addition, it is noteworthy that all variable-speed air conditioners in the market are also reversible. This may indicate a potential pathway to reducing the cost of variable-speed technology for consumers who only desire cooling service (e.g., residents of Chinese cities that have district heating) by introducing variable-speed models that do not have a heat-pump mode.

Similarly, it is possible to use the filtering tools to show the market breakdown for models utilizing different refrigerants. This comparison (not shown here in the interest of space) reveals, interestingly, that all mini-split units utilizing the low-GWP refrigerant R32 have a Level 3 China Energy Label, meaning that R32 air conditioners preferentially have low EE. The reasons for this correlation are unclear, but it may be worth further examination, since the low EE will partially offset the greenhouse mitigation associated with adoption of low-GWP refrigerants (see [3] for further discussion of this point).

Finally, Figure 5 shows a market snapshot for the mini-split market in Saudi Arabia as of late 2016. The impression given is of a dramatically different market from China's. As would be expected for a hot climate like Saudi Arabia's, the distribution of cooling capacities is weighted toward much larger systems than in the Chinese market, and half of the market is made up of cooling-only units. Moreover, all observed models are fixed-speed. The fixed-speed EE distribution is skewed to higher EER values in Saudi Arabia than in China, reflecting Saudi Arabia's higher minimum efficiency standard at an EER of 3.37 W/W (11.5 BTU/Wh). However, the lack of variable-speed models means that the efficiency distribution is also very narrow, with all of the market falling into only two EE labeling categories. The relative energy savings available from variable-speed technology may be smaller in Saudi Arabia's hot climate than in China's more temperate one; however, given the large absolute cooling load in Saudi Arabia, it may still be worth exploring whether introducing variable-speed technology could yield significant energy savings in the Saudi market.

Challenges and future work

In the previous section, we demonstrated prototype data visualizations that primarily serve the baseline-determination use case of the ACMT. We also showed a simple example of using those visualizations for cross-market comparison between the Saudi and Chinese mini-split markets. As quarterly data collection continues in the future, it will become interesting to track progress over time in the adoption of super-efficient technology and of low-GWP refrigerants in the markets covered by the ACMT. The indicators that are developed in service of this market-tracking use case will also

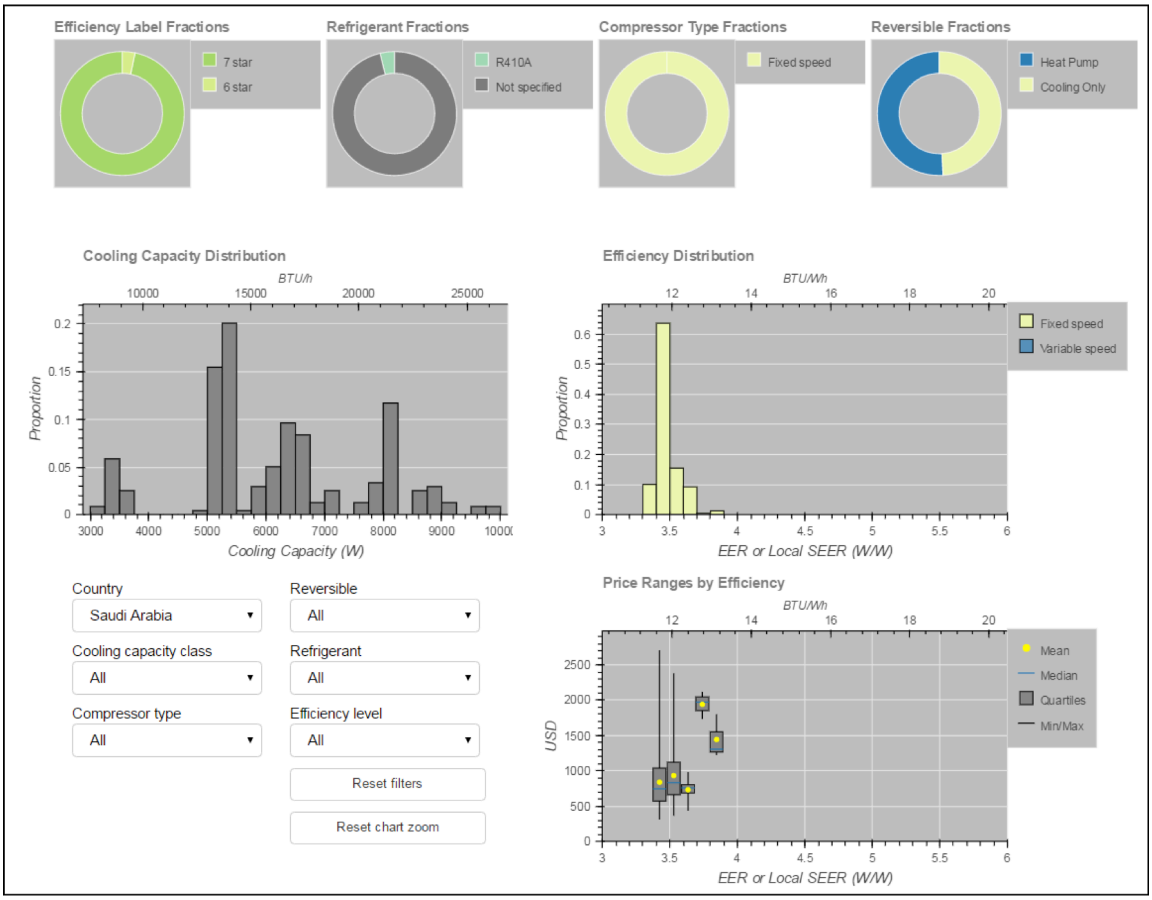

Figure 5. Market snapshot visualization for mini-splits in Saudi Arabia in late 2016. Comparison with the China snapshot from Figure 2 indicates a substantial difference between the two markets in terms of cooling capacity and technology.

enable cross-market comparison of past progress and current performance on EE technology adoption and the transition to low-GWP refrigerants.

However, there is an added complication that must be addressed when comparing EE performance between markets. In the example market comparison shown in the previous section, it was possible to compare the EE distributions in the Saudi and Chinese markets because the Saudi Market comprised only fixed-speed air conditioners, and the EER metric used for fixed-speed systems does not vary with climate. The same would not be true for a comparison of variable-speed systems in two different countries, because the SEER metric is computed according to the weather patterns expected over the cooling season for a given local climate, according to an algorithm that does not allow for direct conversion between climates. There is thus no way for a naïve observer to know whether a SEER of 5 W/W, say, in market A is better or worse, in terms of energy savings potential, than a SEER of 5 W/W in market B. To allow straightforward comparison of arbitrary markets, it will be necessary to develop market-level indicators of EE performance for variable-speed air conditioners that can be compared across different climates. The development of such indicators is an area of ongoing work within the AC Challenge.

As we discussed when describing the use cases for the ACMT, the data underlying the tracker can also be used to help guide procurement decisions for large buyers aiming to purchase high-efficiency space-cooling products. For example, by inspecting the price-efficiency plot in Figure 3, one can see that, although higher-efficiency products cost more on average than lower-efficiency products, there is a broad range of prices at each efficiency level. For instance, as shown in the same plot, the least expensive products in the middle quintile of efficiency have approximately the same price as the median product in the lowest EE quintile, implying that judicious product selection might allow significant energy savings with minimal added cost. Once the basic visualization tools are complete for market snapshots, tracking, and comparison, it will be possible to build more sophisticated tools to help support the procurement goals of AC Challenge participants more directly, including by allowing exploration of individual models that meet specified EE or refrigerant specifications.

Finally, looking beyond the use cases envisioned for the ACMT itself, the underlying data can have important applications for the development of more effective EE policies and programs in individual countries. For example, as detailed in references [7] and [8], it is possible to use appliance data collected via the IDEA project to perform simple cost-benefit analyses of appliance EE in a way that can be uniformly applied across different countries and appliance categories[1]. As the ACMT builds up a significant database of air conditioner models, it will become possible to apply such techniques to help support policymakers in individual countries as they work to meet their specific EE and GHG goals.

Summary

In this paper we have presented the goals and basic functionality of the AC Challenge's ACMT, as well as the strategy and tools used for data collection and management via the IDEA toolkit. Using example data, we also presented a prototype of the data visualization and filtering tools for exploring a snapshot of a selected country's space-cooling market, to determine the current status of EE performance and establish a baseline against which future progress can be measured. We also showed a simple comparison of snapshots in two different countries, demonstrating the significant differences that can exist in the space-cooling market from country to country. As mentioned in the Introduction, a live, public version of the ACMT is now available on the IEA's website [9].

Because space cooling is among the largest and fastest-growing electrical end-uses worldwide, space-cooling EE deployment will be of critical importance for reducing GHG emissions from electricity generation over the coming decades, as well as for reducing demand pressure on electricity grids. In addition, the planned transition to low-GWP refrigerants under the Kigali amendment to the Montreal Protocol will be a crucial step in achieving globally agreed climate goals. By providing a simple toolkit for assessing the state of cooling technology in a given market, tracking progress over time, and comparing among different countries, as well as guiding procurement and policy decisions, the ACMT will serve an essential role in facilitating the global adoption of advanced cooling technologies that are both climate friendly and affordable.

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