Chinese Policy Leadership Would Cool Global Air Conditioning Impacts

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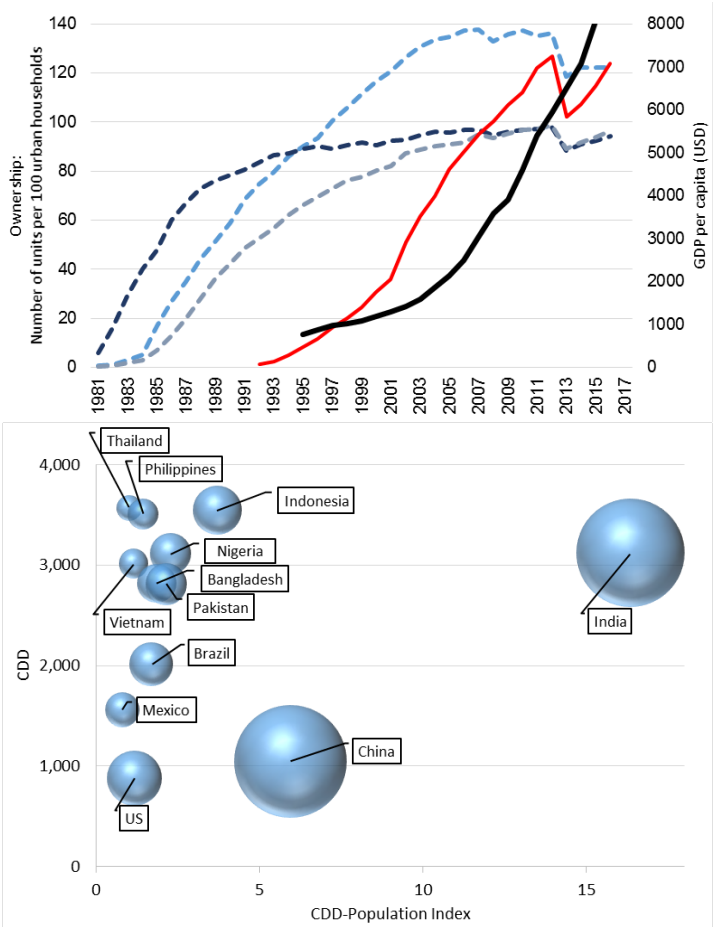
Abstract

Over the next decade, the global stock of room air conditioners is projected grow by 1.6 billion units, with critical implications for energy use and greenhouse gas emissions. At the same time, the phase down of hydrofluorocarbon (HFC) refrigerants under the Kigali Amendment, which entered into force 1 January 2019, provides an opportunity to couple the refrigerant transition with improvements in room air conditioner efficiency. A fast HFC phase down can avoid up to 0.5°C of warming by 2100, and it may be possible to double this with efficiency gains, according to the quadrennial assessment of the Montreal Protocol's Scientific Assessment Panel. Because China produces approximately 70% of the world's room air-conditioners, and about half of this production currently goes to the domestic market, there is a unique opportunity for Chinese leadership to spur economic transition to high quality production and accrue environmental benefits through a policy aligning the efficiencies of all Chinese room air-conditioners with the most efficient Chinese models produced today. This transition can lower costs by taking advantage of the parallel transition away from high-GWP HFC refrigerants under the Kigali Amendment to the Montreal Protocol, which was agreed in October 2016 thanks in large part to leadership by China.

Why does action by China matter?

Global electricity consumption and greenhouse gas emissions due to air-conditioners (ACs) are soaring. According to the International Energy Agency (IEA), worldwide energy demand from ACs is set to triple by 2050, with emissions rising to 2,070 million metric tons of CO2 (MtCO2), from 1,135 MtCO2 in 2016 (IEA, 2018). Electricity demand from space cooling in buildings in China accounted for over 30% of the increase in electricity demand in buildings between 1990 and 2016 (IEA, 2018). In 2016, the market penetration of room ACs (RACs) in urban households reached 124% (up from 5% in the mid-1990s), although rural penetration remained below 47% (see Figure 1(a)).

Today's rapidly rising incomes in populous, hot and humid countries such as India and Indonesia are driving similarly staggering growth in RAC demand with an annual growth rate of 10-15% (see Figure 1(b), Shah et al., 2015; Phadke et al. 2014). If business-as-usual continues, RACs will grow to 3.7 billion units from today's 0.85 billion, and alone could consume over 12,000 terawatt-hours [TWh] of electricity in 2050—equivalent to almost half of all electricity consumed in the world today. Related emissions due to electricity use and hydrofluorocarbon (HFC) refrigerants could reach over 10.2 billion metric tons of CO2-equivalent per year (GT CO2e/year) by 2050 (Shah et al., 2015). Mitigating these impacts is a daunting proposition. Yet the key to global progress lies with a single country.



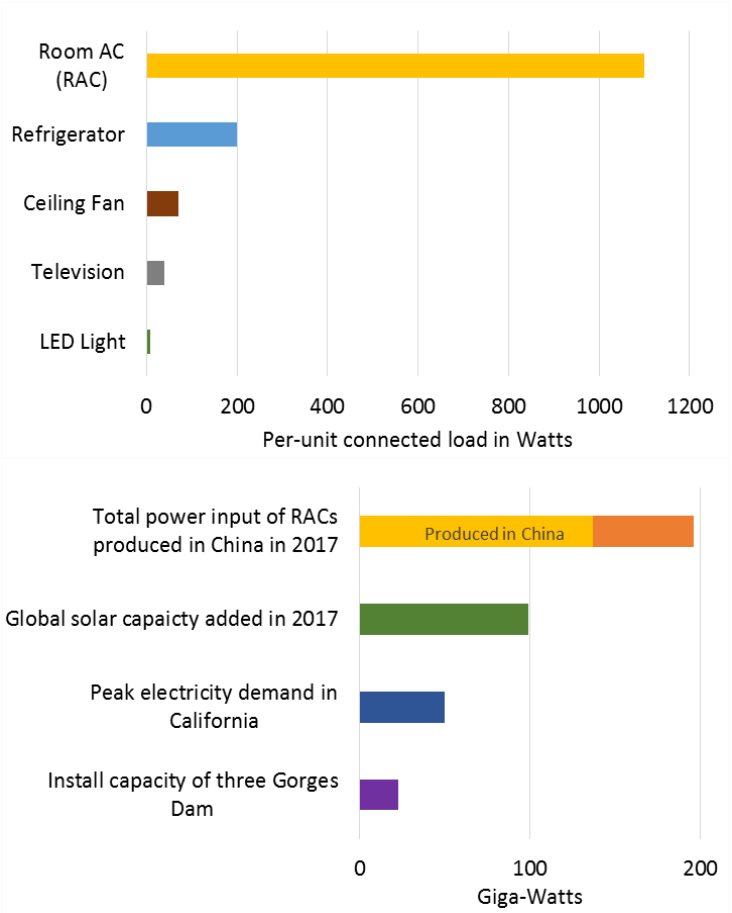
(a) Updated from Shah et al. (2015). The example is illuminating the rapid growth in household appliance ownership as a result of rising incomes and urbanization in China, including India's RAC ownership in 2011. The 1981-2012 data and the 2013-2017 data are based on China Statistical Yearbook 2013 and 2018, respectively (NBSC 2018; 2013). (Note that the ownership decrease between 2012 and 2013 may be due to different statistical methods and data collection.) The saturation of ACs in urban China went from nearly zero in 1992 to about 100% by 2007 i.e. within a span of 15 years.

(b) Adjusted from Phadke et al. (2014). Top 12 countries by AC potential measured in cooling degree days (CDD) which is an index of the energy demand to cool buildings. The CDD in this figure is calculated by subtracting 18°C (65°F) from the average daily temperature, and summing only positive values over an entire year, for the representative cities of the countries. The x axis is the total population of each country. The bubble size indicates the CDD-Population Index, which is calculated by $CDD \times Population/Population_{Thailand}$.

Figure 1. (a) Penetration of key appliances in urban Chinese households and (b) CDD and population of selected economies

Why focus on room air conditioners (RACs)?

A typical RAC requires more than 130 times and 5 times the power of a typical LED bulb and a refrigerator, respectively (see Figure 2(a)). China is the largest exporter and consumer of ACs globally with an export share in the range of 25-37% in 2017 (OEC, 2016; ChinaIOL, 2018). In 2017, approximately 137 million RACs were produced in China (with about 89 million units sold in China and the remaining exported to other countries) (ChinaIOL, 2018). Assuming a typical RAC unit has 1.1 kW of rated power consumption,[1] these 137 million RACs represent 151 gigawatts [GW] of connected load—1.5 times higher than the 100 GW of solar generation capacity installed worldwide in 2017 (see Figure 2(b); YaleEnvironment 360, 2018). Hence, ambitious RAC-efficiency policies in China could have an outsized influence on global energy and emissions in the coming decades.



(a) We assume unit power consumption of typical products as follows; RAC – a 3.5 kW cooling capacity fixed-speed split AC unit that meets EER 3.2, the current China minimum energy performance standard (MEPS) level for fixed-speed RACs, translated into 1.1 kW rated power consumption; Refrigerator – a 250-L refrigerator-freezer combination unit that consumes 200 W; Ceiling fan - a 48-inch ceiling fan that consumes 70 W; TV – a 42-inch LED-backlit liquid crystal display (LCD) TV that consumes 40 W in on-mode; LED light – an LED bulb that emits 800 lumens at 8 W (i.e., 100 lm/W of luminous efficacy).

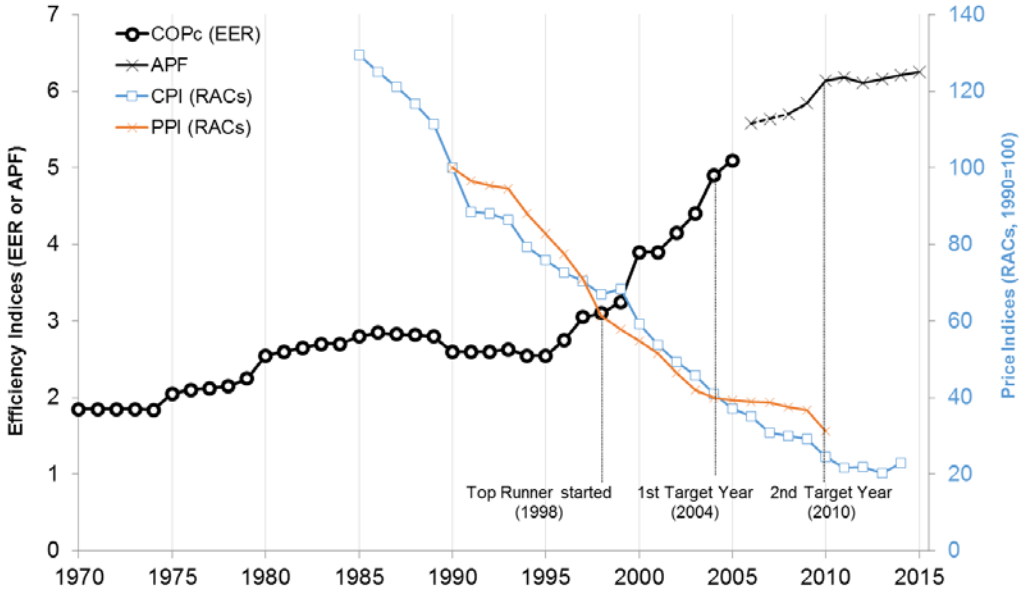
(b) We estimate total power input of RACs sold in the world and produced in China in 2017 by 1.1 kW per unit times 196 million and 137 million units, respectively, assuming that the average cooling capacity of the RACs is 3.5 kW. About 100 GW of solar capacity added globally in 2017 according to SolarPower Europe. In California, the peak load on September 1, 2017 was about 50 GW, according to the California ISO.

Figure 2. (a) Per-unit connected load of an RAC and other end-uses and (b) total connected load of RACs produced in China in 2017, selected comparable electricity demand and generation capacity

[1] 3.5 kW of rated cooling capacity and an efficiency equivalent to energy efficiency ratio (EER) 3.2

What does leadership look like?

China could spur these developments simply by targeting—by 2025—production of RACs that are at least as efficient as the most efficient RACs produced by Chinese companies today, and including use of low global warming potential (GWP) refrigerants. Such a policy would yield successful leaps in Chinese innovation and ambition, similar to those resulting from Japan's successful Top Runner energy-efficiency program[2]. Initiated in 1998, that program required best-available-technology efficiencies to become the norm in 5–7 years. The program stimulated a 60% RAC efficiency increase between 1997 and 2004, following decades of much more modest efficiency improvements (see Figure 3; Phadke et al. 2017).



(a) Source: Phadke et al. (2017). The figure shows trends in RAC efficiency reported as coefficient of performance (COP) and annual performance factor (APF), and RAC prices represented by consumer price index (CPI) and producer price index (PPI) of RACs. Since 1970, the efficiency of RACs in Japan has improved nearly threefold. In particular, efficiency in COP for cooling (COP cooling) improved by over 60% between 1997 and 2004, primarily because of the introduction of the Top Runner Program, a policy to improve the energy efficiency of end-use products by setting mandatory energy-efficiency standards based on the most efficient products on the market. For RAC energy-efficiency metrics, Japan used COPs for cooling and heating; however, for the second target year (2010), modified test methods and replaced the COP metric with an APF that reflects actual outdoor temperature changes and corresponding indoor thermal loads.

Figure 3. RAC efficiency and price trends in Japan

China did not change minimum energy performance standards (MEPS) for fixed-speed RACs since 2008. Instead, China implemented a separate set of MEPS for variable-speed RACs in 2013. Those two MEPS have been unchanged since those times. China is in the process of revising its MEPS and labels at the time of this study. The Phase I of the proposed new standard imposes five grades covering both fixed and variable RACs, with Grade 5 being the threshold for fixed-speed units and Grade 3 being the threshold for variable-speed units. This phase is expected to be effective between late 2019 and 2021

[2] For companies that manufacture or import equipment covered by the Top Runner Program, each equipment's average energy-efficiency value weighted by shipment must achieve a target standard value by the target fiscal year.

and revised to Phase II in 2022 as Grade 3 being the threshold for both types (see Table 1; CNIS, 2019). The proposed 2022 MEPS is estimated to be 32-54% more stringent than the 2010 MEPS for fixed-speed RACs in China SEER. While the past incremental approach targets modest short-term (1- to 3-year) efficiency improvements of around 10%–15%, which gives a relatively weak and uncertain signal to manufacturers, the recent approach is consistent with Made in China 2025 goals.[3]

Table 1. China's new efficiency grade thresholds for RACs, effective late 2019 and 2022.

Type	CC	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Split, Cooling Only (SEER)	CC ≤ 4.5 kW	5.80	5.40	5.00	3.90	3.70
	4.5 kW < CC ≤ 7.1 kW	5.50	5.10	4.40	3.80	3.60
	7.1 kW < CC ≤ 14.0 kW	5.20	4.70	4.00	3.70	3.50
Split, Reversible (APF)	CC ≤ 4.5 kW	5.00	4.50	4.00	3.50	3.30
	4.5 kW < CC ≤ 7.1 kW	4.50	4.00	3.50	3.30	3.20
	7.1 kW < CC ≤ 14.0 kW	4.20	3.70	3.30	3.20	3.10

Grade 5 and Grade 3 become the minimum requirement threshold for fixed-speed and variable-speed units in Phase I. Grade 3 becomes the minimum requirement threshold for both types in 2022.

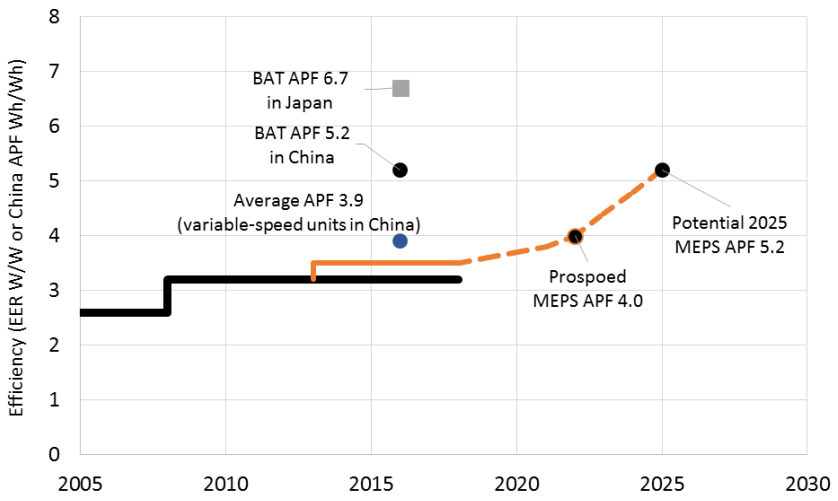
Source: CNIS (2019)

China is particularly well suited to a similar approach shifting from a model of incremental improvement to taking on the mantle of world leading standards, because share of variable-speed RACs was already over 50% in 2016, resulting in a product-weighted average efficiency of APF 3.9, and the most efficient RACs made by Chinese companies are already two to three times more efficient than the typical RAC sold in other markets, including models with low-GWP refrigerants (Park et al., 2017). The best available technology (BAT), i.e., most efficient model, identified from Chinese manufacturers in China has China APF 5.2. The BAT identified in Japan has Japan APF 7.6, translated into China APF 6.7. (See Figure 4 and Table A1 for additional information on these models.)

This political leadership would provide a medium- or long-term policy signal to manufacturers, enabling them to meet the efficiency targets cost-effectively by providing adequate time for investment planning. In contrast, the refrigerant transition under the Montreal Protocol provides long-term policy certainty in consultation with the RAC industry. Combining the transition toward higher efficiency with the transition toward low-GWP refrigerants would allow the industry to exploit synergies in redesigning equipment and retooling manufacturing lines to achieve both goals simultaneously.

[3] State Council, *Made in China 2025* (8 May 2015).

"Encourage companies to pursue supreme quality…continuously contribute to company brand value and the whole image of Made-in-China products…. Support companies to develop green products, … significantly improve product energy saving and environmental protection performances and guide green production and green consumption." http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm



Proposed MEPS 2022 and potential 2025 MEPS are for units with cooling capacity 4.5 kW or less.

Figure 4. Suggested pathway for Chinese leadership

Policies that mandate attainment of best-available efficiencies typically encounter three main concerns. The first is technology availability, but this is not a barrier to China's adoption of such a policy owing to the high efficiency of RACs already made by major Chinese manufacturers. In addition, several studies have shown pathways to these efficiency levels that can be accessed by most manufacturers (Park et al., 2017; Shah et al., 2016; Shah et al., 2013).

The second concern is about higher prices and reduced consumer demand. However, several studies have shown that prices have continued to decline despite major efficiency improvements (Phadke et al., 2017; R D Van Buskirk et al., 2014; Mauer et al., 2013; Chen et al., 2012; Weiss et al., 2010; Dale et al., 2009; Ellis et al., 2007). This is possible because stringent mandates provide economies of scale to efficient products, which reduces their prices. For example, as seen in Figure 3a, under Japan's Top Runner program, RAC efficiencies more than doubled while prices continued to drop (in real terms) at about the same rate as before the program began.

The third concern is about loss of market share in importing countries. In importing countries with strong efficiency standards, such as the European Union (EU), increasing China's standards would better position China for continued export, even as the EU looks to revise its standards within the next few years. Furthermore, market share in importing countries is unlikely to be lost because, as efficient RAC prices drop, most consumers likely will prefer efficient products owing to the bill savings and short payback times (see the next section). In addition, key importing countries may follow China's lead on efficiency targets to reap similar domestic benefits.

If the world is to curb the runaway energy consumption and greenhouse gas emissions due to RACs, China must be a major part of the solution. We suggest a setting a long term target for energy efficiency in line with the best available technology as already considered in China's Top Runner requirements[4] because of its proven effectiveness, its substantial economic and environmental benefits, its long-term certainty for Chinese manufacturers, and the already-demonstrated ability of those manufacturers to

[4] http://www.gov.cn/zhengce/content/2015-04/04/content_9575.htm

produce low-GWP RACs with the required efficiencies. It would be an important step toward keeping a warming world cooler.

What are the expected impacts of leadership?

Karali et al. (2019) modeled the costs and benefits of recently proposed new RAC MEPS in China. The study finds that newly proposed MEPS will contribute to reducing CO_2 emissions about 13% between 2019 and 2050, and bill savings of 2,620 billion RMB to China's consumers. The study also finds that the highest-efficiency scenario, reaching MEPS APF 5.4 in 2025, provides the largest long-term national benefits. Figure 5 shows RAC demand projection for the global market, global RAC sales contributed from China production, and the China market. Figure 6-8 show projected electricity consumption in RAC between 2019 and 2050 over their lifetime, emissions savings, and consumer bill savings contributed from energy saved in RACs under the BAT efficiency scenario. By setting such a long-term target, China can help set the global standard for green cooling with GHG emissions reduction of more than 40 Billion ton (CO_2e). Consumers in China and worldwide will enjoy more than 5 Trillion USD savings, leading to better economic performance and higher consumer welfare.

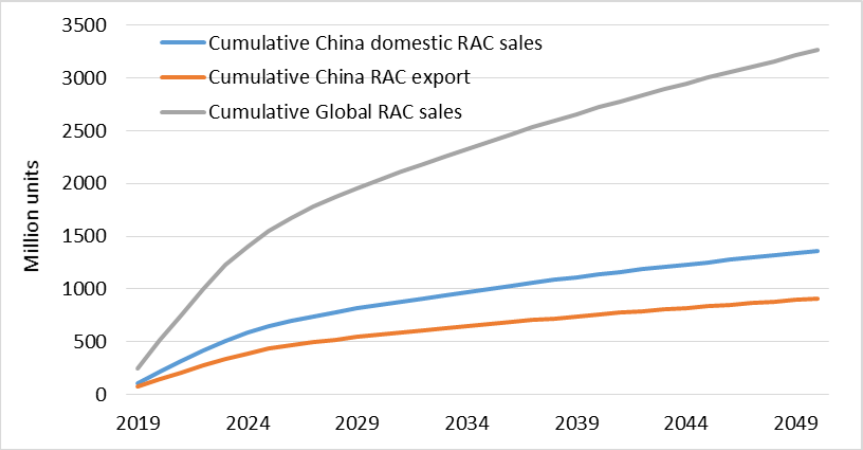


Figure 5. Projected cumulative RAC sales in China and the global market

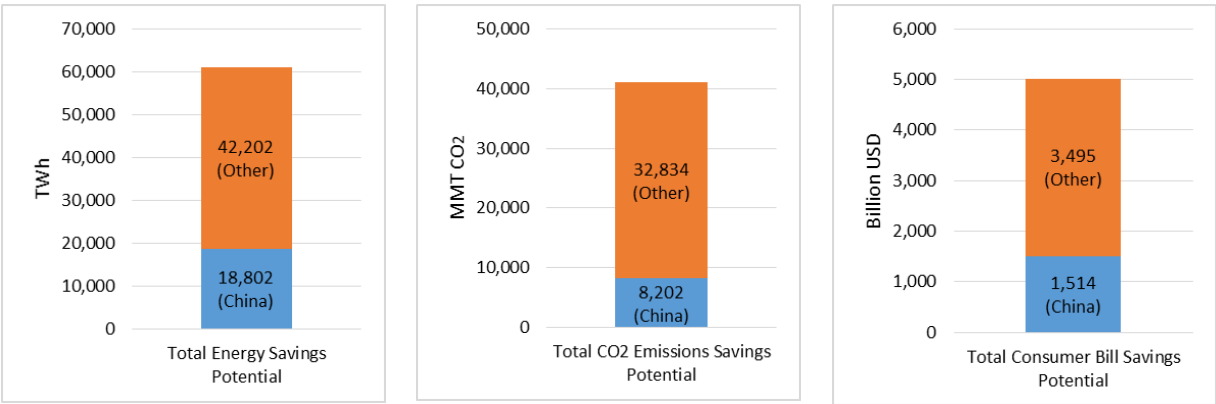


Figure 6. Projected savings potential in energy consumption, emissions, and bill savings in China and the global market (2019-2050)

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Supplemental Information

A. Highest-efficiency RACs in China, Japan, and the United States

Table A2. Selected highest-efficiency RACs in China and the United States

Region	Manufacturer	Model Name	Cooling Capacity (kW)	Efficiency	Price (USD)
China	Midea	KFR-26GW/BP3DN8Y-YA101(B1)	2.6	China APF 5.2	~630
		KFR-35GW/BP3DN8Y-YA101(B1)	3.5	China APF 5.0	~730
	Gree	KFR-26GW/ (26594)FNhAa-A1(b)	2.6	China APF 4.8	~570
		KFR-35GW/ (35595)FNhAa-A1	3.5	China APF 4.8	~790
	Haier	KFR-26GW/ A1YAAA21AU1	2.6	China APF 4.8	~930
		KFR-35GW/ A1YAAA21AU1	3.5	China APF 4.8	~1020
U.S.	Midea	MOCA30-09HFN1-MZA5W	2.6	US SEER 12.3	
		MOCA30-12HFN1-MZ50W	3.5	US SEER 9.4	
	Gree	GWH09YD-D3DN***	2.6	US SEER 11.1	~1,100
		GWH12YD-D3DN***	3.5	US SEER 8.9	~1,150
	Haier	1U09EH2VHA/AW09EH2VHA	2.6	US SEER 8.2	
		1U12EH2VHA/AW12EH2VHA	3.5	US SEER 7.3	
Japan	Hitachi	RAS-X25G	2.5	Japan APF 7.6	~2,230
		RAS-X40G2	4.0	Japan APF 7.6	~2,500
	Panasonic	CS-WX407C2	4.0	Japan APF 7.6	~3,100

Source: Park et al. (2017) and web searches

B. Estimating electricity savings potential from efficiency improvement in RACs

Table A3. Assumptions for the BAT efficiency scenario analysis

Scenario	2019		2030		2050	
	BAU	Efficiency	BAU	Efficiency	BAU	Efficiency
Global annual RAC demand	129 M units		146 M units		164 M units	
Production in China	70% (45% sold in China and 25% sold in other countries*)					
Share of fixed-speed (FSD) units (China)	41%	38%	24%	0%	0%	0%
Share of variable-speed (VSD) units (China)	59%	62%	76%	100%	100%	100%
Share of fixed-speed (FSD) units (Other)	83%	38%	72%	0%	27%	0%
Share of variable-speed (VSD) units (Other)	17%	62%	28%	100%	73%	100%
Annual hours of use	China: GB 21455:2013 temperature bin (1,569 hours/year) Other countries: ISO 16358:2013 reference bin 1817 hours/year *1.29 (adjusted by an average 2353 hours/year weighted by AC sales in other countries)					

Other countries include Brazil, Chile, Colombia, Egypt, India, Indonesia, Mexico, Pakistan, Saudi Arabia, Thailand, UAE, and Vietnam. China and these countries account for 65-70% of the global RAC market.

- Emissions factor (kgCO2/kWh): time series data from CEG LBNL, 0.778 (other countries, AC sales weighted)
- Average electricity price (USD/kWh): 0.08 (China), 0.082 (other countries, AC sales weighted)

Table A3. Efficiency assumptions for the BAT efficiency scenario analysis

	Baseline MEPS (APF)		BAT MEPS 2025 (APF)	
Cooling Capacity (CC)	FSD	VSD	FSD	VSD
CC ≤ 4.5 kW	2.72	3.50	5.40	5.40
4.5 kW < CC ≤ 7.1 kW	2.64	3.30	5.09	5.09
7.1 kW < CC ≤ 14.0 kW	2.55	3.10	4.78	4.78