Assessment of commercially available energy-efficient room air conditioners including models with low global warming potential (GWP) refrigerants

Won Young Park, Nihar Shah, Brian Gerke

October 2017

Lawrence Berkeley National Laboratory

This work was supported by the Institute for Governance and Sustainable Development under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

Key Findings – Refrigerant Trends in RAC market

- Best-performing products, i.e., highly efficient room ACs using low-GWP refrigerants (R-32 and R-290) are commercially available today at prices comparable to similar RACs using high-GWP R-22 or R-410A.
- Where HCFC-22 (R-22) is being phased out, high GWP HFC 410A (R-410A), still dominates RAC sales in most mature markets except in Japan where HFC-32 (R-32) dominates.
- In all of the economies studied except Japan, only a few models are energy efficient and also deploy low-GWP refrigerants. For example, in China, Europe, India, and Indonesia, the highest-efficiency RAC models employ the low-GWP refrigerants R-32 or HC-290 (R-290). RAC manufacturers in China have developed R-290 products although the Chinese market also has highly-efficient R-32 RAC models.
- While highly efficient, cost-competitive (less than 1,000 or 1,500 U.S. dollars in retail price, depending on size) RACs are available, high efficiency is typically bundled as a feature of high-end products.

Key Findings – Best Available RACs

- Variable-speed or inverter products that already dominate mature RAC markets such as Europe, Japan, and South Korea are currently driving high efficiency in RACs.
- RACs are available in most regions and worldwide that surpass the highest efficiency levels recognized by labeling programs.
- Because of the prevalence of fixed-speed RACs using R-22 in many markets among the A5 Parties, there is significant scope to improve RAC efficiency and transition to low-GWP refrigerants using commercially available technology and to design market-transformation programs for high-efficiency, low-GWP equipment.

Content

- Background and Motivation
- Scope and Methods
- Review of Energy Efficient room ACs by Region
- Implications and Possible Future Research

Background and Motivation

- **Previous research:**
  - **quantified the benefits** of leapfrogging to high efficiency in tandem with the transition to low-GWP refrigerants for room ACs (RACs) (Shah et al., 2015).
  - **identified some opportunities for initial action** to co-ordinate energy efficiency with refrigerant transition in economies comprising ~65% of the global RAC market (Shah et al., 2017).
- This study is performed to identify the best performing (i.e., most efficient and low-GWP-refrigerant using) RACs on the market at the time of this study, in order to support an understanding of the best available technology (BAT).
- An understanding of BAT can help support market transformation programs for high efficiency and low-GWP equipment by providing evidence to policymakers on:
  - Technical potential for efficiency improvement
  - Cost of efficient technology
  - Technology drivers and key components for manufacturing efficient equipment
  - Input into further research, e.g., testing, design, etc.
  - Global dynamics regarding leading manufacturers

Scope and Methods

- Economies studied: China, Europe, India, Japan, South Korea, and the United States (U.S.) and other emerging economies (Indonesia and the Philippines) that account for about 70% of the global RAC demand and also have some of the most efficient technology.
- Data Sources: LBNL International Database of Efficient Appliances (IDEA) (China, India, Indonesia, and the U.S.); Gov't databases of Japan, South Korea, and the Philippines; c) Topten or similar websites (China, EU, and India); internet searches and interviews with industry experts.

Scope:

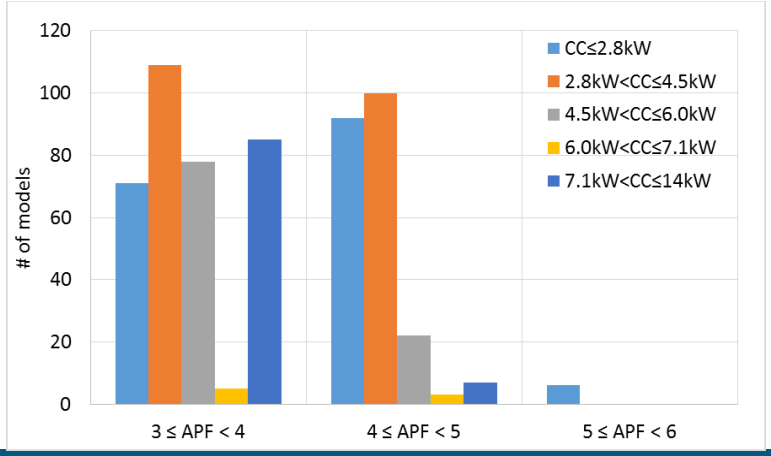
1. Brief overview of RAC energy-efficiency and refrigerant trends,
2. RAC efficiency distribution and leading manufacturers on each market based on the most recent available data,
3. Analysis of the RAC efficiency distribution and leading manufacturers in each market based on the most recent available data.
4. Listing of a few high efficiency low-cost RACs.
5. Implications and possible future research.

Summary of Primary Data

Region	Sources	AC models analyzed
China	· LBNL IDEA (updated 07/2016) · CNIS database · Topten China (updated 03/2016) · Top Runner China (listed 03/2016)	· 578 variable-speed AC models (all reversible type) from LBNL IDEA · Highest-efficiency models selected from all available sources
EU	· Topten EU (updated 11/2016)	· 96 highest-efficiency single split AC models (all reversible type)
India	· LBNL IDEA (updated 09/2016) · www.bijlibachao.com (updated 02/2017)	· 57 highest-efficiency variable-speed AC models (all cooling-only type) selected from the two sources
Japan	· ECCJ database (registered 10/2006-09/2016)	· 2,922 split AC models (all reversible type)
South Korea	· KEA database (registered 01/2013-11/2016)	· 1,309 cooling-only AC models · 638 reversible-type AC models (heat pumps)
U.S.	· LBNL IDEA (updated 07/2017) · US DOE Compliance Certification Database · CEE-AHRI Directory for Efficient Equipment · ENERGY STAR Most Efficient 2017	· 836 mini-split models from LBNL IDEA · Highest-efficiency models selected from all available sources
Indonesia	· LBNL IDEA (updated 02/2017) · MEMR database	· 335 AC models from LBNL IDEA
Philippines	· Government database	· 697 split AC models from the government database

China

Annual RAC demand	41.4 million (2011), 38.4 million (2016)				
Market share of variable-speed RACs	Over 60% of RACs sold in 2016				
S&L vs. Highest-efficiency and BAT low-GWP RACs	Type	MEPS	Most stringent label	Highest-efficiency RAC	BAT low-GWP RAC
	Variable-speed (reversible)	For ACs with CC ≤ 4.5 kW			
		China APF 3.5	China APF 4.5 (Grade 1)	APF 5.45 (R-410A)	APF 5.2 (R-32)
Dominant refrigerants in RACs	R-22 (for fixed-speed units), R-410A (for variable-speed units)				
Low-GWP RACs	R-32 available on the market, including highly efficient R-32 models. R-290 not available yet on the market, but Chinese manufacturers have completed retrofits of production lines for R-290 RACs.				
Leading manufacturers	Haier, Midea, Gree, Aux, Chico, and Changhong (headquartered in China); Daikin, Mitsubishi, and Panasonic (headquartered in Japan)				



Distribution of variable-speed RAC models in China in 2016, by efficiency and capacity

- Total 578 models (reversible type, variable-speed) available in 2016
- Product-weighted average APF: 3.9
- Product-weighted average cooling capacity: 4.1 kW

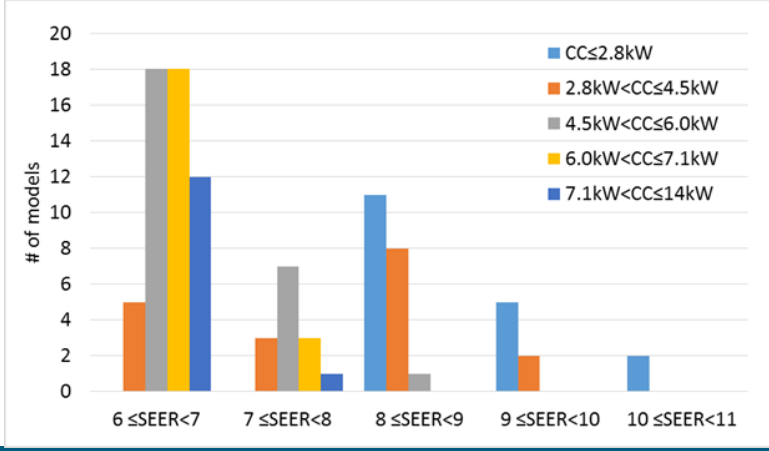
Source: LBNL IDEA

Europe

Annual RAC demand	7.0 million (2011), 5.4 million (2016) (Russia, Italy, Turkey, Spain, and France represent more than 65% of the European market.)
Market share of variable-speed RACs	55%–75% of sales in 2007 (EU)
S&L vs. Highest-efficiency and BAT low-GWP RACs (EU)	

Type	MEPS	Most stringent label	Highest-efficiency RAC	BAT low-GWP RAC
Ductless split	EU SEER 4.60 (GWP > 150 for < 6 kW) EU SEER 4.14 (GWP ≤ 150 for < 6 kW)	EU SEER 8.5 (A+++)	EU SEER 10.5 (R-32)	EU SEER 10.5 (R-32)

Dominant refrigerants in RACs	R-410A
Low-GWP RACs	R-32 available on the market (mainly in high-end models) R-290 available on the market (mainly in portable ACs)
Leading manufacturers	Daikin, Mitsubishi Electric, Panasonic, and Fujitsu General (headquartered in Japan); Samsung and LG (headquartered in South Korea)



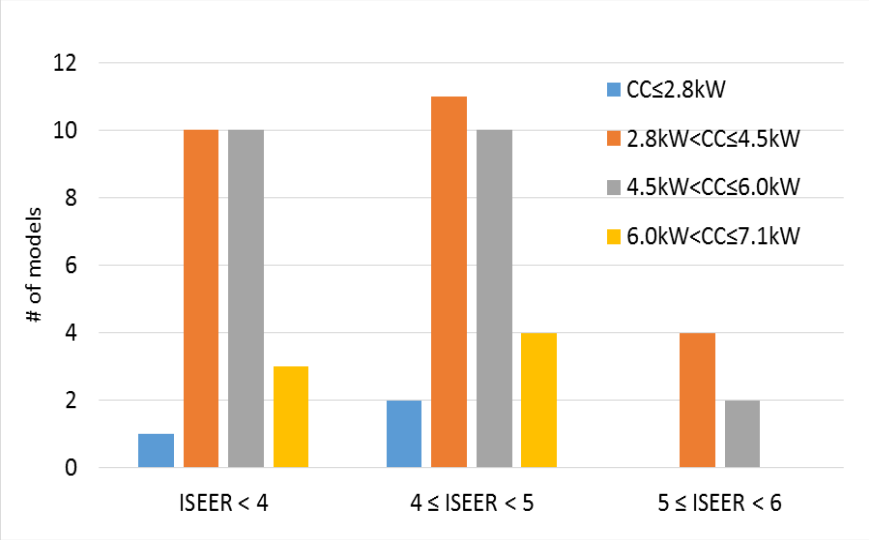
Distribution of highest-efficiency AC models in Europe in 2016, by capacity and efficiency

- Total 96 models (reversible type) available in 2016
- Product-weighted average SEER: 7.3
- Product-weighted average cooling capacity: 5.4 kW

Source: Topten EU

India

Annual RAC demand	3.4 million (2011), 4.3 million (2016)
Market share of variable-speed RACs	~10% of RACs sold in 2016
S&L vs. Highest-efficiency and BAT low-GWP RACs	<table><tr><td>Type</td><td>MEPS</td><td>Most stringent label</td><td>Highest-efficiency RACs</td><td>BAT low-GWP RACs</td></tr><tr><td>RAC</td><td>ISEER 3.1</td><td>ISEER 4.5 (5 Stars)</td><td>ISEER 5.8 (R-32, R-290)</td><td>ISEER 5.8 (R-32, R-290)</td></tr></table>
Dominant refrigerants in RACs	R-22 (mainly because fixed-speed units are still dominant on the market)
Low-GWP RACs	R-32 available on the market (led by Japanese manufacturers) R-290 available on the market (led by Godrej)
Leading manufacturers	Daikin, Hitachi, Panasonic, Voltas, Blue Star, Godrej, LG, Samsung



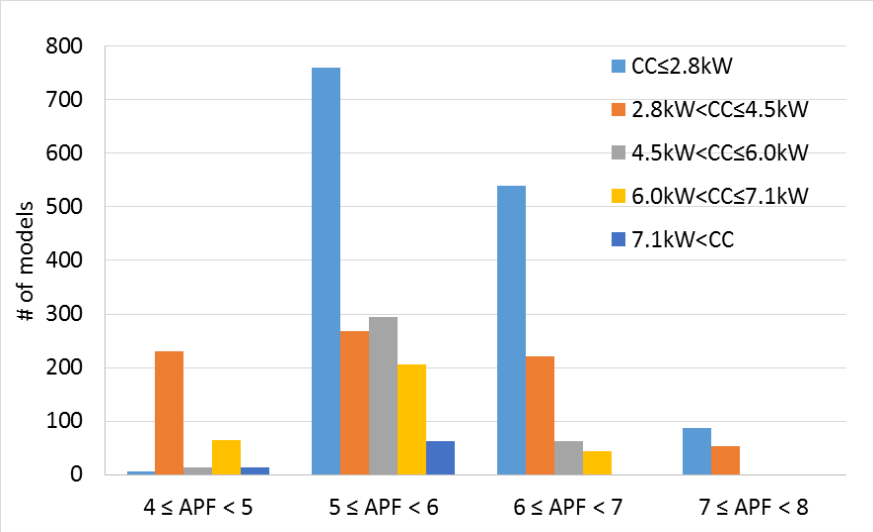
Distribution of highest-efficiency AC models in India, by capacity and efficiency

- Total 57 models
- Product-weighted average ISEER: 4.35
- Product-weighted average CC: 4.6 kW

Source: LBNL IDEA and Bijli Bachao

Japan

Annual RAC demand	8.3 million (2011), 8.4 million (2016)
Market share of variable-speed RACs	100% in new sales
S&L vs. Highest-efficiency and BAT low-GWP RACs	<table><tr><th>Type</th><th>Top Runner standards</th><th>Highest-efficiency RACs</th><th>BAT low-GWP RACs</th></tr><tr><td>Ductless split wall-mounted</td><td>For RACs with CC < 3.2 kW, APF 5.8 (dimension-defined type) or APF 6.0 (dimension-free type)</td><td>Japan APF 7.6 (R-32)</td><td>Japan APF 7.6 (R-32)</td></tr></table> Top Runner standards in Japan serve as MEPS.
Dominant refrigerants in RACs	R-32
Low-GWP RACs	R-32 available on the market
Leading manufacturers	Daikin, Fujitsu, Hitachi, Mitsubishi, Panasonic, Sharp, and Toshiba



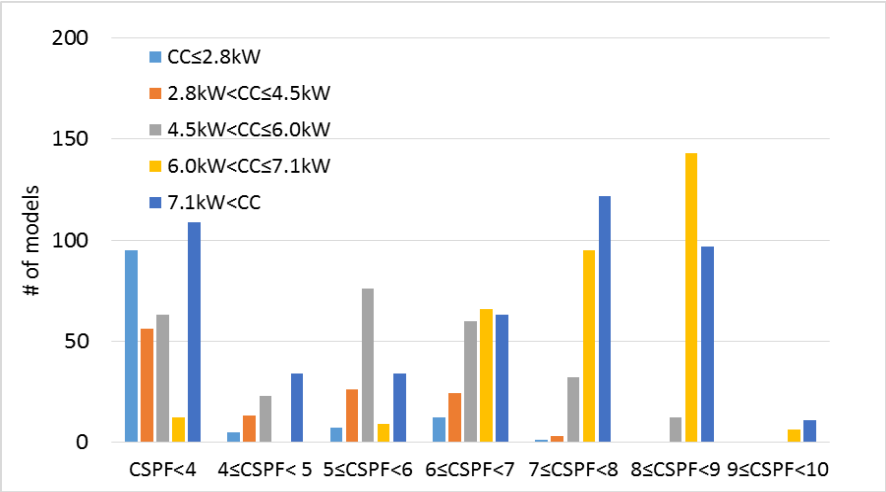
Distribution of AC models in Japan, by capacity and efficiency

- Total 2,922 models (reversible type)
- Product-weighted average APF: 5.8
- Product-weighted average cooling capacity: 3.9 kW

Source: EECJ database

South Korea

Annual RAC sales	8.2 million (2010), 8.8 million (2016)				
Market share of variable-speed RACs	~90% of RACs sold in 2015				
S&L vs. Highest-efficiency and BAT low-GWP RACs	Type	MEPS	Most stringent label	Highest-efficiency RAC	BAT low-GWP RAC
	Split ACs	For ACs with 4 kW ≤ CC < 10 kW		CSPF 9.7 (R-410A)	Not available
		2.97	9.36 (Energy Frontier) 7.20 (Grade 1)		
Dominant refrigerants in RACs	R-410A (variable-speed units), R-22 (fixed-speed units)				
Low-GWP RACs	R-32 expected to be available on the market				
Leading manufacturers	Samsung, LG, and Carrier				



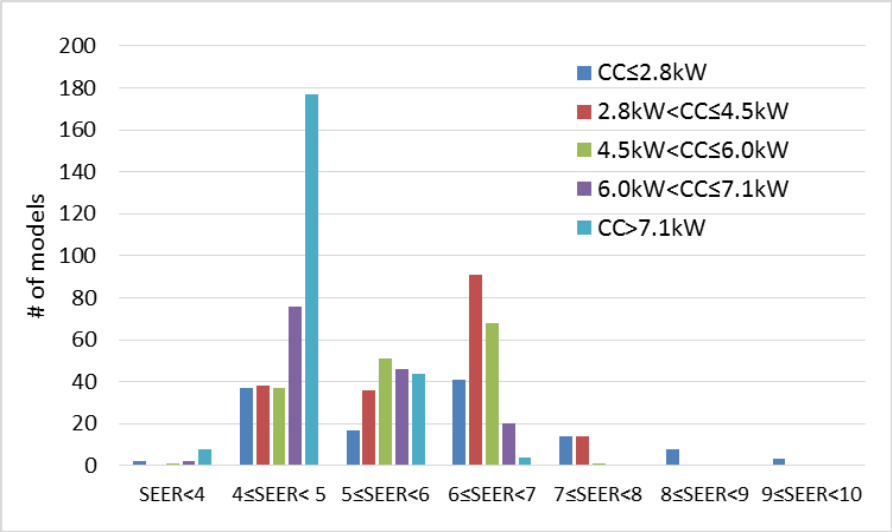
Distribution of AC models in South Korea, by capacity and efficiency

- Total 1,309 models (cooling-only type)
- Product-weighted average CSPF: 6.0
- Product-weighted average cooling capacity: 6.5 kW

Source: KEA database

United States (U.S.)

Annual RAC sales	6.6 million (2011), 7.9 million (2016) * mini-splits ~0.8 million (2016)				
S&L vs. Highest-efficiency RACs (mini-splits)	Type	MEPS	Most stringent label	Highest-efficiency RACs	BAT low-GWP RAC
	Split heat pumps	SEER 4.10 HSPF 2.40	SEER 5.27 HSPF 2.49 EER 3.66	SEER 11.7 (R-410A)	Not available
Dominant refrigerants in RACs	R-410A				
Low-GWP RACs	R-32 available for self-contained systems (not mini-splits) on the market				
Leading manufacturers (mini-splits)	Mitsubishi Electric, Gree, Fujitsu General, Daikin, Carrier, Panasonic, and LG				



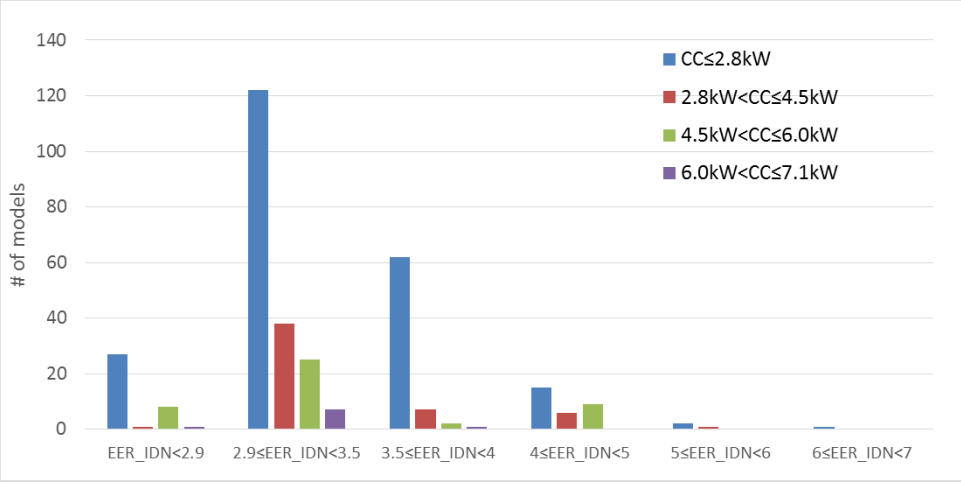
Distribution of mini-split AC models in the U.S. in 2017, by capacity and efficiency

- Total 836 models (mini-splits)
- Product-weighted average SEER: 5.4
- Product-weighted average cooling capacity: 6.2 kW

Note that SEER on this figure is expressed in W/W for the purpose of this study. AC efficiency in the U.S. is typically expressed in Btu/(W·h). 1 Btu/h is equivalent to 0.293 watts.

Source: LBNL IDEA

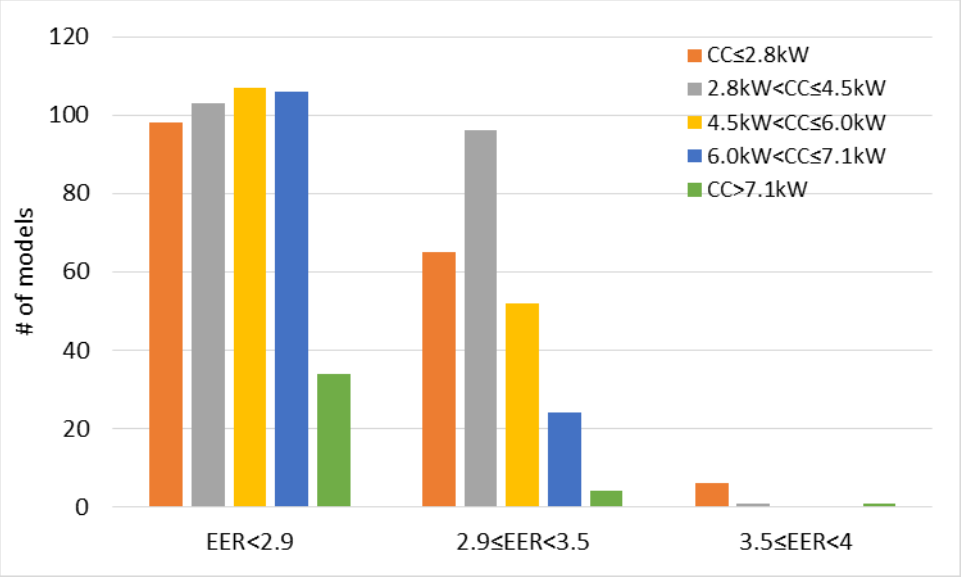
Indonesia and Philippines



Distribution of split AC models in Indonesia in 2017, by capacity and efficiency

- Total 335 split AC models
- Product-weighted average EER 3.3 / EER_IDN 3.4
- Product-weighted average cooling capacity: 2.7 kW

Source: LBNL IDEA

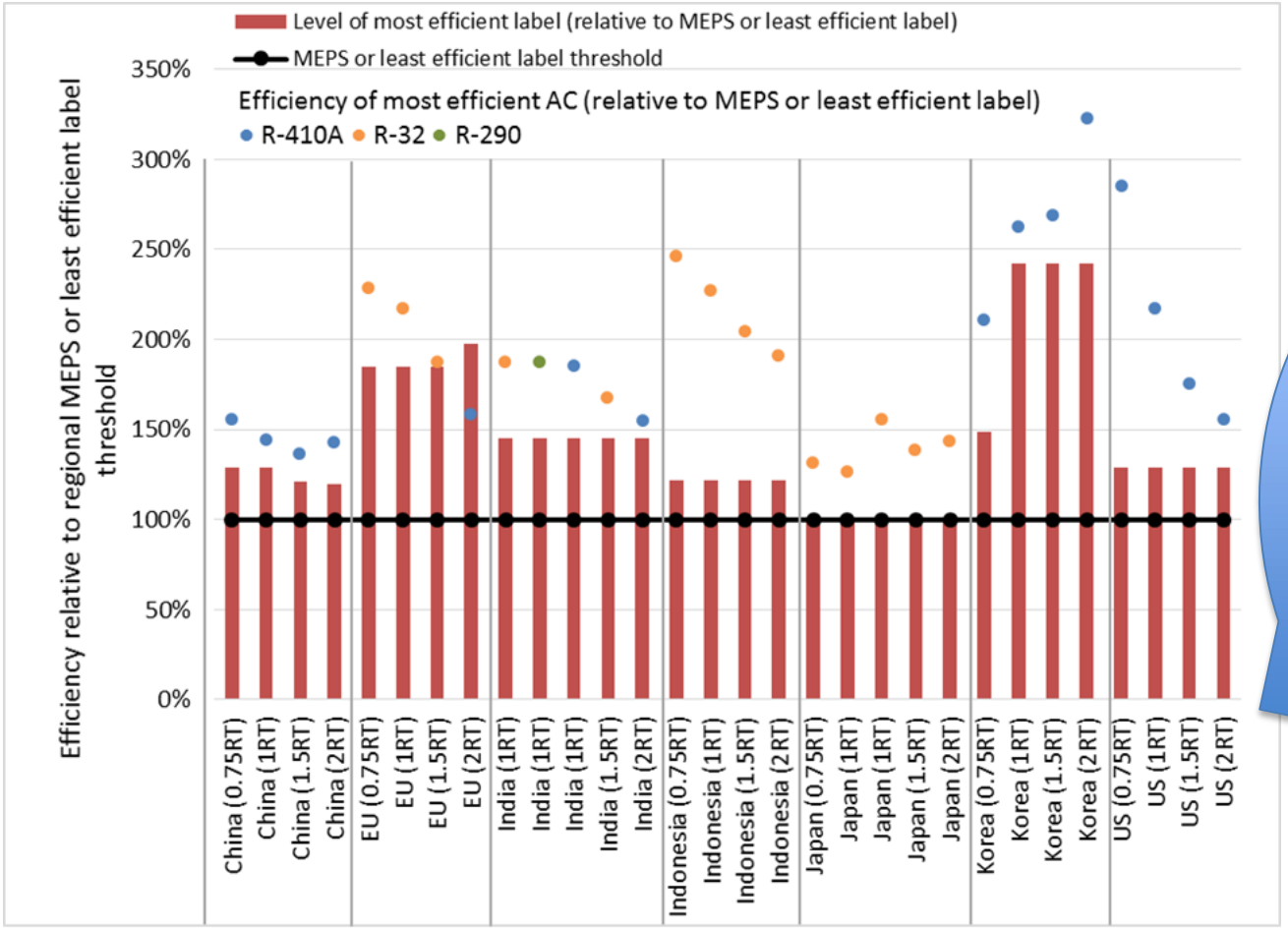


Distribution of split AC models in the Philippines in 2016, by capacity and efficiency

- Total 697 split AC models
- Product-weighted average EER: 2.9
- Product-weighted average cooling capacity: 4.5 kW

Source: GOVPH (2016)

Opportunities for efficiency improvement in RACs



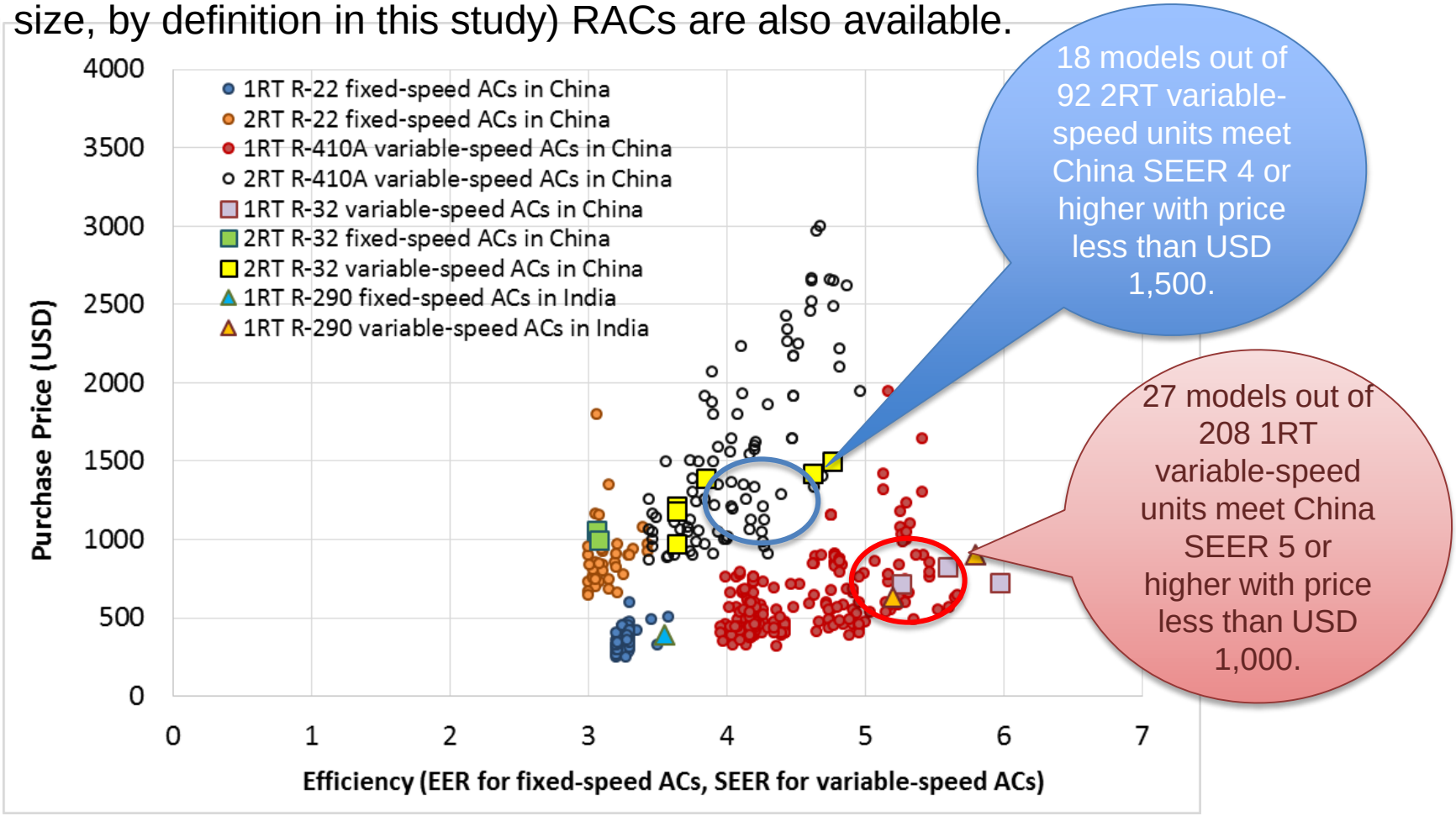
RACs are available in most regions and worldwide that surpass the highest efficiency levels recognized by labeling programs.

Efficiency of most-efficient models relative to MEPS or least-efficient labels

For example, the blue dot and red bar at "US (0.75RT)" should read that the efficiencies of the most efficient U.S. RAC (11.7 W/W) and the most efficient label (ENERGY STAR) requirement (5.27 W/W) are 2.85 times (285%) and 1.29 times (129%) as high as the U.S. MEPS (4.1 W/W). See Table B1 in Appendix B for information on AC models analyzed.

2) Price vs. Efficiency: China

High efficiency is typically a feature of high-end products. However, highly efficient, cost-competitive (<USD 1,000 or <USD 1,500 retail price, depending on size, by definition in this study) RACs are also available.



Data source: LBNL IDEA

Number of models: 74 (1-RT fixed-speed), 208 (1-RT variable-speed), 40 (2-RT fixed-speed), 92 (2-RT variable-speed)

Examples of highly-efficient and cost-competitive RACs

Highly efficient, cost-competitive RACs with low-GWP refrigerants such as R-32 and R-290 are also commercially available in China, India, and Indonesia.

Region	Brand	Model Name	CC (kW)	Seasonal Efficiency	Purchase price (USD)	Refrig-erant
China	Midea	KFR-26GW/BP3DN8Y-YA101(B1)	2.6	China APF 5.2	660	R-32
		KFR-35GW/BP3DN8Y-YA101(B1)	3.5	China APF 5.1	710	R-32
India	Daikin	JTKM35SRV16	3.5	ISEER 5.8	710	R-32
		JTKM50SRV16	5.0	ISEER 5.2	810	R-32
	Godrej	GSC 12 FIXH 7 GGPG	3.5	ISEER 5.8	825	R-290
		GSC 12 GIG 5 DGOG	3.5	ISEER 5.2	700	R-290
		GSC 18 GIG 5 DGOG	5.0	ISEER 4.9	840	R-290
Indonesia	Daikin	FTKC25PVM4	2.5	EER_{IDN} 4.14	361	R-32
		FTKC35PVM4	3.5	EER_{IDN} 4.14	472	R-32
		FTKC50NVM4	5.2	EER_{IDN} 4.95	644	R-32

Source: LBNL IDEA and web searches

Further Work

- Because of the **prevalence of fixed-speed RACs using conventional R-22 in many emerging markets among the A5 Parties**, there is a large scope to:
  - Update corresponding S&L thresholds as well as
  - Design other types of market transformation program measures such as incentive or procurement programs for high efficiency and/or low-GWP RACs.
- The highest-efficiency and/or cost-competitive RAC models need to be further analyzed through testing, teardown and design simulation to:
  - Identify the leading manufacturers (EE champions)
  - Understand the underlying driving technologies for high efficiency, low-GWP and/or low-cost.
  - Estimate the potential for the adoption of low-GWP refrigerants to improve efficiency and cost.
- Cost-effectiveness of efficiency improvements in RACs from a consumer perspective can be assessed by consumer bill savings over the lifetime of the RACs, consumer payback period, and the return on consumer investment (due to increased retail price).
- Given that energy savings potential available from RACs coupled with low-GWP refrigerants could vary by regional characteristics such as local climate conditions and forecasted RAC demand, there could be opportunities to achieve bigger energy savings by adopting regional seasonal energy efficiency metrics in hot climate countries.

Acknowledgments

We sincerely thank

Gregory Rosenquist, Amol Phadke, Virginie Letschert, Chao Ding, Yi Qu, Durwood Zaelke, Richard Duke, Stephen O. Andersen, Gabrielle Dreyfus, Nancy Sherman, Xiaopu Sun, Marco Gonzalez, Dennis Clare, Richard Ferris, Romina Picolotti, Paul Kellett, Alexander Hillbrand, Balaji Natarajan, CHENG Jianhong, LIU Meng, and Dae Hoon Kim

for providing review comments, insights, and/or data.

We thank Elizabeth Coleman for the administrative support.

More Information

Full report can be downloaded from

https://escholarship.org/uc/item/01h8g7zb

Additional contact:

Nihar Shah: nkshah@lbl.gov

Won Young Park: wypark@lbl.gov