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Improving the energy efficiency of room air conditioners in China: Costs and benefits

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HIGHLIGHTS

- Variable speed units provide cost-effective solution to improve efficiency.
- Fixed speed units are not economically competitive at higher efficiency ratings.
- New standard brings accumulative CO_2 reductions of 12.8% between 2019 and 2050.
- Accumulative bill saving is 2620 billion RMB between 2019 and 2050.
- Continuous revision of the new standard could more than double the overall impact.

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ABSTRACT

China is the world's largest consumer of room air conditioners, and it contributes about a quarter of global space cooling CO_2 emissions. We model the costs and benefits of recently proposed new room air conditioner minimum energy performance standards (MEPS) in China. Our results suggest that newly proposed MEPS brings accumulative CO_2 emissions reductions of 12.8% between 2019 and 2050, and accumulative bill saving of 2620 billion RMB to China's consumers. The benefits of the proposed MEPS decrease with longer MEPS revision intervals and increase with shorter intervals—indicating that the intervals should be balanced to maximize benefits while accommodating constraints due to air conditioner manufacturer design cycles. We also model potential nationwide benefits from higher MEPS. Across two increasingly aggressive MEPS scenarios, China's room air conditioner electricity consumption and CO_2 emissions in 2050 are both reduced by 15–53% compared to the proposed MEPS. The highest-efficiency scenario (reaching MEPS of annual performance factor 5.4 in 2025) provides the largest long-term national benefits. These results could inform development of a Chinese regulatory regime that effectively updates room air conditioner MEPS. Because China is the world's largest manufacturer of room air conditioners, the economic, energy, and emissions benefits resulting from higher Chinese MEPS could also have a global reach.

1. Introduction

Global urbanization, electrification, increasing standards of living and demand for comfort, and falling air conditioner (AC) prices are expected to substantially increase the direct emissions from AC refrigerants and the indirect emissions associated with AC energy use. The past decade witnessed a rapid increase in AC ownership, particularly in emerging economies. In 2016, ACs and electric fans accounted for about a fifth of total electricity used in buildings worldwide. In addition, cooling demand was roughly 10% of the total global electricity consumption in that year [1]. According to the International Energy Agency [1], worldwide energy demand from ACs is set to triple by 2050, with emissions rising to 2070 million metric tons of CO_2 ($MtCO_2$), from 1135 $MtCO_2$ in 2016. Coupled with growing hydrofluorocarbon (HFC) use in ACs, as a replacement for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), emissions from AC systems—without further controls—could partially negate the climate benefits achieved under the Montreal Protocol [2].

Emerging economies likely will drive the growth of AC ownership in coming decades. Growth potential is very high in many of these countries because relatively small proportions of their large and growing populations currently own ACs, and increasing per-capita

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Nomenclature

Δmfc	total incremental manufacturing cost
Δrp	retail price
$age(t)$	age of the AC in year t
$APF(m)$	efficiency rating of the design combination m
$baselinepowerinput$	power requirement of the baseline room AC
$bs(m, t)$	savings on the electricity bill with design combination m in year t
CC	cooling capacity
$cost_m(i)$	incremental cost of component i
$cumulativebs(m, t)$	cumulative savings on the electricity bill with design combination m in year t
$discount$	consumer discount rate
EER	energy efficiency ratio
$es_m(i)$	percent energy savings gained from component i
$fprice$	electricity price at year t
m	design combination
$markup$	markup rate from manufacturing cost to user price
ns	net savings
$p(m)$	payback
$SEER$	seasonal energy efficiency rating
t	year
$t\_es(m)$	overall percent savings of the design combination m
$UEC(m)$	annual electricity consumption of the design combination m

Table 1
Room AC sales by region between 2011 and 2017 (in million units).
Source: ChinaIOL [3] for China, JRAIA [15] for other regions.

	2012	2013	2014	2015	2016	2017
China	99.8	128.5	126.9	107.4	117.5	140.0
Asia (excluding China)	20.3	21.4	21.7	21.8	23.3	24.7
Europe	6.3	6.1	4.9	4.7	5.4	5.8
North America	7.5	7.9	8.2	8.1	8.0	8.1
South America	6.6	7.1	7.4	6.6	5.8	6.1
Middle East	3.7	4.7	4.8	4.7	4.6	4.4
Africa	2.2	2.3	2.3	2.3	2.4	2.3
Oceania	0.8	0.8	0.9	0.9	0.9	1.1

incomes, rising urbanization, and greater demand for thermal comfort are expected to expand AC ownership and use [3,4]. For example, whereas about 90% of residential buildings in the United States and Japan had central or room ACs in 2011, in 2013 room AC market penetrations were only 3% in India, 6% in Indonesia, and 16% in Brazil [5,6,1]. IEA [1] predicts that about half of global cooling demand growth by 2050 will come from emerging economies, including China, India, and Indonesia. China has already become the world's largest consumer (and manufacturer) of ACs. In 2016, its market penetration of room ACs in urban households reached 124% (up from 5% in the mid-1990s), although rural penetration remained below 47% [7]. That same year, China owned 35% of the 1.6 billion units of global AC stock [1]. In 2017, Chinese consumers purchased 73% of the approximately 193 million room AC sold worldwide, [8], Table 1).[2] In addition, China manufactured 70% of the world's RACs in 2017 [9].

Consequently, China's energy use for space cooling has increased dramatically, growing from 6.6 TWh in 1990 to 450 TWh in 2016 [1]. Because most of China's power generation is from coal-fired power plants, it led the world in CO_2 emissions from space cooling in 2016, contributing about 28% of global space cooling emissions (Fig. 1). In 2015, total electricity demand from room ACs accounted for about 30% of the peak summer load in some large and medium-sized Chinese cities [4]. During the summer heatwave of 2017, cooling demand pushed China's electricity demand to record highs [10]. China's cooling demand is expected to continue growing. Its cooling energy use per person is still less than 20% of the value observed in the United States (U.S.) [1].

Although China has adopted more than 60 mandatory minimum energy performance standards (MEPS) since the late 1980s related to residential appliances and commercial equipment, including room ACs, some of its existing MEPS are outdated and not very stringent. Because its MEPS for fixed-speed-drive (FSD) and variable-speed-drive (VSD) room ACs were last revised in 2010 and 2013, respectively, these standards do not reflect the market-based efficiency improvements that have resulted from national subsidy programs [11]. In addition, in most climate regions VSD compressors enable an AC unit to respond to changes in cooling requirements, improving performance and reducing refrigerant flow rates compared to the performance and refrigerant flow of conventional ACs with FSD compressors that cycle on and off [12]. VSD products that make ACs highly efficient already dominate mature AC markets such as Australia, Europe, Japan, and the U.S., and have rapidly increasing shares in emerging economies such as India [13].

Having two separate standards for FSD and VSD room ACs with much lower MEPS requirement for FSD enables inefficient FSD ACs to remain in the market. In recent years, China has been working on updating its room AC efficiency metrics and MEPS so that FSD and VSD ACs are covered under a single harmonized standard for the first time. The revised standard is expected to be published by the end of 2019 and be effective by the middle of 2020.[3]

Various existing studies evaluate the energy savings, emissions reductions, and economic benefits related to energy-efficiency standards and improvements for ACs and other appliances. Mahlia et al. [14] predict the potential mitigation of emissions through room AC energy-efficiency standards in Malaysia. Kwong et al. [15] analyze the energy-savings potential and cost-effectiveness of radiant cooling systems in Malaysia. Grignon-Masse et al. [16] assess the environmental impacts of energy-efficient European ACs using a lifecycle analysis approach. Rosas-Flores et al. [17] estimate the energy savings and CO_2 emissions reduction potential of urban and rural household appliances, including ACs, in Mexico. Borg and Kelly [18] focus on the electricity consumption and peak load impacts of appliance efficiency improvements in European households. Similarly, McNeil et al. [19] analyze the impact of energy-efficient appliances on Indonesia's peak load, finding that ACs will be the main driver of peak growth by 2025.

However, few studies discuss the impact of room AC efficiency standards and improvements in China. Those that do are now mostly outdated and underestimate the growth of AC ownership. Lin and Rosenquist [20] review Chinese AC standards and analyze the cost-effectiveness of the previously proposed standards in terms of the impact on energy savings, electric generation capacity, and CO_2 emissions reductions. Zhou et al. [21] estimate the energy-saving and CO_2-emission-reduction potential of China's appliance standards, including room AC standards, before 2010. Yu et al. [4] investigate the electricity savings and CO_2 emission reductions from room ACs under three different efficiency-improvement scenarios over the 2005–2025 period. Wu et al. [22] review the policy rules of energy-efficiency standards in China compared with standards in other countries, and they propose two methods to combine the global warming potential (GWP) of room AC refrigerants with energy-efficiency evaluation metrics.

Our paper investigates the impact of newly revised standard

[2] Room AC sales accounted for 93% of total global AC sales in 2017 [8].

[3] Available here: http://www.cnis.gov.cn/gbzqyj/201903/t20190314_24782.shtml.