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Abstract

After boiling summer brought brown-out to most part of the country in 2004, China announced a new set of minimum energy efficiency standards for room air conditioners in September 2004, with the first tier going into effect on March 1, 2005 and the reach standard taking effect on January 1, 2009. This represents a milestone in China's standard setting process since the reach standard levels are significantly more stringent than previous standards for other appliances. This paper first analyzes cost-effectiveness of China's new standards for room air conditioners, and then attempts to evaluate the impact of the new standards on energy savings, electric generation capacity, and CO2 emissions reductions.

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Introduction

Since 2002, China has experienced wide spread power shortage, leading to the rationing of power in 24 out of 31 provinces across country in 2004. While most observers point to the strong economic growth in China as the primary cause for such shortage, incremental air-conditioning load is also a leading contributor. It is estimated that about 30 million new room air conditioners were installed in 2004 along, adding roughly 20 GW in peak capacity, which easily eclipse the generating capacity of the Three Gorges Dam. In major cities along the eastern seashore such as Shanghai, air-conditioning load accounts for 40% of the peak summer load.

It is therefore understandable that China decided to update its minimum energy efficiency standard (MEPS) for room air conditioners. The revised standard was published in September, 2004, with the first tier going into effect on March 1, 2005 and the reach standard taking effect on January 1, 2009. This represents a milestone in China's standard setting process since the reach standard levels are significantly more stringent than previous standards for other appliances. This paper first reviews the requirements of the new Chinese standards for air conditioners, and then analyzes its cost-effectiveness, and finally attempts to evaluate the impact of the new standards on energy savings, electric generation capacity, and CO2 emissions reductions.

China's New Standard for Room Air Conditioners

China's new standard for air conditioners sets two tiers of performance requirements, with the first tier going into effect on March 1, 2005, and the second tier going into effect on January 1, 2009. The 2005 requirements are listed in Table 1.

The measured value of energy efficiency ratio (EER) of room air conditioners must be greater than or equal to the values shown in Table 1.

Table 1. Energy Efficiency Ratios (EER)

Category	Rated Cooling Capacity (CC） *W*	EER *W/W*
Single-package	-	2.30
Split	CC ≤4500	2.60
	4500<CC≤7100	2.50
	7100 < CC ≤ 14000	2.40

In addition to setting the minimum requirement, China's new AC standard also include classification requirements for the newly established Energy Information Label, as well as the certification requirement for CECP's Energy Conservation Label.

Rating requirements (measured in EER) for specific Energy Efficiency Grades are listed in Table 2.

Table 2. Energy Efficiency Grade Specifications

Category	Rated Cooling Capacity (CC) *W*	Energy Efficiency Grade EER *W/W*				
		5	4	3	2	1
Single-package	-	2.30	2.50	2.70	2.90	3.10
Split	CC ≤4500	2.60	2.80	3.00	3.20	3.40
	4500<CC≤7100	2.50	2.70	2.90	3.10	3.30
	7100 < CC ≤ 14000	2.40	2.60	2.80	3.00	3.20

For China's voluntary energy endorsement label (managed by China Standard Certification Center), the EER requirements of room air conditioners must be greater than or equal to the values shown in Table 3.

Table 3. Energy Efficiency Specification

Category	Rated Cooling Capacity (CC) *W*	EER *W/W*
Single-package	-	2.90
Split	CC ≤4500	3.20
	4500<CC≤7100	3.10
	7100 < CC ≤ 14000	3.00

Moreover, a tighter standard goes into effects on 1 January 2009. The requirements of the 2009 standard for room air conditioners are listed in Table 4.

Table 4. Energy Efficiency Ratios (EER) in 2009

Category	Rated Cooling Capacity (CC) *W*	EER *W/W*
Single-package		2.90
Split	CC ≤4500	3.20
	4500<CC≤7100	3.10
	7100 < CC ≤ 14000	3.00

In order to compare the stringency of the Chinese standards, a collection of standards around the world are presented below in Tables 5 through 9.

Table 5. U.S. and Canadian Air Conditioner Standards

Category	EER *W/W*
Window	2.87
Central	3.37*

* Converted from seasonal energy efficiency ratio (SEER) of 13. SEER is in units of Btu/Whr.

Table 6. South Korean Air Conditioner Standards[1]

Category	Rated Cooling Capacity (CC) *W*	EER *W/W*
Window	-	2.88
Split	CC<4000W	3.37
	4.0 kW ≤ RCC < 10.0 kW	2.97
	10.0 kW ≤ RCC < 17.5 kW	2.76

Table 7. Singapore Air Conditioner Standards

Category	EER *W/W*
Window	2.73

Table 8. European Union Labeling Requirements

Category	Energy Efficiency Grade EER *W/W*						
	G	F	E	D	C	B	A
Window	<2	2.0	2.2	2.4	2.6	2.8	>3.0
Split	<2.2	2.2	2.4	2.6	2.8	3.0	>3.2

Table 9. Japanese Air Conditioner Standards

Category	Rated Cooling Capacity W/W	EER W/W	
Window		**AC-only**	**Heat pump**
	-	2.67	2.85
Split		**AC-only**	**Heat pump**
	CC<2500W	3.64	5.27
	2500-3200W	3.64	4.90
	3200-4000W	3.08	3.65
	4000-7100W	2.91	3.17
	>7100W	2.81	3.10

Where the standards cover products in several categories, the most dominant product type in China today is the split air conditioners with a cooling capacity smaller than 4500 Watts. Therefore it can be seen that the 2009 Chinese requirement for this product group will be higher than the EU label A, and only trails the requirements of Japan and South Korea. While the US standard is technically more stringent, it is set for residential central system, which carries significant duct losses.

For window air conditioners, the 2009 Chinese standard would be the highest with a minimum EER of 2.9, compared to 2.87 in the US, 2.85 in Japan, and 2.88 in South Korea.

[1] As of March 2006.

Life-Cycle Cost Analysis of Air Conditioner Standards

One of the factors used to judge the economic feasibility of air conditioner standards is consumer life-cycle costs (LCC) savings. If a more efficient air conditioner, i.e., a unit that meets possible new standards, provides consumer LCC savings relative to a minimally compliant product, the more efficient unit is generally assessed as being economically feasible.

The LCC is the sum of the purchase cost (*PC*) and the present value of operating expenses (*OC*) discounted over the lifetime (*N*) of the equipment. If operating expenses are constant over time, the LCC simplifies to

$$LCC = PC + PWF \bullet OC,$$

where the present worth factor (PWF) is dependent on the discount rate (r) and the equipment lifetime (N) and is defined as

$$PWF = 1/r \bullet [\ 1 - 1/(1+r)^N\ ].$$

The LCC analysis described below was conducted with a 6 percent real discount rate and an equipment lifetime of 12.5 years.[2]

In order to assess the economic feasibility of increased Chinese air conditioner standards, an LCC analysis was performed on two different sized split system room air-conditioning heat pumps: 3500 Watt (W) cooling capacity and 7100 Watt (W) cooling capacity (Rosenquist and Lin, 2005). The above cooling capacity units were determined to be the most popular sized air-conditioning units in China. Table 10 summarizes the physical characteristics of the two representative units (i.e., baseline units) for which the LCC analysis was conducted. By defining baseline units, more efficient designs, otherwise known as design options, can be evaluated to determine if standards are economically feasible. Note that the rated EERs of the two baseline units have efficiencies roughly equal to the current minimum EER standards (see Table 1). At the time the LCC analysis was conducted, many air conditioner models in China had efficiencies that were roughly equal to the current minimum standards.

Table 10. Baseline Characteristics of 3500 W and 7100 W Split System Room Air-Conditioning Heat Pumps

		Heat Pump Split (single evaporator)	
Rated Cooling Capacity, CC (W)		3500	7100
Rated EER (W/W)		2.57	2.55
Refrigerant		R-22	R-22
Flow Control Device		Short Tube (assumed)	Short Tube (assumed)
Evaporator	Face area (m^2)	0.206	0.303
	Fin type	Hydrophilic Slit Fin	Hydrophilic Slit Fin

[2] The lifetime assumption is based on industry estimate of average lifetime of ACs in China. No benchmark discount rate is available from China. However, interest rate for loans over 5 years was 6.12% by the end of 2005.

		Tube type	Grooved	Grooved
Condenser		Face area (m^2)	0.381	0.502
		Fin type	Hydrophilic Slit Fin	Hydrophilic Slit Fin
		Tube type	Grooved	Grooved
Compressor		Manufacturer	Panasonic Wanbao	Copeland
		Model Number	2K23S225BUA	ZR34KH-PFJ-522
		Type	Rotary	Scroll
		Cooling capacity (W)	4000	8200
		Displacement (cm^3)	21.4	46.1
		Efficiency (W/W)	2.81	3.02
Fan	**Evaporator-side**	Air volume (m/h^3)	463	1014
		Power Input (W)	50	80
		Type	PSC	PSC
	Condenser-side	Air volume (m/h^3)	1400 (assumed)	2040 (assumed)
		Power Input (W)	75 (assumed)	150 (assumed)
		Type	PSC	PSC

Tables 11 and 12 show the cost-efficiency and LCC results for the 3500 W and 7100 W baseline units. Specific design options were added to the baseline units and their impact on manufacturer cost, consumer retail price, cooling capacity, EER, annual energy consumption (AEC), operating cost (OC), payback period (i.e., the ratio of the change in consumer retail price over the change in operating cost), and LCC were determined. Note that in Tables 11 and 12, only a limited number of design options were evaluated. For example, increases in evaporator size were not considered so as to prevent any significant changes to the indoor cabinet. In addition relatively small increases in condenser size were considered to limit the size of the outdoor cabinet.

Table 11. Cost-Efficiency and LCC Results for 3500 W Split System Room Air-Conditioning Heat Pump

No.	Design Option	Manufacturer Cost Incr. *Yuan*	Manufacturer Cost Total *Yuan*	Retail Price *Yuan*	Cooling Capacity *Watts*	EER *W/W*	AEC* *kWh/yr*	OC** *Yuan/yr*	Payback Period *Years*	LCC *Yuan*
0	Baseline	-	-	2600	3299	2.57	1148	689	-	8541
1	0 +3.0 EER Compressor	40	40	2660	3307	2.75	1074	644	1.3	8214
2	1 +3.16 EER Compressor	61	101	2751	3313	2.90	1018	611	1.9	8015
3	2 + 0.419 m^2 Condenser	56	157	2834	3325	2.96	997	598	2.6	7992
4	3 +Cond^ Fan Motor +10%	20	177	2864	3325	2.98	992	595	2.8	7995
5	4 +Evap^ Fan Motor +10%	20	197	2894	3329	2.99	987	592	3.0	7997
6	5 +Cond^ Fan Motor +20%	20	217	2923	3329	3.02	978	587	3.2	7982
7	6 +Evap^ Fan Motor +20%	20	237	2953	3333	3.03	973	584	3.4	7989

* AEC based on annual operating hours of 895.

** OC based on electricity price of 0.6 yuan/kWh.

^ Cond = Condenser; Evap = Evaporator

Table 12. Cost-Efficiency and LCC Results for 7100 W Split System Room Air-Conditioning Heat Pump

No.	Design Option	Manufacturer Cost Incr. *Yuan*	Manufacturer Cost Total *Yuan*	Retail Price *Yuan*	Cooling Capacity *Watts*	EER *W/W*	AEC* *kWh/yr*	OC** *Yuan/yr*	Payback Period *Years*	LCC *Yuan*
0	Baseline	-	-	5000	6814	2.57	2369	1421	-	17,254
1	0 + 3.25 EER Compressor	177	177	5264	6857	2.77	2203	1322	2.7	16,661
2	1 + 0.551 m^2 Condenser	70	247	5368	6884	2.82	2163	1298	3.0	16,557
3	2 +Cond^ Fan Motor +10%	30	277	5413	6884	2.83	2153	1292	3.2	16,548
4	3 +Evap^ Fan Motor +10%	30	307	5458	6891	2.84	2144	1286	3.4	16,548
5	4 +Cond^ Fan Motor +20%	30	337	5502	6891	2.86	2135	1281	3.6	16,548
6	5 +Evap^ Fan Motor +20%	30	367	5547	6897	2.87	2128	1277	3.8	16,556

* AEC based on annual operating hours of 895.

** OC based on electricity price of 0.6 yuan/kWh.

^ Cond = Condenser; Evap = Evaporator

Figures 1 and 2 show the LCC as a function of EER for the 3500 W and 7100 W air-conditioning heat pump units. Because a limited set of design options were evaluated, the maximum efficiency points are below the new set of standards that are to become effective in China in 2009 (see Table 3). Thus, the LCC analysis does not reveal whether the new set of standards, 3.2 EER for the 3500 W unit and 3.1 EER for the 7100 W unit, are economically feasible. Although the LCC analysis does not analyze the 2009 standard levels, the maximum efficiencies, 3.0 EER for the 3500 W unit and 2.9 EER for the 7100 W unit, do yield LCC savings. Because the maximum efficiencies analyzed are close to the new standard levels, it seems reasonable to expect that the new standard levels would be economically feasible.

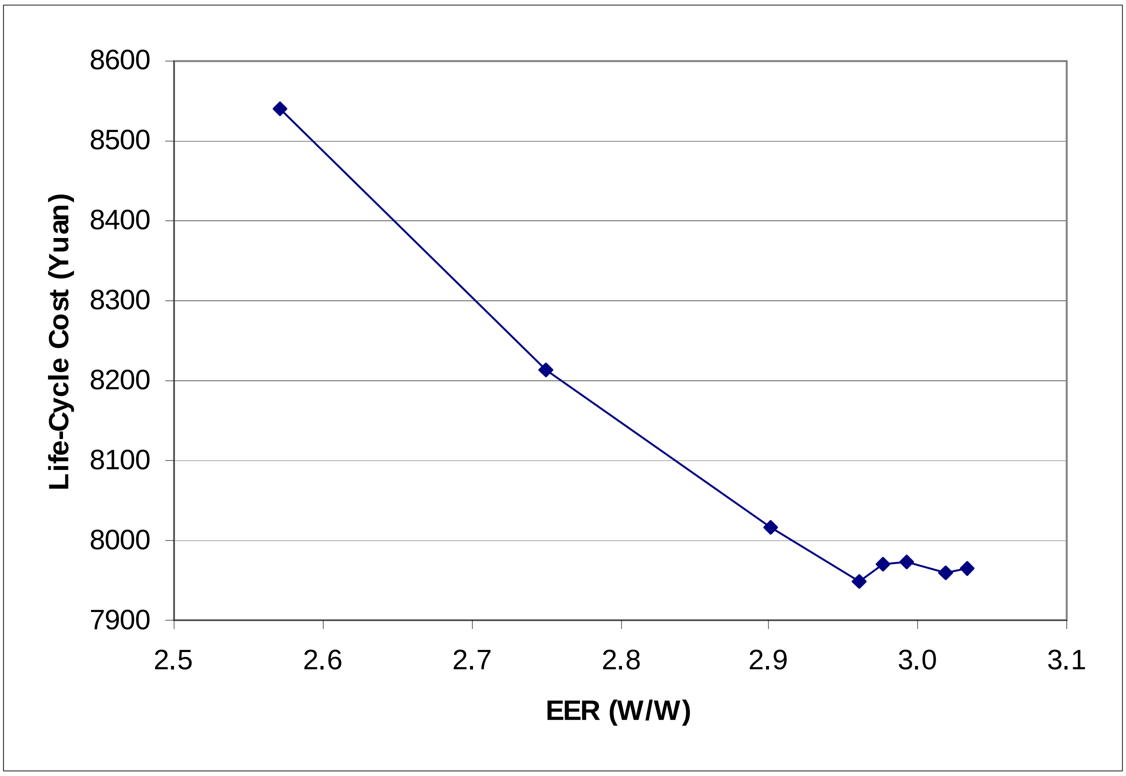

Figure 1. LCC Results for 3500 W Split System Air-Conditioning Heat Pump

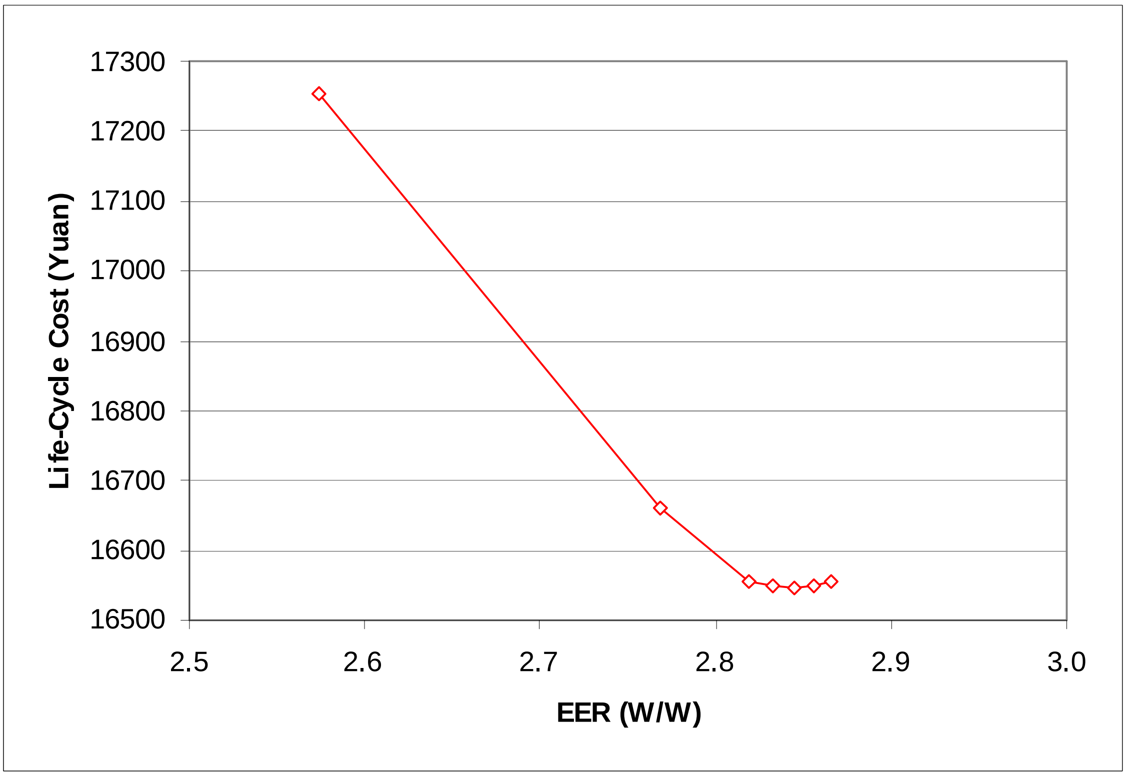

Figure 2. LCC Results for 7100 W Split System Air-Conditioning Unit

Energy Savings from the New Standard

Given that China is one of the largest consumer markets for room air conditioners in the world, the impacts of China's new standards will be very large. According to a recent report (Lin, 2005), the savings are likely to be 10 TWh of electricity and 2.7 million tons of carbon by 2010, 46 TWh of electricity and 12.3 million tons of carbon by 2020 (Table 13). Three quarters of the expected savings by 2020 stem from the more stringent reach standard to go in effect in 2009.

The peak demand reduction calculation depends on an accurate assessment of the coincident peak factor for room air conditioners in China. The reductions are likely to be about 4.5 GW in 2010 and 20.4 GW by 2020. The 2020 peak demand reduction estimate exceeds the 17 GW capacity of the Three Gorges Dam.

Table 13. Expected Energy Savings from the Room Air Conditioner Standard

Year	Stock	Shipments	Energy Savings	CO2 Savings	Carbon Savings	Peak Savings*
	millions	*millions*	*million kWh*	*million tonnes*	*million tonnes*	*GW*
2000	67	17.3				
2001	85	18.3				
2002	106	21.6				
2003	133	28.2				
2004	161	29.6				
2005	189	31.0	714	0.7	0.2	0.3
2006	218	32.6	1,464	1.4	0.4	0.6
2007	248	34.2	2,251	2.2	0.6	1.0
2008	278	35.9	3,077	3.0	0.8	1.4
2009	308	37.7	6,587	6.4	1.8	2.9
2010	337	38.5	10,166	9.9	2.7	4.5
2011	365	39.3	13,817	13.5	3.7	6.1
2012	390	40.0	17,541	17.1	4.7	7.7
2013	414	40.8	21,339	20.9	5.7	9.4
2014	435	41.7	25,188	24.6	6.7	11.1
2015	453	42.5	29,034	28.4	7.7	12.8
2016	469	43.3	32,837	32.1	8.8	14.5
2017	484	44.2	36,573	35.7	9.7	16.1
2018	497	45.1	40,142	39.2	10.7	17.7
2019	510	46.0	43,360	42.4	11.6	19.1
2020	522	46.9	46,113	45.1	12.3	20.4
Cumulative Total:		755	330,201	323	88	-

Conclusion

China's recent efforts to regulate the efficiency of room air conditioners have been shown to yield significant consumer economic savings as well as national benefits of avoided construction of large number of power plants and avoided emissions of GHG and other local pollutants. Relative to air conditioners that meet China's previous set of air conditioner standards, air conditioner designs with efficiencies that are just below the standards that are to become effective in 2009 yield consumer life-cycle cost savings ranging from approximately 550 yuan for 3500 W cooling capacity units to 700 yuan for 7100 W cooling capacity units. The benefits of air conditioner standards are not limited to consumers. Air conditioner standards (both the current standards and the 2009 standards) are projected to yield cumulative national energy savings of over 330 billion kWh. The resulting reduction in national energy consumption is projected to lower power plant carbon emissions by 88 million tonnes.

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