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Mitigating Carbon Emissions: the Potential of Improving Efficiency of Household Appliances in China

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Mitigating Carbon Emissions: the Potential of Improving Efficiency of Household Appliances in China

Executive Summary

China is already the second largest energy consumer and emitter of the greenhouse gases (GHG) in the world after the United States, and its demand for energy is expected to continue to grow rapidly in the foreseeable future, due to its fast economic growth and its low level of energy use per capita. It is widely expected that China is likely to overtake the US in energy consumption and GHG emissions during the first half of the 21st century.

Therefore, there is considerable interest in the international community in searching for options that may help China slow down its growth in energy consumption and GHG emissions through energy efficiency improvement and adopting more environmentally friendly fuel supplies such as renewable energy.

This study examines the energy saving potential of three major residential energy end-uses: household refrigeration, air-conditioning, and water heating. China is already the largest consumer market in the world for household appliances, and increasingly the global production base for consumer appliances. Sales of household refrigerators, room air-conditioners, and water heaters are growing rapidly due to rising income and a booming housing market. At the same time, the energy use of Chinese appliances is relatively inefficient compared to similar products in the developed economies. Therefore, the potential for energy savings through raising the energy efficiency of Chinese appliances is substantial.

This study focuses particularly on the impact of more stringent energy efficiency standards for household appliances, given that such policies are found to be very effective in improving the efficiency of household appliances, and are well established both in China and around the world.

Results of this study show that there is substantial room for energy efficiency improvement in residential energy use in China, and most can be achieved through adopting existing technologies and practices. Raising minimum energy performance standards for the three appliances discussed in this analysis could bring substantial reductions in energy consumption and carbon emissions. The estimated savings in primary energy could reach 1278×10^{15} joules in 2020 and 3070×10^{15} joules in 2030.

In terms of end-use energy savings, annual electricity savings due to efficiency improvement in refrigerators could reach 72.6 TWh in 2020 and 109 TWh in 2030. Such savings represent reduction of 41% and 55% of baseline refrigeration energy use in 2020 and 2030, respectively.

Similarly, annual electricity savings due to efficiency improvement in room air-conditioners could reach 36 TWh in 2020 and 136 TWh in 2030. Again, such savings amount to reductions of 13.5% and 34% of baseline residential air-conditioning energy use in 2020 and 2030, respectively.

Energy savings due to more efficient water heater technologies are large as well. By 2020, such savings could reach 2.4 billion cubic meters per year, and further rise to 10.6 billion cubic meters by 2030. These savings represent reduction of 12% and 42% of the baseline natural gas use in 2020 and 2030, respectively. The steeper rise in savings after 2020 reflects the larger savings due to the introduction of heat-pump water heaters.

In fact, 76% of the savings in 2030 would be attributed to the introduction of heat-pump technology. In other words, the savings due to heat-pump technology is three times as large as those due to conventional gas combustion technologies (Figure E-1).

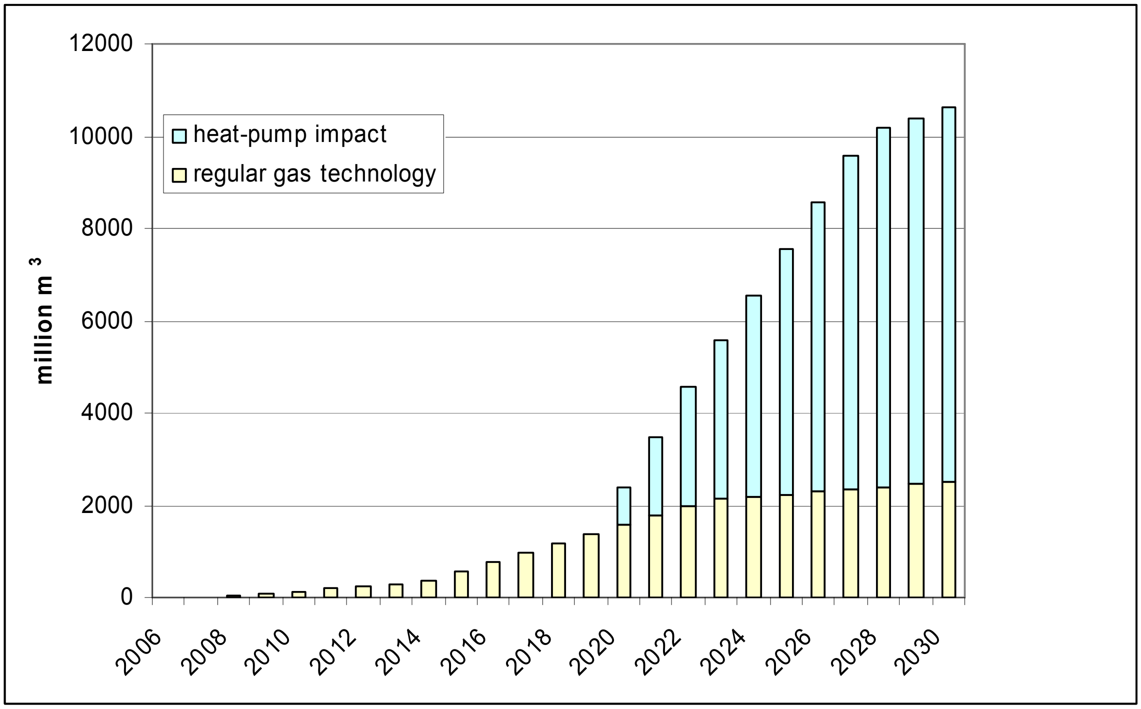


Figure E-1: Natural Gas Savings due to More Efficient Water Heaters.

All together, the potential to reduce carbon emissions through efficiency improvement in refrigerators, room air-conditioners, and gas water heaters are substantial: almost 19 million tons of carbon per year by 2020, and 46 million tons of carbon per year by 2030. In addition to such environmental benefits, the avoided costs associated with the power plants that would not have to be built would be over US $ 60 billion by 2030.

Therefore, it behooves both the Chinese government and interested international parties to promote improvement in appliance energy efficiency in China through the development of more stringent standards for appliances and effective enforcement mechanisms, and the transfer of more efficient technologies for appliances to the Chinese market.

Minimum energy performance standards for appliances have been found to be effective in raising appliance efficiency both in China and worldwide. China has certainly made rapid progress in recent years in establishing a framework of formulating energy efficiency standards and labeling requirements for home appliances and other energy-consuming products. However, government funding for standard development are far below the level that is necessary to meet the need both to expand energy efficiency standards to more product categories and to update existing standards to more stringent requirement.

At present, the technical support organization for standard development in China – China National Institute of Standardization (CNIS) – relies heavily on contributions from manufacturers to support the development process. While manufacturers' participation is healthy for the development of technically sound standards, over-reliance on their support could have negative consequences as well: for example, standard development or update could be delayed; and standard levels might be less stringent than those that may be achieved with full government support. In addition, there is little participation from the environmental advocacy group in the standard setting process to count-balance the influence of the manufacturers, as there are in the more developed countries. Moreover, many standards won't be developed due to insufficient government funding, leaving large potential for energy savings untapped.

There are also certain technical challenges in raising standard levels much higher than the current level, since domestic manufacturers may not have the state-of-the-art technology. This is illustrated in the case of room air-conditioners: the 2005 Chinese standard is much lower than corresponding requirements in Japan and Korea. Transfers of more efficient technologies to the Chinese market could greatly help raising the energy efficiency of household appliances in China. Given that China is a leading exporter of many appliance products, efficiency gains in China could have large spillover effect globally as well.

Further, to truly capture the full potential of appliance standards and labeling programs, there needs to be vigorous enforcement. Implementation and enforcement of standards have always been a serious concern in China, in part due to insufficient government funding and in part due to more fragmented appliance market: there are many more manufacturers and retail outlets to monitor. In addition, there is little precedence to follow in terms of enforcement actions given the nascent nature of the appliance standards program in China. Introduction of international best practices in enforcement and monitoring of standard compliances could help China build a more effective mechanism to sustain the momentum of efficiency improvement in the market place.

Mitigating Carbon Emissions: the Potential of Improving Efficiency of Household Appliances in China

Introduction

China is already the second's largest energy consumer in the world after the United States, and its demand for energy is expected to continue to grow rapidly in the foreseeable future, due to its fast economic growth and its low level of energy use per capita. From 2001 to 2005, the growth rate of energy consumption in China has exceeded the growth rate of its economy (NBS, 2006), raising serious concerns about the consequences of such energy use on local environment and global climate. It is widely expected that China is likely to overtake the US in energy consumption and greenhouse gas (GHG) emissions during the first half of the 21st century.

Therefore, there is considerable interest in the international community in searching for options that may help China slow down its growth in energy consumption and GHG emissions through improving energy efficiency and adopting more environmentally friendly fuel supplies such as renewable energy.

This study examines the energy saving potential of three major residential energy end uses: household refrigeration, air-conditioning, and water heating. China is already the largest consumer market in the world for household appliances, and increasingly the global production base for consumer appliances. Sales of household refrigerators, room air-conditioners, and water heaters are growing rapidly due to rising incomes and booming housing market. At the same time, the energy use of Chinese appliances is relatively inefficient compared to similar products in the developed economies.

Therefore, the potential for energy savings through improving appliance efficiency is substantial.

This study focuses particularly on the impact of more stringent energy efficiency standards for household appliances, given that such policies are found to be very effective in improving the efficiency of household appliances, and are well established both in China and around world (CLASP, 2006).

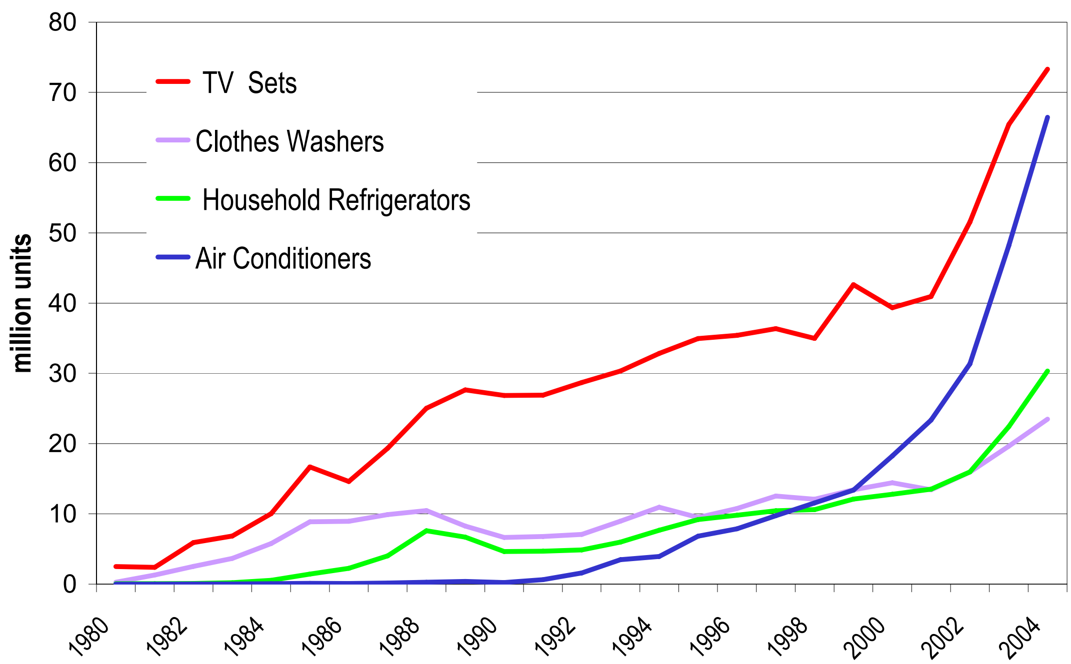
Appliance Market in China

Over the last 25 years, the growth of the Chinese economy has generated strong demand for increased comfort and convenience, creating a booming market for household appliances. While such demands were first met by imported products in the early 1980s, the domestic appliance manufacturers have responded quickly, establishing their own brand names through more affordable prices and comprehensive after-sale services. Such a combination led to booming sales, and by the end of 1990s China became one of the largest appliance markets in the world. In their home court, Chinese appliance makers now have a commanding advantage.

In 1980, there was little home appliance manufacturing in China: the total output of household refrigerators in that year was less than 50,000 units. By 2004, China's output of color televisions, room air-conditioners, refrigerators, and clothes washers had each reached 73.3 million, 66.5 million, 30.3 million, and 23.5 million units, respectively (NBS 2005). This phenomenal growth is driven first by huge domestic demand and then by rising exports. In fact, China has become not only the largest appliance producer in the world but also the leading hub of production for many multinational firms. In 2004, exports of appliances from China were valued at US$17.2 billion, a 37% increase over 2003 (Appliance, 2005).

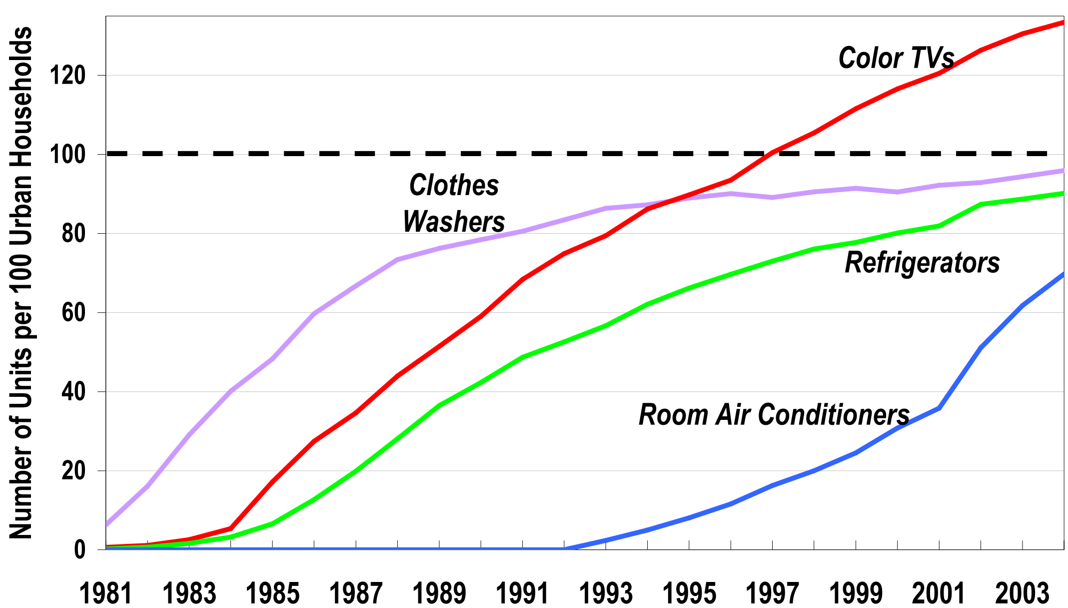
Appliance ownership has risen rapidly as well, particularly in urban China. In early 1980s, it was rare to find major electric appliance in any Chinese households. By 2004, penetration of color TVs had reached 133 units per 100 urban Chinese household (i.e., homes having on average more than one television set). Penetration levels have reached to 96% for clothes washers, 90% for refrigerators, and 70% for room air-conditioners, respectively, for urban households (NBS, 2005).

Figure 1: Appliance Production in China, 1980-2004



Increasingly, electric appliances have also become a part of rural life as well, as income level and access to electricity have improved. In 2004, three quarters of rural Chinese households owned a color television, and close to 40% a washing machine.

Figure 2: Appliance Ownership in Urban China



Such a rapid rise in appliance ownership has contributed significantly to the growth of China's electricity use. Electricity consumption in China grew from 300 TWh in 1980 to 2187 TWh in 2004, with an average annual growth rate of over 8 percent. In the same time span, residential electricity use grew twice as fast, averaging 15 percent growth per year. The rapid rise in air-conditioner ownership poses a particular challenge to China's over-stretched electricity system. In Shanghai, air-conditioning load accounts for 40% of peak load during the summer[1]. In fact, the electricity needed to support the annual addition of millions of air-conditioners will quickly overtake the total capacity of Three Gorges Dam. While booming industries have often been blamed for China's current electric shortage, the growth of consumer appliances played an important role as well.

China's Energy Efficiency Standards and Label Programs for Household Appliances

To counter such rapidly rising demand for electricity, China has introduced a host of energy efficiency programs for household appliances since the late 1980s, including minimum energy efficiency standards (MEPS), energy conservation product label, and energy efficiency information label.

In 1989, the former State Bureau of Technical Supervision (SBTS) issued the first set of standards related to energy efficiency. They included minimum energy efficiency standards for 8 types of products: refrigerators, room air conditioners, clothes washers, television sets, automatic rice cookers, radio receivers, electric fans, and electric irons. Since then, China has significantly expanded its standards program, both covering more product categories and raising the stringency of the performance levels. At present, the Administration of Quality Supervision, Inspection, and Quarantine (AQSIQ) has succeeded SBTS as the standard setting agency in China, with the China National Institute of Standardization (CNIS) providing much of the technical analyses in the development of the standards.

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[1] "Shanghai in battle against power shortfall," Shanghai Daily, May 9, 2005, http://www.china.org.cn/english/government/128107.htm

The products regulated under the standards program now include almost 20 types of consumer, lighting, and industrial products. In 2004, China even enacted its first fuel efficiency standards for automobiles. The stringency of the standards has also been raised: for example, the standard for room air-conditioners has been raised in 2005 from a coefficient of performance (COP) of 2.2 to 2.6 in the most popular category (4500 watt and below); a further rise is due in 2009 as well.

Figure 3: Summary of China's Minimum Efficiency Standards

	1989	1990	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Domestic refrigerators/freezers		◆				◆				◆			
Room air conditioners		◆					◆					◆	
Clothes washers		◆								◆			
Electric irons		◆											
Automatic rice cookers		◆											
Televisions		◆											◆
Radio receivers and recorders		◆											
Electric fans		◆											
Fluorescent lamp ballasts							◆					○	
Small electric motors								◆					
Compact Fluorescent lamps										◆			
Linear Fluorescent lamps										◆			
Instantaneous Gas Water Heaters												○	
External power supplies												○	
Commercial packaged AC												◆	

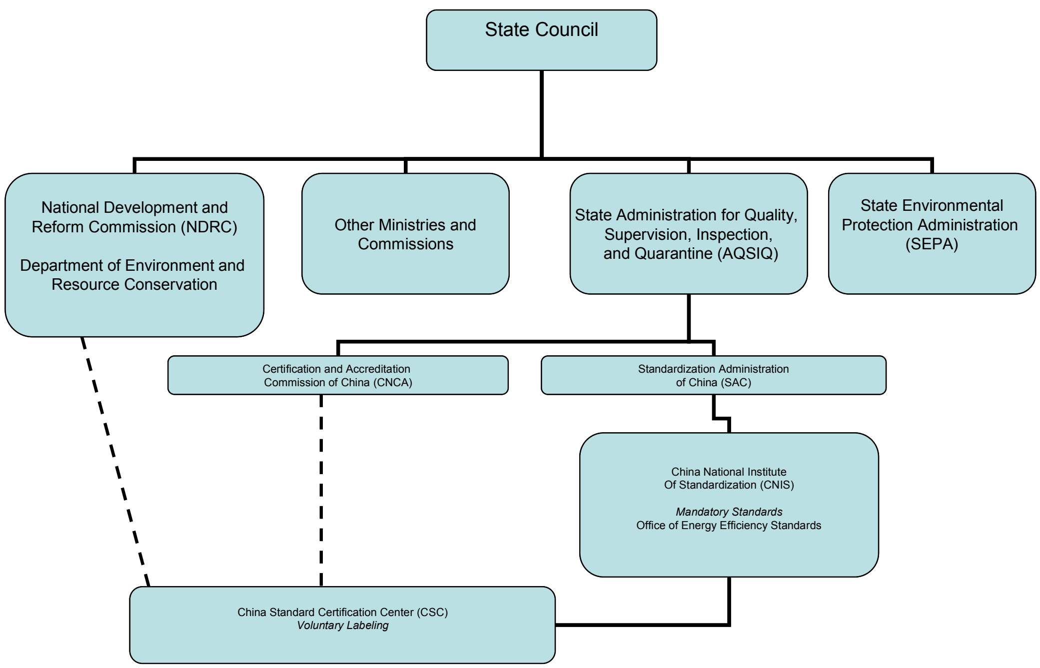
◆ Implemented
○ Revision or development

In March 2005, China has also launched a categorical energy information label aimed at assisting consumers with their purchasing decisions. The label classifies appliances into five efficiency categories, with level one being the most efficient, and level five set at the minimum efficiency standard requirement. At the moment, the information label is only applied to refrigerators and room air-conditioners, and is likely to be extended to other appliances in the future.

Rounding out the programs is China's energy conservation products certification program run by China Standard Certification Center (CSC). In contrast to the previous two programs, the CSC certification program is voluntary: an endorsement label is granted to products that are certified to meet both quality assurance and energy performance specifications. Products under this certification program now include 41 types of consumer appliances, lightings products, and office equipment, as well as selected industrial equipment.

Standard Setting Process and Institutions

China's National Development and Reform Commission (NDRC) is responsible for the overall management of China's economic policies. NDRC's Department of Resource Conservation and Comprehensive Utilization is charged with setting national energy conservation policies and implementing China's Energy Conservation Law (ECL), and has been responsible for supervising the development of energy efficiency standards and labels in China.



China's State General Administration of Quality Supervision, Inspection, and Quarantine (AQSIQ) is the government agency authorized to issue all standards except for those related to environmental safety and selected petroleum products. Minimum energy efficiency standards (MEPS) are only a small part of AQSIQ's total project portfolio.

China National Institute of Standardization (CNIS) is a research institution under the supervision of AQSIQ. CNIS provides technical support to AQSIQ in the development of mandatory minimum energy efficiency standards including data collection and analysis. CNIS is also responsible for the development and management of China's energy information labeling program under the supervision of NDRC and AQSIQ.

China National Technical Committee for Energy Basics and Management Standards is a technical committee under CNIS that is responsible for the coordination of technical research and the review of standards. The committee is comprised of researchers, academics, and policy-makers, as well as representatives from manufacturing companies.

China Standard Certification Center (CSC) is an independent certification agency that was established in 1998 to administer a voluntary endorsement energy labeling program. While CSC operates with a certain degree of autonomy, it still follows policy guidance from the National Development and Reform Commission (NDRC) and China National Certification and Accreditation Commission (CNCA), and is affiliated administratively with CNIS.

Despite the multiple program components -- including MEPS, information, and endorsement labels -- the management of China's appliance standards and labeling programs remains fairly centralized: NDRC and AQSIQ set the national agenda while CNIS and CSC develop and implement relevant program components.

Analytic Model

The basic analytical model for this analysis is an appliance stock vintage model which tracks appliance sales and retirement, as expressed below,

$$Stock = \Sigma(Sales - Retirement)$$

The stock of appliance is built through tracking of annual sales, both historical and future projections. The composition of stock by vintage allows modeling of efficiency changes over time, such as specified by successive efficiency standards.

Total energy consumption (TEC) is thus arrived as follows,

$$Total\ Energy\ Consumption = \Sigma Stock(i) * UEC(i)$$

where UEC is the unit energy consumption of specific appliance. Product UEC is determined by a combination of efficiency and usage levels that reflect both current practices and standards.

Then the impact of rising efficiency level can be determined as follows,

$$Energy\ Saving = TEC\ (baseline\ efficiency) - TEC\ (target\ efficiency)$$

While baseline efficiency is determined through examination of current practices, the target efficiency is based on the review of world best practices and the assumed timeline of their adoption in China.

GHG emission factors are estimated based on the current mix of fuel in China's power generation. Coal will continue to dominate China's electric generation, followed by hydro electric stations. In the future, natural gas, nuclear, and wind generation will see rapid growth; however, their shares in overall generation will remain small.

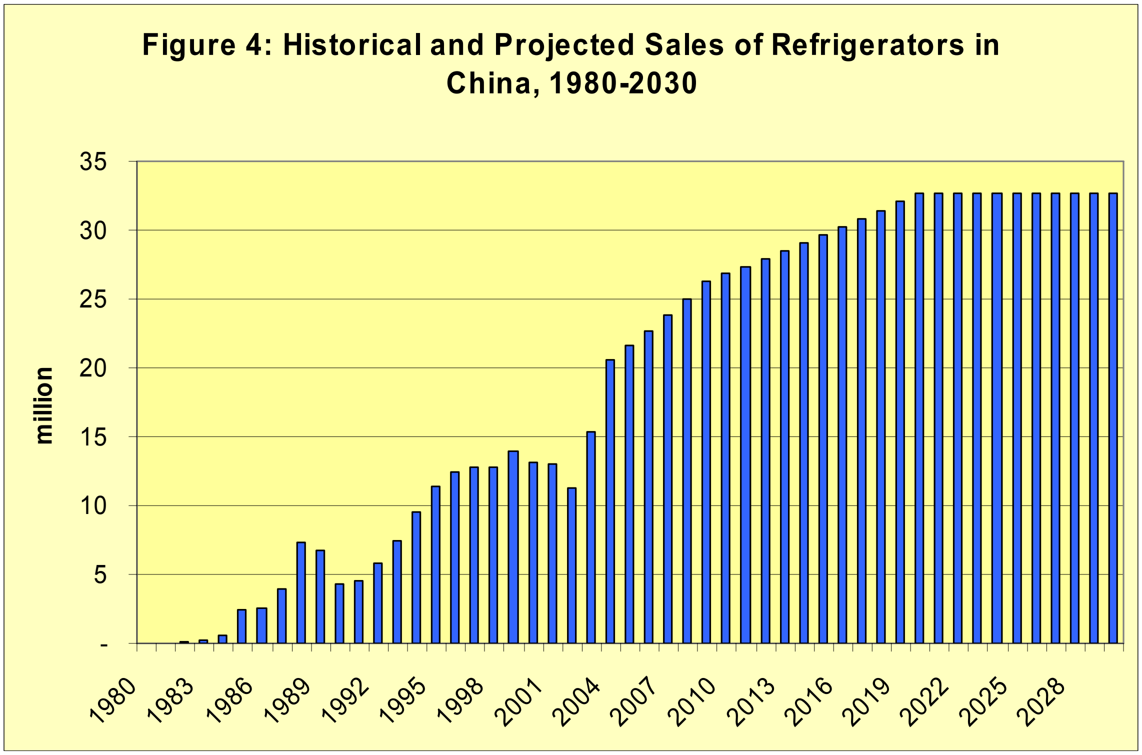
Product Specific Analyses

Due to different market and usage characteristics of refrigerators, room air-conditioners, and water heaters in China, we will analyze the potential for energy efficiency improvement for each product separately.

Refrigerators

Figure 4 presents both historical and projected sales of refrigerators in China. Data up to 2004 are from various Chinese sources that document the production, export, and import volumes of household refrigerators and freezers[2]. Therefore, the figures represent "apparent consumptions," which excludes consideration of stock changes. The latest figures from 2004 show that China produced 28 million units of refrigerators and 6.2 million unit of freezers, while the export volumes are 11 million for refrigerators and 2.5 million for freezers, and little was imported (Appliance Magazine, 2005). Therefore, the domestic sales of the refrigerators and freezers are about 20.6 million units.

[2] Various China Statistical Yearbook, and Appliance Magazine.



Sales from 2005 to 2030 are projected with an annual growth rate of 5% from 2004 to 2010, and an annual growth rate of 2% from 2010 to 2020, and zero growth from 2020 to 2030.[3] Future sales are projected to stabilize around 33 million from 2020 onward. It is expected that future growth in refrigerator sales comes from increasing ownership in rural areas and urbanization.

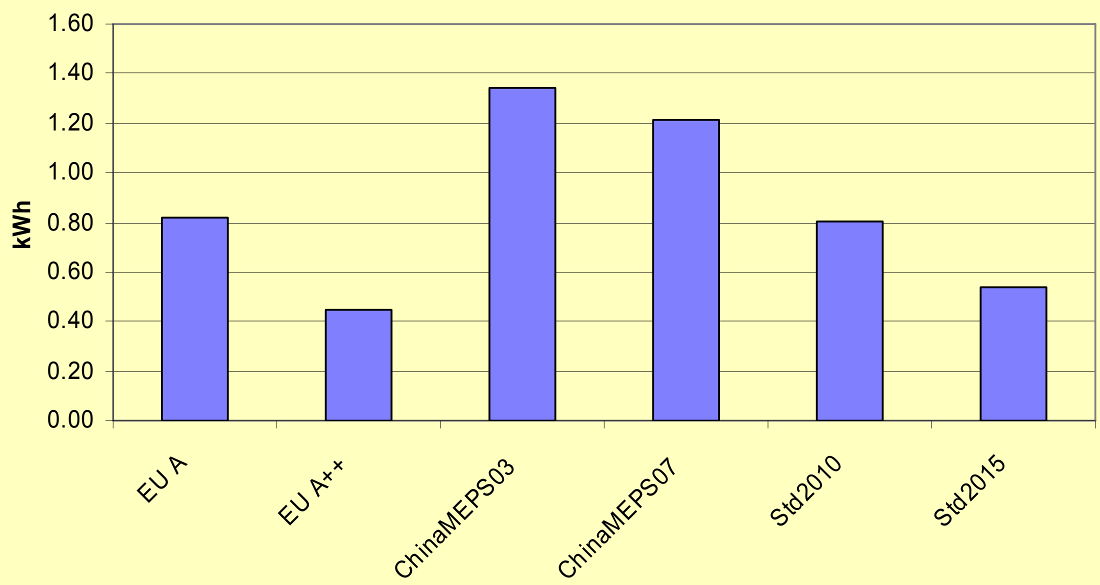
Refrigerators historically have been among the first consumer products subject to minimum energy performance standard. Since 1989, the minimum energy performance standard for household refrigerators and freezers has been updated twice. The current standard has been in force since 2003, and another more stringent level will become effective in 2007.

Figure 5 presents the maximum daily consumption value prescribed in the Chinese standards as well as in the European labeling scheme for refrigerators with a

[3] Growth rates are taken from a CNIS 2003.

total volume of 220 liters. This is the most popular class of refrigerators in China today. The common size for refrigerators in US is about 550 liters, and those for Europe and Japan are between 300 and 400 liters. Since China and EU both use the IEC (International Electrotechnical Commission) test protocol for refrigerators, the EU label value is presented here as a comparison. Finally, two potential standard levels are presented here to represent the target efficiency level for Chinese refrigerators in the future.

Figure 5: Daily Energy Use Comparison (220liter refrigerators)



It can be seen from this comparison that despite recent progress, energy use in typical Chinese refrigerators is still significantly higher than those in more advanced economies. Even the 2007 Chinese standard still lags behind by a large margin. Therefore, further raising the stringency of the Chinese standard could potentially have a large energy saving impact. To assess such impacts, two additional standard levels are proposed here: the first one would go into effect in 2010 and is 40% more efficient than the 2003 standard (or slightly better than the EU A level requirement), and the second would go into effect in 2015 and is 60% more efficient than the 2003 standard (or just about the EU A++ label requirement).

It should be noted that these levels are used here to represent the current world best practices, not the lowest energy use possible. As refrigeration technology continues to advance, it is expected that lower energy use can be achieved as well.

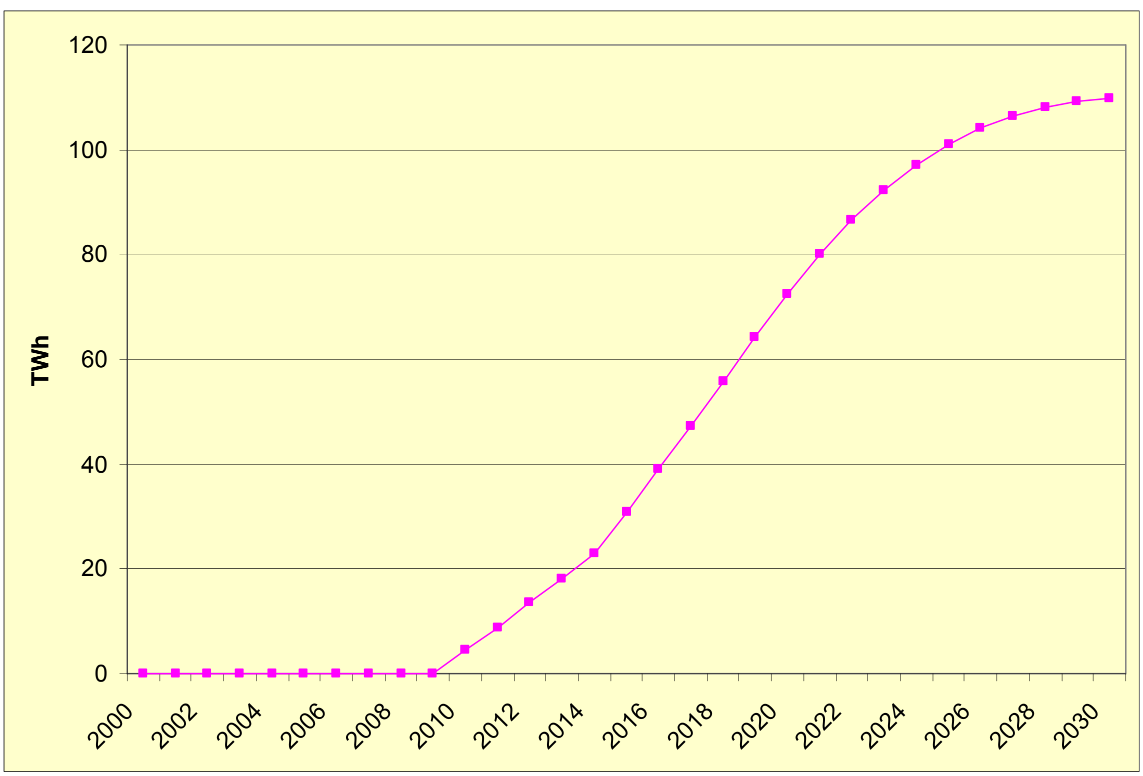


Figure 6: Annual Electric Savings due to Tighter Refrigerator Standards in China

Figure 6 shows that further raising the MEPS for refrigerators in China could have a substantial impact on energy use. Assuming more stringent standards becoming effective at 2010, the electricity savings could reach 72 TWh by 2020, a reduction of 41% off the baseline which assumes no further efficiency improvement after 2007. Similarly, annual electricity savings would reach 110 TWh per year by 2030, a reduction of 55% off baseline usage. In addition, such savings would also avoid or delay construction of new power plants: 8.3 GW in 2020, and 12.5 GW in 2030. With capital cost of building power plants and associated transmission and distribution estimated to be about US $1000/kW, avoiding the construction of such generating capacity would lead to a cost saving of US $ 12.5 billion by 2030.

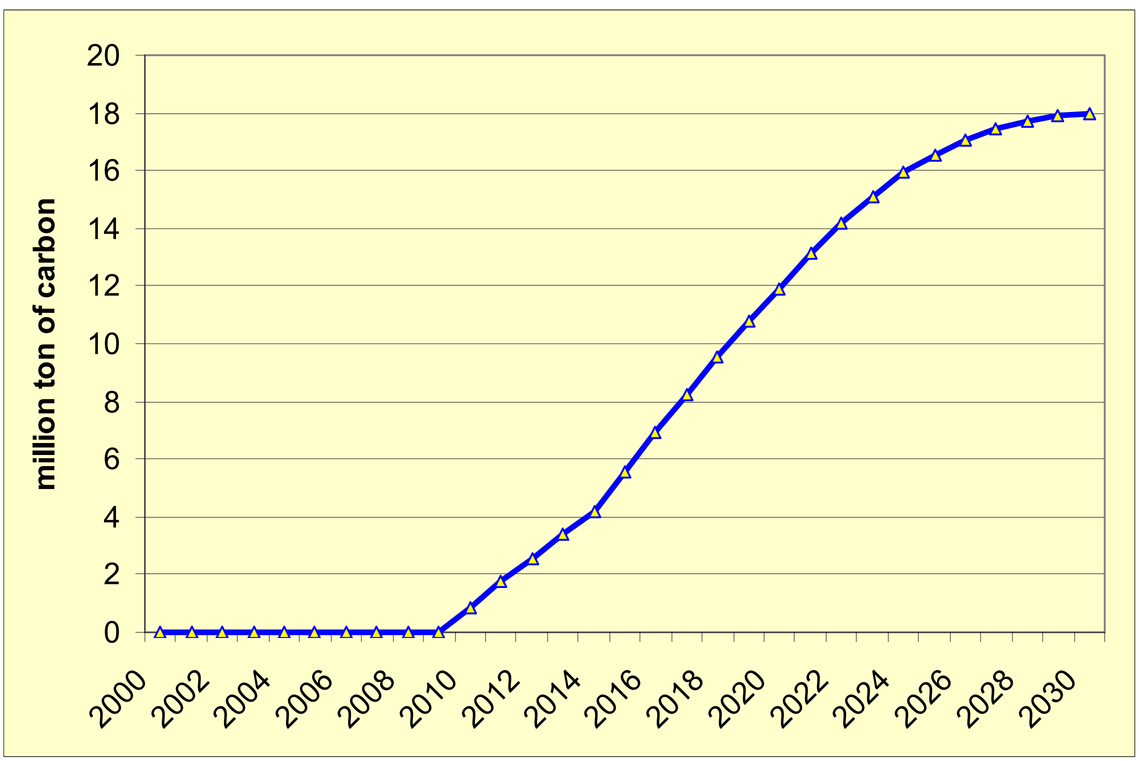


Figure 7: Avoided Carbon Emissions due to Tighter Refrigerator Standards in China

Given that coal continues to dominant China's power generation[4], the expected reduction of carbon emissions is substantial as well. By 2020, such avoided emissions could reach roughly 12 million tons of carbon per year, and by 2030, to 18 million tons of carbon per year.

Room Air-Conditioners

Although room air-conditioners were introduced to the Chinese market only in the 1990s, it has experienced explosive growth due to rising income in recent years. Figure 8 presents sales volumes from 1990 to 2030. Data up to 2004 are from various Chinese sources documenting production, export and import. Import has been minimal in recent years due to availability of domestic brands and foreign makers shifting their production base to China. The latest figures from the China Household Electrical Appliance Association show that China produced roughly 56.9 million units of room air-conditioners in 2004, while exporting 23.3 million to other regions. Thus apparent consumption was about 33.6 million in 2004.

[4] Emission factor is first estimated based on 2003 generation mix. Future factors are adjusted for expected improvement in generation efficiency and higher shares of non-fossil fuel in the generation mix. Detailed assumptions are provided in the Appendix.

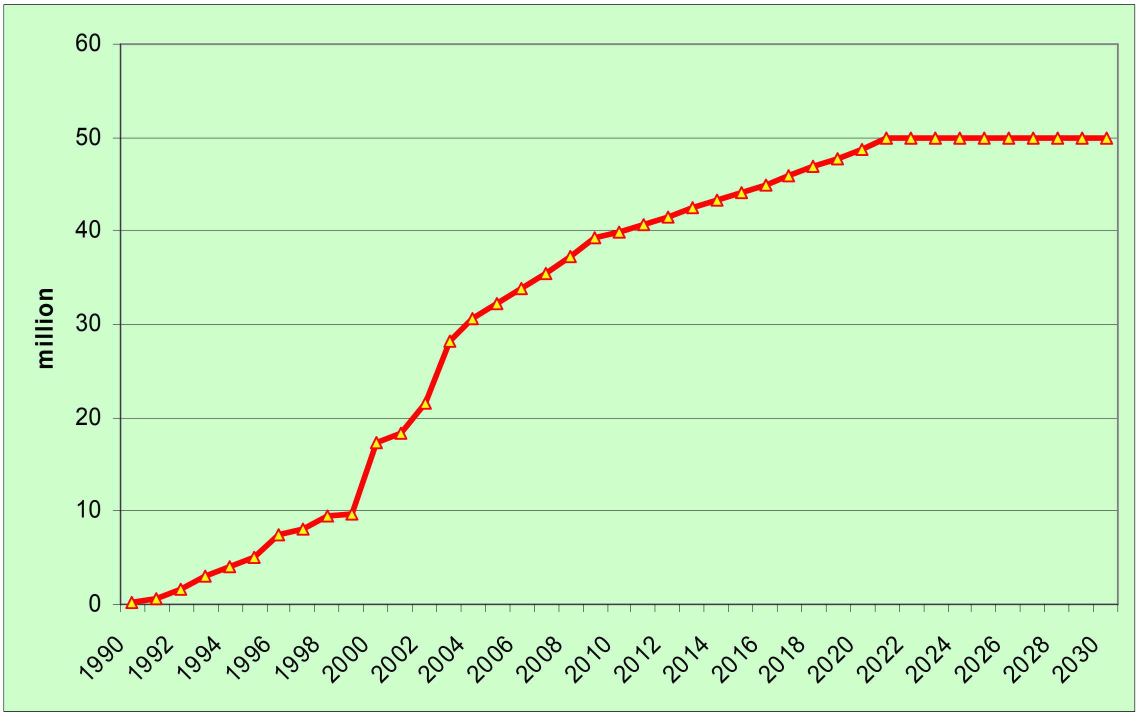


Figure 8: Sales of Room Air-Conditioners in China, 1990-2030

Future sales are projected based on an annual growth rate of 5% from 2004 to 2010, an annual growth rate of 2% from 2010 to 2020, and zero growth thereafter[5]. Projected sales would reach 40 million in 2010, and 50 million from 2021-2030.

A minimum energy performance standard for room air-conditioners was first introduced in 1989, and it has since been updated twice. The current standard went into effect on March 1, 2005, and a second more stringent level is scheduled for 2009.

The requirement for China's 2005 standard for room air-conditioners are summarized in table 1 below. Energy Efficiency Ratio (EER) is defined as the ratio of the rated cooling capacity (watt) over the rated input power (watt) of air-conditioners.

Table 1: Requirements of Energy Efficiency Ratios (EER), 2005

[5] Growth rates assumptions are taken from CNIS 2003.

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

The requirement for China's 2009 standard for room air-conditioners are summarized in table 2 below.

Table 2: Requirement for Energy Efficiency Ratios (EER) in 2009

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

It should be noted that the most popular residential air-conditioner in China is a split type unit with a cooling capacity between 2500-4500 watts. The current requirement is an EER of 2.6, and by 2009, the minimum EER will be raised to 3.2.

The 2009 requirement would put the efficiency of Chinese air-conditioners in the same league with those of US and Korea, but it still lags significantly behind those found in Japan. Therefore, further raising the standard for Chinese air-conditioners could save a large amount of energy.

Table 3: Efficiency Requirement (EER) of Japan's Top Runner Program for Room Air-Conditioners

window		*Heat pump*	*AC-only*
		2.85	2.67
split		*Heat pump*	*AC-only*
	CC<2500W	5.27	3.64
	2500-3200W	4.90	3.64
	3200-4000W	3.65	3.08
	4000-7100W	3.17	2.91
	>7100W	3.10	2.81

Table 4: Efficiency Requirement of South Korea's Standard for Room Air-Conditioners

window	**EER**	2.88
split	CC<4000W	3.37
	4000-10,000W	2.97
	10,000-17,500	2.76

Table 5: Labeling Requirement for Room Air-Conditioners in the European Union (EER)

	G	F	E	D	C	B	A
window	<2	2	2.2	2.4	2.6	2.8	>3
split	<2.2	2.2	2.4	2.6	2.8	3	>3.2

In this analysis, it is assumed that EER for Chinese air-conditioners would be raised to 4.0 in 2015, and again to 5.0 in 2020. Accordingly, the energy use of average Chinese air-conditioners would decline, other things being equal. However, the decline is offset by longer hours of usage due to rising demand for comfort in Chinese households. In this analysis, the hours of usage is assumed to rise from the current average of 300 hours per year, to 400 hours in 2010, 500 hours in 2015, and 600 hours in 2020.

The annual energy consumption of an air-conditioner can be expressed as follows

$$UEC(ac) = Hours * CC / COP$$

where UEC(ac) is the unit energy consumption of air-conditioners per year, Hours is the annual hours of usage, CC is the cooling capacity, and COP is the coefficient of power.

Figure 9 shows that these improvements in energy efficiency could effect large electricity savings. For example, electricity savings could reach 36.6 TWh by 2020, a reduction of 13.5% off the baseline usage, which assumes no further efficiency improvement after 2009. Further, annual electric savings would rise to 136 TWh by 2030, which represents a reduction of 34% off the baseline usage.

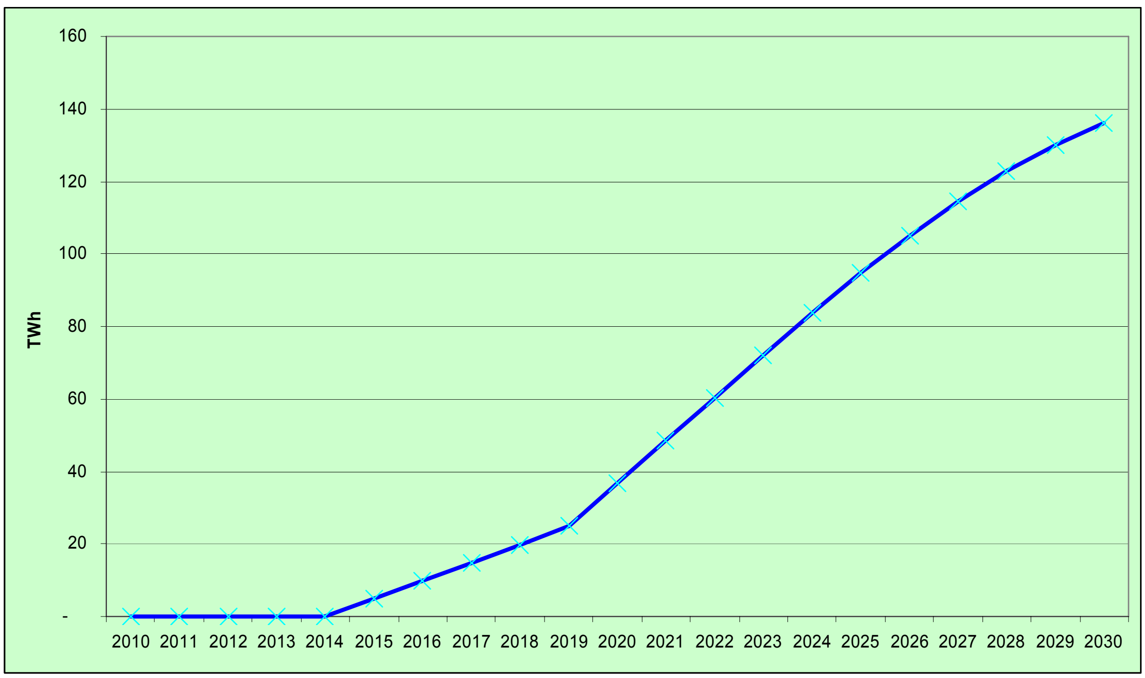


Figure 9: Electricity Savings due to Higher Standards for RAC in China

Consequently, the avoided carbon emissions associated with such electricity savings could reach 6 million tons of carbon per year by 2020, and 22 million tons per year of carbon by 2030.

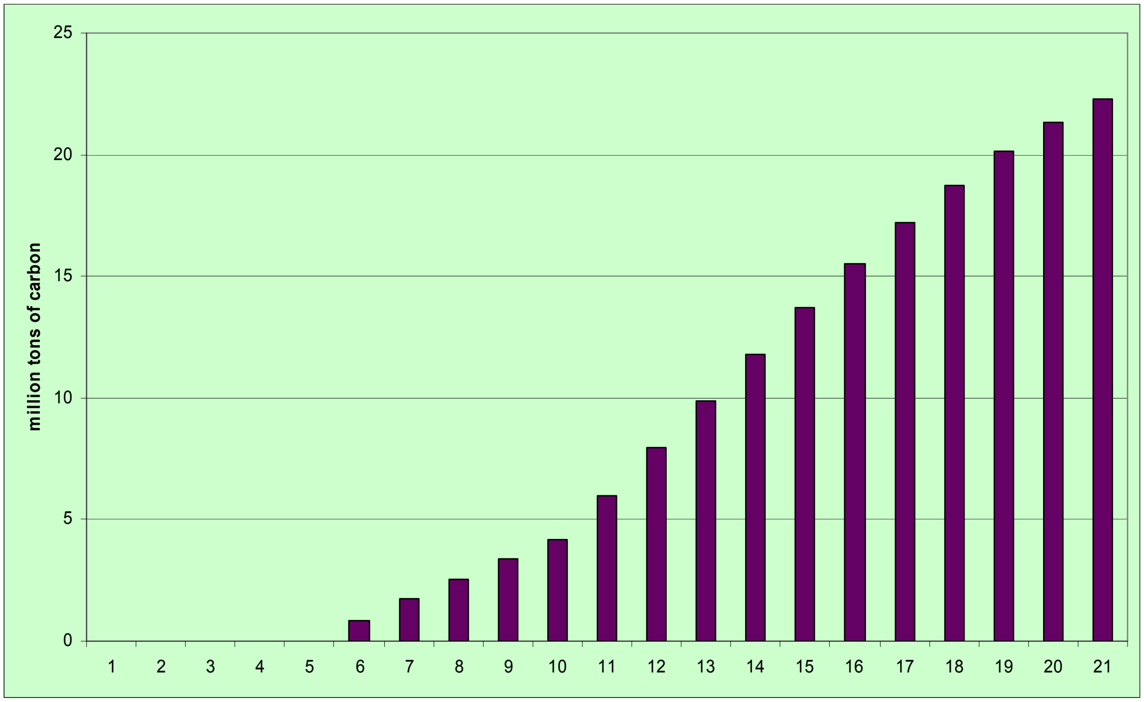


Figure **10: Avoided Carbon Emissions due to Higher Standards for RAC in China**

In addition to the large avoided carbon emissions and other pollutions, the reduced air-conditioner electricity use could also have a large peak saving impact as well. By 2030, such effect could reach 48 GW, or equivalent to avoiding the construction of 48 large power plants, at a cost saving of US $48 billion.[6]

Gas Water Heaters

There are three types of domestic water heaters in China: gas water heaters, electric water heaters, and solar water heaters. The most popular type is the gas water heaters (57.4%), followed by electric water heaters (31.3%), and solar water heaters (11.3%).[7] Among gas water heaters, the instantaneous type is dominant type with 94%

[6] This estimate is based on a capital cost of US $1000/kW for generation, and associated transmission and distribution in present value.
[7] CNIS unpublished report, 2006.

of market share. Therefore, we focus on the energy saving potential of instantaneous gas water heaters in this analysis.

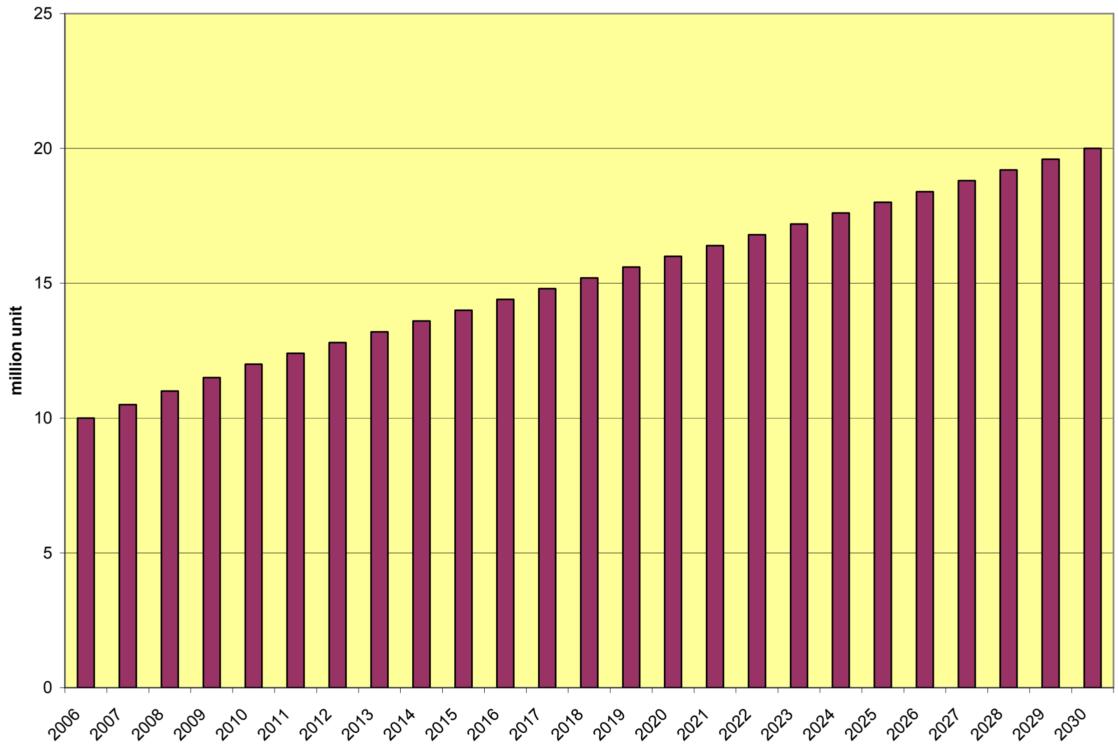


Figure 11: Gas Water-Heater Sales Projection in China, 2006-2030

According to a recent CNIS report, the current stock of gas water heaters is estimated to be around 62 million units. Future sales are estimated to be 10 million units in 2006, and would rise by 2 million unit every five years until 2020 (Fu, 2005). Using the same increment, total sales of gas water heaters is projected to reach 20 million by 2030.

Testing at the National Test Laboratory for Gas Appliances in Tianjin indicates that the average efficiency of gas water heaters is about 86.9%[8]. To assess the impact of raising energy efficiency of water heaters through standards, we assume that the

[8]燃气快速热水器能效测试结果报告(Testing report on the energy efficiency of instantaneous gas water heaters, National Quality Supervision and Testing Center for Gas Appliances, 2005)

minimum standards for gas water heaters to be raised to 88% by 2008 and 96% by 2015. Current baseline usage is estimated to be 182 m^3 of natural gas per unit in north China and 146 m^3 natural gas per unit in south China, with an average usage of 161 m^3 per water heater per year.[9] These numbers may be small in comparison to energy use for hot water in developed countries, since Chinese households use hot water heaters mostly for taking showers. Hot water for drinking is either heated on a stove (coal or gas) or by electric thermos.

Table 6: Annual Energy Usage of Gas Water Heaters in China

	Average Efficiency	UEC (m3/year)
Baseline	86.4%	161
MEPS at 88%	88.7%	157
MEPS at 96%	96.0%	145

Recently, more efficient water heaters based on heat-pump technologies have been introduced in Japan. According to data provided by the Tokyo Electric Company, the coefficients of performance (COP) for such water heaters are about 4.5. Currently, the prices for these water heaters are quite high: market price is about 500,000 yen, with an installation cost of 200,000 yen. Thus, total cost of purchase is about US $6,000[10]. This is much higher than the typical cost of gas water heaters in China, which is about US $100 on average.

Of course, the new Japanese heat-pump water heaters are much larger than the typical Chinese gas water heaters: for example, the two models listed in the Panasonic catalogue have tank capacity of 370 and 460 liters[11], while the typical gas water heaters in China have a capacity of 8 to 10 liters. Functionalities differ as well: the Japanese

[9] Fu Z., 2005, research note on gas water heaters.
[10] US $1 = 118 Japanese yen
[11] See http://www.mew.co.jp/sumai/catalog/pagepdf/ZBCT1B61M-26.pdf

heat-pump water heaters serve the entire domestic hot water loads (kitchens, showers, and bathtubs), and even some space heating load (floor heating, for example), while the Chinese gas water heaters only serve hot water loads for kitchens and showers, at the moment at least.

Therefore, at present, the Japanese heat-pump based water heaters are unlikely to be a replacement candidate for the Chinese home market, due to different sizes and functionalities, and price premiums. However, the situation may change in the future, since it is expected that the price for heat-pump based water heaters will decline as the technology is further refined and the scale of production increases. Moreover, as Chinese households become more affluent and acquires larger dwellings, their need for hot waters is likely to increase as well, thus demanding larger water heaters with a fuller array of functionalities.

Perhaps, the most promising market for the heat-pump water heaters is in the small commercial market, such as in restaurants and small hotels, where demand for hot-water is much greater. This market is currently served by coal or gas boilers.

Table 7: Efficiency comparison between gas and heat-pump water heaters (WH)

	Gas WH	Heat-Pump WH
Capacity (liters)	10	370
site efficiency (COP)	0.86	4.55
conversion efficiency		33%
primary energy efficiency	86%	150%

It goes beyond the scope of this analysis to speculate on what water heaters would look like in China in the future. We will focus instead on the efficiency gains due to the introduction of heat-pump waters heaters over conventional gas water heaters. Data presented in table 7 indicates that heat-pump based water heaters have much higher efficiency than conventional gas water heaters, even after taking into consideration of thermal conversion efficiency for power generation. Therefore, introduction of heat-pump water heaters would lead to large energy savings. For the purpose of evaluating the effect of such a technology, we assume that the efficiency requirement would further rise to 150% starting in 2020.

Figure 12 shows that raising MEPS level for gas water heaters could lead to large saving in natural gas consumption in China. By 2020, such savings would reach 2.4 billion cubic meters per year, and further rise to 10.6 billion cubic meters by 2030, a reduction of 42% off baseline usage. The steeper rise in savings after 2020 reflects the larger savings due to the introduction of heat-pump water heaters. In fact, 76% of the savings in 2030 would be attributed to the introduction of heat-pump technology. In other words, the savings due to heat-pump technology is three times as large as those due to conventional gas combustion technologies.

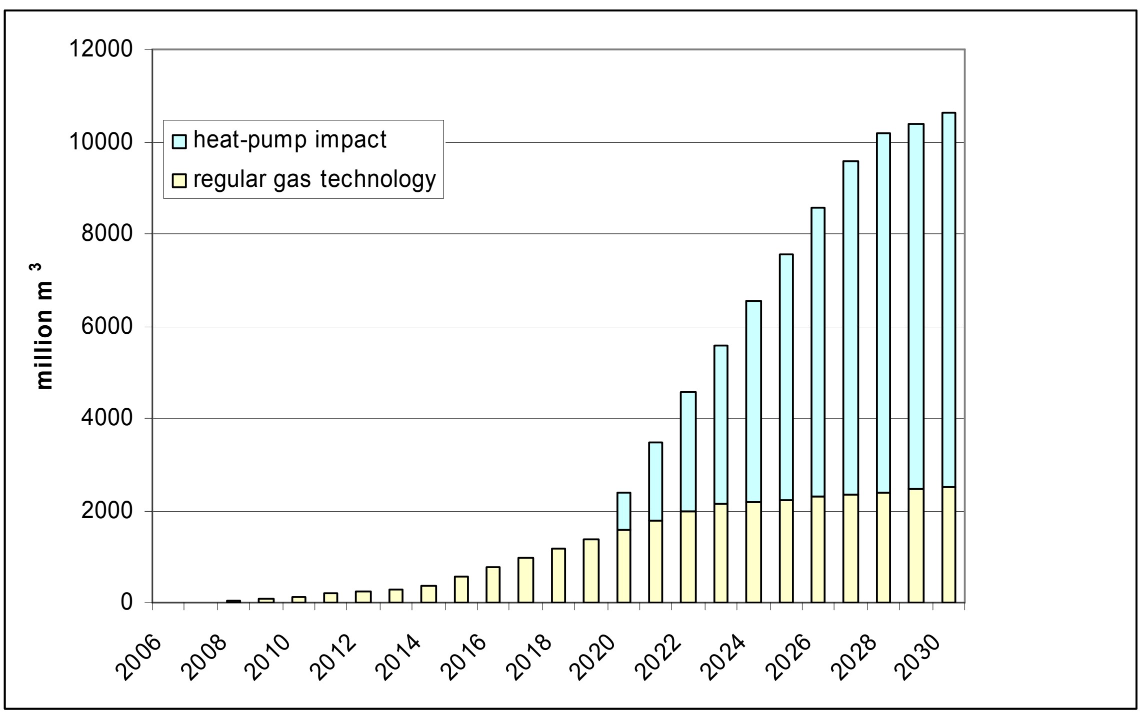


Figure 12: Natural Gas Savings Due to Gas Water Heater Standards in China

The corresponding reduction in carbon emissions is presented in figure 13. Largely due to low carbon intensity of natural gas, the avoided carbon emissions from higher efficiency in water heaters would be about 1.34 million tons of carbon in 2020 and 5.94 million tons of carbon by 2030.

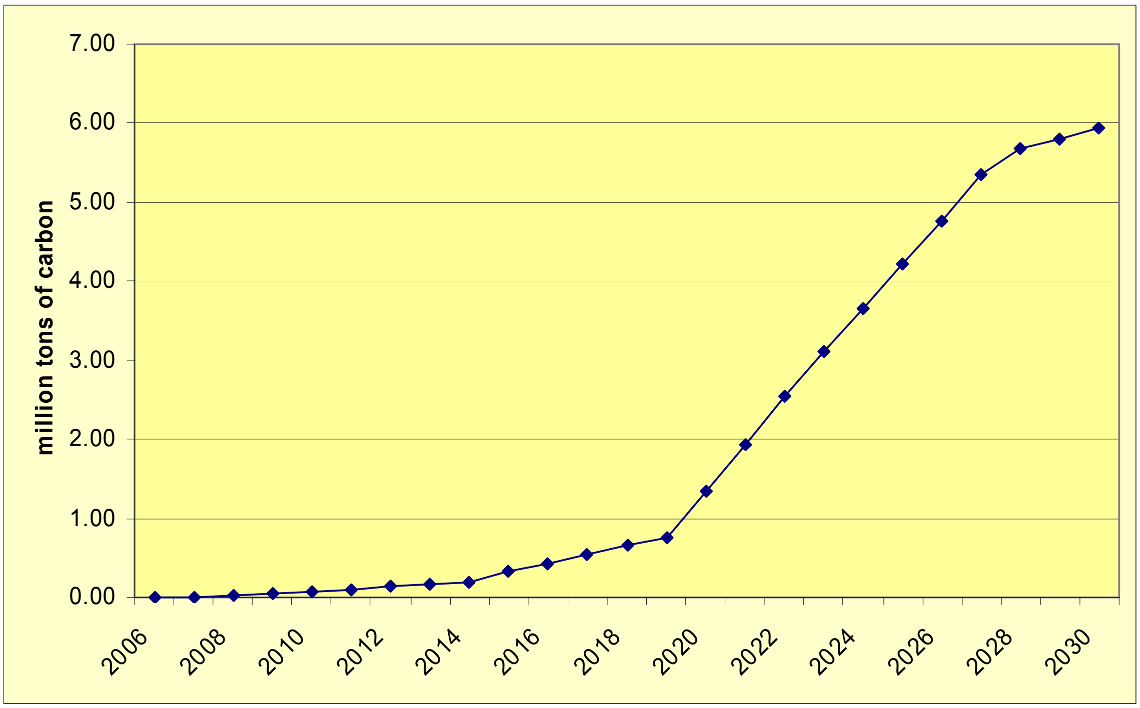


Figure 13: Avoided Carbon Emissions due to Tighter Standards for Gas Water Heaters

National Impact Analysis on Energy Saving and Avoided Carbon Emissions

Results in three previous sections show that there is substantial room for energy efficiency improvement in residential energy use in China. Most can be achieved with adopting existing technologies and practices. Raising the minimum energy performance standards for the three appliances discussed in this analysis could bring substantial reductions in energy consumption and carbon emissions. Figure 14 presents the source energy saving by products. Electricity savings are converted to site energy use using the average thermal efficiency of the power generation in China. The estimated savings in primary energy could reach 1278×10^{15} joules in 2020 and 3070×10^{15} joules in 2030.

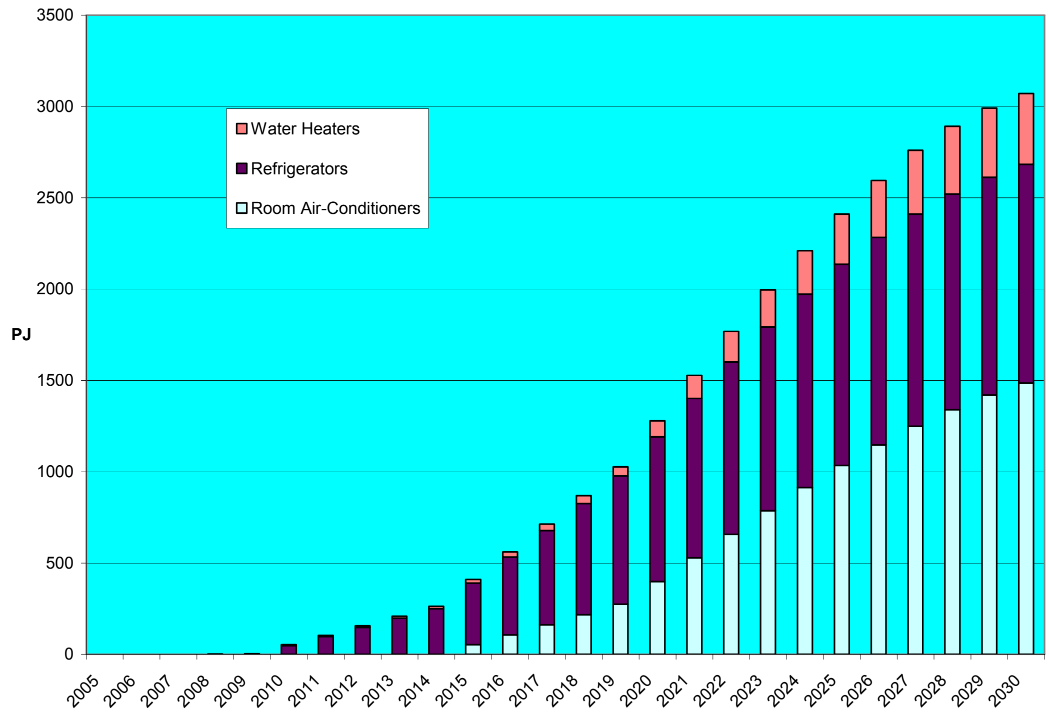


Figure 14: Primary Energy Savings by Product

It can be seen that the largest savings are due to improvement in efficiency for refrigerators and air-conditioners. This is attributable to three factors: first, sales of refrigerators and air-conditioners are large, secondly, the relative efficiency improvement is steeper and assumed to occur earlier, than those applied to water heaters; and thirdly, baseline energy use per unit is greater for refrigerators and air-conditioners than that of gas water heaters.

However, savings due to more efficient water heater technologies are large as well. By 2020, such savings would reach 2.4 billion cubic meters per year, and further rise to 10.6 billion cubic meters by 2030.

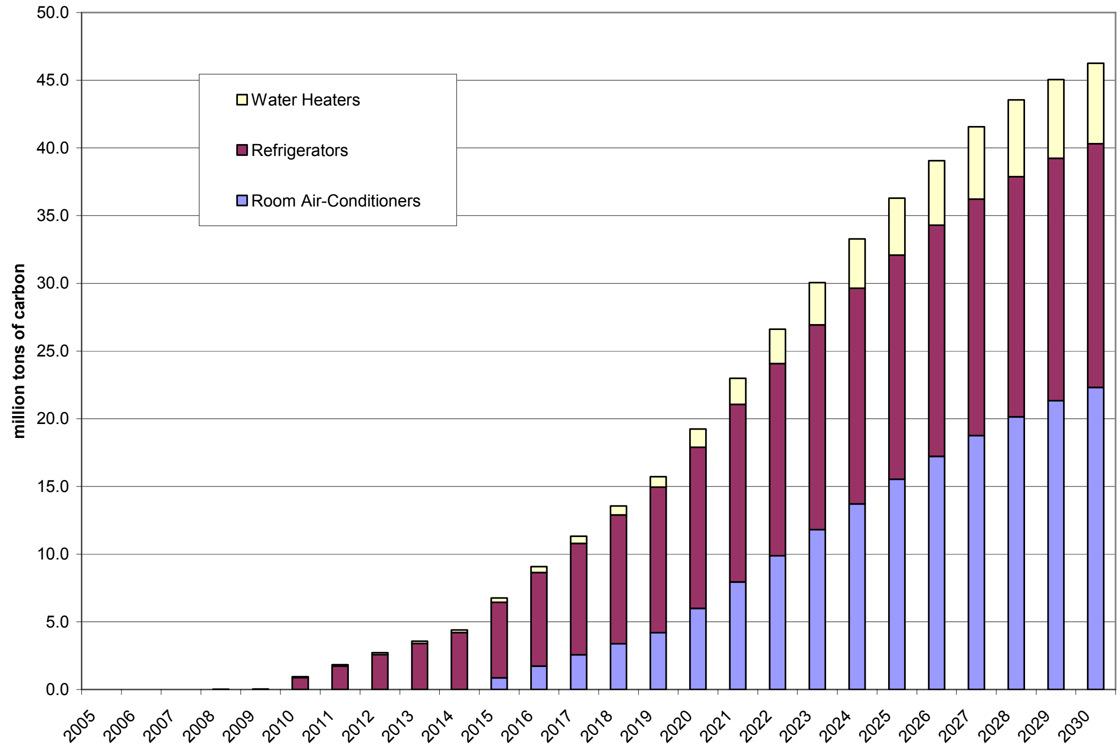


Figure 15: Avoided Carbon Emissions due to Efficiency Improvement in Appliances

Figure 15 presents total avoided carbon emissions due to improvement in energy efficiency in refrigerators, room air-conditioners, and gas water heaters. Most avoided emissions are due to improvement in refrigerators and air-conditioners. In addition to reason cited above, low carbon content of natural gas is also a cause of the smaller role of improvement in water heater efficiency in reducing carbon emissions in China.

However, all together, the potential to reduce carbon emission are substantial: almost 19 million tons per year by 2020, and 46 million tons per year by 2030. In addition to such environmental benefits, avoided costs associated with power plants that would not have to be built would be over US $ 60 billion by 2030.

Conclusions

The large potential in reduction of carbon emissions identified in this study suggests that it would behooves both the Chinese government and interested international parties to promote improvement in appliance energy efficiency in China through the development of more stringent standards for appliances and the transfer of more efficient technologies to the Chinese market.

Minimum energy performance standards for appliances have been found to be effective in raising appliance efficiency both in China and worldwide. China has certainly made rapid progress in recent years in establishing a framework of formulating energy efficiency standards and labeling requirements for home appliances and other energy-consuming products. However, government funding for standard development are far below the level that is necessary to meet the need both to expand energy efficiency standards to more product categories and to update existing standards to more stringent requirements.

At present, the technical support organization for standard development in China, CNIS, relies heavily on contributions from manufacturers to support the standard development process. While manufacturers' participation is healthy for the development of technically sound standards, over-reliance on their support could have negative consequences as well: for example, standard development or update could be delayed; and standard levels could be less stringent than possible. Moreover, many standards won't be developed due to insufficient government funding, leaving large potential for energy savings untapped.

There are also technical challenges in raising standard levels much higher than the current level, since domestic manufacturers may not have the start-of-the-art technology. This is illustrated in the case of room air-conditioners: the 2005 Chinese standard is much lower than corresponding requirement in Japan and Korea. Raising the minimum energy efficiency standard at a regular interval could certainly help promote the wide adoption of more efficient technologies. Given that China is a leading exporter of many appliance products, efficiency gains in China could have large spillover effect globally as well.

Moreover, to truly capture the full potential of appliance standards and labeling program, they need to be enforced vigorously. Implementation and enforcement of standards have always been a serious concern in China, in part due to insufficient government funding and in part due to more fragmented appliance market: there are many more manufacturers and retail outlets to monitor. In addition, there is little precedence to follow in terms of enforcement actions given the nascent nature of the appliance standard program in China. Introduction of international best practices in enforcement and monitoring of standard compliances could help China build a more effective mechanism to sustain the momentum of efficiency improvement in the market place.

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Appendix: Key Assumptions

As discussed in the methodology section, energy saving estimates are based on tracking the energy use through a vintage model. In short,

$$Stock = \Sigma(Sales - Retirement)$$

And total energy consumption for a particular end-use is calculated as follow,

$$Total\ Energy\ Consumption = \Sigma Stock(i) * UEC(i)$$

where UEC is the unit energy consumption of specific appliance. Product UEC is determined by a combination of efficiency and usage levels that reflect both current practices and standards. In this section, key assumptions used are discussed.

<u>Sales Forecasts</u>

For refrigerators, future sales up to 2030 are projected with an annual growth rate of 5% from 2004 to 2010, an annual growth rate of 2% from 2010 to 2020, and zero growth from 2020 to 2030. Future sales are projected to stabilize around 33 million from 2020 onward.

Future sales for room air-conditioners are projected based on an annual growth rate of 5% from 2004 to 2010, an annual growth rate of 2% from 2010 to 2020, and zero growth thereafter. Projected sales would reach 40 million in 2010, and 50 million from 2021-2030.

Future sales for gas water heaters are estimated to be 10 million units in 2006, and would rise by 2 million unit every five years until 2020 (Fu, 2005). Using the same increment, total sales of gas water heaters is projected to reach 20 million by 2030.

A summary of sales forecast is presented in table below.

Table A-1: Sales Forecasts of Three Major Appliances in China (millions)

	Room Air-conditioners	***Refrigerators***	***Gas Water-Heaters***
2005	32.2	16.9	8.0
2010	40.0	21.6	12.0
2015	44.1	27.5	14.0
2020	48.7	35.1	16.0
2025	50.0	35.1	18.0
2030	50.0	35.1	20.0

Despite the large volume of sales indicated here, the saturation levels of these three appliances are well within the reasonable range, given the large number of households in China. For example, in 2020, saturation of room air-conditioners is only about 124% (Table A-2). Since one family can deploy several units of room air-conditioners within the house, it is not hard to imagine that the saturation level could go beyond 200% in aggregate. Similarly, saturation levels for refrigerators and gas water-heaters in 2020 would be about 88% and 31%, respectively. The low level for gas water-heaters is partly due to the fact that many households would install electric water-heaters.

Table A-2: Saturations of Three Major Appliances in China

	No. of Households (millions)	***Room Air-conditioners***	***Refrigerators***	***Gas Water-Heaters***
2010	405	85%	50%	14%
2015	421	111%	62%	25%
2020	438	124%	76%	28%
2025	456	130%	88%	31%
2030	474	131%	91%	33%

<u>UEC</u>

Unit energy consumption for the three appliances are presented in the table below. The baseline numbers reflect current efficiency requirement, and expected changes in usage pattern. The target numbers reflect increased efficiency through higher standards and expected changes in usage patterns.

For room air-conditioners, the difference in 2015 would be 547 kWh per year in the baseline versus 438 kWh per year in the target scenario, or a reduction of 20%. In 2030, the reduction would be about 36%. For refrigerators, the difference in 2020 would be 489 kWh per year in the baseline versus 325 kWh per year in the target scenario, a reduction of 34%. In 2030, the reduction would reach 56%. For gas water-heaters, the difference in energy use would be 161 m^3 per year versus 145 m^3 per year in 2015, a reduction of 10%. In 2020, the reduction would be 42%.

Table A-3: Annual Energy Consumption Per Appliance

	Room Air-Conditioner (kWh)		**Refrigerators (kWh)**		**Gas Water-heaters (m^3)**	
	baseline	target	baseline	target	Baseline	target
2006	404		516		161	
2007	404		470		161	
2008	404		475		161	157
2009	438		480		161	157
2010	438		489	325	161	157
2011	438		489	325	161	157
2012	438		489	325	161	157
2013	438		489	325	161	157
2014	438		489	325	161	157
2015	547	438	489	219	161	145
2016	547	438	489	219	161	145
2017	547	438	489	219	161	145
2018	547	438	489	219	161	145
2019	547	438	489	219	161	145
2020	656	420	489	219	161	93
2021	656	420	489	219	161	93
2022	656	420	489	219	161	93
2023	656	420	489	219	161	93
2024	656	420	489	219	161	93
2025	656	420	489	219	161	93
2026	656	420	489	219	161	93
2027	656	420	489	219	161	93
2028	656	420	489	219	161	93
2029	656	420	489	219	161	93
2030	656	420	489	219	161	93

The rises in baseline energy consumption are due to larger units for refrigerators and longer usage hours for room air-conditioners (from 300 to 600 hours per year).

Lifetime:

Lifetime for refrigerators and air-conditioners in China is about 12.5 years, and that for gas water heaters is about 8.5 years.

Carbon Emission Factor

China's generation fuel mix is dominated by coal. In 2003, primary electricity generation from hydro, nuclear, and renewable sources accounts for 16.5% of total generation. Thermal efficiency in coal power plants remains low at 33%. It is expected that coal's dominance in power generation will decline somewhat in the future. Still, the share of thermal generation is likely to be around 75% in 2020. However, thermal efficiency is expected to improve substantially in the next 20-30 years as China builds large quantity of new power plants. It is assumed that by 2020 the efficiency of thermal generation would reach 42%.

These improvements would lead to a decline in the carbon intensity of power generation in China from 0.230 in 2003 to 0.164 kg carbon/kWh in 2020 and onward.

Table A-4: Carbon Emission Factors of Electricity

	Thermal electricity share (%)	***Thermal efficiency (%)***	***Adjustment factor***	***Carbon Emission Factor (kg C/kWh)***
2003	83.5%	33.3%	100%	*0.230*
2005	82.5%	34.4%	96%	*0.220*
2010	80.0%	36.9%	87%	*0.199*
2015	77.5%	39.5%	78%	*0.180*
2020	75.0%	42.0%	71%	*0.164*
2025	75.0%	42.0%	71%	*0.164*
2030	75.0%	42.0%	71%	*0.164*