Title

Avoiding 100 New Power Plants by Increasing Efficiency of Room Air Conditioners in India: Opportunities and Challenges

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Avoiding 100 New Power Plants by Increasing Efficiency of Room Air Conditioners in India: Opportunities and Challenges

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Abstract

Electricity demand for room ACs is growing very rapidly in emerging economies such as India. We estimate the electricity demand from room ACs in 2030 in India considering factors such as weather and income growth using market data on penetration of ACs in different income classes and climatic regions. We discuss the status of the current standards, labels, and incentive programs to improve the efficiency of room ACs in these markets and assess the potential for further large improvements in efficiency and find that efficiency can be improved by over 40% cost effectively. The total potential energy savings from Room AC efficiency improvement in India using the best available technology will reach over 118 TWh in 2030; potential peak demand saving is found to be 60 GW by 2030. This is equivalent to avoiding 120 new coal fired power plants of 500 MW each. We discuss policy options to complement, expand and improve the ongoing programs to capture this large potential.

Contents

1 Introduction

Room air conditioner (AC) demand is growing rapidly at rate of 20% on average per year over the last ten years and is likely to be a major contributor to the need for new power plants in India. In 2010, the room AC saturation amongst urban households was only 3% compared to 100% in China ([1]–[3]). With rising incomes and urbanization, falling AC prices, and a hot climate, it is expected that the AC ownership is going to rapidly increase in India. Based on the projections in [4], the authors have estimated the electricity demand from ACs to increase to 239 TWh/yr by 2030, which translates to a peak demand contribution of about 143 GW. Meeting this demand requires construction of nearly 300 new coal fired power plants of 500 MW each. We show in this paper that the efforts to accelerate the adoption of efficient ACs can lead to reduction of the AC demand by more than 40% cost effectively; this translates to avoiding building more than 100 new coal power plants of 500 MW each. Since most of the AC stock in India is yet to be purchased, the demand could be reduced at lower costs if the actions are taken now compared to actions taken after most of the stock is installed.

Limited technical and economic analysis exists on options to improve the efficiency of room ACs in India, the cost effectiveness of these options, and the total saving potential. In this paper, we undertake a detailed engineering-economic assessment of the efficiency potential of room ACs in India and verify some of our findings using efficiency and prices observed in the market.

In section 2, we summarize the current status of the room AC efficiency and related policies in India, and compare them to other countries and regions. We show the engineering options to improve the efficiency of room ACs and the costs of these options in India, and estimate the cost of saving electricity by implementing these options in section 3. In section 4, we present the correlation of air conditioner ownership with income and weather, and estimate the electricity demand from room ACs in 2020 and 2030. In section 5, we estimate the total electricity and peak demand saving potential by improving the efficiency of room ACs. In section 6, we conclude the analysis by providing insights for policies and programs to accelerate the penetration of efficient ACs and realize the electricity savings.

2 Current status of room AC efficiency and related policies

2.1 Status of the room AC market

AC market in India is dominated by room ACs, which make up nearly 99% of the annual sales [5]. The room AC market in India has seen a rapid growth in the last several years as shown in the following chart. Since 2004, except the small drop in 2011, room AC sales have grown at an average annual growth rate of 17%.

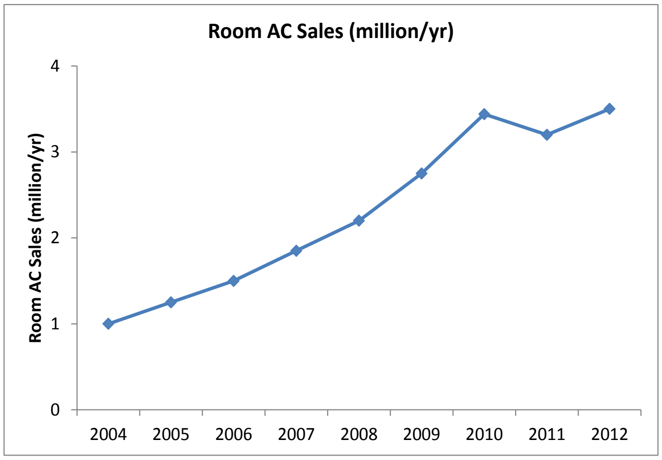

Figure 1: Sales of Room ACs (split and window units) in India

(Data Source: [6])

The Room AC market is increasingly dominated by split ACs (split-packaged non-ducted units). In the financial year 2011-12, split units accounted for 75% of the total room AC sales, while the window units (single packaged non-ducted) accounted for the remaining 25% [6].[1] Rooms ACs are primarily used in the residential, and small and medium commercial sector. According to [5], about 80% of the window units and 50% of the split units are sold in the residential market; moreover, the current market trends indicate that share of the residential sector is increasing faster than that of the commercial sector [7].

2.2 Status of efficiency and related policies

Since 2006, the Bureau of Energy Efficiency (BEE), a nodal agency for implementing energy efficiency policies in India, has initiated a standards and labeling (S&L) program for different electrical appliances. The energy efficiency labels in India are given in the form a star rating - from one-star to five-star; five-star being the most efficient. The labeling program has been made mandatory for all room ACs sold in India since 2012. This implies that any room AC must earn at least one-star label before it could be marketed in the Indian market. Therefore, the efficiency level for one-star label serves as the *de facto* Minimum Energy Performance Standard (MEPS). The following chart shows the current and future ranges of the energy efficiency ratios (EER) for different star ratings in India.

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[1] The Indian financial year starts in April and ends in March. For example, financial year 2011-12 started in April 2011 and ended in March 2012.

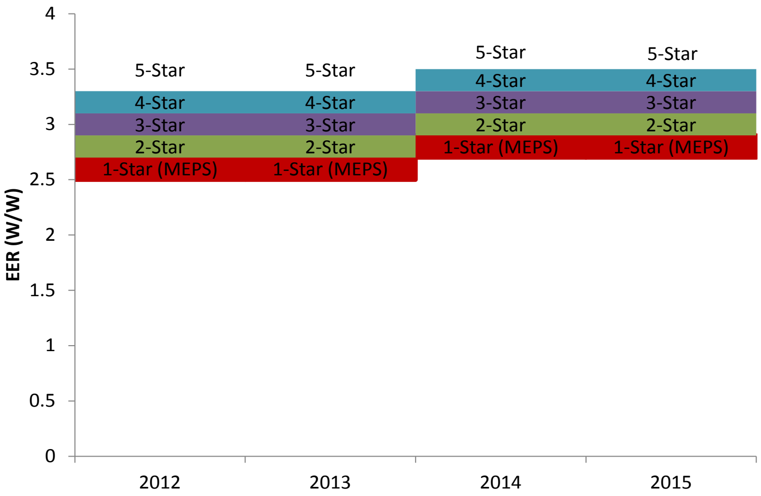


Figure 2: Current and Future Schedule of energy efficiency labels for Room ACs (split units) in India

(Data Source: [8])

It can be seen from the chart that the current MEPS for split ACs in India is an EER of 2.5, which is scheduled to increase to 2.7 by January 2014. Similarly, all ACs with EER of 3.3 and above are currently labeled as 5-star, which is scheduled to increase 3.5 by January 2014.

MEPS and maximum efficiency labels of the Indian room ACs, however, are significantly lower than that compared with other countries as shown in the following table.

Table 1: Minimum, Maximum and Average EER (W/W) in the room AC market (split units) in different countries

	EER (W/W)		
Country	**Min**	**Max**	**Average**
Australia	2.67	4.88	3.16
Brazil	2.92	4.04	3.19
Canada	2.14	4.33	3.6
China	2.9	6.14	3.23
EU	2.21	5.55	3.22
India	2.5	3.8	2.9
Japan	2.37	6.67	4.1
Korea	3.05	5.73	3.78
Mexico	2.42	4.1	2.92
Russia	2.5	3.6	2.79
South Africa	2.28	5	2.91
UAE	2.14	3.22	2.69
USA	-	4.6	3.04

(Data Source: [9], [10])

For countries which implement product specific MEPS (all countries shown in the table except Japan and South Africa), the minimum EER is influenced by MEPS whereas the average and the maximum EER depend on several factors such as market conditions, energy efficiency policies etc. Compared to several countries, MEPS in India is less stringent. For example, in China, the MEPS is 16 % more stringent than India; the average EER of the Indian room AC market is comparable with the products with lowest energy efficiency rating in China.

We understand that the EER values are not directly comparable across different countries because of the minor differences in the test procedures followed in each country. Moreover, comparison of the MEPS and market average EERs between different countries offer few insights for improving energy efficiency policies and programs. This is primarily because of the differences in the weather conditions, usage patterns, electricity rates, and discount rates across countries. These factors influence the efficiency of the air conditioners in the market as well as the level of MEPS. Therefore, in this paper, we assess the costs and benefits of improving efficiency of room ACs only in the Indian context.

3 Techno-economic analysis of efficiency improvement options for Room ACs in India

In this section, we first summarize the efficiency improvement options considered, of the amount of efficiency gains, and estimate the corresponding incremental costs. We then estimate the cost of conserved electricity (CCE) for each of these options, and then compare it to the cost of supply from several perspectives to provide insights into the cost effective efficiency improvement levels.

3.1 Options are improving the efficiency of the room ACs

Following on from [9], we present a list of design options that can improve the efficiency of room air conditioners and estimate the incremental cost of such options. In this paper, we have considered only such design options that can be directly applied within the standard room air conditioner technologies currently on the market; these options will show energy savings under the existing product energy performance test procedures and they can be integrated into current products (i.e. do not imply changing the basic product configurations). The following room air conditioner features were considered for design improvements, namely: compressor efficiency, compressor control, heat exchanger performance, expansion valves, crankcase heaters and controls, and standby power use [9]. For each design option, there are up to five levels of efficiency improvement. The following table summarizes these options, levels of efficiency improvement, possible efficiency improvement over the base case and incremental manufacturing cost.

Table 2: Summary of the efficiency improvement options and incremental manufacturing cost

	Base Case (Market Average)	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Option 1: Compressor Efficiency (Increase compressor efficiency)	Base case compressor	**6.5%** improvement at Rs 1,310	**12.3%** improvement at Rs 4,138	**18.7%** improvement at Rs 12,270		
Option 2: Compressor Control (Variable speed drives)	Single-speed compressor control	**20%** improvement at Rs 4138	**20.7%** improvement at Rs 8067	**24.8%** improvement at Rs 11996		
Option 3: Heat Exchanger (Increase exchanger efficiency)	Base case heat exchanger	**9.1%** improvement at Rs 3391	**16%** improvement at Rs 7271	**21.3%** improvement at Rs 11122	**24.8%** improvement at Rs 14948	**28.6%** improvement at Rs 18753
Option 4: Expansion Valve (Use thermostatic or electrostatic valves)	No expansion valve control	**5%** improvement at Rs 728	**8.8%** improvement at Rs 2038			
Option 5: Crankcase heater efficiency and crankcase heater control (increase efficiency & reduce heating period)	Base case crankcase heating and control	**9.8%** improvement at Rs 1048	**10.7%** Improvement at no incremental manufacturing cost.			
Option 6: Standby (Reduce standby load)	Base case standby loads	**2.2%** improvement at Rs 786				

(Source:[9]

Note: 1. EER for the base case air conditioning unit is taken as the market average EER.

2. All the efficiency improvement numbers are relative to the base case.

3. Design options 2, 4 and 5 require a seasonal metric to show savings and will not show savings under EER metric even though annual energy consumption may be lower, due to savings during operation at partial load.)

The efficiency gains associated with these options depend on the seasonal load characteristics assumed and hence depend on the climate and usage factors. In India, a room air conditioner is assumed to run for about 8 hours every day for 6 months in a year i.e. 1440 hours/year. This assumption is in agreement with multiple other sources such as [10]–[13].

3.2 Incremental Costs of Efficiency Improvement

Table 2 shows the incremental manufacturing cost for each design option. However, the final price that the customers pay (which we term as the installed cost) includes the manufacturer's selling price, installer margin and tax. To arrive at the installed cost for each design option, we have used a set of multipliers developed in [9], which represent the mark up from the original manufacturer's cost.

The following chart shows the total manufacturing cost and total installed cost against the EER for each design option. The chart also shows the actual retail price in the Indian market for a few room AC units selected randomly against their EERs. The retail price data was taken from www.compareindia.com.

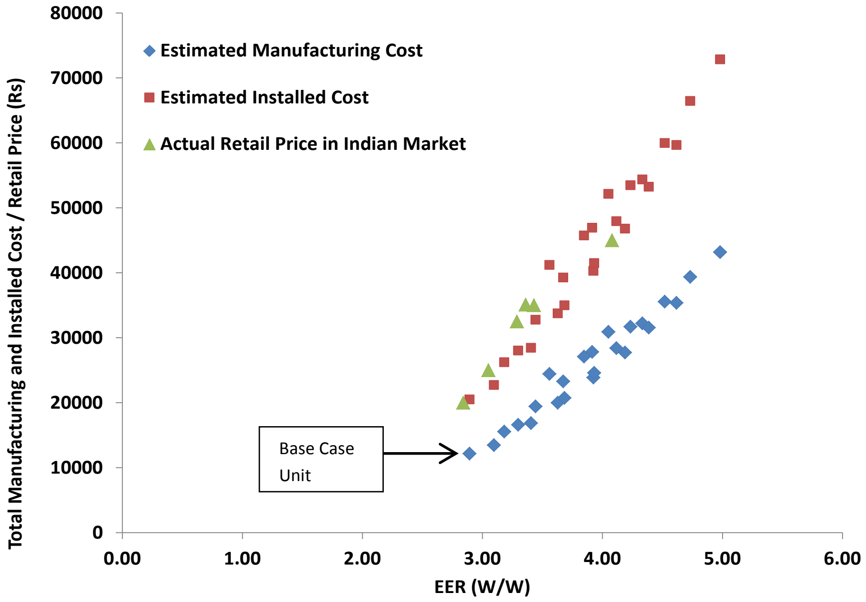


Figure 3: Total Manufacturing Cost, Installed Cost and Actual Retail price for a range of EERs

(Data Source: [9], [14])

3.3 Cost-Effectiveness of Efficiency Improvement

3.3.1 Cost of Conserved Electricity

In this analysis, the cost effectiveness of efficiency improvement options and the corresponding savings potential is assessed by comparing the cost of conserved electricity (CCE) for these options with the cost of electricity. CCE is estimated by dividing the incremental cost of the design change by the incremental energy saving due to the efficiency gain.

$$CCE = \frac{Annualized\ incremental\ cost\ of\ efficient\ AC}{Annual\ electricity\ saved\ by\ efficient\ AC}$$

CCE, therefore, could be readily compared against the consumer tariff or the marginal cost of supplying electricity. If the CCE is lower than the consumer tariff, it will be cost-effective for consumers to invest in the efficient AC. Similarly, if the CCE is lower than the long run marginal cost of electricity, investing in a market transformation program would be cost-effective relative to building new power plants.

In this analysis, we have estimated two types of CCE: cost to the manufacturer of conserved electricity, CCE_m and cost to the consumer of conserved electricity, CCE_c. CCE_m uses the incremental manufacturing cost, while CCE_c uses the incremental installed cost of the higher efficiency models. Naturally, CCE_m is lower than CCE_c because it does not include the distributor markups and installation costs. Therefore, CCE_m can be used to measure the cost-effectiveness of a market transformation program such as an upstream incentive program, while CCE_c would be used to measure the cost effectiveness of a standards program or a downstream incentive program targeting the consumer [9].

We understand that the seasonal energy efficiency ratio (SEER) metric provides a fuller picture of the energy efficiency of a room AC, since it accounts for AC operation at partial loads. However, in India, MEPS and labels are prescribed using EER; therefore, in this paper, we have chosen to use EER as the efficiency metric. If SEER metric is used, potential energy savings accounted for by the efficiency metric could be higher by nearly 20% [9]. For more discussion on EER and SEER, refer to [9].

3.3.2 Electricity costs and consumer tariffs in India

Consumer electricity tariffs in India include government subsidies and cross subsidies among consumer classes. However, under the current power sector reforms, there is a strong push for tariff rationalization and reduction of the amount of such cross-subsidy. The domestic fuel sector in India (mainly coal and gas) is severely constrained [15]. Therefore, a significant part of the marginal generation capacity addition is based on imported coal or imported LNG. Imported coal prices have been increasing in the world market and are significantly above the domestic coal prices in India [16]. The following table shows the average consumer tariffs and the long run marginal costs of electricity supply (including the transmission and distribution costs).

Table 3: Consumer Tariffs and Long Run Marginal Cost of Power Supply

Consumer Tariffs	
Average residential tariff (Rs/kWh)	4.5
Average commercial tariff (Rs/kWh)	6.0
Long Run Marginal Cost of Electricity Supply	
Cost of generation – imported coal (Rs/kWh)	3.5
Transmission and distribution loss %	15%
Transmission and distribution infrastructure cost (Rs/kWh)	1
Long Run Delivered cost of electricity supply (Rs/kWh)	5.12

Note: The cost numbers shown here are the approximate 2013 values and do not account for discount rates.

(Data Source: Authors’ calculations)

3.3.3 Cost-Effective Electricity Saving Potential

The following chart shows the cost of conserved electricity from consumers’ perspective (CCE_c) against the EERs of all the design options discussed in the earlier sections. It also shows the average consumer electricity tariff for residential consumers and the long run marginal cost of electricity supply. As shown in the chart, CCE is lower than the consumer tariff up to an EER of nearly 4.21; this implies that from consumers’ perspective, achieving an efficiency gain up to an EER of 4.21 is cost-effective i.e. consumers would be better off if they bought an AC with EER of up to 4.21. This makes a strong case for setting the MEPS at the cost-effective EER from consumers’ perspective. From the utility’s perspective, the long run marginal cost of power supply is higher than the CCE up to an EER of about 4.7; this implies that the utility would find it cost effective to offer a downstream incentive (like a consumer rebate) than investing in a new power plant.

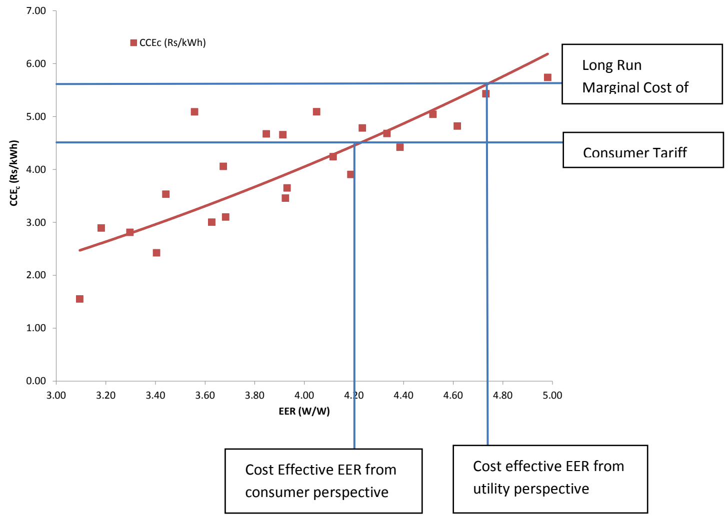


Figure 4: Cost of Conserved Electricity and Cost-effective energy saving Potential

Note that the marginal cost of peak power supply is higher than the marginal cost of coal based power supply; given the potential peak power saving from efficient ACs, from utility’s perspective, the cost effective EER could actually be much higher.

4 Current and future electricity demand from Room ACs and energy and peak power saving potential

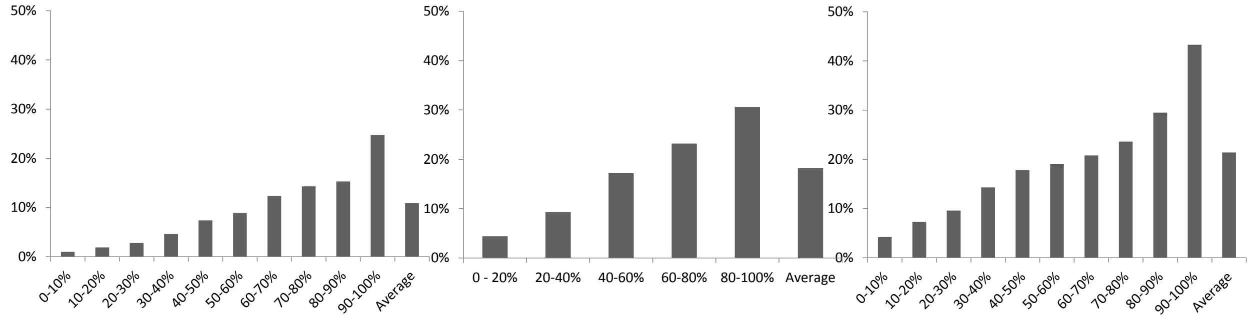
In this section, we estimate the current AC stock in India and project the future demand for air conditioners in India and their contribution to total electricity consumption and peak demand.

4.1 Future Demand for Air Conditioners

Ceiling fan is the most common household and commercial appliance used for space cooling in India. However, the saturation level of ceiling fans in urban households is more than 90% [1]. The demand for other space cooling appliances like air coolers and air conditioners has been increasing rapidly, as shown in the subsequent sections of this paper.

4.1.1 Current Stock of Air Conditioners in India

Unfortunately, India does not conduct a national level electric load survey. The national sample survey, conducted by the ministry of program implementation and statistics of the federal government of India, does collect information on household appliances; but it includes air coolers and air conditioners together in the same category The following chart shows the total saturation of air conditioners and air coolers in the urban Indian households over the last ten years by expenditure class.

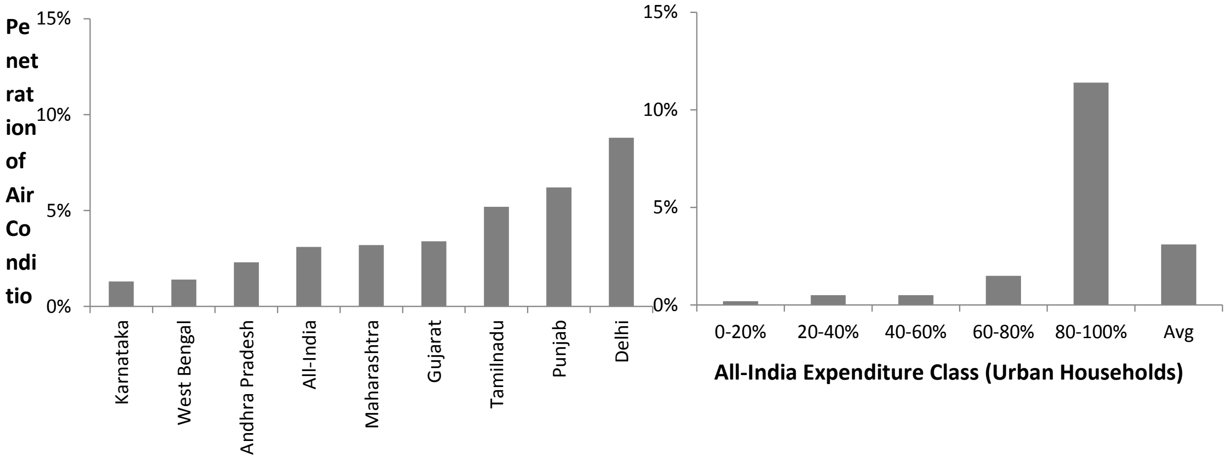


(a) 1999-2000 **(b) 2004-2005** **(c) 2009-2010**

Figure 5: Saturation of air conditioners and air coolers in urban Indian households by expenditure decile

(Data Source: [1], [2], [17])

There are two important observations that can be made from these charts, namely: (a) ownership of air coolers and air conditioners has increased significantly across all income classes. On average, the penetration of air coolers and air conditioners has doubled between 2000 and 2010. The increase in ownership in the top 2 income deciles is even more striking. (b) There is a non-linear relationship between incomes and the ownership of air coolers and air conditioners. The appliance ownership in the highest expenditure decile is significantly higher than that in the lower deciles. Unfortunately, the national sample survey does not report the ownership numbers of air coolers and air conditioners separately except in the 2004-05 survey. The following chart shows the average saturation of air conditioners in urban households in 2004-05 in: (a) several Indian states, and (b) by expenditure class.



(a) Average saturation in key states

(b) Average saturation by expenditure class

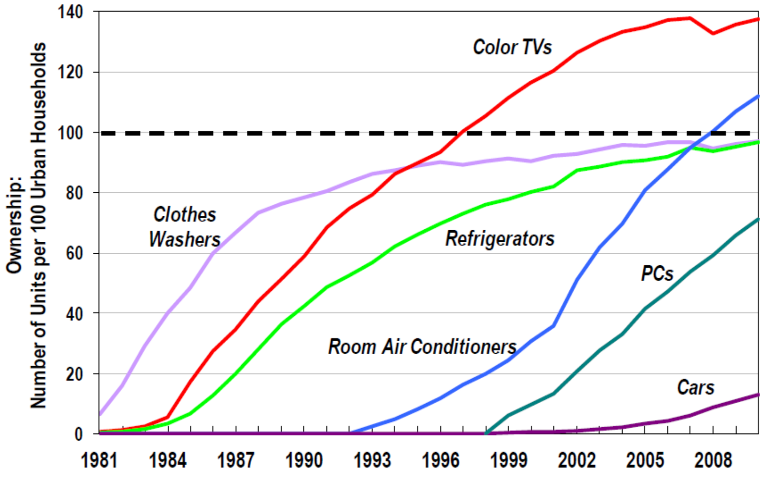
Figure 6: Saturation of air conditioners in urban households in 2004-05

(Data Source: [2])

The relationship between AC ownership and income (or expenditure) is clear from the above chart (b). Moreover, in states like Delhi and Punjab , where the temperatures and incomes are higher than the national average, the AC penetration is significantly higher than other states. Note that, on average, air conditioners account for about 15% of the total air cooler and air conditioner saturation in 2005. However, in the higher expenditure brackets and in urban areas with higher average incomes like Delhi, the share of air conditioners is as high as 30-60% [2], [18]. Moreover, several media reports suggest that the share of air cooler in the Indian market is slowly being taken over by air conditioners. Nevertheless, in order to be conservative, we assume that in 2010, air conditioners accounted for 15% of the air cooler and air conditioner ownership. This implies that, on average, the saturation of room ACs in the urban Indian households in 2010 was about 3.1% i.e. about 4 million. .

4.1.2 Projecting the Future Room AC Stock

The example of China is illuminating for understanding the rapid growth in household appliance ownership as a result of rising incomes and urbanization. The saturation of air conditioners in urban China went from nearly zero in 1992 to about 100% by 2007 i.e. within a span of 15 years [3]. The following chart shows the penetration of key electrical appliances in urban Chinese households between 1981 and 2010.



Rural households lag urban households in ownership by 10-20 years

Figure 7: Penetration of key appliances in urban Chinese households between 1981 and 2010

(Source: [3])

In India, while average household incomes have risen significantly over the last decade, prices of electrical appliances have dropped in real terms as shown in the following chart.

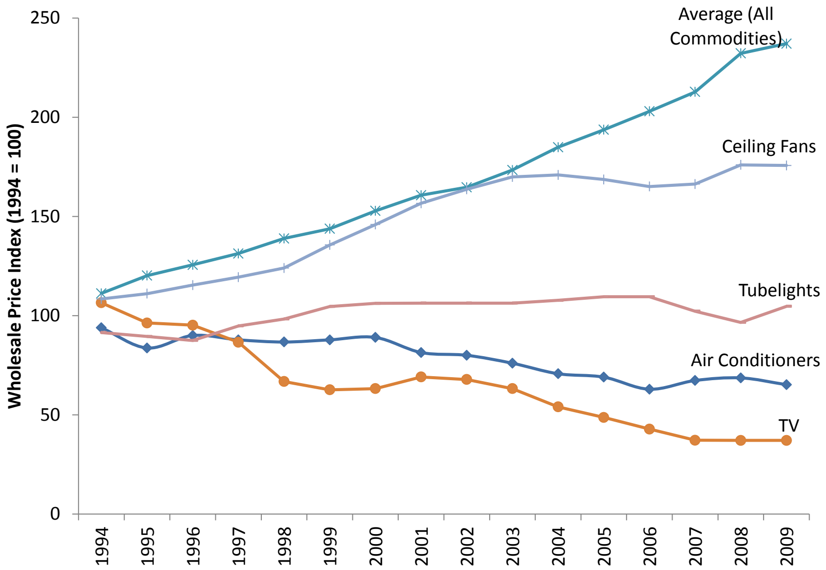


Figure 8: Wholesale Price Indices of the key electrical appliances and average of all commodities (1994=100)

(Data Source: [19])

Moreover, most of the major Indian cities are populous and have very high number of cooling degree days compared to other cities in the world as shown in the following table:

Country	Metropolitan area	Cooling Degree Days per year	Population, million (2005)
India	Chennai	3954	6.9
Thailand	Bangkok	3884	6.6
India	Mumbai	3386	18.2
India	Calcutta	3211	14.3
India	Delhi	2881	15
USA	Miami	2423	5.4
Brazil	Rio de Janeiro	2401	11.5
China	Hong Kong	2107	7
China	Shenzhen	2107	7.2
China	Guangzhou	2072	8.4
China	Shanghai	1129	14.5
Greece	Athens	1075	3.1
China	Beijing	840	10.7
USA	Los Angeles	837	12.3
Spain	Madrid	805	5.6
Argentina	Buenos Aires	512	12.6
Mexico	Mexico City	245	19.4

(Data Source: [20])

In short, Indian cities have significantly high cooling requirement; the AC and air cooler ownership in India shows a strong correlation with urbanization and income, and there is a non-linear relationship between income and AC ownership. With rising incomes and falling prices AC ownership in India could potentially witness growth similar to China. In this paper, we have estimated the future AC stock based on [4]. The future stock is estimated by dividing the electricity saving projected in [4] by unit energy consumption of the efficient AC. Note that these projections in [4] have been made using the current sales and sales growth data; which implies that they do not take into account the price effect (potential reduction in AC prices), the income effect (rapid increase in incomes and urbanization, and non-linear relationship between income and AC ownership), and weather effect (high cooling degree days make ACs a highly desired appliance above certain income threshold). Therefore, we believe that [4] gives fairly conservative estimates of the future AC stock. However, we are not aware of any other study that has projected the stock by considering the income, weather and price effects; moreover, one may not be able to project the stock correctly given the limitations of the publicly available data (for example air coolers and air conditioners being reported together). This also highlights the need for a comprehensive survey based analysis for estimating the current and future stock of the key electrical appliances.

The AC stock projections based on [4] are shown in the following table.

Table 4: Room AC Consumption and Stock in 2020 and 2030

	2010	**2020**	**2030**
Total Electricity Consumption by room ACs for Business as Usual (BAU)	8	77	239

(TWh/yr)			
Total stock of room ACs (millions)	4	37	116
Total number of urban households (millions)	99	127	159
Room AC penetration in urban areas assuming all room ACs are installed in urban households (total stock as % of urban households)	4%	30%	73%

(Data source: [1], [4], [21], [22],)

We estimate that about 30% of the urban households are likely to own a room air conditioner by 2020 and about 73% are likely to own a room air conditioner by 2030.

Note that the projected electricity consumption has been estimated by holding the efficiency of the room ACs constant at the current market average level (EER of 2.89). Globally, AC efficiency has been increasing historically as a result of several policy actions such as standards and labeling; however, historical efficiency data for India is not available publicly. Moreover, as explained in the following section, we believe that the total room AC stock projected in this table is conservative.

The following chart shows the historical and projected GDP per capita in India and China.

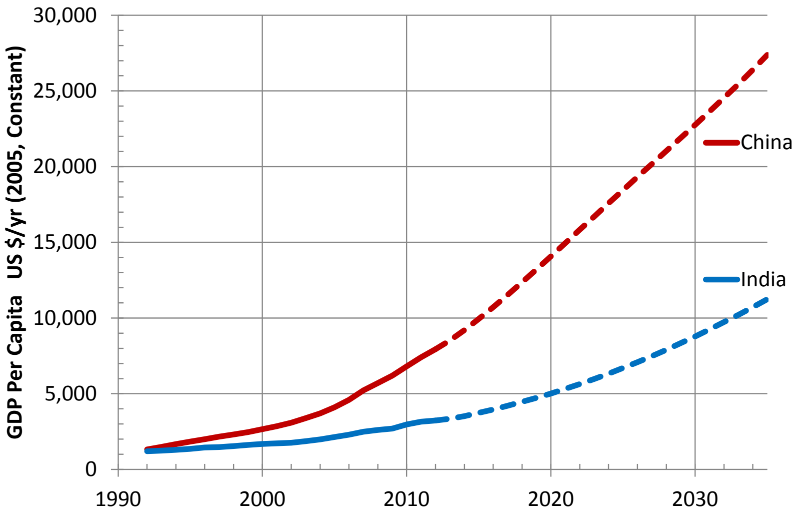


Figure 9: Historical and projected GDP per capita (2005 constant US$) of India and China (Actuals up to 2012)[2]

(Data Source: [23])

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[2] We understand that the per capita incomes presented in the chart are national averages. Urban incomes may be higher than national averages. However, in general, the trend and the difference between Indian and Chinese values would not be very different.

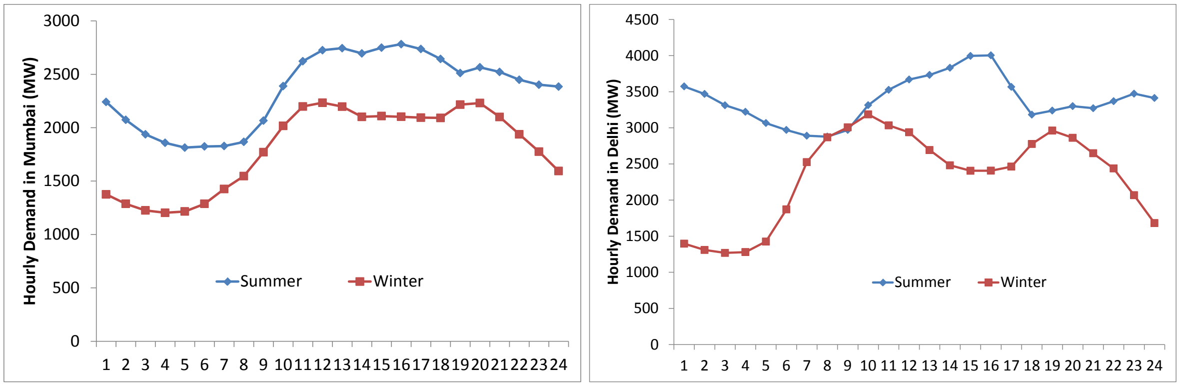
In 2007, while the room AC penetration reached nearly 100% in urban China, the average per capita income was $5,224/year (2005 constant dollars) [23]. In India, the average per capita income would be $5,322/year (2005 constant dollars) in 2021 [23]. By 2030, the average per capita income in India would be $8,787/year (close to China's projected per capita income in 2013) [23]. Figure 5 and Figure 6 show the empirical evidence that the ownership of an air conditioner is highly correlated with the household income. Therefore, we believe that the room AC penetration presented in Table 4 is only conservative.

4.2 Contribution of ACs to the Peak Electricity Demand

In this section, we describe the usage pattern of the space cooling load in India and assess the impact of high penetration of room ACs on peak demand.

Several load surveys in India have found that the space cooling demand in India is highly coincident within a sector and also with the peak demand [11], [13], [18], [24]. Based on these surveys, the following observations could be made: (a) If a household or a commercial establishment owns an AC, its contribution to the peak demand is significant, (b) Residential and commercial space cooling demand has a significant seasonal correlation, (c) diurnally, residential AC demand peaks at night and commercial AC demand peaks in the afternoon. However, during the afternoon, there are a few hours where residential and commercial demands coincide, and (d) space cooling is the only end-use that shows significant seasonal variation.

The following charts show the hourly system demand curves on average summer and winter days in two major Indian cities: Mumbai and Delhi. More than 75% of the load in these cities is residential and commercial; moreover, these cities have a modest level of AC penetration in the residential and commercial sector. Therefore, the system level data essentially represents the pattern in which these two consumer types use the electricity.



(a) Mumbai **(b) Delhi**

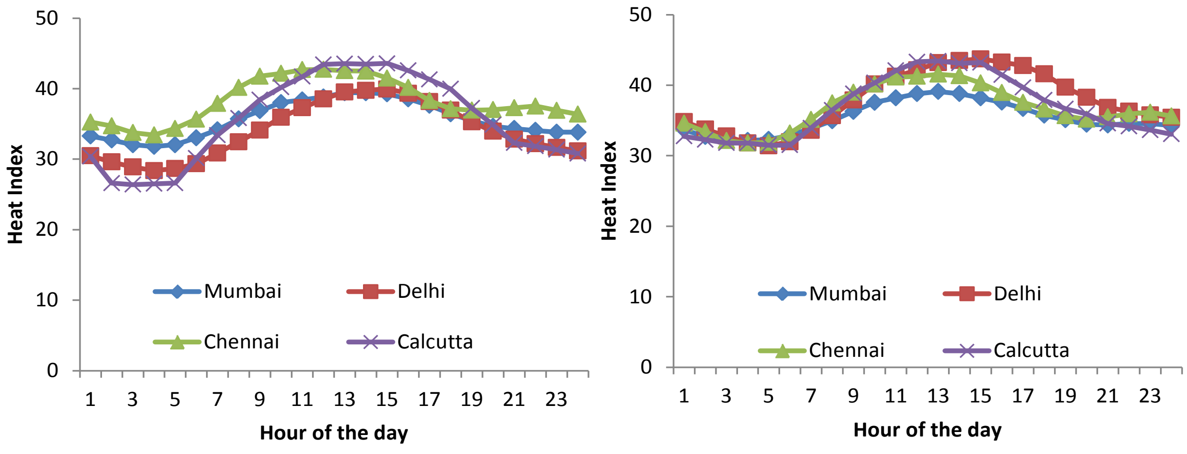
Figure 10: Average Hourly Demands in Summer and Winter in Mumbai and Delhi

(Data Source: [25], [26])

Both Mumbai and Delhi systems are afternoon peaking in the summer; coincidence of the residential and commercial space cooling demand in the afternoon causes the system demands to peak in summer afternoons. Since space cooling is responsible for the seasonal variation in electricity demand in both sectors, the peak demand in winter drops by nearly 40% and 25% respectively in Mumbai and Delhi.

4.3 Coincidence of the space cooling demand across regions in India

So far, we have shown that the space cooling demand from residential and commercial sector makes a significant contribution to the peak demand. The following chart shows the hourly heat indices in four large Indian cities located in different geographic regions in the country.[3]



(a) May **(b) June**

Figure 11: Average Hourly Heat Indices of Major Indian Cities in May and June

(Data Source: [28])

It can be seen that the average heat index pattern during the summer months in India is very similar across geographic regions in India. There would be some daily variation due to local conditions, but in general, the space cooling demand may have a high peak coincidence across geographic regions.

4.4 Estimation of the Peak Demand from room ACs

Because of the reasons mentioned in the previous section, we have assumed a peak coincidence factor of 0.7 for the room ACs in India.[4] The demand for space cooling would peak during summer afternoons. The following table shows our estimates of the peak demand contribution from room ACs.

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[3] Heat Index measures the actual felt temperature to the human body. It is a combination of temperature and relative humidity of the air [27].

[4] Peak coincidence factor is the probability of appliance use coinciding with the system peak demand. Lighting appliances in India typically have a high peak coincidence factor (0.9 or 1) since they are typically used in the evening peak hours [11].

Table 5: Projected Peak Demand from room ACs

	2010	**2020**	**2030**
Total stock of room ACs (millions)	4	37	116
Business As Usual (BAU) Electrical load per AC (W)	1500	1500	1500
Peak Coincidence factor	0.7	0.7	0.7
Transmission & Distribution Loss	15%	15%	15%
Peak demand contribution from room ACs (GW)	5	46	143

Note that because of the daily variations in heat indices, the actual peak coincidence and therefore the peak demand contribution from ACs may be more or less than what we have estimated. More work is needed to account for such variations possibly by introducing random variables while estimating the daily peak demands.

5 Saving Potential

5.1 Energy Saving Potential

Based on the efficiency improvement design options discussed in the previous sections, the total technical potential for saving electricity by improving efficiency of the room ACs in India is found to be 118 TWh at bus-bar in 2030. The efficiency supply curve is shown in the following chart:

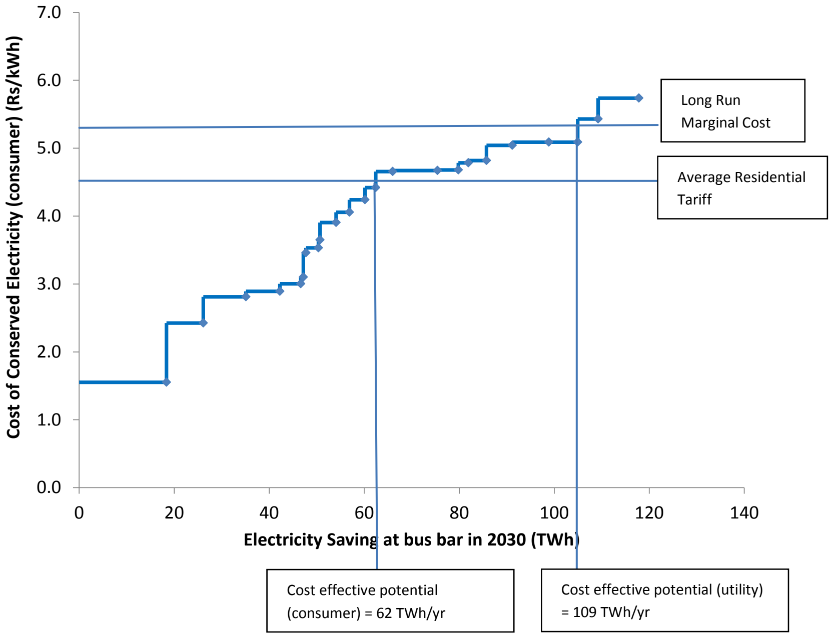

Figure 12: Efficiency Supply Curve in 2030 for Room ACs in India

The cost-effective saving potential from consumers' perspective is 62 TWh at bus-bar while the cost-effective saving potential from the utility perspective is found to be 109 TWh at bus-bar in 2030.

5.2 Peak Saving Potential

The following chart shows the peak demand from room ACs in 2020 and 2030. The chart also shows the peak saving potential in the form of wedges; each wedge refers to an efficiency improvement design option presented in section 3.1.

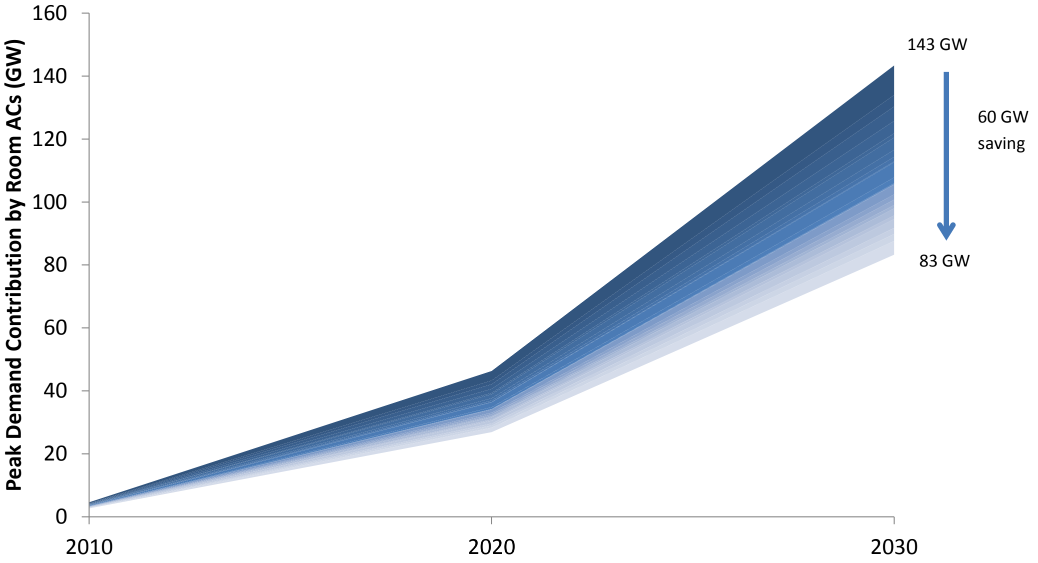

Figure 13: Peak Demand Contribution by room ACs and Peak Saving Potential

By 2030, enhancing the AC efficiency can save nearly 60 GW of peak demand at bus-bar. This is equivalent to saving nearly 120 power plants of 500 MW each. Note that power system has to be planned for meeting the total energy as well as peak demand. High seasonal or diurnal variation in demand makes inefficient use of the generation and transmission assets and therefore increases the total cost of system operation. Reduction in the peak demand lowers the power system investment and also improves the capacity factor of the existing power plants.

6 Conclusions

In this paper, we have showed the design options and estimated the incremental cost for enhancing efficiency of room air conditioners in India. Electricity consumption by room ACs is expected to increase from 8 TWh in 2010 to 239 TWh by 2030. Such growth would have significant impact on the Indian power sector and would require unprecedented construction of new power plants. We find that 40% of the energy consumed by room ACs could be saved cost-effectively by enhancing their efficiency. This translates to a potential energy saving of 118 TWh at bus-bar or a peak demand saving of 60 GW by 2030. This potential saving is equivalent to avoiding the construction of 120 new coal-fired power plants of 500 MW each. In order to realize this large cost-effective potential, a coordinated approach of market push (standards) and market pull (awards, labels, and incentives) is needed. Indian MEPS is one of the lowest in the world; therefore, the stringency level of the standards and labeling program in India need to be revised significantly. In addition, exploring the adoption of a seasonal metric such as SEER, may allow for the efficiency metric to encourage further savings available from ACs that perform well at part load such as those with variable speed compressors. Given that the AC demand reduction is cost-effective from consumer as well as utility perspective, ratepayer funds can be used to undertake incentive programs. Such funds for ACs could potentially be collected from high electricity consumption customers to ensure equity. Because the space cooling demand in India is temporally coincident across regions, the contribution of room ACs to the peak demand could be significant. Therefore, standards for making the room ACs demand response ready are recommended. It is also important to pursue efforts such as improved building design and cool rooms to reduce or postpone the electricity demand from ACs. More research and analysis is required for assessing the use of climate specific space cooling technologies like modified evaporative ACs designed specifically for humid climates. For estimating the peak demand contribution and saving from ACs more accurately, daily and hourly variations in the space cooling demand (i.e. heat indices) should be considered. Therefore, an important future work emerging out of this analysis is developing a methodology for estimating the impact of space cooling demand on the power system more accurately. This analysis could be performed by introducing a random variable for local weather changes, and elementary load-flow analysis.

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