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

Dr. Amol Phadke, Dr. Nikit Abhyankar, and Dr. Nihar Shah

Lawrence Berkeley National Laboratory, Berkeley, USA

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.

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], [2], [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 power plants. 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%.

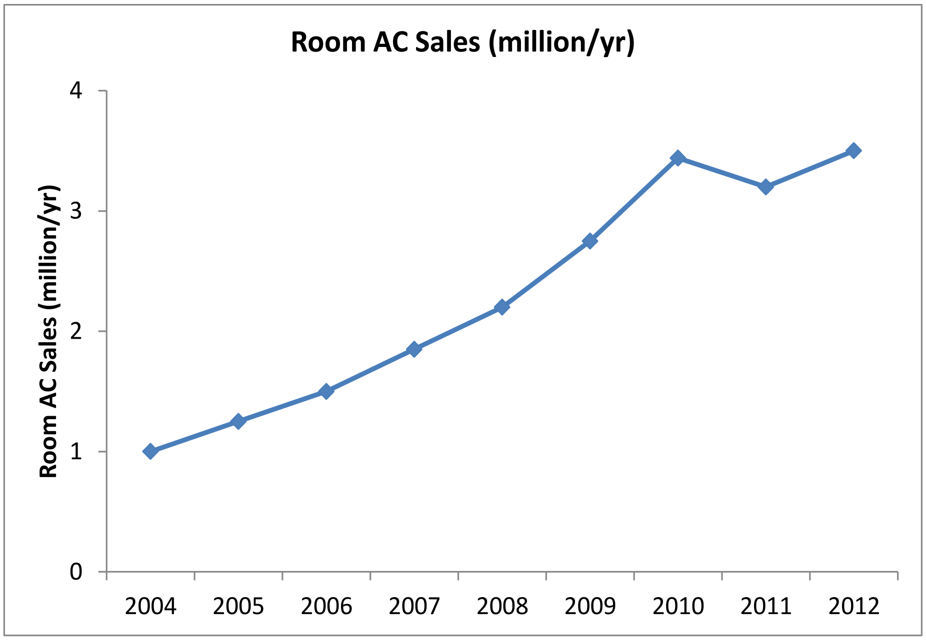


Figure 1: Sales of Room ACs (split and window units) in India

(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 the 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.

[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.

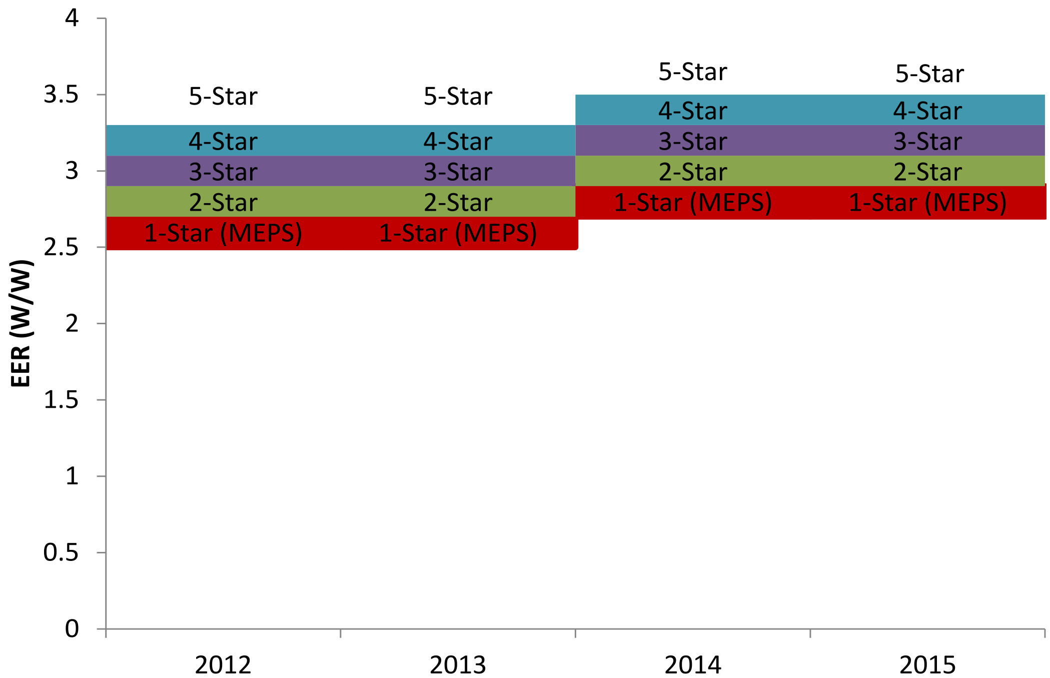


Figure 2: Current and Future Schedule of energy efficiency labels for Room ACs (split units) in India

(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.

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.

Table 1: Minimum, Maximum and Average EER (W/W) in the room AC market (split units) in different countries (illustrative)[2]

	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])

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 cost-benefit 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, 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 Various options to improve 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.

[2] This data should be treated as illustrative as no overlapping datasets were available to cross-check these data points. [9], [10].

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], [11], [12], [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.

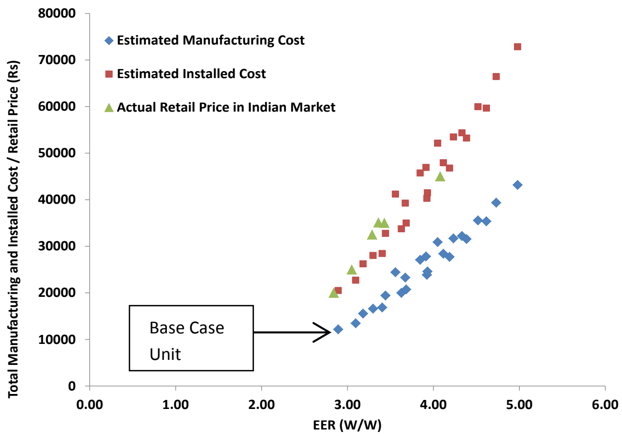


Figure 3: Total Manufacturing Cost, Installed Cost and Actual Retail price for a range of EERs

(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) provides a fuller picture of the energy efficiency of a room AC, since it captures 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. If SEER metric is used, potential energy savings could be higher by nearly 20%, if part load conditions are prevalent often [9]. For more discussion on EER and SEER, refer to [9].

3.3.2 Electricity costs and consumer tariffs in India

Consumer 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. Therefore, most of the marginal generation capacity addition is coming in the form of 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. 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 cost (Rs/kWh)	1
Long Run Delivered cost of electricity supply (Rs/kWh)	5.12

Note: The cost numbers shown here are the 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.

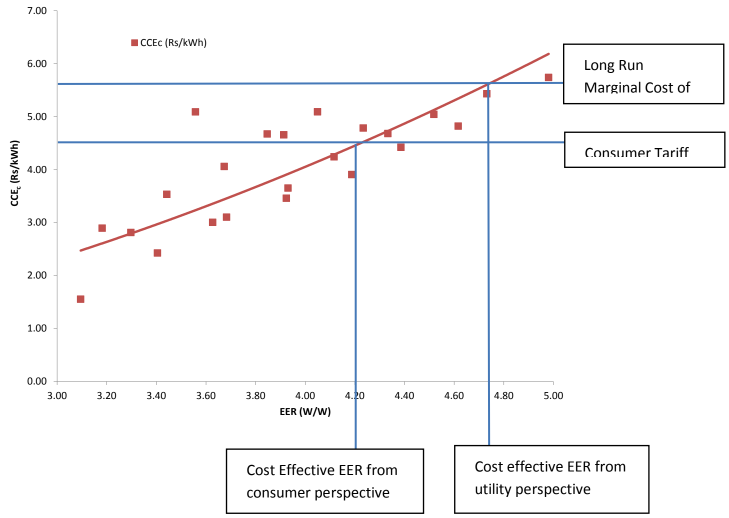


Figure 4: Cost of Conserved Electricity and Cost-effective energy saving Potential

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

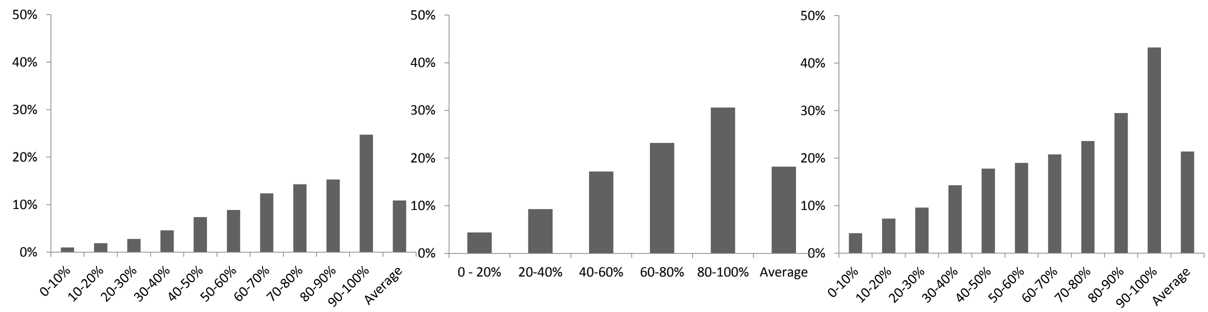
In this section, we estimate the current AC stock in India and project the future demand for air conditioners in India and their contribution to total electricity consumption and peak demand.

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, national level electric load survey is not conducted in India. 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 reports air coolers and air conditioners together. 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], [15])

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.

In major cities like Delhi, where the temperatures and incomes are higher than the national average, the air cooler and air conditioning appliance penetration is significantly higher. Note that, on average, air conditioners account for about 15% of the total air cooler and air conditioner saturation. 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], [16]. This implies that, on average, the saturation of room ACs in the urban Indian households in 2010 was about 3.1% (15% of the air cooler and air conditioner ownership). While average household incomes have risen significantly over the last decade, prices of electrical appliances have dropped in real terms. Most of the major Indian cities are populous and have very high number of cooling degree days compared to other cities in the world.

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. Moreover, a few media reports have indicated that the share of air coolers in the Indian market is slowly being taken over by air conditioners. With rising incomes and falling prices, room AC penetration is expected to increase rapidly in India.

4.2 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]. Because of the factors mentioned in the previous section, we believe that the AC ownership in India is may witness a similar growth. 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. The stock projections 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) (TWh/yr)	8	77	239
Total stock of room ACs (millions)	4	37	116
Room AC penetration in urban areas (total stock as % of urban households)	3%	22%	47%

(Data source: [1], [4], authors' calculations)

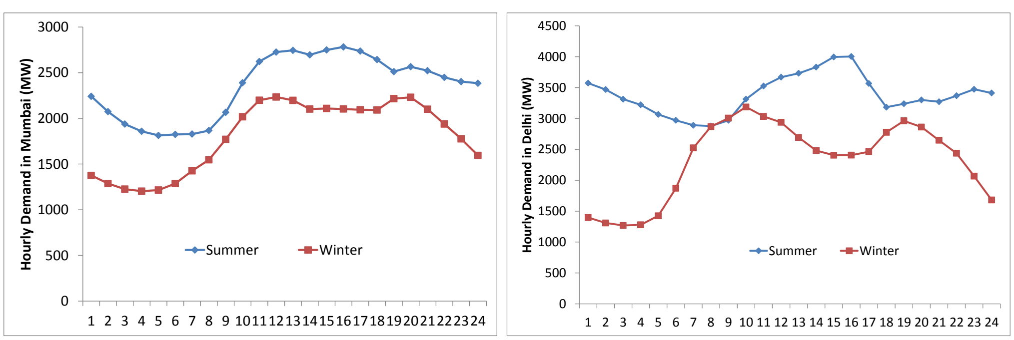
As shown in the table, we estimate that about 22% of the urban households will own a room air conditioner by 2020 and about 47% would own a room air conditioner by 2030. Given the projected incomes and urbanization in India, we believe that these are fairly conservative estimates of the future AC stock.

4.3 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], [16], [17]. 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. But 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**

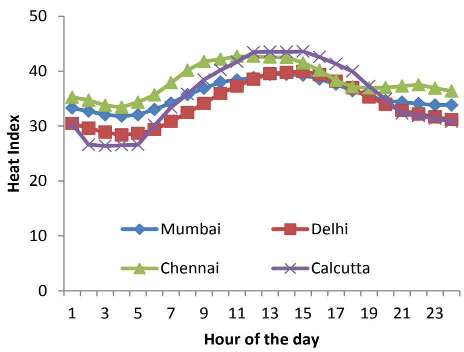
Figure 6: Average Hourly Demands in Summer and Winter in Mumbai and Delhi

(Data Source: [18], [19])

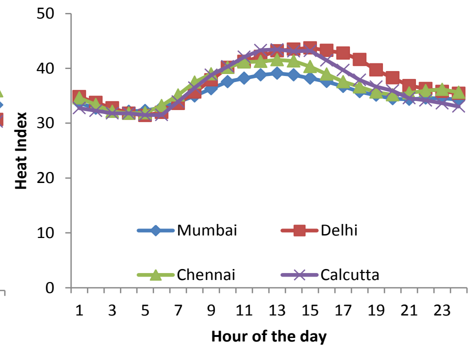
Both Mumbai and Delhi systems are afternoon peaking in the summer; coincidence of the residential and commercial space cooling demand in the afternoon causes the system demands to peak in summer afternoons. Since space cooling is responsible for the seasonal variation in electricity demand in both sectors,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

4.4 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.



(a) May



(b) June

Figure 7: Average Hourly Heat Indices of Major Indian Cities in May and June

(Data Source: [20])

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.

4.5 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. The demand for space cooling would peak during summer afternoons. The following table shows our estimates of the peak demand contribution from room ACs.

Table 5: Projected Peak Demand from room ACs

	2010	**2020**	**2030**
Total stock of room ACs (millions)	4	37	116
BAU Electrical load per AC (W)	1500	1500	1500
Peak Coincidence factor	0.7	0.7	0.7
T & D 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:

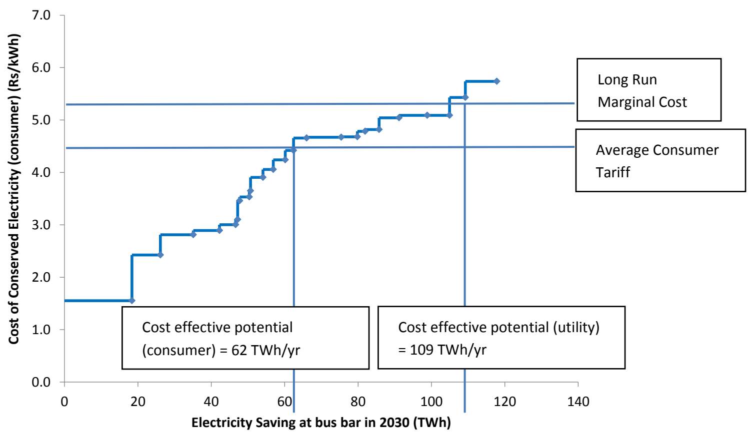


Figure 8: Efficiency Supply Curve in 2030 for Room ACs in India

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.

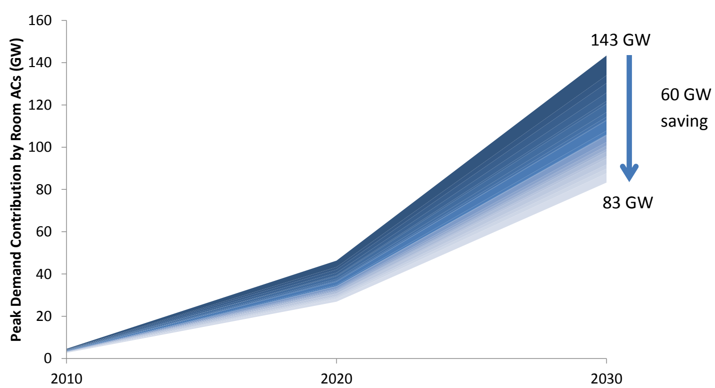


Figure 9: Peak Demand Contribution by room ACs and Peak Saving Potential

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 standards and labeling program in India need to be revised significantly. 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 can 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 would 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 AC demand. 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.

References

[1] NSSO, “Household Consumption of Various Goods and Services in India (2009-2010),” National Sample Survey Organization, Ministry of Statistics and Program Implementation, Government of India, Feb. 2012.

[2] NSSO, “Household Consumption of Various Goods and Services in India, 2004-05,” National Sample Survey Organization, Ministry of Statistics and Program Implementation, Government of India, Apr. 2007.

[3] N. Zhou, N. Zheng, J. Romankiewicz, and D. Fridley, “LBNL China Group Cooperation on Energy Efficiency in China: Standards and Labeling,” Lawrence Berkeley National Laboratory, 2012.

[4] V. Letschert, L.-B. Desroches, J. Ke, and M. McNeil, “Estimate of Technical Potential for Minimum Efficiency Performance Standards in 13 Major World Economies,” Lawrence Berkeley National Laboratory, Jul. 2012.

[5] E. Caliò, “Splits Systems India: A multi client study,” BSRIA, Mar. 2011.

[6] PWC, “Analysis of the impact of super efficiency on AC manufacturers/ suppliers in India,” PriceWaterhouseCoopers India, Jun. 2012.

[7] A. Chunekar, K. Kadav, D. Singh, and G. Sant, “Potential Savings from Selected Super-Efficient Electric Appliances in India,” Prayas Energy Group, Pune (India), Jun. 2011.

[8] MoP, “Energy Consumption Standards for Star Labeled room Air Conditioners.” Ministry of Power (Government of India), Jan-2012.

[9] N. Shah, P. Waide, and A. Phadke, “Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners,” Lawrence Berkeley National Laboratory, 2013, LBNL 6164E.

[10] BEE, “Verified Energy Savings Related with the Activities of ‘Bureau of Energy Efficiency’ for the year 2009-10,” Bureau of Energy Efficiency, Government of India, Sep. 2010.

[11] N. Abhyankar and A. Phadke, “Impact of large-scale energy efficiency programs on utility finances and consumer tariffs in India,” *Energy Policy*, vol. 43, pp. 308–326, Apr. 2012.

[12] BEE, “Verified Energy Savings Related with the Activities of ‘Bureau of Energy Efficiency’ for the year 2008-09,” Bureau of Energy Efficiency, Government of India, Jul. 2009.

[13] A. Garg, J. Maheshwari, and J. Upadhyay, “Load research for residential and commercial establishments in Gujarat,” Energy Conservation and Commercialization (ECO III), Bureau of Energy Efficiency (BEE), Indian Institute of Management Ahmedabad, Mar. 2010.

[14] CompareIndia, “Survey of air conditioners in the Indian market.” Mar-2013.

[15] NSSO, “Consumption of some important commodities in India (1999-2000),” National Sample Survey Organization, Ministry of Statistics and Program Implementation, Government of India, Jul. 2001.

[16] NDPL, “Load research survey,” North Delhi Power Limited, 2011.

[17] N. Abhyankar, “Load Survey of Residential and Commercial Consumers in Maharashtra,” Lawrence Berkeley National Laboratory (forthcoming), 2011.

[18] MSLDC, “Hourly Demand Data from the State Load Dispatch Center.” Maharashtra State Load Dispatch Center, 2012.
[19] DSLDC, “Hourly Demand Data from the State Load Dispatch Center.” Delhi State Load Dispatch Center, 2012.
[20] ASHRAE, “International Weather for Energy Calculaions (Database),” American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2012.