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Cost-Benefit of Improving the Efficiency of Room Air Conditioners (Inverter and Fixed Speed) in India

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Executive Summary

Improving efficiency of air conditioners (ACs) typically involves improving the efficiency of various components such as compressors, heat exchangers, expansion valves, refrigerant and fans.[1] We estimate the incremental cost of improving the efficiency of room ACs based on the cost of improving the efficiency of its key components. Further, we estimate the retail price increase required to cover the cost of efficiency improvement, compare it with electricity bill savings, and calculate the payback period for consumers to recover the additional price of a more efficient AC. We assess several efficiency levels, two of which are summarized below.

Table S1: Cost-benefit of efficiency improvement from a consumer perspective

ISEER[2] (Watt/Watt)	**Retail price increase required to cover the cost of efficiency improvement (Rs. %)**		**Net consumer savings = Bill savings over lifetime – increase in retail price (Rs.)**		**Simple payback period (years)**	
	Average estimate	Range with sensitivity analysis	Average estimate	Range with sensitivity analysis	Average estimate	Range with sensitivity analysis
Improvement from 2.8 to 3.5	4900 (~15%)	2450-7350 (7-20%)	26300	23700-29000	0.7	0.4-1.1
Improvement from 2.8 to 4	10000 (~30%)	5000-15000 (15-50%)	34100	30700-37500	1.5	0.8-2.3

Note: Assuming a least cost strategy to improve efficiency based on the cost of efficient components

The finding that significant efficiency improvement is cost effective from a consumer perspective is robust over a wide range of assumptions. If we assume a 50% higher incremental price compared to our baseline estimate, the payback period for the efficiency level of 3.5 ISEER is 1.1 years. Given the findings of this study, establishing more stringent minimum efficiency performance criteria (one star level) should be evaluated rigorously considering significant benefits to consumers, energy security and environment.

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[1] Improvements in efficiency due to switching to low-GWP refrigerants are between +/-10%. Since alternate refrigerants are still being tested and not commercialized yet in any equipment, we do not consider them here. See (Shah et al 2015) for more details.

[2] In 2015, BEE adopted the ISO 16358 standard but modified the temperature bin distribution to account for the hotter weather in India. BEE has developed the ISEER metric to be able to capture the seasonal energy efficiency performance of both fixed speed and inverter ACs. Hence we use ISEER as the room AC performance metric for this analysis. The units for this metric are Watt/Watt or W/W.

Introduction

Recent studies by the US Department of Energy, the European Ecodesign Initiative and the Super-efficient Equipment and Appliance Deployment (SEAD) Initiative have shown significant cost effective potential for improving room air conditioner efficiency (DOE, 2011, EuP, 2009, Shah et al, 2013, Phadke et al, 2013). In this paper, we assess the cost and benefit of improving the efficiency of Room ACs using recently collected data in India on the cost of key components of a Room AC with improved efficiency.

Cost-benefit of efficiency improvement for a Room AC from a consumer perspective can be assessed by comparing the additional price of an efficient product with reduced electricity bills. One simple approach to estimate the additional price for efficiency improvement is to compare the prices of baseline efficiency products to efficient products available in the market. However, in several instances, efficient products (for example five star ACs)[3] are sold as premium products with additional features bundled with efficiency and are likely to have higher cost margins.[4] Hence the price difference between a baseline efficiency model (one star or two stars) and a higher efficiency model (five star) could be due to several factors in addition to efficiency and is typically significantly higher than what is required for just improving efficiency. Although statistical approaches can be used to estimate the price increase due to efficiency alone based on prices observed in the market, they face several limitations including the inability to estimate varying profit margins across products. Further, assessment based on retail prices alone cannot provide estimates of costs of improving the efficiency beyond what is currently available on the market in a certain region or a country.

The retail price increase required to cover the cost of efficiency improvement can be based on a bottom up estimate of the incremental cost of efficiency improvement and an estimate of the price based on an estimate of the mark-up seen for baseline models which cover typical wholesale and retail costs. This has been the preferred methodology in the US and EU to assess the impact on consumers of increasing the stringency of the minimum energy performance standard (MEPs) which specify the minimum efficiency requirement for a product to be sold in the market. This approach is used because the current price of an efficient product (e.g., a five star AC) is not a good predictor of its future price if it becomes the baseline product (e.g. a one or two star AC) with a revision of the stringency of MEPs given that baseline products are likely to have lower margins. Studies have shown that the price of efficient products (which are typically sold as premium products) drops when they become the base-line products with the increasing stringency of MEPs (see Spurlock, 2014). Further, as discussed previously, a bottom up estimate of incremental costs is possible even for efficiency levels that are currently not available in a particular region or country. Next, we summarize this bottom up methodology which we use in this study.

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[3] Room AC efficiency in India is rated through a “star rating system” established by the Bureau of Energy Efficiency. Efficiency levels progress from one-star which is the lowest efficiency to five-star which is the highest efficiency rating in the system. The rating is revised approximately every two years.

[4] Examples of some non-energy related features are sleep mode of operation, air filtering, occupancy and image sensors, ionization etc.

Summary of Methodology

Based on the estimates of reduction in AC electricity consumption due to improvement of efficiency of its key components, we analyze the performance of an AC under several configurations of more efficient components (288 unique design combinations, for example of different compressor and heat exchanger designs)[5]. Since our analysis is based on the EU Ecodesign preparatory study, the AC performance is analyzed using energy savings estimates in that study. From these we estimate AC performance in the Indian SEER (ISEER metric) by developing a relationship using performance data between the ISEER and EER for fixed speed ACs and a relationship between the ISEER and the EUSEER for variable speed ACs considering the temperature profile specified by the Bureau of Energy Efficiency (BEE) for the ISEER metric.[6]

Based on the cost estimates of more efficient components and the results of the analysis, we estimate the incremental cost of each design combination. We then estimate the lowest cost design configuration to reach a certain level of efficiency to develop a cost curve for efficiency improvement. Note that we use estimates of cost of more efficient components in India that were developed by the Collaborative Labels and Standards Project (CLASP) and Price Waterhouse Coopers (PWC) using market research and interviews with appliance and component manufacturers.

We then estimate the price increase required to cover the cost of efficiency improvement based on estimates of mark-ups to cover wholesale and retail costs, profit margins, and taxes, reported in CLASP, 2015. We estimate the electricity bill savings due to efficiency improvement and compare these with the price increase required for improving efficiency to estimate payback periods, life cycle costs, and net consumer benefits. See Figure 1 below for the summary of this methodology.

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[5] The permutations and combinations of different design options to improve efficiency shown in Table 1 below with each other leads to 288 unique designs of different compressors, heat exchangers, expansion devices and fixed or variable speed drives.

[6] While the EU energy savings estimates are evaluated at the ISO 5151 T2 conditions and the ISEER is evaluated at ISO 5151 T1 test conditions, we assume that the energy performance of both the baseline and more efficient ACs shown in Table 1 below is affected similarly at higher temperatures as a first order approximation.

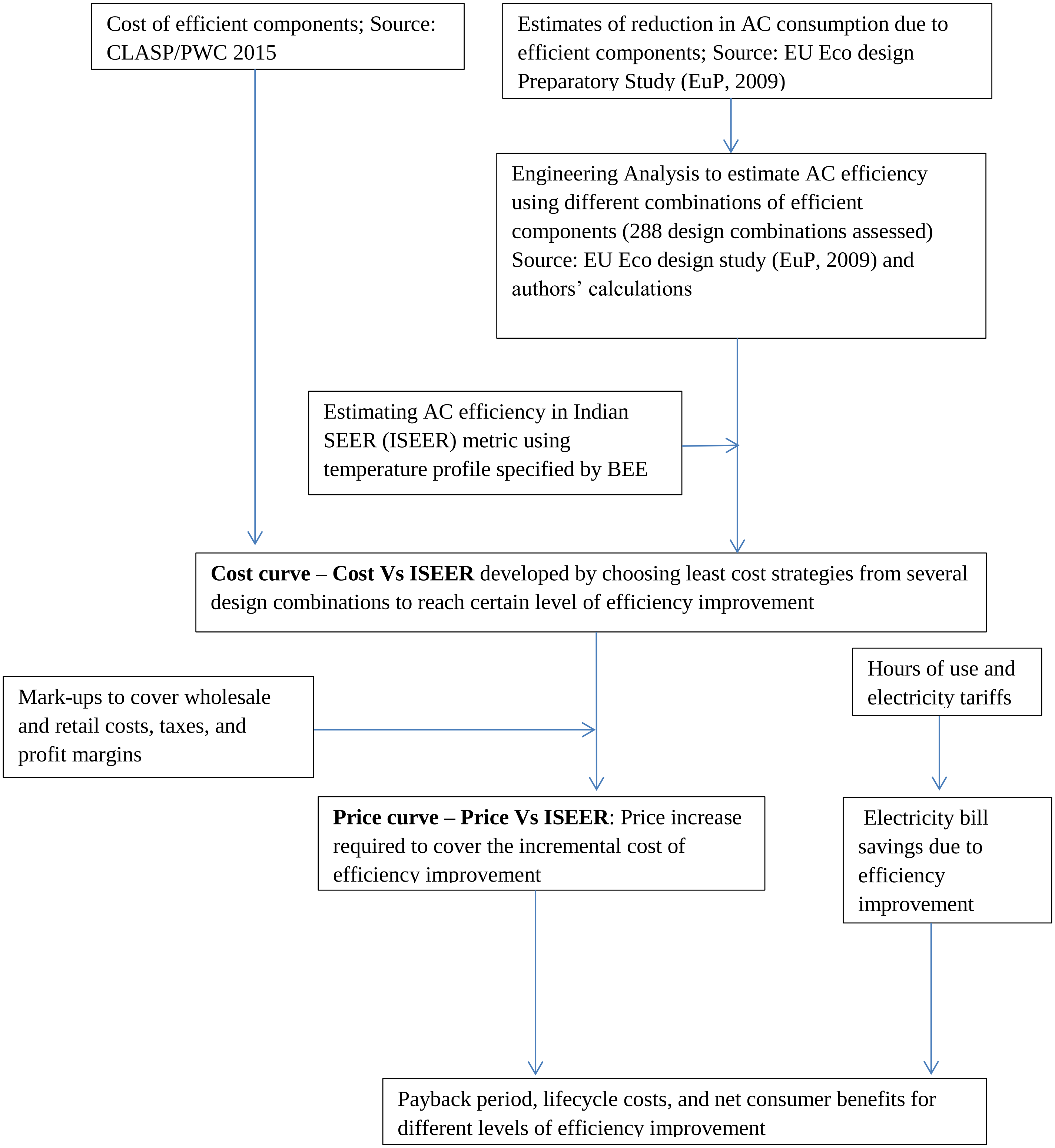

Figure 1: Methodology for estimating payback period, lifecycle cost and consumer benefits from increased efficiency

Methodology Validation

We provide an explanation of why a certain design combination leads to a particular level of efficiency improvement and also provide an estimate based on a simple and transparent engineering analysis. Further, we show that the efficiency levels analyzed are widely commercially available in the global market by identifying models which reach those efficiency levels. We also provide an initial validation of our price prediction for higher efficiency models by observing prices of such models in the global market.

Detailed Methodology

Incremental Costs of Efficiency Improvement

We use a methodology similar to those used in the US and EU Minimum Energy Performance Standards (MEPS) rulemaking process to the estimate the incremental cost of efficiency improvement based on the incremental cost of key components used in higher efficiency ACs. We use estimates of energy savings for the AC as a whole from using more efficient components that were assessed by the EU Ecodesign preparatory study.

Table 1 summarizes the key efficiency improvement options using efficient components and corresponding energy savings estimates based on the EU Ecodesign study. Appendix C discusses these energy efficiency options in more detail. The cost estimates of the efficiency improvement for the components considered in this study were recently collected by CLASP and PWC through interviews with AC and component manufacturers in India (CLASP, 2015).

Table 1 shows that improving the efficiency of a compressor from 2.8 EER to 3.2 EER will reduce the AC electricity consumption by about 10%. This is because such improvement in the efficiency of the compressor will reduce the electricity consumption of the compressor by about 13%. We assume that the compressor consumes about 60-80% of the energy consumed by the AC varying by load and operating conditions, it will lead to overall electricity consumption reduction of approximately 10%.

Table 1: Component-wise incremental costs of efficiency improvement for 1.5 ton ACs (Source: CLASP and PWC, 2015)

Component	Energy Savings from Base Case[1]	Incremental Manufacturing Cost (Rs)		Retail Price Increase from Base Case (Rs) [2]	
		Baseline	**Range** (50% lower to 50% higher than baseline)	**Baseline**	**Range**
Baseline Compressor (2.8 EER), 1.5 TR Cooling Capacity	-	-		-	
3.0 EER compressor	5.5%	200	100-300	480	240-720
3.2 EER compressor	10.5%	400	200-600	960	480-1440
3.4 EER compressor	15.0%	575	280-860	1,380	690-2070
Alternating Current Compressor variable speed drive	21.0%	3,600	1800-5400	8,640	4320-12960
Direct Current Compressor variable speed drive	23.0%	5,400	2700-8100	12,960	6480-19440
Variable speed drives for fans and compressor	26.0%	6,300	3150-9450	15,120	7560-22680
UA value of both heat exchangers increased by 20%	7.5%	1,470	735-2200	3,528	1760-5290
UA value of both heat exchangers increased by 40%	13.5%	3,240	1620-4860	7,776	3880-11660
UA value of both heat exchangers increased by 60%	17.5%	4,210	2100-6310	10,104	5050-15150
UA value of both heat exchangers increased by 80%	21.0%	6,080	3040-9120	14,592	7300-21890
UA value of both heat exchangers increased by 100%	24.0%	7,350	3675-11000	17,640	8820-2640
Thermostatic Expansion Valve	3.5%	250	125-375	600	300-900
Electronic Expansion Valve	6.5%	1500	750-2250	3600	1800-5400

[1] Energy savings estimates are based on EuP, 2009 energy savings data as per EU test procedure. These will be different if the ISEER metric is used. We apply an additional adjustment for conversion of these values to ISEER as discussed above.

[2] Estimates based on reported component costs from CLASP, 2015 and a markup of 140% for assembly, wholesale and retail costs and taxes as discussed earlier. PWC and CLASP estimate manufacturing cost of a baseline model to be 14500 (see Appendix B) and a price of baseline model to be 34,800 which indicates a mark-up of 140%. Cost for Thermostatic Expansion Valve is interpolated based on EuP, 2009 and reported cost for Electronic Expansion Valve based on CLASP, 2015.

Several combinations of efficient components can be used to reduce the consumption of an AC and reach a certain efficiency level. We draw upon the simulations of AC performance with different design combinations of efficient components conducted in the EU Ecodesign study. Note that the EU Ecodesign study verified the simulated performance using actual performance data on efficient ACs. Since that study reported AC performance in EU SEER metric, we discuss how we adjusted these estimates for our analysis to report AC performance in the ISEER metric by taking into account the temperature profile specified by BEE for the ISEER metric.

Estimating AC Performance in the ISEER Metric

Most countries in the world, including India and the EU use the International Organization for Standardization (ISO) standard 5151 test procedure for testing the performance of room ACs.

Until 2014, the standards and labeling program in India only covered fixed speed ACs and the prevalent metric to measure Room AC performance was the Energy Efficiency Ratio (EER). In 2013, the ISO issued the ISO standard 16358 procedure for calculating the seasonal performance metric for both fixed-speed and inverter ACs using a weighted average based on a standard temperature bin distribution, of AC performance using ISO 5151 test data. For cooling only operation, this metric is known as the cooling season performance factor (CSPF).

In 2015, BEE has adopted the ISO 16358 standard but modified the temperature bin distribution to account for the hotter weather in India to calculate the Indian SEER (ISEER) metric for fixed speed and inverter ACs. BEE has developed the ISEER metric to measure the performance of Room ACs in India in the future. Hence we use ISEER as the room AC performance metric for this analysis. The units for this metric are Watt/Watt or W/W.

Based on this Indian temperature distribution, and test data on several AC models, we established a relationship between the ISEER and EER for fixed speed ACs and ISEER and EU SEER for variable speed ACs based on performance data of variable speed AC models.

An Illustrative Example: Design combinations and incremental cost of increasing ISEER from 2.8 (W/W) to 3.5(W/W)

Although several combinations of more efficient components can be used to improve the AC efficiency, as an example, we consider efficiency improvement in two components, the compressor and the expansion valve.

Based on the preparatory study done for the EU Ecodesign regulation (EuP, 2009) the baseline room AC model with 2.8 EER uses a 2.8 EER compressor and a capillary tube expansion valve.[7]

Based on the data in Table 1, using a 3.4 EER compressor instead of 2.8 EER compressor reduces the electricity consumption of the baseline room AC by 15%. The estimate of 15% energy savings are verified with actual performance measurements conducted as part of the EU Ecodesign study. Improving the EER of a compressor from 2.8 to 3.4 will reduce the compressor electricity consumption by roughly 21% (3.4/2.8-1) and given that compressor accounts for about 70% of the electricity consumed by the AC, it reduces the energy consumption of the AC by about 15%. Using heat exchangers with UA value 20% higher than the baseline model increase energy savings by about 7.5% of a baseline AC model. The engineering simulations shown in the EU Ecodesign Study show that by using these two options, the consumption of the baseline AC can be reduced by 20%. If improving the efficiency of the compressor and using an electronic expansion valve reduces the AC energy consumption by 15% and 7.5%

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[7] Note that the 2.8 EER is roughly equivalent (after rounding) to a 2.8 ISEER level for fixed speed ACs.

respectively, simultaneously implementing these options will reduce the AC energy consumption by roughly [1- (1-0.15)*(1- 0.075)] = 0.21, i.e., just over 21%. This is because reduction due to a second option applies to the already reduced energy consumption from the first option and hence the total energy savings are less than a simple addition of savings from the two options. Incremental cost of improving the ISEER from 2.8 to 3.5 is Rs. 2045 (Rs. 575 for the efficient compressor + Rs. 1470 for the efficient heat exchangers)

Price Increase Required to Cover the Cost of Efficiency Improvement

The price increase required to cover the cost of efficiency improvement is estimated as:

Price increase required = incremental cost of efficiency improvement*mark-up for a baseline product

Mark-up is estimated based on estimates of manufacturing costs and the retail prices observed in the market. Based on the PWC-CLASP 2015 report, manufacturing cost of a baseline 1.5 Ton Room AC is about Rs. 14500 and the retail prices of baseline (1-2 star) models is about Rs. 34,800.[8] Hence the total mark-up for base line products in the market is about 140% which means that cost increase of Rs. 1000 to improve efficiency will require a price increase of approximately Rs. 2400 to cover items such as profit margins, wholesale, and retail costs. Across many markets the markup for baseline models is found to stay the same even after the revision of MEPS (Spurlock, 2013) i.e. in the Indian context, even if the star labels are revised the markup for one and two star products (entry-level) is expected to remain the same. Figure 2 shows a sensitivity analysis of the retail prices for 50% higher and lower costs.

The mark-up for a 5 star high efficiency models on the market may be higher due to other non-efficiency related features and also because these products are marketed as “premium” products implying other pricing and brand positioning strategies. The markup on premium products is between 200-240% based on data collected by CLASP.

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[8] Source: CLASP

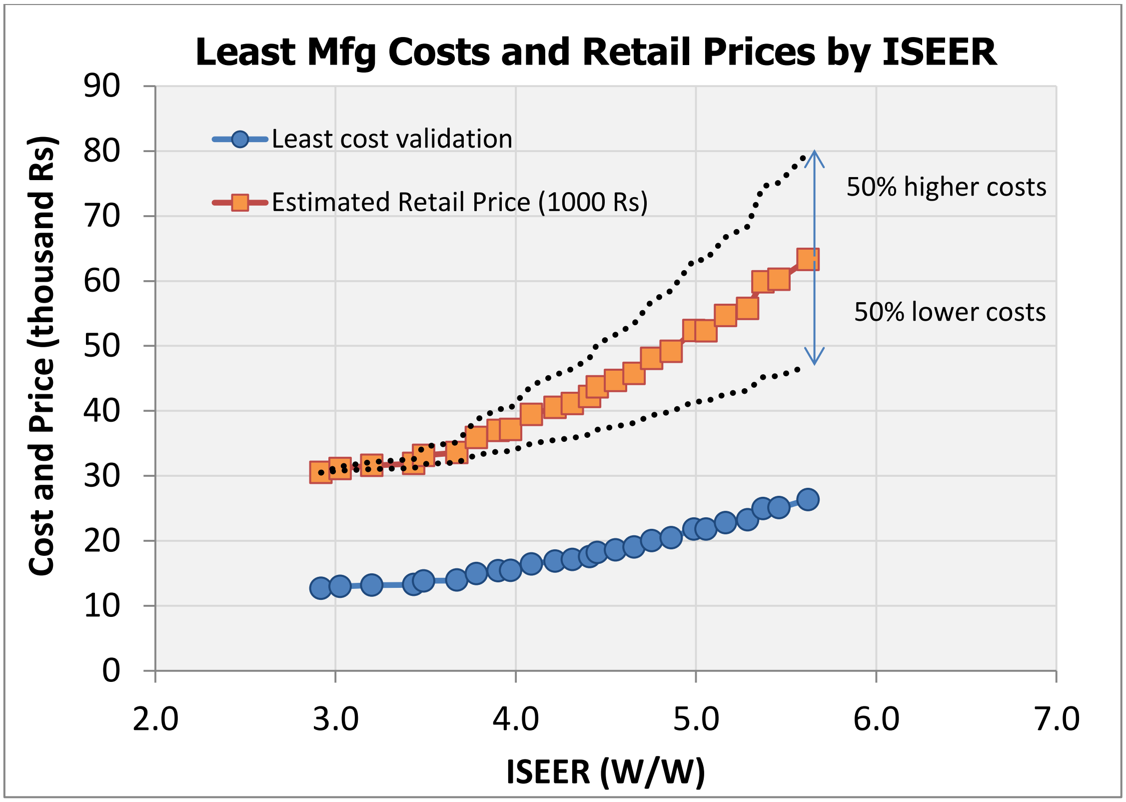

Figure 2: Sensitivity analysis for total markup. Total markup is assumed to be 140%.[9]

Alternative Strategies to Reach ISEER of 3.5 and Estimates of the Price Increase

Incremental cost of improving the ISEER from 2.8 to 3.5 is about Rs. 2045 (Rs. 575 for the efficient compressor + Rs. 1470 for efficient heat exchangers) and will require a retail price increase of Rs. 4900 (based on a 140% mark-up) to cover the incremental cost of efficiency improvement.

In arriving at an estimate of the incremental cost of efficiency improvement as discussed above, we estimated the least cost approach to improving efficiency based on the cost data collected by PWC and CLASP. However, various manufacturers may have other approaches to arrive at the same level of efficiency. In Table 2 below, we outline various ways to achieve the ISEER level of about 3.5 (W/W) and estimate additional manufacturing costs, retail prices (assuming 140% markup), annual bill savings, and payback periods. Annual bill savings are estimated assuming 1600 hours of operation per year (based on hours of use specified by the Bureau of Indian Standards) and an electricity tariff of Rs. 7/kWh which is typical tariff for residential consumers in higher consumption slabs given that use of AC corresponds to being in a higher consumption slab. Note that we test the sensitivity of our findings to alternative assumptions of hours of use and electricity tariffs.

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[9] ISEER levels calculated are shown for an India-specific temperature distribution being considered by India's Bureau of Energy Efficiency (BEE) that considers temperatures from 24 deg. C to 43 deg. C and considering 1600 hours of use annually.

Table 2: Range of additional manufacturing costs, retail prices, and payback period for achieving ISEER of 3.5 W/W

ISEER (W/W)	Compressor	Heat Exchanger	Expansion Valve	Incremental Manufacturing Cost (Rs.)	Additional Retail Price (Rs.)	Electricity Consumption (kW)	Annual Energy Consumption (kWh/yr)	Annual Bill Saving (Rs/yr)	Payback Period (yrs)
3.5	3.4 EER Compressor (Rs. 575)	UA value of HX increased by 20% (Rs. 1470)	Capillary Tube	2045	4908	1.5	2400	4200	1.2
3.5	3.2 EER Compressor (Rs. 400)	UA value of HX increased by 40% (Rs. 3240)	Capillary Tube	3640	8736	1.5	2400	4200	2.1
3.5	3.0 EER Compressor (Rs. 200)	UA value of HX increased by 40% (Rs. 3240)	Thermostatic Expansion Valve (Rs. 250)	3690	8856	1.5	2400	4200	2.1

Least Cost Curve for Improving Efficiency

Based on the data on costs of and savings due to efficient AC components (shown in Table 1), we estimated efficiency improvements and incremental costs of all possible design combinations (288) of efficient components (e.g. more efficient heat exchangers, compressors, variable speed drives, and expansion valves) to estimate the lowest cost of improving efficiency of a Room AC at various levels of efficiency improvement.

This cost versus efficiency curve (see Figure 2) approximates the decisions undertaken by manufacturers in designing higher efficiency air conditioners. As seen in Figure 2, if least cost strategies are implemented, an energy efficiency improvement of approximately 20% (to an ISEER of 3.5 W/W) can be achieved at a relatively modest incremental retail price of about 15% and a more substantial increase in energy efficiency of approximately 30% (to an ISEER of 4 W/W) can be achieved at an incremental price of Rs 9360 (~27%).

Figure 2 also shows retail prices where the incremental cost of the components is 50% higher and 50% lower than our baseline estimates. Studies have shown that the actual incremental costs and prices are typically significantly lower than those estimated by bottom up analysis because such analyses do not taken into account future price reduction in efficient technology due to learning or economies of scale (see Dale et al., 2013 and Taylor et al, 2015). We show the effect of such a scenario by showing retail prices assuming 50% lower incremental manufacturing costs for efficient components. We also model a scenario where incremental manufacturing costs are 50% higher to test the robustness of finding if costs are higher than what we have estimated.

We have also shown actual retail prices of split room AC models in India and Korea to provide an initial validation of our price predictions. For India, we have shown prices of 1.5 Ton models only.

Note that while improving the efficiency of Room ACs, manufacturers may consider criteria other than cost and hence the strategies arrived with a least cost criteria may not always mimic the design decisions of the manufacturers. Our cost-benefit analysis, which considers a least cost for efficiency improvement strategy, suggests adoption of inverters only beyond ISEER of 4.5.

Engineering based techno-economic analysis including this analysis typically show that improving efficiency adds to costs which leads to increase in retail prices at a given point in time. However, several studies tracking efficiency and price trends over time have shown that efficiency of appliances and their components improves over time while the prices continue to decline. For example in Japan, between 1995 and 2008, efficiency improved by 180% while prices dropped by over 50 % in real terms (See Appendix B for details). While, several factors such as economies of scale, and changes in mark-ups have been identified as potential drivers for this overall trend, the primary driver is likely technological learning. Hence the revision of the stringency of the minimum energy performance standard (one star level) *may not* result in increase in prices in real terms compared to the levels before the revision. For example, a more stringent standard could speed up technological change or increase economies of scale in production of the new minimum efficiency level products, thereby reducing the prices of those products further than this bottom-up engineering analysis reflects.

Commercial Availability of Efficient ACs

Given that the current labeling program in India only covers fixed speed ACs, independent information from the Indian market on performance is only available for fixed speed ACs. Currently, Godrej's NXW inverter AC which with an estimated ISEER of 5.2 is one of the most efficient inverter AC on the Indian market and is sold at Rs. 57,500.[10]

Cost-Benefit of Efficiency Improvement from a Consumer Perspective

Figure 2 above shows the estimates of retail price increases required to cover the cost of efficiency improvement which the consumers have to bear. Efficiency improvements also lead to reduced electricity consumption and bills. Table 3 below shows increase in retail prices, consumer bill savings over the lifetime of the ACs, consumer payback period, and the return on consumer investment (due to increased retail price) given the bill savings.

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[10] see:http://www.godrejappliances.com/GodrejAppliances/product.aspx?id=6&menuid=346&catid=92&productid=4153&subcatid=122&subsubcatid=736

Table 3: Bill savings, payback period, and return on investment (ROI) for consumers for more efficient ACs compared to a baseline AC with ISEER of 2.8.

ISEER (W/W)	**Retail price increase required to cover the cost of efficiency improvement (Rs. %)**	**Bill savings per year for 1000 & 1600 hours of use (Rs.)**	**Bill savings over lifetime for 1000 & 1600 hours of use (Rs.)**	**Simple payback period for 1000 & 1600 hours of use (years)**
3.5	4900, ~15%	2625 -4200	18300 -29400	1.9-1.2
4	9360, ~27%	3950- 6300	27500-44100	2.4-1.5

Note: Electricity tariff of Rs. 7/kWh which is typical tariff for residential consumers that are likely to have ACs; lifetime of seven years based on anecdotal evidence; Simple payback period is calculated by dividing the incremental cost of an efficient AC by the corresponding annual electricity cost savings.

Table 3 shows that modest price increase required to cover the cost of efficiency results in significant bill savings leading to a short payback period. These results indicate that increasing stringency of MEPs is likely to lead to large consumer benefits.

Based on the incremental costs in Table 1, and as discussed in the example above, Figure 3 shows the simple payback period (in years) corresponding to various energy efficiency levels. Dotted lines show payback periods if the costs were assumed to be 50% higher and 50% lower at each efficiency level. Simple payback period is calculated by dividing the incremental cost of an efficient AC by the corresponding annual electricity cost savings.

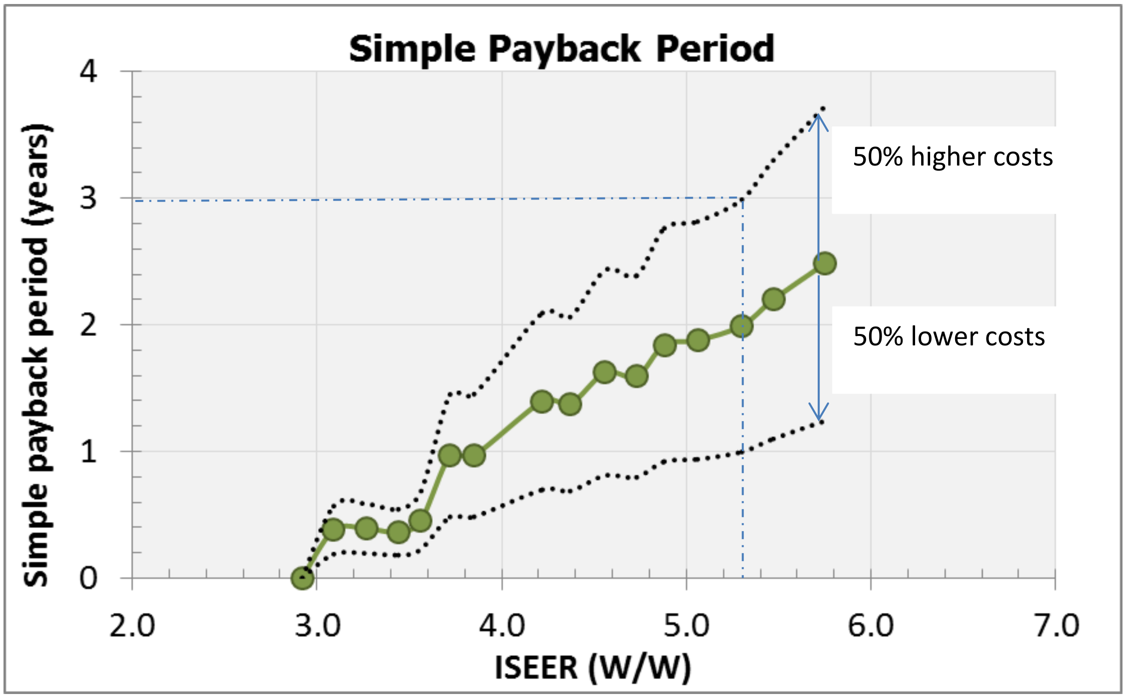

Figure 3: Payback Period versus increased efficiency for room ACs in India

Note: Payback periods are estimated assuming the average electricity price of Rs 7/kWh. Life of an AC is assumed to be 7 years.

If one considers a three year payback as a criterion for consumer cost effectiveness, efficiency improvement of ISEER from 2.8 to over 5.2 ISEER is cost effective depending on the assumptions about costs.

Consumer benefits and payback period depends on their electricity tariff. Table 4 shows alternative assumptions tested and the corresponding payback period ranges for 3.5 ISEER and 4.0 ISEER for a range of electricity tariffs.

Table 4: Sensitivity of payback period estimates to electricity prices and incremental costs

Base case electricity price	Sensitivity case electricity price	Rationale	Effect on payback period for 3.5 ISEER (yrs)[11]	Effect on payback period for 4.0 ISEER (yrs)
Rs. 7/kWh	Rs5-10/kWh	Tariffs vary across states and consumer categories. In some states commercial tariffs are as high as Rs. 10/kWh whereas for some exceptions, tariffs are as low as Rs 5/kWh for residential consumers for the appropriate slab (higher consumption slab)	0.5-1.0	1.1-2.1

Consumer benefits will be lowest in the scenario where electricity price and hours of use are lower and incremental price is higher. Even in such a scenario, the payback period for improving the ISEER to 3.5 is less than three years indicating significant net consumer benefits even under such an unlikely worst case scenario from a consumer benefits perspective.

Conclusions

If a least cost strategy is followed, significant efficiency improvement can be achieved at a modest incremental cost which requires a modest increase in retail price. This price increase will be paid back relatively quickly through electricity bill savings.

- ISEER improvement by 20% to 3.5(W/W) will require a retail price increase of Rs. 4900 (~15% increase over baseline) to cover the cost of efficiency improvement.
- ISEER of a Room AC improvement by over 30% to 4(W/W) will require a retail price increase of Rs. 9360 (~27% increase over baseline) to cover the cost of efficiency improvement.
- Increasing the stringency of MEPS is one of the key strategies to ensure improvement in the efficiency of the AC models sold in the market and should be evaluated rigorously considering the findings of this study.

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[11] Please note that higher electricity prices result in lower payback period as the electricity bill savings from efficiency are higher. Hence the 5Rs/kWh electricity price obtains the higher range of payback periods, i.e. 1.0 year for a 3.5 ISEER and 2.1 years for a 4 ISEER efficiency level, while the 10Rs/kWh electricity price results in the lower range of payback periods i.e. 0.5-1.1years for 3.5 and 4 ISEER efficiency levels respectively. The payback periods are presented in ascending order for the ease of the reader.

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Appendix A: Trends in Efficiency and Prices for Room ACs and Appliances

Table A-1: Nominal wholesale price indices of various appliances and commodities in India Data Source: (OEA 2009; OEA 2013)

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Air Conditioners	93.9	83.7	90.0	87.8	86.7	87.8	89.0	81.4	80.0	76.0	70.7	69.0	62.9	67.3	68.6	65.2	72.2	65.3	69.4
Cereal + Pulses	113.1	121.4	132.5	139.8	146.6	173.6	175.1	172.4	172.7	176.3	176.6	183.4	201.2	213.8	227.5	260.7	305.1	351.0	386.4
Electricity (Domestic)	111.3	120.1	128.9	153.6	160.5	174.9	194.9	220.3	234.3	248.0	256.8	254.2	258.6	265.8	268.9	275.2	276.3	295.4	311.0
Petrol	106.5	106.5	122.9	142.3	148.3	147.9	151.3	159.8	158.2	175.2	197.9	223.4	253.4	242.5	264.5	237.3	266.6	362.4	422.9
Average (All Commodities)	111.2	120.2	125.6	131.3	138.9	143.8	152.8	160.7	164.7	173.4	184.9	193.7	203.0	212.8	232.2	237.1	253.4	290.9	332.2
TV	106.5	96.3	95.2	86.6	66.8	62.6	63.2	69.1	67.8	63.2	54.0	48.7	42.8	37.2	37.1	37.1	36.1	30.4	26.6
Ceiling Fans	108.4	111.1	115.4	119.4	124.0	135.6	145.9	156.6	163.7	169.9	170.9	168.6	165.1	166.3	176.0	175.7			
Tubelights	91.5	89.5	87.5	94.8	98.3	104.6	106.2	106.3	106.3	106.3	107.7	109.5	109.5	102.2	96.6	104.7	108.0	103.9	92.4
Electricity (Average)	113.6	124.2	132.1	147.2	154.6	165.3	191.6	219.3	236.0	246.2	252.2	260.9	269.6	272.8	275.9	275.7	280.2	305.1	313.8
Refrigerator														93.77	94.55	95.90	102.68	118.97	119.62

Table A-2: Real (inflation adjusted) wholesale price indices of various appliances and commodities in India Data Source: (OEA 2009; OEA 2013)

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Air Conditioners	84	70	72	67	62	61	58	51	49	44	38	36	31	32	30	27	28	22	21
Cereal + Pulses	102	101	105	106	106	121	115	107	105	102	96	95	99	100	98	110	120	121	116
Electricity (Domestic)	100	100	103	117	116	122	128	137	142	143	139	131	127	125	116	116	109	102	94
Petrol	96	89	98	108	107	103	99	99	96	101	107	115	125	114	114	100	105	125	127
Average (All Commodities)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
TV	96	80	76	66	48	44	41	43	41	36	29	25	21	17	16	16	14	10	8
Ceiling Fans	97	92	92	91	89	94	95	97	99	98	92	87	81	78	76	74	0	0	0
Tubelights	82	74	70	72	71	73	70	66	65	61	58	57	54	48	42	44	43	36	28
Electricity (Average)	102	103	105	112	111	115	125	136	143	142	136	135	133	128	119	116	111	105	94
Refrigerator													90	85	82	81	91	83	76

Note: All prices are converted to 1994 base year and compared with the average WPI for all commodities. The 2009 OEA report used 1994 as the base year series and the 2013 report used 2005 as the base year.

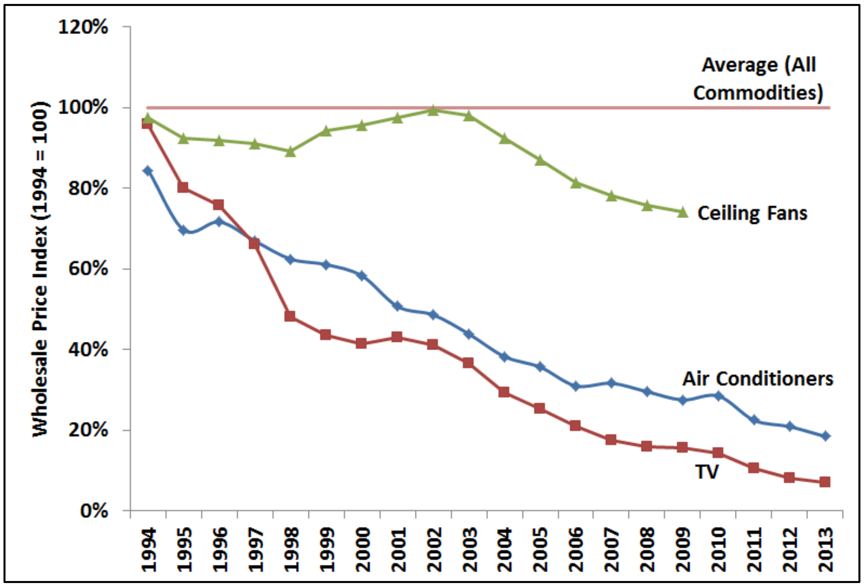
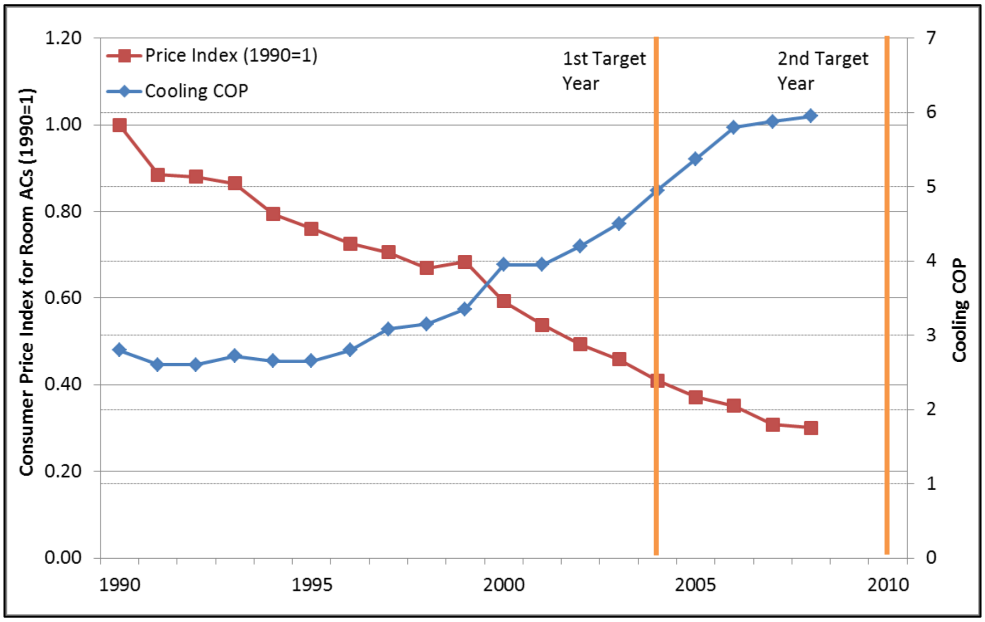


Figure A-1: Real (inflation adjusted) prices of various appliances in India Data Source: (OEA 2009; OEA 2013)



Authors' calculation based on Kimura 2010, Shibata 2012, and CPI data from the Japanese Bureau of Statistics

Figure A-2: Room AC (2.8kW) Efficiency[12] and Price Trends in Japan

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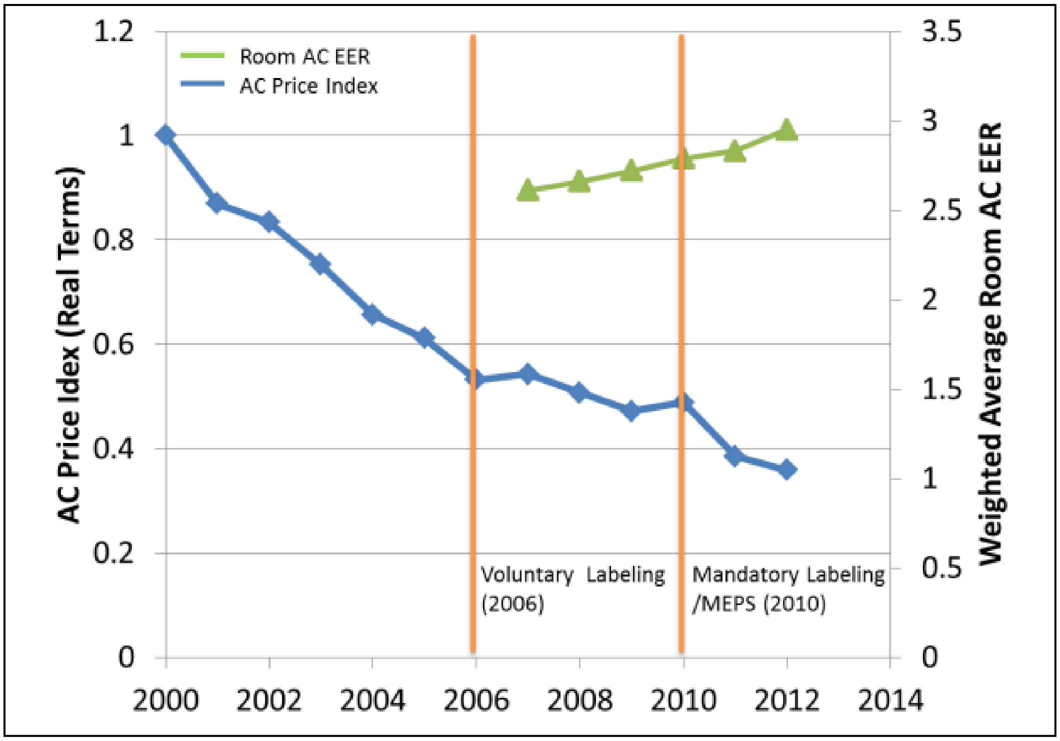
[12] For energy efficiency metric for ACs, Japan used the average coefficient of performance (COP) combined with cooling and heating COPs, but for the second target year (2010), modified test methods and replaced the COP metric



Authors' calculation based on OEA 2009, OEA 2013

Figure A-3: Room AC Efficiency and Price Trends in India

Appendix B: Incremental Costs and Energy Savings for Key Components

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with annual performance factor (APF) which reflects the actual changes of outdoor temperature and corresponding indoor thermal load.

Table B-1: Incremental Costs and Energy Savings for Compressors for 1.5 TR ACs.

Source	CLASP, 2015					EuP, 2009
	Compressor EER	Manufacturing Cost (USD)	Incremental manufacturing Cost (USD)	Estimated Retail Price Increase (USD)	Estimated Retail Price Increase (INR)	Energy Savings from Base Case
Base Case	2.8	59	0	0	0	0
CP1	3	62	3	7.2	480	5%
CP2	3.2	65	6	14.4	960	10%
CP3	3.4	68	9	21.6	1380	15%

Table B-2: Incremental Costs and Energy Savings for Heat Exchangers (HX) for 1.5 TR ACs

	CLASP, 2015					EuP, 2009
	% increase in HX UA value	Manufacturing Cost (INR)	Incremental Manufacturing Cost (INR)	Estimated Retail Price Increase (INR)	Estimated Retail Price Increase for 2 HX (INR)	Energy Savings from Base Case
Base Case	0%	1500	0	0	0	0%
HE1	20%	2200	700	1470	3528	7.5%
HE2	40%	3050*	1550	3240	7776	13.5%
HE3	50%	3500	2000	4210	10104	17.5%
HE4	80%	4400*	2900	6080	14592	21.0%
HE5	100%	5000	3500	7350	17640	24.0%

*****Costs for 40% and 80% increase in area were interpolated based on reported values in PWC, 2014 for 20%, 50% and 100% increase respectively in heat exchanger (HX) area. Retail Price increase includes estimated increase in cost of Chassis.

Appendix C: Bill of Materials costs for fixed speed ACs in India

Table C -1 Bill of Materials costs for fixed speed ACs in India

	Component	Cost Low Range Rs	Cost High Range Rs
Indoor Unit	Heat Exchanger	1200	1370
Indoor Unit	Fan motor	600	680
Outdoor Unit	Compressor	3400	4100
Outdoor Unit	Heat Exchanger	1500	1940
Outdoor Unit	Sheet Metal	1200	1550
Outdoor Unit	Fan blade	200	570
Outdoor Unit	Fan Motor	450	640
Outdoor Unit	Refrigerant	450	800
Outdoor Unit	Others	2000	2850
	Total	11000	14500

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