**WORKING PAPER**

# INDIA CAN AVERT POWER SHORTAGES AND CUT CONSUMER BILLS WITH STRONGER AC EFFICIENCY STANDARDS

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# CONTENTS

# EXECUTIVE SUMMARY

## 1. THE CHALLENGE: LOOMING POWER SHORTAGES

- India's electricity demand is growing faster than anticipated, driven by strong economic growth and rapid adoption of room air conditioners (ACs). India adds 10–15 million new ACs annually, with another 130–150 million expected over the next decade. Between 2019 and 2024 alone, room ACs added an estimated **30–35 GW** to peak demand.
- Without policy intervention, room ACs could contribute **120 GW to the peak demand by 2030** and **180 GW by 2035** —nearly **30%** of the total.
- Even with all under-construction generation and storage projects online, **power shortages are expected as early as 2026**.

## 2. THE SOLUTION: STRENGTHEN ROOM AC EFFICIENCY STANDARDS

- Experience from India and around the world shows that **Minimum Energy Performance Standards (MEPS)**—when paired with comparative star labels—are among the most effective tools for driving appliance efficiency.
- To unlock their full potential, it is critical to **strengthen the 1-star MEPS level**, rather than only raising the efficiency of higher-tier labels. If MEPS updates remain too weak or too infrequent, the market may drift toward low-efficiency products—undermining the effectiveness of the labeling program as a whole.
- Equally important is the need for a **long-term MEPS roadmap—spanning 8 to 10 years—**to provide manufacturers with investment clarity and supply chain certainty.

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## 3. THE MARKET IS READY FOR AN AMBITIOUS MEPS REVISION (1-STAR LEVEL)

India's AC market has matured significantly, with a wide range of high-efficiency models already available. An ambitious MEPS trajectory is not only feasible but necessary to accelerate market transformation and ensure long-term energy security. We recommend the following MEPS revision trajectory:

- **2027**: Set 1-star at ISEER 5.0 - equivalent to the 5-star level today. 600+ AC models (20% of the models offered in the market) already exceed this level.
- **2030**: Set 1-star at ISEER 6.3 - on par with the most efficient AC sold in India today. Leading domestic and international manufacturers (e.g., Godrej, Voltas, Blue Star, Hitachi, Daikin etc.) offer such super-efficient models at competitive prices, signalling supply chain readiness.
- **2033**: Set 1-star at ISEER 7.4 on par with the most efficient AC available globally. This will need several supporting measures such as bulk procurement programs for ultra-efficient ACs, revising test procedures to account for dehumidification etc.

This roadmap is fully aligned with India's G20 commitment to double energy efficiency improvements.

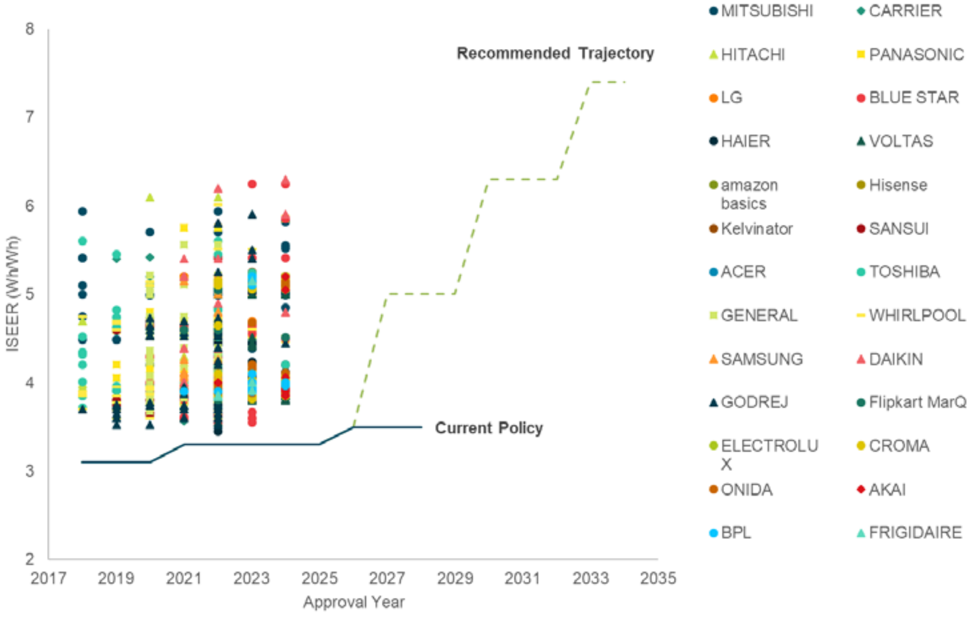


**FIGURE ES-1: India's Room Air Conditioner units and the recommended MEPS (1-Star) trajectory.**

Each plotted point represents a variable speed AC unit offered for sale in India in 2024, with colors denoting manufacturers and the Y-axis reflecting AC efficiency in ISEER. Efficiency level for each unit is taken from its label as reported on the BEE website

## 4. MASSIVE GRID AND CONSUMER BENEFITS

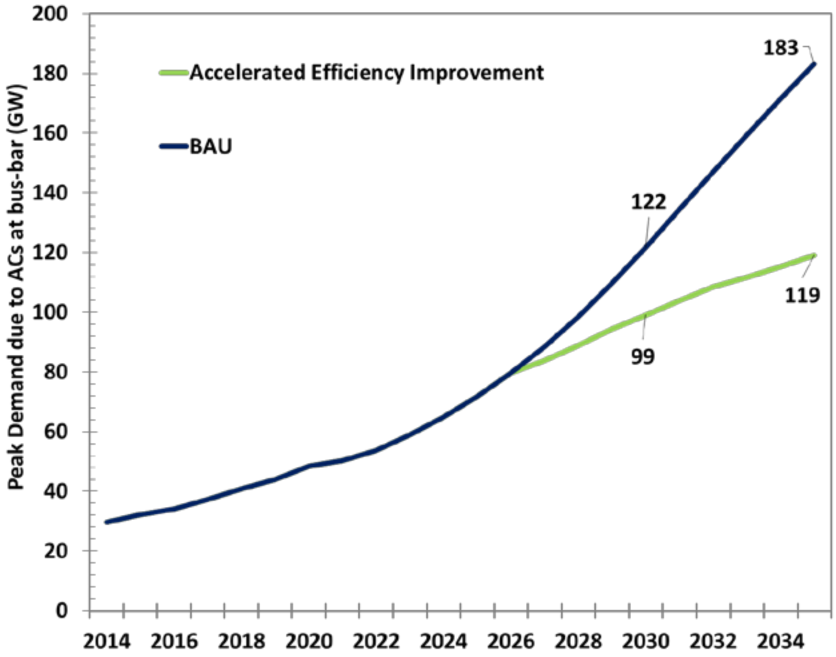


**FIGURE ES-2: Projected national peak electricity demand due to ACs in the Business-As-Usual (BAU) case and the Accelerated Efficiency Improvement case, the recommended trajectory for MEPS revision.**

- **Avoid 10 GW of peak demand by 2028, 23 GW by 2030 and 64 GW by 2035** » averts power shortages and saves **₹750,000 crore ($85 billion)** in avoided power infrastructure investments.
- **Reduce electricity use by 118 TWh/year** by 2035 » equivalent to installing 60 GW of solar power plants.
- **Net consumer savings** of ₹66,000–225,000 crore ($8–26 billion), even after accounting for the incremental cost of efficient ACs.

## 5. EFFICIENCY IS AFFORDABLE

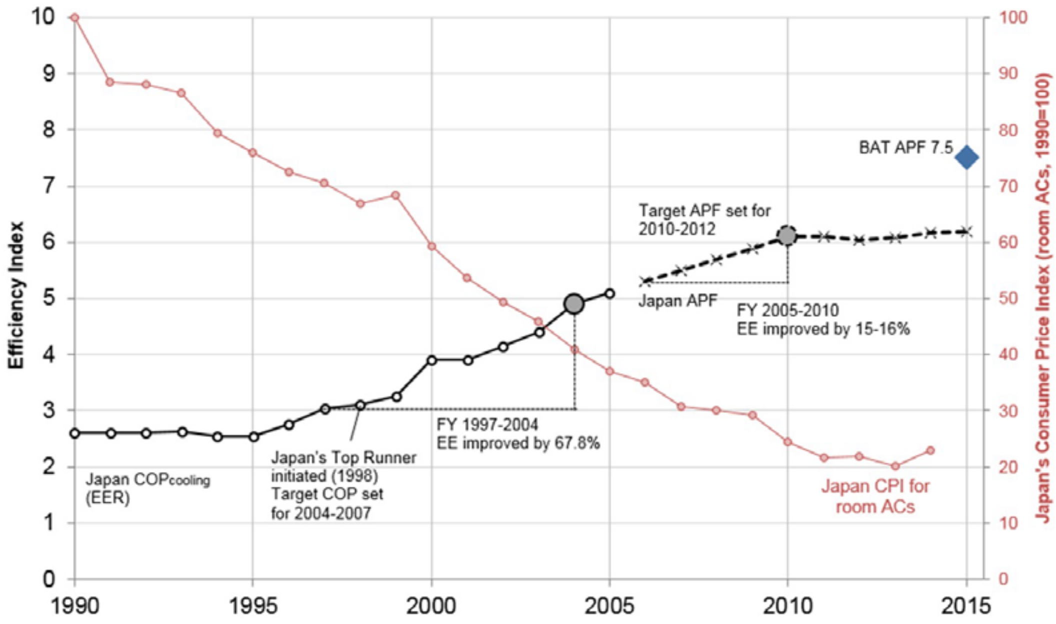


**FIGURE ES-3: Room AC efficiency index (black) and room AC consumer price index (red) in Japan (1990-2015)**. Between 1995 and 2010, AC efficiency nearly doubled, while inflation-adjusted AC prices reduced by 80%.

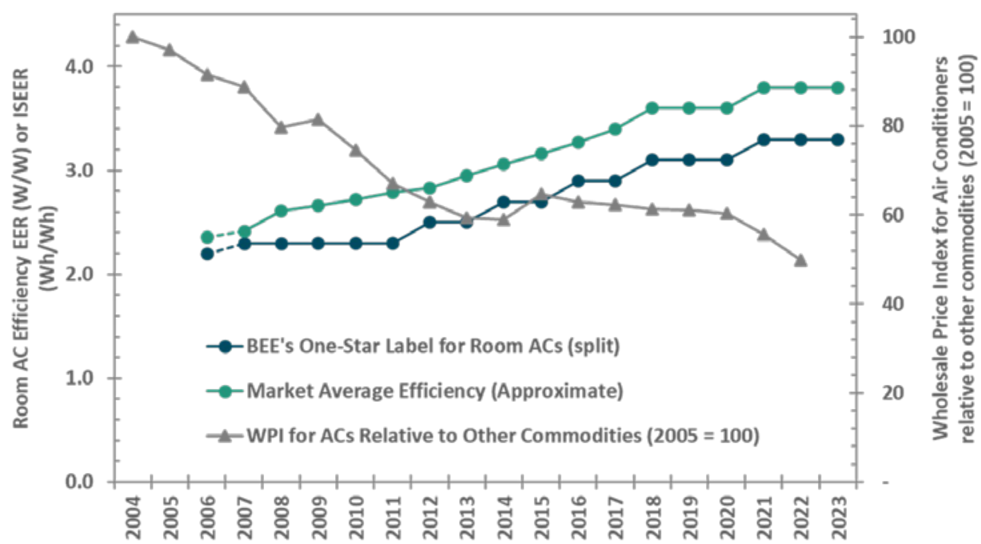


**FIGURE ES-4: Room AC efficiency (blue, green) and room AC wholesale price index (grey) in India (2006-2023)**. Between 2007 and 2023, room AC efficiency improved by 60%, while inflation adjusted AC prices nearly halved.

Note: Efficiency metric uses EER prior to 2016, and ISEER after 2016.

Evidence from India and international markets shows that **tightening efficiency standards does not raise AC prices**. In fact, historical data reveal that:

- AC prices often **decline** even as MEPS become more stringent
- Prices are primarily driven by **economies of scale, brand positioning, competitive pressure, and supply chains**.

## 6. SUPPORTING MEASURES

- Expand **bulk procurement (e.g., EESL)** and targeted consumer incentives to drive down costs and increase market share of ultra-efficient models.
- A **mix of fiscal tools**—including tiered production-linked incentives, targeted GST reductions, and duties on inefficient components—can accelerate market transformation towards efficient ACs.
- Revise **test procedures** to account for **dehumidification performance** (aligned with Global Cooling Prize).

## 7. THE COST OF INACTION

Weak or delayed MEPS revisions risk locking India into decades of inefficient cooling technologies, worsening shortages and driving costly grid expansion.

Strengthening MEPS is not only a powerful energy savings strategy—it is also a **crucial reliability tool** and a necessary step toward India becoming a **global leader in affordable, sustainable cooling**.

# ABSTRACT

India is experiencing a rapid surge in electricity demand driven by the widespread adoption of room air conditioners (ACs), propelled by rising incomes, urbanization, and increasingly severe heat waves. We estimate that between 2025 and 2035, India will add an additional 130-150 million new room ACs, and without targeted interventions, room ACs alone could contribute over 180 GW to India's peak load by 2035, straining the power system and necessitating costly investments in new capacity.

This paper evaluates the potential of accelerating room AC efficiency improvements to address this challenge. We propose an aggressive revision of Minimum Energy Performance Standards (MEPS)—raising the 1-star label to ISEER 5.0 by 2027 (equivalent to today's 5-star level), ISEER 6.3 by 2030 (on-par with the most efficient ACs currently sold in India by leading domestic and multinational manufacturers), and ISEER 7.4 by 2035 (on-par with the most efficient AC currently sold globally). Our analysis shows that this strategy could reduce peak demand by over 60 GW by 2035, avoid ₹7.5 trillion in generation and grid investments, and deliver up to ₹2.2 trillion in net consumer savings. Drawing on empirical data from India and global markets, we find that super-efficient ACs are already widely available and cost-effective. Strengthening standards, combined with targeted programs, can transform India into a global leader in sustainable and affordable cooling while avoiding looming power shortages and generating massive consumer benefits.

# 1. RAPIDLY RISING SPACE COOLING DEMAND

India is on the brink of an explosive growth in space cooling demand—driven by rising incomes, urbanization, and increasingly hot and humid weather. Among various cooling options, room air conditioners (ACs) are becoming the dominant choice, especially in urban homes and commercial spaces.

Between 2006 and 2023, room AC sales in India rose nearly tenfold—from around 1 million to nearly 11 million units per year—a growth rate of 10–15% annually (Figure 1). Growth has been especially rapid in recent years: between 2019 and 2024 alone, India added nearly 50 million new ACs in aggregate, contributing an estimated 30–35 GW to national peak electricity demand. About two-thirds of these AC units are bought by households, while the remaining third serve the commercial sector (Abhyankar et al., 2017).

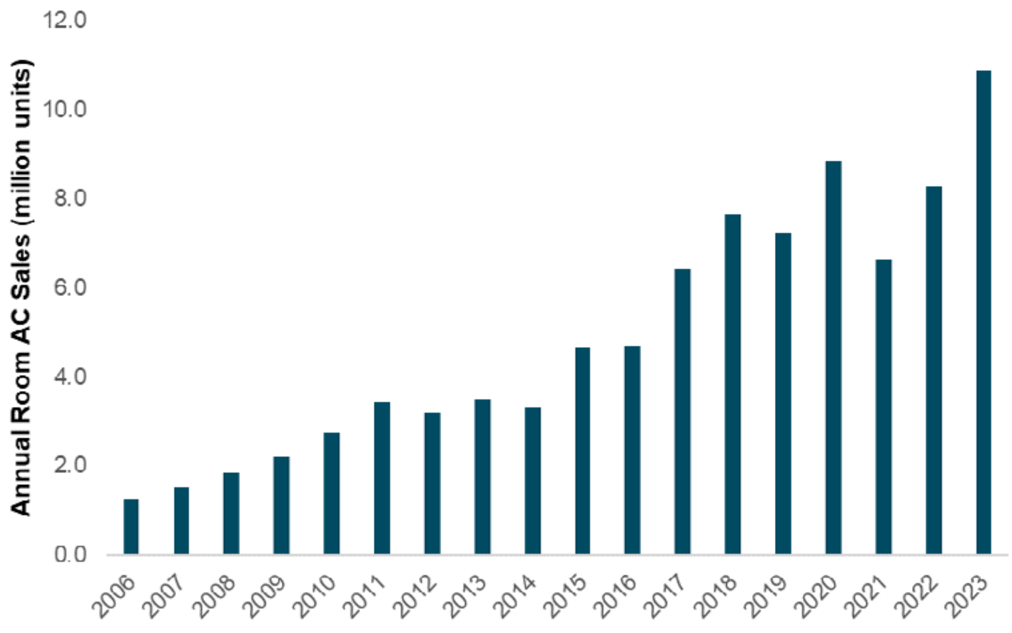


**FIGURE 1:** Room AC sales in India FY 2006 to FY 2023

Data source: (BEE, 2024; Abhyankar et al., 2017; Phadke et al., 2013)

India's trajectory mirrors past trends in other emerging economies such as China. China's urban AC penetration jumped from just 5% in the mid-1990s to nearly 100% by 2008, adding over 200 million ACs and 200 GW of peak load in just 15 years (figure 2). In fact, room AC sales in China rose from 51.5 million units in 2010 to nearly 100 million units in 2020 (Duan et al, 2023). By 2023, China's AC penetration in urban households exceeded 150%, reflecting widespread ownership of multiple units. This drove a surge in cooling energy use—from 7 TWh in the early 1990s to 450 TWh by 2016 (Karali et al., 2020; Duan et al., 2023).

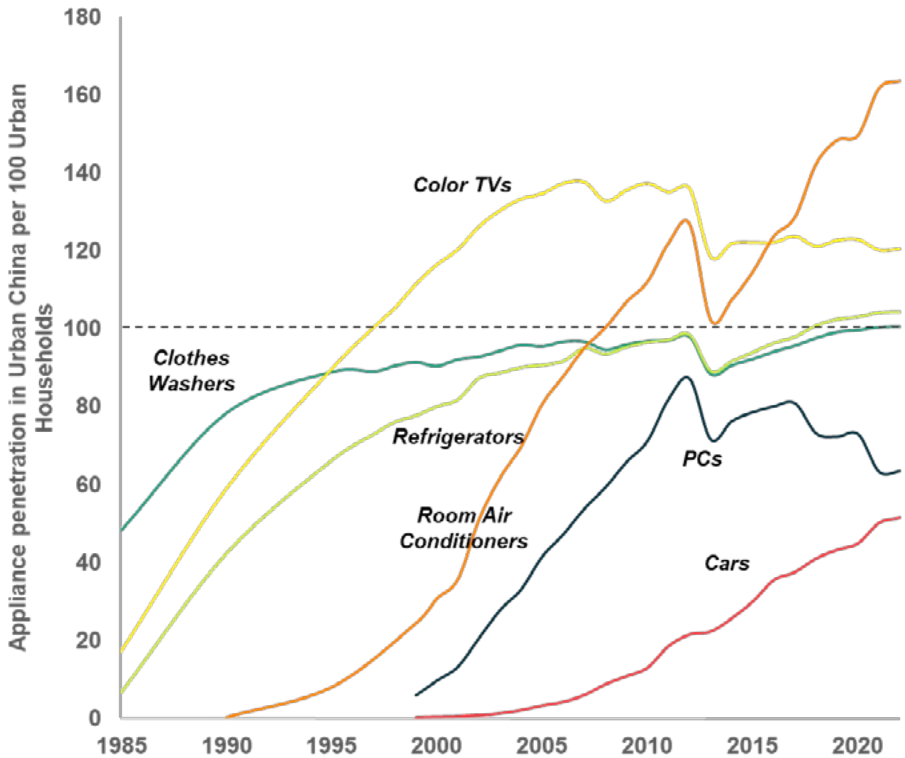


**FIGURE 2:** Appliance penetration in urban China per 100 Urban households, selected appliances from 1985 to 2023

Data Source: (Karali et al, 2020; Abhyankar et al., 2017; China Statistical Yearbook, 2023).

India now finds itself at a similar turning point. Room AC ownership in Indian urban households is currently around 10% on average, but reaches 20–25% in higher-income groups and is growing rapidly (Figure 3). In cities like Delhi, Mumbai, and Bangalore, penetration is already much higher.

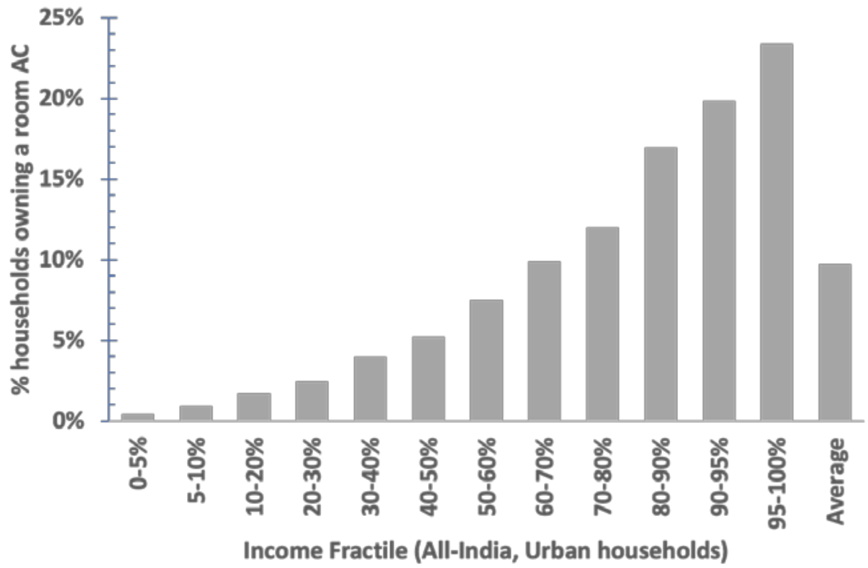


**FIGURE 3: Households owning an air conditioner in urban areas by income fractile in 2023 (all-India)**. Note that the chart represents the percentage of households that own at least one air conditioner. While some households may own multiple units, the survey does not capture the number of units per household.

Data source: NSS (2024)

A global comparison makes the opportunity even clearer. Figure 4 plots cooling degree days (CDD) against urban AC penetration for major economies. India stands out—a large population, high cooling demand, and still low AC penetration. This indicates massive potential for market growth in the coming years.

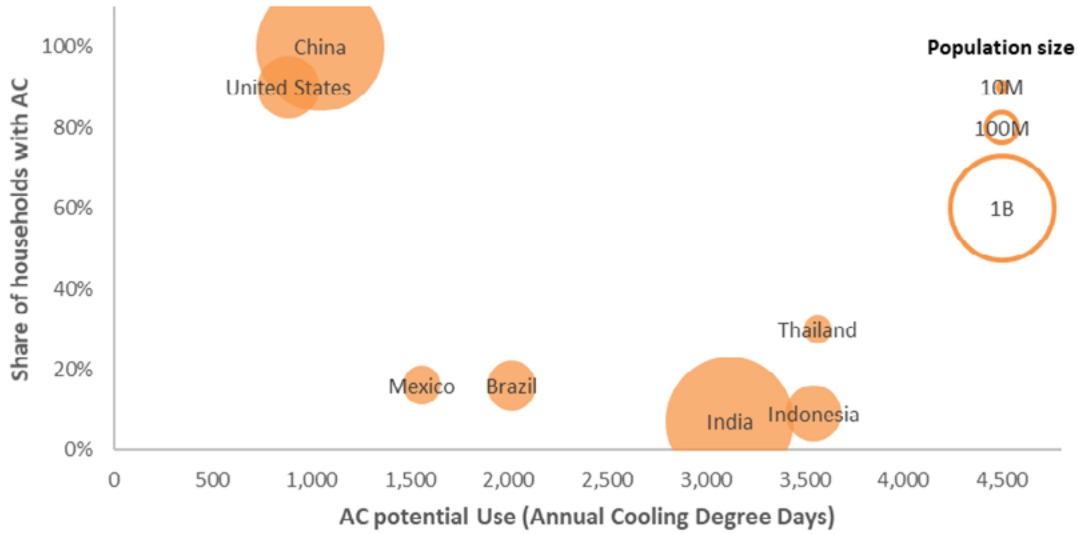


**FIGURE 4: Cross-country comparison of air conditioning market potential. The y-axis shows the share of urban households with an installed AC unit.** The x-axis represents the annual cooling degree days (CDD), a metric of the potential need for air conditioning based on warm temperatures. Country markets are plotted as bubbles, with the bubble size corresponding to the total population.

Data source: Davis, L. W., & Gertler, P. J. (2015), Whirlpool India (2021) and International Energy Agency. (2018).

In summary, India's AC market is expanding quickly—but is still in early stages. As incomes rise and temperatures climb, millions of households will purchase their first ACs in the coming decade. Without strong energy efficiency policies in place, this growth will lead to a steep rise in electricity demand, especially during summer peak hours, as witnessed in recent years, creating pressure on the power grid and increasing energy costs for consumers and the system.

The objective of this paper is to assess the impact of enhancing room AC efficiency on energy consumption, peak demand and grid reliability, and consumer benefits. We particularly focus on revising the room AC minimum energy performance standards (MEPS) and labels and propose a long-term vision for standards and label revision in India.

# 2. THE GROWING IMPACT OF ROOM ACS ON INDIA'S PEAK POWER DEMAND

The impact of room air conditioners (ACs) on India's electricity system is becoming increasingly pronounced—particularly during periods of extreme heat. This was starkly illustrated during the May 2024 heatwave, when electricity demand surged to record levels. The national evening peak crossed 240 GW, while the afternoon peak (during solar hours) exceeded 250 GW, far surpassing previous projections. Room ACs alone were responsible for an estimated 40-45 GW of evening peak demand, making them one of the largest contributors to the strain on the grid.

As AC penetration continues to rise—fueled by income growth, urbanization, and escalating temperatures—peak demand is expected to increase sharply, particularly during evening and nighttime hours. This trend presents major challenges for grid reliability and long-term resource planning, especially as demand increasingly misaligns with solar generation availability.

The growing influence of space cooling load on peak demand is particularly pronounced in urban centers like Delhi (Figure 3). Over the past decade, Delhi's electricity consumption and peak demand have nearly doubled, overcoming the COVID-related slowdowns. Peak demand increased from ~4,500 MW in 2010 to over 8,500 MW in 2024. Notably, Delhi's load profile has undergone a significant seasonal shift: summer peak demand in July now far exceeds winter peaks, driven almost entirely by the proliferation of space cooling. Moreover, Delhi now exhibits two distinct summer peaks: first around 3 PM, corresponding to commercial cooling demand, and second, around midnight, driven by residential AC use. The midnight peak load creates unique grid reliability challenges, as it occurs well after solar generation tapers off, requiring new investments in firm capacity—such as battery storage or thermal plants—to meet demand. These trends are not limited to Delhi. Similar dual-peak load shapes are emerging in other major Indian cities and are expected to intensify in the years ahead.

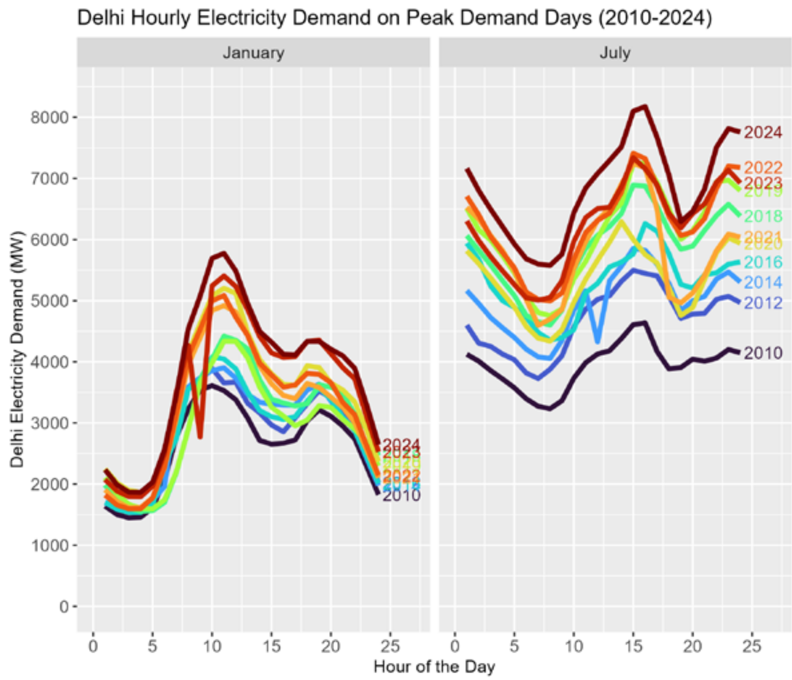


**FIGURE 5:** Hourly demand (actual) on peak load days in Delhi in January and July (2010-2024)

Data sources: DSLDC (2024)

We underscore that, although our focus is on increasing the AC efficiency, it is only one strategy for meeting cooling demand sustainably. Improving appliance efficiency needs to be complemented by other strategies that reduce cooling demand (e.g., employing cool roofs, efficient building design, and energy management systems) and that deliver cooling efficiently at minimal cost (e.g., using efficient ceiling fans). Additionally, air conditioners can enhance grid reliability and flexibility through demand response (DR) programs by helping manage super-peak events and addressing ramping challenges in a renewable energy (RE)-dominant grid.

Cooling DR can serve as both a critical flexibility resource and a valuable reliability asset by enabling the strategic modulation of cooling loads—either through simple thermostat setpoint adjustments or by offering a smart, curtailable load that can respond dynamically to grid conditions.

This would reduce dependence on costly supply-side resources that would otherwise operate at very low capacity factors. This is particularly evident in Delhi's load curve, where peak space cooling demand occurs around midnight (12–1 AM)—several hours after solar generation ends. Meeting this late-night peak typically requires significant investments in energy storage or firm capacity. While improving AC efficiency will help lower overall cooling demand, smart cooling DR programs can further shift or moderate demand, reducing the need for additional infrastructure without compromising consumer thermal comfort.

# 3. INDIA'S ROOM AC MARKET HAS OUTPACED EFFICIENCY STANDARDS

India's room AC market is evolving rapidly, with manufacturers and consumers adopting higher-efficiency products at a pace that exceeds current regulatory requirements. However, the official Minimum Energy Performance Standards (MEPS)—reflected in the 1-star rating level—have not kept up with this market transformation, leaving significant efficiency gains unrealized.

Room ACs in India fall under the mandatory star labeling program administered by the Bureau of Energy Efficiency (BEE). The labeling system uses a 1-star to 5-star scale based on annual energy consumption, with the 1-star label acting as the de facto MEPS. Historically, BEE has revised label thresholds every few years, but the last update occurred in 2021, and the next revision is planned only for 2026–2028.

Table 1 shows the evolution of ISEER thresholds (India's Seasonal Energy Efficiency Ratio) across star levels for variable speed ACs since 2016. Over the last decade, the MEPS (1-star level) has improved at an average rate of only 2–3% per year—far slower than the pace of technology development or global best practices.

**TABLE 1:** ISEER levels for star labels for variable speed room ACs in India

| | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1-star** | 2.7 | 2.7 | 3.1 | 3.1 | 3.1 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.5 | 3.5 | 3.5 |
| **2-star** | 2.9 | 2.9 | 3.3 | 3.3 | 3.3 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.8 | 3.8 | 3.8 |
| **3-star** | 3.1 | 3.1 | 3.5 | 3.5 | 3.5 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 4.3 | 4.3 | 4.3 |
| **4-star** | 3.3 | 3.3 | 4 | 4 | 4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 5 | 5 | 5 |
| **5 star** | 3.5 | 3.5 | 4.5 | 4.5 | 4.5 | 5 | 5 | 5 | 5 | 5 | 5.6 | 5.6 | 5.6 |

Data sources: (BEE, 2016-2024)

Note: India uses the Indian seasonal energy-efficiency ratio (ISEER) metric to measure AC efficiency. ISEER is based on International Standards Organization (ISO) standard 16358 but uses an India-specific temperature distribution.

The Indian AC market has shifted rapidly toward variable speed or inverter technology, with over 75% of new sales in 2023 comprising variable speed models (Figure 6).

These ACs are inherently more efficient and respond well to higher standards. Typically, 2-star or 3-star ACs serve as the market average in India. In FY 2023, 3-star models accounted for 59% of all sales, while 5-star models represented 23%, indicating a strong consumer shift toward higher-efficiency products (Figure 7).

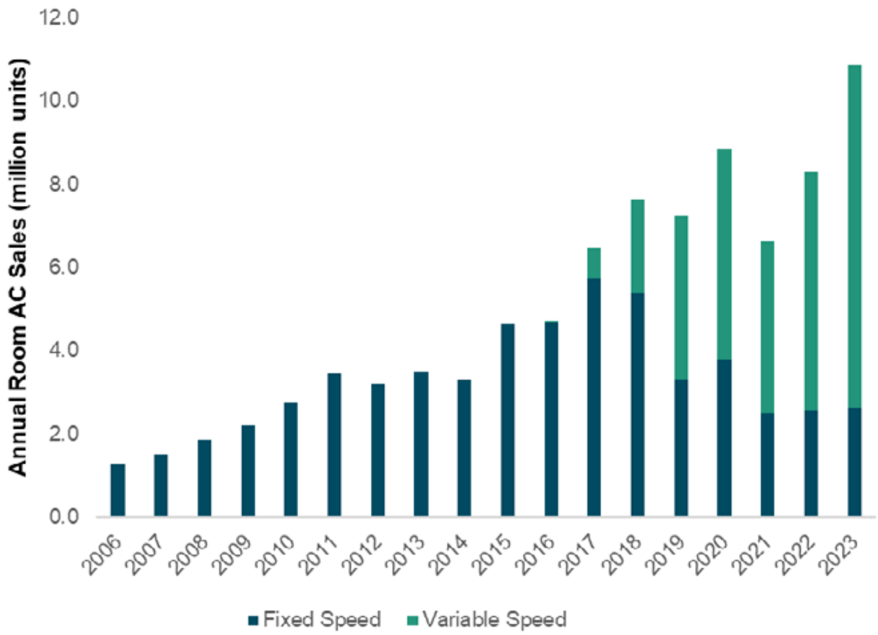


**FIGURE 6:** Room AC sales in India split into fixed speed and inverter ACs

Data Sources: BEE (2024)

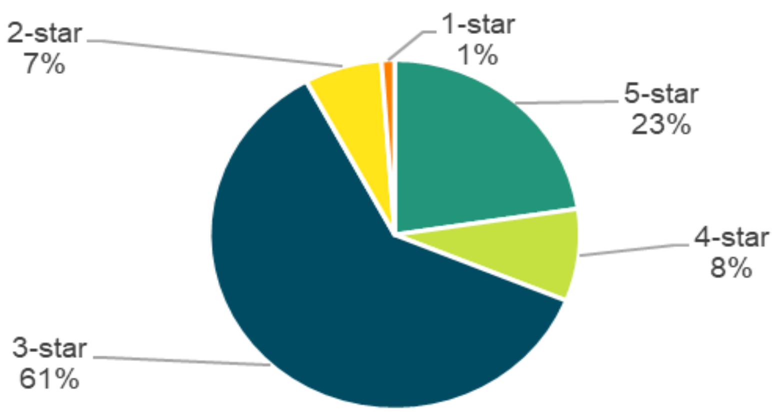


**FIGURE 7:** Split of room AC sales by star label (FY 2023), total sales 10.8 million units.

Data Sources: BEE (2024)

Moreover, many manufacturers already offer models that significantly exceed current efficiency thresholds. As of 2024, more than 600 inverter AC models (20% of all listed units) are rated above the 5-star threshold, with over 20% of all available models having ISEER ratings above 5.0 (Figure 8). The most efficient unit on the Indian market has an ISEER of 6.3 (Daikin model FTKF35UV16UA+RKF35UV16UA). Multiple manufacturers—both Indian (e.g., Godrej, Blue Star) and multinational (e.g., Daikin, Hitachi, Whirlpool)—offer models with ISEERs above 6.0, showing that the technological capability and supply chain for super-efficient ACs already exist.

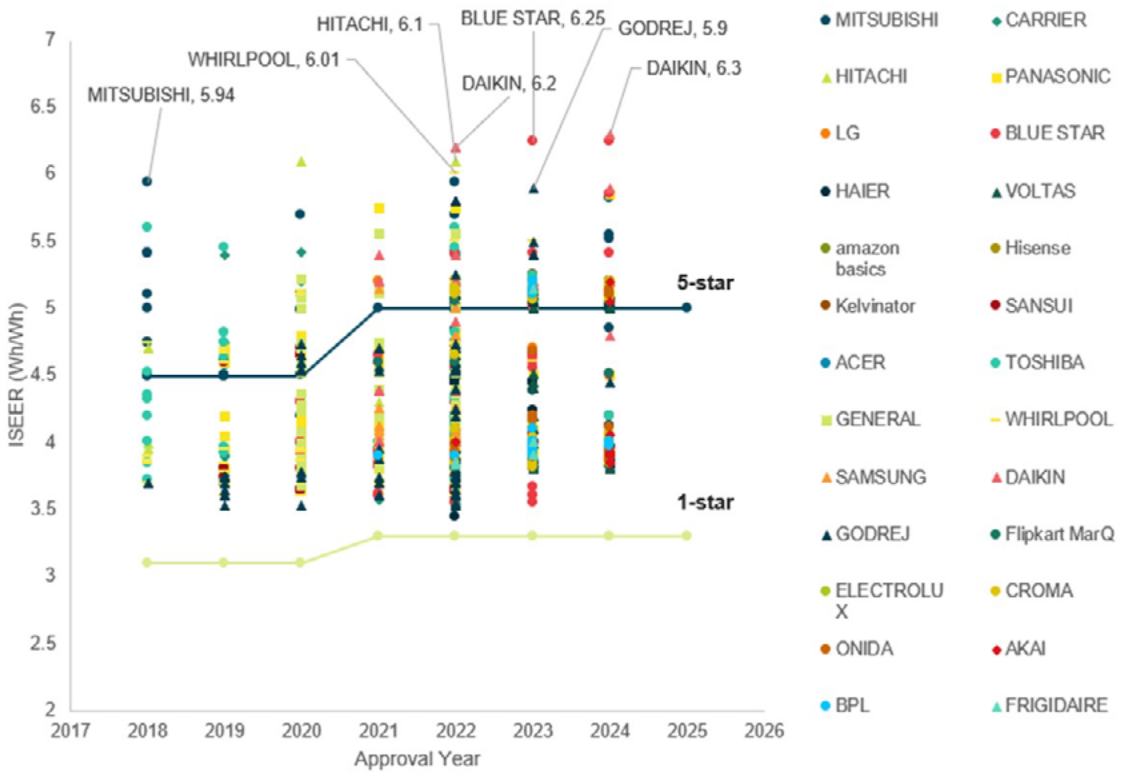


**FIGURE 8: India's room AC units efficiency and star labels. Each plotted point represents a variable speed AC unit offered for sale in India in 2024**, with colors denoting manufacturers and the Y-axis reflecting AC efficiency in ISEER. Efficiency level for each unit is taken from its label as reported on the BEE website. The lines show 1-star and 5-star efficiency labels for room ACs from 2018 to 2025 as specified by BEE.

Data source: BEE (2024) - www.beestarlabel.com

More than 50% of AC units currently available in the Indian market have an ISEER above 4.0, over 40% exceed ISEER 4.3, and more than 20% surpass ISEER 5.0—clearly indicating that the market may be more driven volumes and commercial viability and may not be constrained by technical capability, supply chain limitations, or manufacturing capacity for producing high-efficiency ACs.

# 4. METHODS

We assess the technical feasibility, peak demand impacts, electricity consumption effects, and consumer benefits of accelerating room AC efficiency improvements in India. We build on our prior in-depth technical and engineering analysis of room AC efficiency feasibility and costs, complemented by detailed stock turnover modeling. Below, we summarize our assumptions on room AC sales and the results from the stock turnover model.

**TABLE 2:** Projected Room AC Sales and Estimated Stock in India

| | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|
| **Room AC Sales** (million units/yr) | 7.5 | 14 | 23 | 34 |
| **Room AC Stock** (million units) | 45 | 72 | 126 | 202 |

We project that between 2025 and 2035, room AC sales will increase by 2.5 times, adding over 130 million new ACs into the system, resulting in a massive increase in space cooling energy consumption and peak demand.

Detailed methodology and other assumptions are given in the appendix.

We assess the following two scenarios of room AC efficiency improvement in India:

- **Business-As-Usual (BAU)** scenario follows the Bureau of Energy Efficiency (BEE) stipulated star labels through 2028 and assumes that efficiency improvements continue at the historical rate of one-star ratchet every three years (e.g., the previous cycle's 2-star label becomes the new 1-star standard), translating to a 2–3% annual efficiency increase. By 2033, the one-star level is projected to reach an ISEER of 4.3. This scenario serves as the reference case for our analysis.

- **Accelerated Efficiency Improvement** scenario assumes that starting in 2027, MEPS are revised at an ambitious rate, in line with India's commitment to double the historical rate of energy efficiency improvement and the vision of becoming a global leader in sustainable and affordable cooling technologies. MEPS trajectory looks like the following:

» **2027**: Set 1-star at ISEER 5.0 - equivalent to the 5-star level today. 600+ AC models (20% of the models offered in the market) already exceed this level.

» **2030**: Set 1-star at ISEER 6.3 - on par with the most efficient AC sold in India today. Leading domestic and international manufacturers (e.g., Godrej, Voltas, Blue Star, Hitachi, Daikin etc.) offer such super-efficient models at competitive prices, signalling supply chain readiness.

» **2033**: Set 1-star at ISEER 7.4 - on-par with the most efficient ACs sold globally. One such model is Samsung # AF18J9975WWK with 2-ton cooling capacity and cooling efficiency of Korean CSPF 9.4, equivalent to ISEER 7.4. Achieving this will need several supporting measures such as bulk procurement programs for ultra-efficient ACs, revising test procedures to account for dehumidification etc.

This Accelerated Efficiency Improvement scenario implies a 8% annual efficiency improvement, more than double the rate under the BAU scenario.

Figure 9 illustrates the projected MEPS (one-star levels) for both the BAU and Accelerated Efficiency scenarios up to 2035.

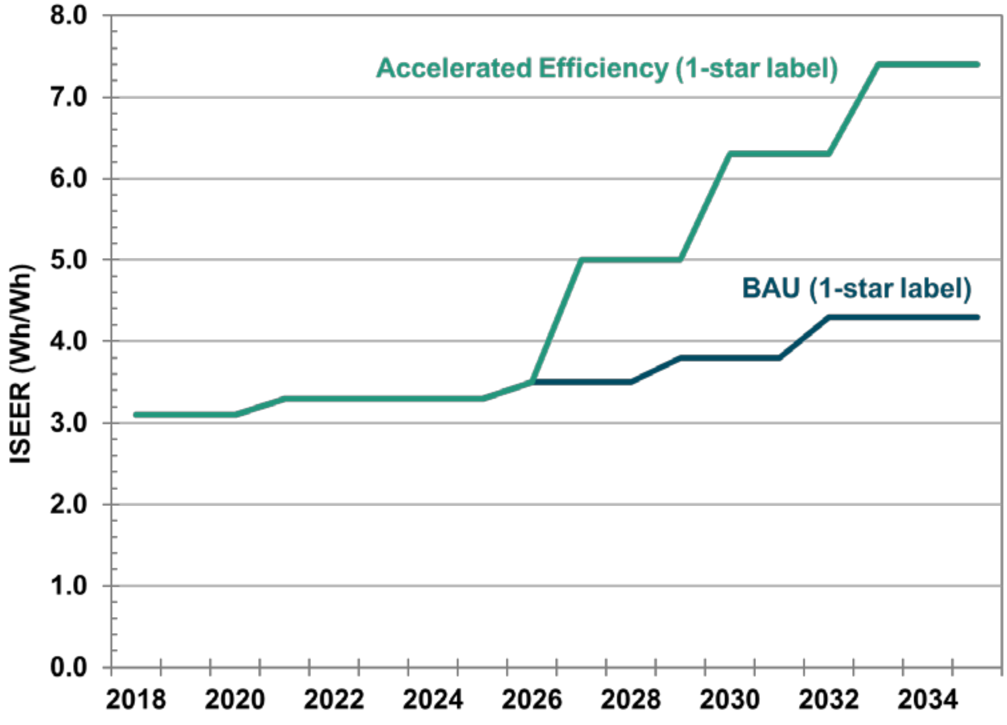


**FIGURE 9:** One-star label (de-facto MEPS) in the BAU and Accelerated Efficiency. scenarios and AC units currently.

Other details on our methods, assumptions, and data can be found in the appendix.

# 5. RESULTS

## 5.1. INDIAN AC MANUFACTURERS APPEAR READY FOR AGGRESSIVE MARKET TRANSFORMATION

Currently, over 20% of AC units in the Indian market have an ISEER above 5, meaning they would remain unaffected in the Accelerated Efficiency scenario even if the 1-star label threshold were raised to ISEER 5.0 (Figure 10). By 2030, the 1-star label is assumed to increase to ISEER 6.3, on-par with the most efficient AC models sold today by leading AC manufacturers in India. In contrast, under the BAU revision case, nearly 40% of the current models would remain available even in 2034/2035, highlighting the slow pace of market transformation if labels were revised at the historical pace.

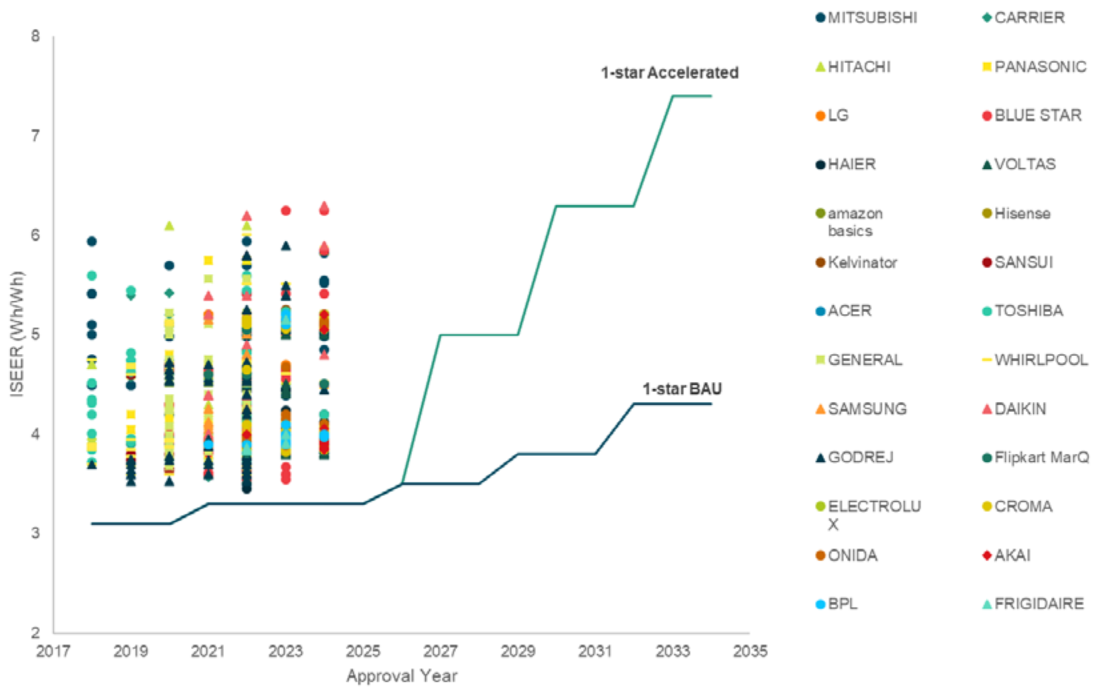


**FIGURE 10: India's Room AC Units and MEPS in the BAU and Accelerated Efficiency scenarios**. Each plotted point represents a variable speed AC unit offered for sale in India in 2024, with colors denoting manufacturers and the Y-axis reflecting AC efficiency in ISEER. Efficiency level for each unit is taken from its label as reported on the BEE website. The lines show 1-star efficiency labels for the BAU and Accelerated Efficiency scenarios.

Data source: BEE (2024) - www.beestarlabel.com

A common concern raised against tightening room AC efficiency standards is that it could strain domestic manufacturers by requiring new technologies or supply chains. However, as illustrated in Figure 10, super-efficient ACs are already being sold in India, including models from domestic manufacturers such as Godrej. This clearly indicates that the technical capability and production capacity to manufacture high-efficiency ACs already exists within the Indian market.

Rather than posing a constraint, ambitious efficiency improvements present a strategic opportunity for Indian manufacturers. By scaling up the production of high-efficiency models, domestic firms can enhance their competitiveness under the "Make in India" initiative and take advantage of the government's Production-Linked Incentive (PLI) scheme, which specifically targets high-efficiency air conditioners and their key components. This policy support can help accelerate the development of robust local supply chains, reduce reliance on imports, and drive innovation in advanced cooling technologies.

Indian manufacturers are also well-positioned to become global leaders in efficient cooling, particularly in Southeast Asia, Africa, and Latin America, where climatic conditions closely resemble India's and demand for affordable, high-performance cooling is rising. Exporting the world's most efficient ACs from India could unlock significant economic opportunities, stimulate innovation-led growth, and position India as a hub for sustainable cooling technologies—while aligning with its broader industrial, export, and climate objectives.

## 5.2. ROOM AC EFFICIENCY WILL BE CRUCIAL FOR AVOIDING LOOMING POWER SHORTAGES

India's electricity demand has rebounded sharply in the post-COVID period—growing much faster than previously projected, and placing significant stress on the power system. Peak demand growth, particularly during the summer months, has consistently exceeded forecasts. In 2024, India's national evening peak demand crossed 240 GW, and the solar-aligned afternoon peak exceeded 250 GW, both setting new records.

POSOCO's Resource Adequacy (RA) report (2025) warns of widening power shortages beginning as early as 2025–2026, particularly during evening peak hours when solar generation declines. These shortages are expected to be most severe during summer months, when space cooling demand surges. The report emphasizes that without aggressive demand-side interventions, India could face a firm capacity shortfall of over 20–25 GW by FY2026, even with all currently planned thermal and hydro projects being commissioned on time.

A major driver of India's rising peak electricity demand is the rapid growth in room AC ownership, particularly in urban residential and commercial sectors. In 2024, room ACs alone contributed an estimated 50-60 GW to the national evening peak, making them one of the largest single loads on the grid. Between 2019 and 2024, nearly 50 million new ACs were added, driving approximately 30-35 GW of new peak demand.

This trend is set to intensify: India is projected to add 130 million additional room ACs between 2025 and 2035. **Without targeted policy action (BAU scenario), room ACs could account for over 120 GW of peak demand by 2030 and 180 GW by 2035** (Figure 11), representing nearly 30% of the country's projected evening peak load.

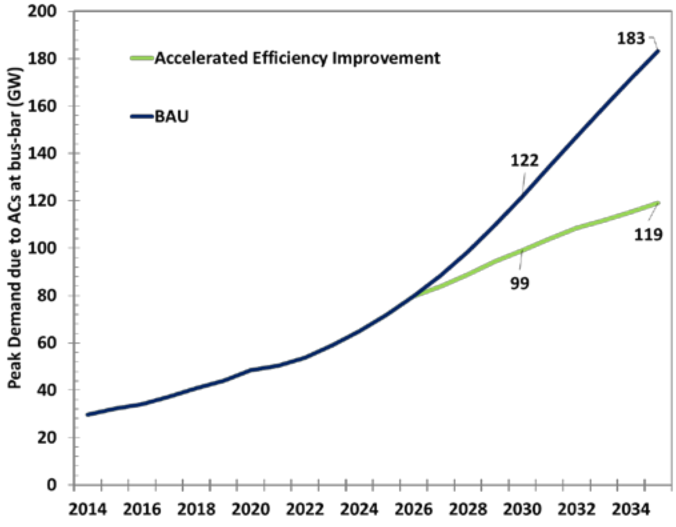


**FIGURE 11: Projected peak demand (national) due to room ACs**. The projection is made for two scenarios: BAU and Accelerated Efficiency Improvement

Under the Accelerated Efficiency Improvement scenario—where MEPS are tightened aggressively starting in 2027—**AC-driven peak demand can be reduced by 23 GW by 2030 and over 60 GW by 2035**. This is equivalent to avoiding the need for 120 large (500 MW) thermal power plants (~$60-70 billion in generation capacity investments), along with $25–30 billion in additional transmission and distribution infrastructure.

Efficiency improvements can also provide critical near-term relief to the power system. For instance, if India's electricity demand continues to grow at 7.5% annually—consistent with recent post-COVID trends—evening peak demand is expected to rise by 78 GW between 2024 and 2028, with room ACs alone accounting for roughly 40% of this increase. Even after factoring in 44 GW of under-construction firm generation (coal, nuclear, and hydro) and ~8 GW of energy storage, India could still face a 26 GW peak capacity shortfall by 2028 (Table 3).

However, accelerating room AC efficiency improvements starting in 2027 could reduce peak demand by approximately 12 GW by 2028, narrowing the projected shortfall to around 14 GW. If peak demand grows faster than 7.5% per year, or if there are delays in commissioning new firm generation, the role of AC efficiency becomes even more critical in preventing capacity shortages. Conversely, under a more moderate demand growth scenario (6% annually), enhanced AC efficiency alone could nearly eliminate the risk of peak power shortfalls.

These outcomes underscore the strategic value of appliance efficiency as a demand-side resource. Tightening room AC standards is therefore not only a long-term energy savings measure, but also an immediate and essential tool for strengthening grid reliability.

**TABLE 3:** Projected evening peak demand, under-construction firm generation capacity, and peak shortfall in 2028

| | Formula | Demand growth = 6% p.a. | Demand growth = 7.5% p.a. | Demand growth = 10% p.a. |
|---|---|---|---|---|
| Evening Peak in 2024 (GW) | A | 234 | 234 | 234 |
| Evening Peak in 2028 (GW) | B | 295 | 312 | 343 |
| Net addition to the evening peak demand (GW) | C = B - A | 61 | 78 | 109 |
| New Firm Capacity (Under Construction / contract, including storage) (GW) | D | 52 | 52 | 52 |
| Net Firm Capacity Shortfall (GW) | E = C - D | 8 | 26 | 57 |
| Peak Demand Reduction due to room ACs (GW) | F | 10 | 12 | 17 |
| Potential Peak Shortages (GW) | G = E - F | 0 | 14 | 39 |

Note: All numbers in GW and all-India aggregate. Totals may not match due to rounding. "Firm" capacity includes only thermal (coal, nuclear, and hydro) and excludes any other renewable capacity. This is a simplistic exercise for developing an intuitive understanding. These are NOT simulation results. An implicit assumption behind this simplistic calculation is that the maximum firm capacity support by the existing generation capacity cannot go beyond 2024 summer levels (~221 GW). Also, RE generation is not given any evening peak capacity credit. Finally, all new hydro capacity, including ROR plants have been generously given full capacity credit. No delays are assumed in commissioning the under-construction power plants.

Source: Abhyankar et al (2024)

## 5.3. EFFICIENCY IMPROVEMENTS DO NOT LEAD TO HIGHER AC PRICES: EMPIRICAL EVIDENCE FROM GLOBAL MARKETS INCLUDING INDIA

A common concern regarding aggressive AC efficiency revisions is the potential for increased room AC prices, making them less affordable for consumers. However, empirical data from global markets, including India, consistently show that improving AC efficiency does not result in higher consumer prices. On the contrary, efficiency improvements often coincide with lower costs, driven by economies of scale, enhanced manufacturing processes, and competitive market dynamics. This evidence dispels the notion that stricter efficiency standards lead to higher prices, reinforcing that consumers can benefit from both improved efficiency and affordability.

### 5.3.1. JAPAN

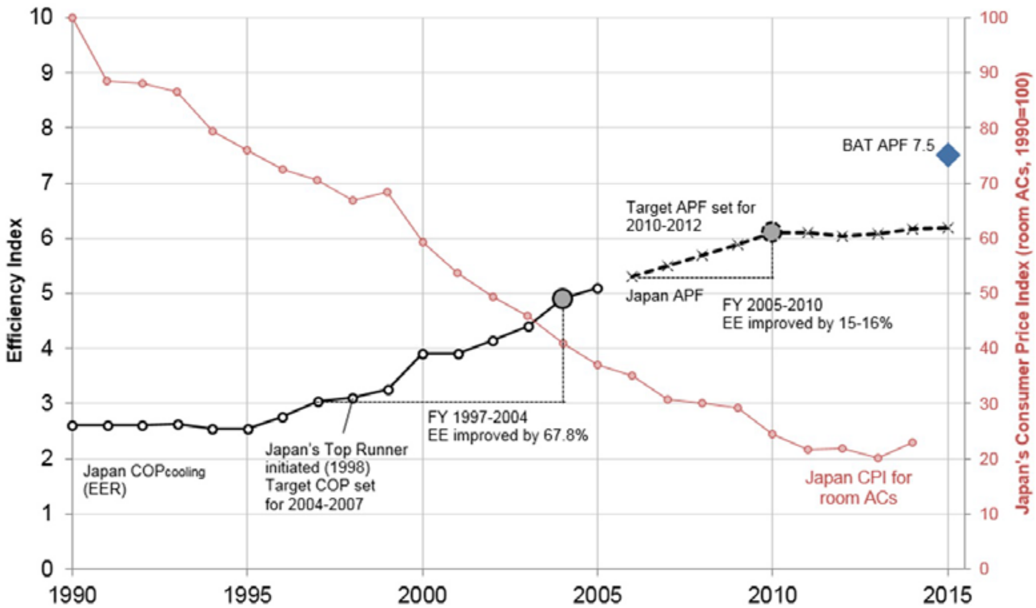


**FIGURE 12: Room AC efficiency index (black) and room AC consumer price index (red) in Japan (1990-2015)**. Between 1995 and 2010, AC efficiency nearly doubled, while inflation-adjusted AC prices reduced by 80%.

Figure 12 illustrates trends in room AC efficiency in Japan, measured as coefficient of performance (COP) and annual performance factor (APF), alongside inflation-adjusted consumer price index (CPI) for room ACs.

One of the main policies to promote room AC energy efficiency in Japan is the Top Runner program launched in 1997. The program mandated that, by 2004, all AC manufacturers had to have a sales-weighted, fleet-average COP of 5.3 (W/W) for small ACs and 4.9 (W/W) for larger ACs, which was ~60% more efficient than the market average efficiency in 1997 (representing an improvement of more than 7.5%/year). This target COP was determined by the COP of the most efficient AC model available on the market at the time. Industry met this target by producing more efficient ACs and discontinuing the sale of inefficient ACs. Manufacturers used several technical measures to improve efficiency, including incorporating variable-speed compressors, micro-channel heat exchangers, and electronic expansion valves. Significant efficiency improvements were also achieved by increasing the size of heat exchangers and increasing refrigerant flow. Between 1995 and 2005, room AC efficiency in Japan improved by nearly 100% (from a COP of 2.55 to 5.10, a rate of 7.2% per year). Prior to the Top Runner program, room AC efficiency had not improved substantially over time in Japan.

In 2006, a new target was established for 2010, which required a further improvement of about 20%. The efficiency metric was changed to APF to enable accurate crediting of the savings achieved by variable-speed/inverter ACs and their performance in both cooling and heating mode. Industry also met the 2010 target.

The top runner program was successful in increasing the average room AC efficiency by over 90% since 1996, while inflation-adjusted prices declined by more than 80%. The rate of price reduction remained steady, even as efficiency improved substantially. Electricity prices did not exhibit a rising trend during this period, suggesting that efficiency improvements were not driven by changes in electricity costs but rather by market forces and technological advancements.

### 5.3.2. KOREA

In 1992, the Korean government implemented the Energy-Efficiency Label and Standard Program to improve the energy efficiency of key products, including appliances and vehicles, that account for a majority of the country's energy consumption (Lee, 2010). Mandatory MEPS were published in 2002 and took effect in 2004 for window and split AC units up to 23-kW cooling capacity. In September 2011, the government launched the Energy Frontier Program, which sets energy-efficiency criteria for key appliances at 30-50% more efficient than grade 1 (which was the most efficient criterion in 2011). The first phase of the program included four major appliances: TVs, refrigerators, ACs, and clothes washers (Lee, 2010). Samsung and LG together make up more than 80% of the Korean AC market. Industry experts indicate that both brands want most of their models to qualify under the Grade 1 or the Frontier criteria to be competitive in the market. Therefore, these efficiency requirements, despite being voluntary, have likely driven overall efficiency improvement in ACs on the Korean market.

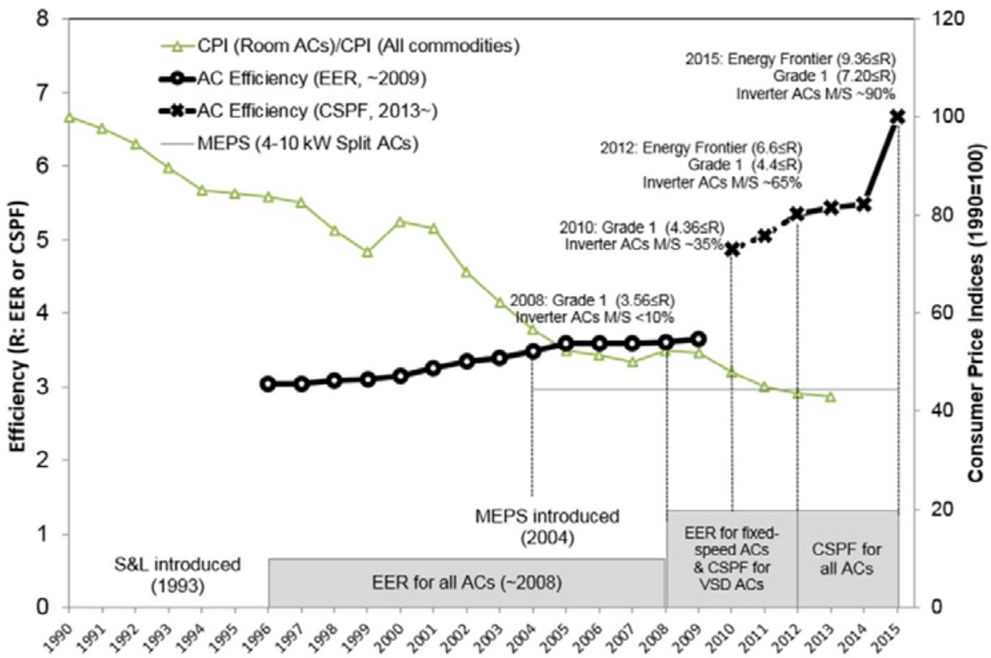


**FIGURE 13:** Room AC efficiency index (black) and room AC consumer price index (green) in Korea (1990-2015)

Sources: EERs for 1996-2008 are product-weighted averages (IEA, 2010). Mixed efficiencies with EER and CSPF for 2009-2010 and CSPF for 2013-2015 are product-weighted averages estimated using Korean Energy Agency's (KEA's) database (KEA, 2015). CPIs are from (KOSIS, 2014). Variable speed drive (inverter) ACs are estimated to account for more than 85% of the AC sales in the market in 2013 and more than 90% of AC sales in 2015 (KEA, 2015). The dotted lines are authors' estimates.

Figure 13 shows that the Grade-1 efficiency criterion has increased efficiency requirements by more than 100% since 2008, and most new models by LG and Samsung meet either the Grade 1 or the Frontier criteria, resulting in significant improvement in average AC efficiency compared to 2008 levels. The share of inverter/variable-speed ACs increased from less than 10% to more than 90% within a span of eight years, and efficiency improved by more than 100% (~12% per year). During this period, inflation-adjusted room AC prices (CPI) continued to decline.

### 5.3.3. INDIA

Between 2007 and 2023, driven primarily by BEE's S&L policies and global technological trends, room AC efficiency in India improved by 60%. At the same time, inflation-adjusted air conditioner prices nearly halved, reinforcing the idea that higher efficiency does not necessarily lead to increased costs (figure 14).

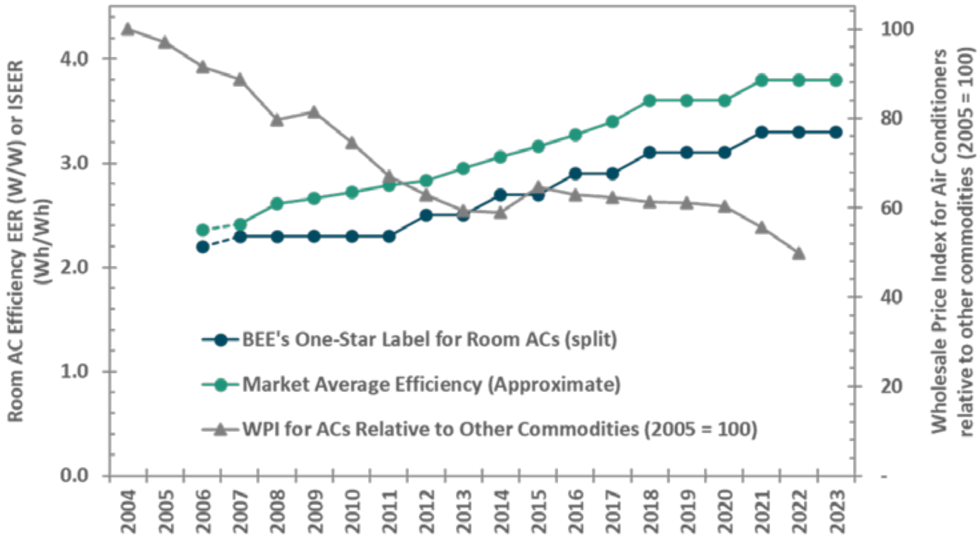


**FIGURE 14: Room AC efficiency (blue, green) and room AC wholesale price index (grey) in India (2006-2023)** Efficiency metric uses EER prior to 2016, and ISEER after 2016.

Data Sources: Bureau of Energy Efficiency. (2018) and Office of the Economic Adviser. (2023).

Market research in India indicates that energy efficiency is not the primary driver of AC retail prices. Instead, pricing is shaped by brand positioning, product differentiation, smart connectivity, and stock availability. Notably, several no-frills 5-star (or higher) models are available at prices comparable to the market average for 2-star or 3-star units, dispelling the notion that efficiency improvements necessarily increase consumer costs.

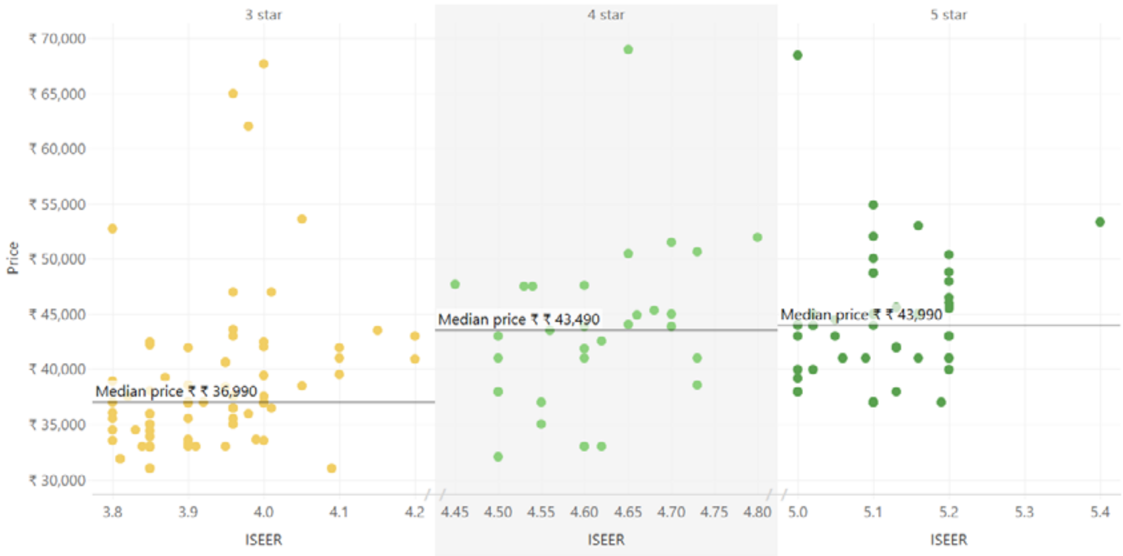


**FIGURE 15:** Room AC retail prices (2024) against efficiency levels (ISEER)

Source: Chunekar et al (2024)

Figure 15 shows the actual retail prices of room ACs in India in 2024, plotted against their efficiency levels (ISEER), confirming that efficiency has a weak correlation with AC prices. While the median price difference between 3-star and higher-efficiency models is approximately Rs 7,000, some super-efficient models (ISEER 5.2) are priced similarly to the median 3-star AC. Additionally, 4-star and 5-star models show little to no price difference. These findings suggest that brand reputation, unique product features, and stock availability play a more significant role in determining AC prices than energy efficiency alone.

## 5.4. ROOM AC EFFICIENCY INCREASE WILL RESULT IN MASSIVE CONSUMER SAVINGS

Our analysis finds that accelerating room AC efficiency improvement is highly cost-effective for consumers. The electricity bill savings over the appliance life significantly outweigh the incremental cost of purchasing a more efficient unit (Figure 16).

Under the BAU scenario, the one-star efficiency level in 2027 is projected to be ISEER 3.5. In the Accelerated Efficiency scenario, we assume this threshold is tightened to ISEER 5.0. Figure 16 compares median retail prices and estimated annual electricity costs for these two efficiency levels, assuming a marginal tariff of ₹8.9/kWh and 1,250 operating hours per year.

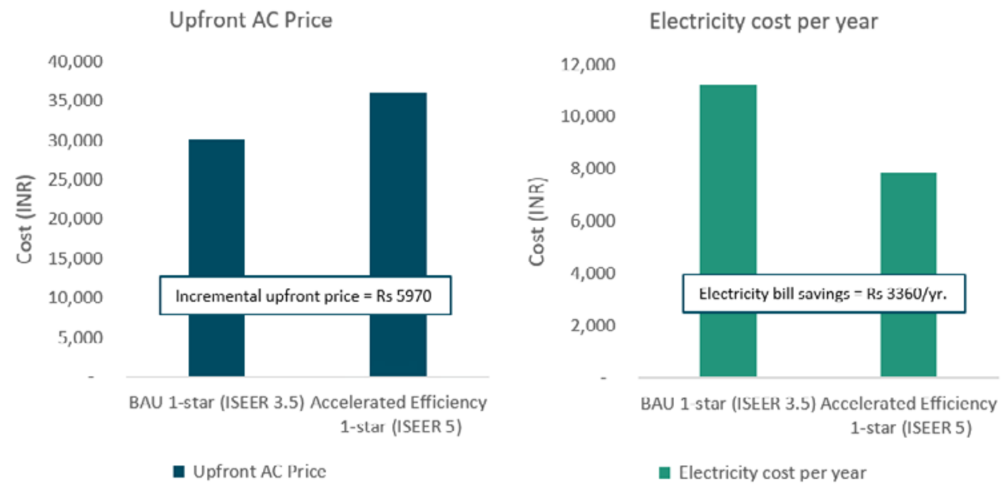


**FIGURE 16:** Estimating the consumer benefit for an individual consumer (1 ton)

Note: For estimating consumer electricity bill savings, it is crucial to use marginal electricity tariffs rather than average electricity tariffs because the savings from increased energy efficiency primarily reduce consumption in the highest tariff block, where electricity rates are the most expensive.

The incremental upfront price of a median 1-ton AC with ISEER 5 is Rs 5,970 compared to an median ISEER 3.5 AC. The higher-efficiency AC consumes 377 kWh less per year, resulting in annual electricity bill savings of Rs 3,360. This implies a payback period of under two years. Over the life of the AC, the net consumer benefit, estimated as NPV of electricity bill savings minus the incremental upfront price, would be as high as Rs 13,240. For commercial consumers, where marginal electricity tariffs are significantly higher, the net consumer benefits will increase and the payback period will shorten further. The consumer economics would look very similar for a 1.5 ton AC, where the incremental upfront price would be Rs 16,600 and the annual electricity bill savings would be Rs 5,270, implying a payback period of nearly 3 years and a net consumer benefit of about Rs 13,000.

Note that these consumer benefit assessments are highly conservative, as they are based on current market retail prices. However, as discussed in the previous section, historical trends show that as MEPS tighten, room AC prices continue to decline in real terms. This suggests that future MEPS revisions are unlikely to impose additional costs (in real terms) on consumers.

In aggregate, the impact of improved efficiency is substantial. Under the Accelerated Efficiency Improvement scenario, **annual room AC energy consumption could be reduced by over 40 TWh per year by 2030, and by nearly120 TWh per year by 2035**—equivalent to the output of over 60 GW of solar PV capacity (Figure 17).

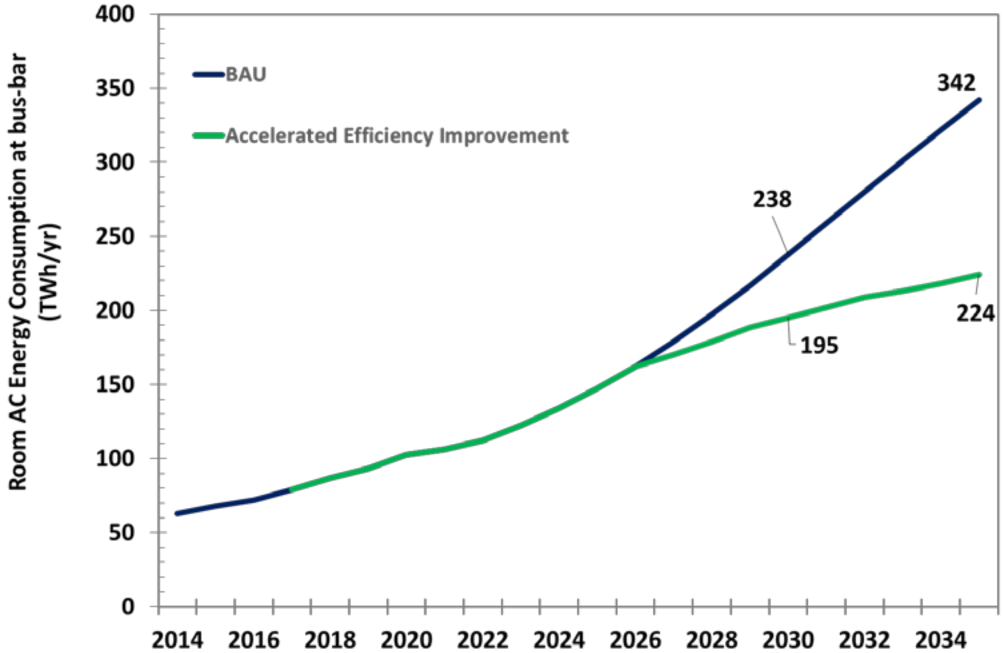


**FIGURE 17:** Room AC Energy Consumption at bus-bar (national total) for BAU and Accelerated Efficiency scenarios

To quantify the **aggregate consumer benefit**, we estimate the **NPV** of electricity bill savings minus any additional purchase cost, for all units sold between 2027 and 2035. We consider two cases for estimating the upfront price of efficient ACs:

i. **Realistic**: Accelerating efficiency improvements do not increase inflation-adjusted AC prices relative to the BAU scenario, consistent with the observed trends in India, Japan, and Korea (Taylor, Spurlock, & Yang, 2015; Van Buskirk, Kantner, Gerke, & Chu, 2014).

ii. **Conservative**: AC prices do increase as a result of accelerated efficiency improvements. We estimate the incremental prices based on detailed engineering cost assessments and actual retail market prices (see Abhyankar et al, 2017, Shah et al., 2016 and appendix for details).

Figure 18 shows the aggregate net consumer benefit from Accelerated Efficiency Improvement between 2027 and 2035.

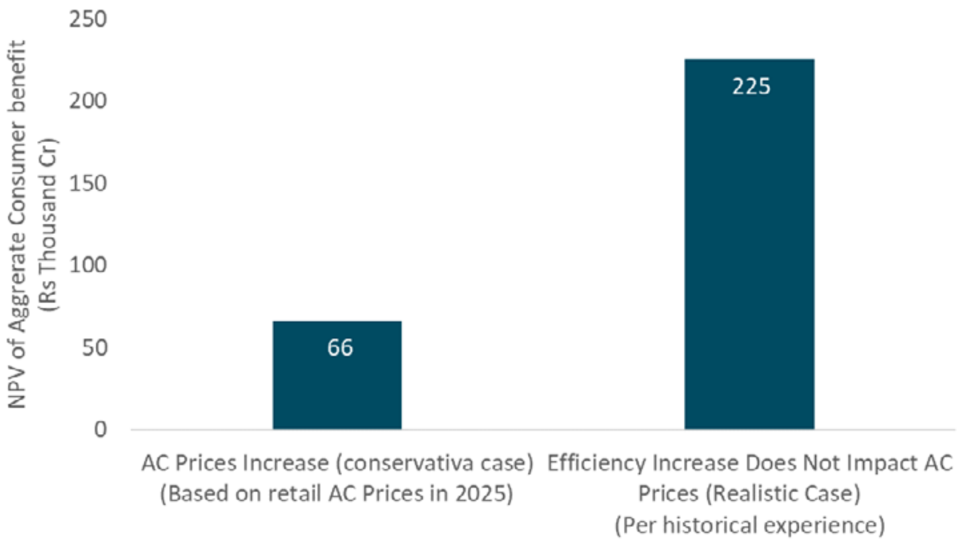


**FIGURE 18:** NPV of net consumer benefit from accelerated efficiency improvement

Key Assumptions: Hours of room AC use: 1,250 hours/yr; marginal electricity tariff: Rs 8.9/kWh in 2025 increasing at 2% per year; Discount rate: 8% for estimating NPV; median life of AC: 7.3 years. Note that the net benefits estimates are merely indicative because the electricity prices and hours of use may change in the future.

Between 2027 and 2035, **net consumer benefit would range from Rs 66,000 crore (US$ 8 billion)** in the conservative case (if AC prices increase with efficiency) t**o Rs 225,000 crore (US$ 26 billion)** in the realistic case (if efficiency improvements do not impact AC prices).

While manufacturers may face additional costs to produce higher-efficiency models, these are largely captured in incremental retail prices. Moreover, tighter efficiency standards can offer scale / volumes to efficient products and may help lower their manufacturing costs and prices, as observed empirically in multiple countries. Additionally, they can strengthen the global competitiveness of Indian AC manufacturers, opening up export opportunities and incentivizing local production of high-performance components. A broader evaluation of industry-side effects would further reinforce the case for accelerated MEPS—but even without this, the consumer and system-level benefits are both clear and compelling.

# 6. POLICIES AND PROGRAMS TO ACCELERATE ROOM AC EFFICIENCY IMPROVEMENT

## 6.1. A CLEAR CASE FOR ACCELERATED STAR LABEL RATCHETING

Experience in India and internationally shows that **MEPS and comparative star labels are among the most effective tools for driving appliance efficiency**. In India, 3-star ACs dominate the market, and the average unit sold typically aligns with the 2- or 3-star efficiency level—even as labeling thresholds have remained relatively lenient in recent years.

To accelerate market transformation, **it is essential to strengthen the MEPS (1-star level)** rather than just nudging the upper end of the star scale. If MEPS revisions remain weak or infrequent, the market risks drifting toward lower efficiency tiers, blunting the overall impact of the labeling program. Importantly, this does not necessarily mean more frequent updates—just the ambition of each revision cycle needs to be much steeper.

Equally important is the need for a **long-term MEPS roadmap—spanning 8 to 10 years**—to provide manufacturers with investment clarity and supply chain certainty, and to guide utilities and consumers toward more efficient technologies.

We propose the following long-term trajectory for MEPS (1-star level):

- **2027**: Set 1-star at ISEER 5.0 - equivalent to the 5-star level today. 600+ AC models (20% of the models offered in the market) already exceed this level.
- **2030**: Set 1-star at ISEER 6.3 - on par with the most efficient AC sold in India today. Leading domestic and international manufacturers (e.g., Godrej, Voltas, Blue Star, Hitachi, Daikin etc.) offer such super-efficient models at competitive prices, signalling supply chain readiness
- **2033**: Set 1-star at ISEER 7.4 - (equivalent to on-par with the today's most efficient commercially available AC sold globally). This will need several supporting measures such as bulk procurement programs for ultra-efficient ACs, revising test procedures to account for dehumidification etc.

Figure 19 illustrates the recommended MEPS (one-star) trajectory (green line) alongside BEE's historical and current policy (black line).

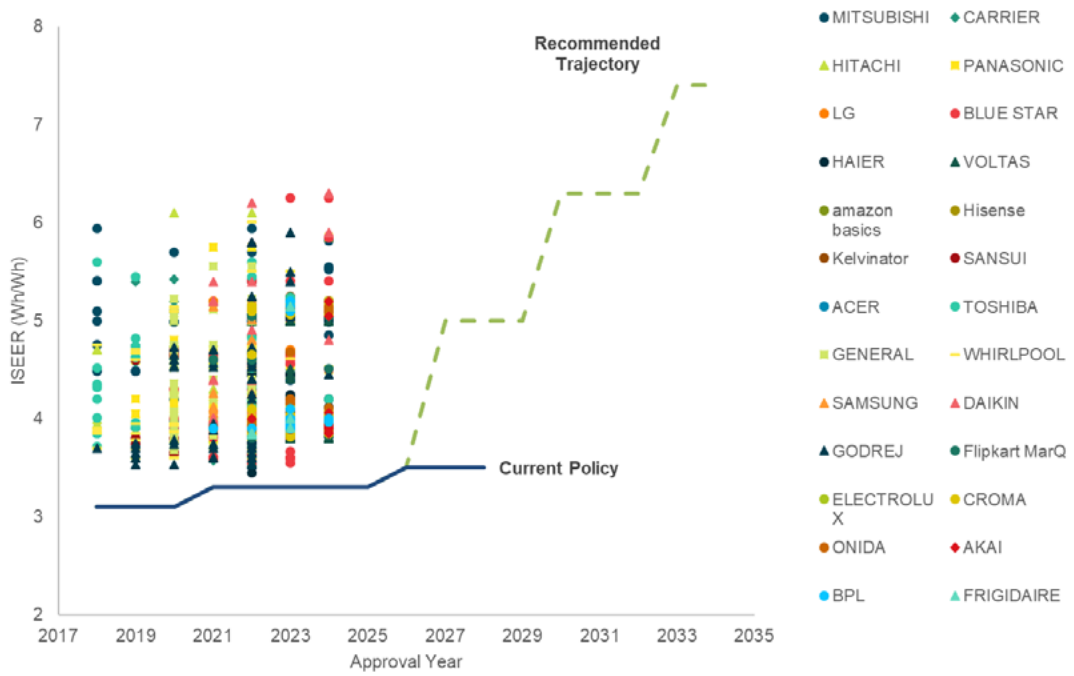


**FIGURE 19: Recommended trajectory for room AC (variable speed) 1-star label (green line)**. The chart also shows BEE's current policy as well as historical 1-star levels (black line).

This pathway would **more than double the historical rate of efficiency improvement** (from~3% to ~8% per year), aligned with the country's global commitments and vision of becoming a global leader in sustainable and affordable cooling technologies.

This approach would reduce peak demand and overall electricity consumption without compromising cooling services for consumers, while also helping India avoid locking in inefficient technologies that would persist in the market for years.

## 6.2. BULK PROCUREMENT AND INCENTIVES TO SUPPORT MEPS TIGHTENING

While tightening standards is essential, complementary programs are needed to scale demand for efficient products and smooth the transition for manufacturers and consumers.

India has already demonstrated the success of this approach. Programs like EESL's Super-Efficient AC Procurement Initiative—inspired by the UJALA LED program—have shown that large-scale, aggregated procurement can drive down costs and rapidly transform the market. Such initiatives also serve to prime the supply chain for mass production of high-efficiency units.

Targeted incentive programs can further accelerate adoption by addressing upfront cost barriers, especially among lower-income households. However, program design must be carefully calibrated to minimize free-rider effects—where consumers who would have purchased efficient models anyway benefit from subsidies. Lessons from Mexico's refrigerator replacement program (Boomhower & Davis, 2014) suggest that smaller, well-targeted incentives can be just as effective as larger ones.

Fiscal instruments such as 5-10% production-linked incentives (PLI) for incremental sales of high-efficiency ACs can provide an effective supply-side signal to the manufacturers. For example, a 5% incentive could be offered for units that meet the recommended 2027 MEPS threshold (ISEER 5.0), and scaled up to 10% for units that exceed the recommended 2030 level (ISEER 6.3 or higher). This tiered structure would reward manufacturers who invest in efficient models early. On the supply side, a customs duty on imported inefficient compressors can nudge the market away from inefficient AC components and incentivize domestic manufacturing. On the demand side, a targeted Goods and Services Tax (GST) reduction on domestically manufactured high-efficiency ACs can directly lower upfront costs for consumers. For instance, ACs exceeding the recommended 2027 MEPS could qualify for a GST rate reduction, with ACs exceeding the recommended 2030 MEPS eligible for a complete waiver.

Bulk procurement and incentives also play a critical role in introducing ultra-efficient models into the market—such as globally most efficient products or the global cooling prize winner products —creating a pipeline for future MEPS revisions. When aligned with a progressive MEPS trajectory, these measures can help de-risk early investments and build momentum for market transformation.

## 6.3. EXTEND THE EFFICIENCY FRAMEWORK TO OTHER COOLING TECHNOLOGIES

As India's cooling demand diversifies, it is important to extend energy efficiency policies to other types of space-cooling equipment, including:

- Chillers
- Variable Refrigerant Flow (VRF) systems
- Ducted and packaged ACs
- Rooftop units

Applying a similar accelerated trajectory to these products will require enabling measures, including:

- Development of standardized test procedures
- Expansion of testing lab capacity
- Definition of appropriate efficiency metrics
- Integration of standards with building codes and regulatory frameworks

These steps will ensure that India builds a comprehensive, forward-looking cooling efficiency ecosystem—not just for room ACs, but across all major cooling segments. This will be essential to achieving national energy security, climate goals, and resilient infrastructure planning.

# 7. DEHUMIDIFICATION AND INDIA'S PROPOSED TEST PROCEDURE CHANGES

In India's hot-humid climate, controlling indoor humidity (dehumidification) is as important as lowering air temperature for comfort. Air conditioners that effectively remove moisture can maintain comfort at higher thermostat setpoints, thereby saving energy. However, conventional efficiency metrics focus mainly on cooling output and energy use under standard conditions, without fully reflecting latent (moisture) removal performance. This oversight can lead to AC designs that score high in lab tests but struggle to control humidity in real-world operation—especially at part loads or conversely AC designs that overcool in order to reach acceptable humidity levels, but at a high energy cost. Kalanki et al (2025).

The Global Cooling Efficiency Accelerator launched by RMI and the Clean Cooling Collaborative, is building the evidence base to support updated efficiency standards and has initiated preliminary consultations with key stakeholders. By measuring an AC's moisture removal ability under humid conditions, the revised test will better reflect real-world comfort performance. Going forward, star ratings and MEPS should increasingly reward models that provide efficient cooling and effective dehumidification and also more accurately reflect such energy savings and better comfort to consumers.

Improved dehumidification performance not only enhances comfort but also yields energy savings. Recent field study on the Global Cooling Prize winning units showed that these units used up to 50% less energy than typical ACs (Kalanki et al, 2025), as shown in figure 20.

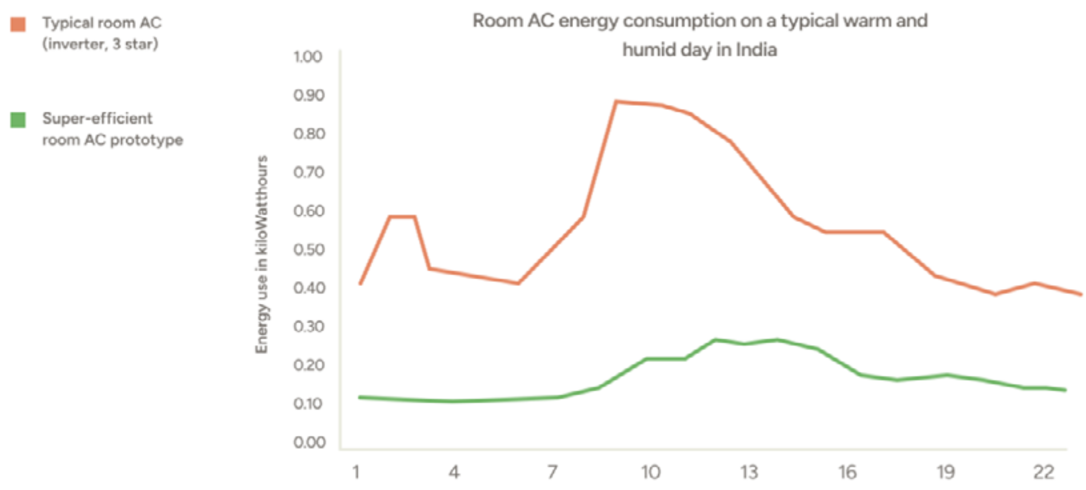


**FIGURE 20:** Super efficient ACs can reduce AC peak load by 50% (Kalanki et al 2025)

Studies show that on a hot, humid day, more than half of an AC's energy consumption can go into removing moisture. An AC that keeps indoor humidity in check allows occupants to be comfortable at a higher temperature or with shorter runtimes. Each 1°C increase in setpoint can reduce cooling electricity use by roughly 6–8%. Therefore, units optimized for latent removal can deliver the same comfort with less cooling output, directly cutting energy use. Incorporating humidity performance into efficiency standards will push manufacturers to adopt features that maintain comfort more efficiently.

# 8. GLOBAL COOLING PRIZE AND INDIA'S ROLE

India has taken a leading role in spurring innovation for next-generation cooling. The Global Cooling Prize (GCP)—an international innovation competition launched in 2018—was co-initiated by the Government of India alongside global partners. The contest challenged manufacturers worldwide to develop residential cooling solutions with dramatically lower energy consumption and climate impact. India's involvement was central: prototypes were tested under Indian climate conditions, and an Indian company was among the finalists. In 2021, two teams (Daikin and Gree) were declared joint winners after demonstrating prototypes with five times less climate impact than today's standard ACs. These breakthrough designs use novel technologies and refrigerants to achieve ultra-efficient cooling, and the manufacturers plan to commercialize them by the mid-2020s.

The Global Cooling Prize illustrates how frontier cooling technologies can be accelerated toward market viability. By providing R&D support, clear performance targets, and real-world field testing, the GCP enabled manufacturers to overcome barriers and prove that ultra-efficient cooling is feasible. The next step is to bring these innovations to the mass market. India can facilitate this by linking GCP outcomes with programs for large-scale deployment including through the World Bank's recently launched "AHEAD" program. For instance, bulk procurement initiatives run by Energy Efficiency Services Limited (EESL) have demonstrated the ability to drive down costs through economies of scale. In a recent program, EESL procured 50,000 super-efficient ACs (about 20% more efficient than the 5-star baseline) at prices comparable to standard models – illustrating a model that could be replicated for GCP technologies.

Furthermore, insights from the GCP can inform future updates to India's MEPS and labeling. If cooling products with step-change efficiency are becoming available, setting more ambitious MEPS levels in upcoming revisions becomes more practical. Incorporating advances from the GCP into the policy roadmap—for example, by tightening efficiency standards further, revising the test procedure to better reflect dehumidification performance to consumers and encouraging low-GWP refrigerants—will ensure that the best technologies become the new normal. India's leadership in the Global Cooling Prize not only demonstrates its commitment to climate-friendly cooling but also provides a pathway to bring cutting-edge solutions into its domestic market through supportive policies and programs.

# 9. KEY CAVEATS

While this analysis presents a compelling case for accelerating room AC efficiency improvements in India, several key caveats must be acknowledged:

- **Uncertainty in Future Market and Technological Trends**

  The projections in this study assume that historical trends in efficiency improvements, cost reductions, and market dynamics will continue. However, external factors—such as supply chain disruptions, global technological advancements, and shifts in consumer preferences—could alter these trajectories.

- **Heatwaves and Urban Heat Island Effect**

  s climate change accelerates, rising temperatures could lead to greater-than-anticipated cooling demand, potentially offsetting some of the gains from improved energy efficiency. Urban heat island effects and shifting weather patterns are also likely to intensify the need for space cooling, contributing to faster air conditioner adoption and higher peak electricity loads. Our estimates should therefore be considered conservative. They are based on a normal-year baseline and do not account for the intensifying impact of extreme heat events such as heatwaves, which can significantly amplify cooling demand. Furthermore, the analysis does not include the positive feedback loop wherein increased AC usage releases waste heat, elevating ambient urban temperatures and further driving up AC demand—a compounding effect particularly relevant in densely populated cities.

- **Behavioral and Socioeconomic Factors**

  While efficiency improvements lower per-unit energy consumption, the rebound effect—where consumers use more cooling due to lower operating costs—could partially offset expected energy savings. Additionally, socioeconomic factors, such as income growth and increased AC affordability, may drive higher adoption rates, impacting overall electricity demand.

- **Manufacturing and Supply Chain Considerations**

  While Indian AC manufacturers already produce high-efficiency models, rapid regulatory changes could pose challenges related to scaling up production capacity, ensuring component availability, and maintaining cost competitiveness. Strategic industry support and incentives may be required to smooth the transition.

- **Electricity Tariff and Consumer Savings Assumptions**

  Our consumer savings estimates depend on assumed electricity tariffs and usage patterns, which may change over time. Future electricity pricing reforms, variations in peak vs. off-peak tariffs, and demand-side management programs could influence the actual financial benefits realized by consumers.

- **Implementation Challenges in Policy and Standards Revisions**

  The effectiveness of proposed MEPS and labeling revisions depends on strong regulatory enforcement, compliance monitoring, and periodic policy updates. Past experience suggests that delays in implementation or weak enforcement mechanisms could limit the impact of efficiency policies.

- **Integration with Other Cooling Strategies**

  While improving AC efficiency is a critical strategy, it must be complemented by broader cooling interventions, including passive cooling techniques (e.g., cool roofs, shading, and ventilation), efficient building design, and demand-side management programs. A holistic approach is necessary to achieve sustainable cooling growth.

- **Informal Second-Hand AC Market**

  As efficiency standards tighten, there is a risk that older, inefficient units may continue to operate through informal resale, particularly in lower-income or rental segments. This potential leakage effect underscores the value of exploring replacement programs and complementary measures such as voluntary buy-back schemes, scrappage programs, support for certified recyclers, and awareness campaigns - to ensure the full benefits of MEPS are realized across the market.

Despite these caveats, the findings strongly support an accelerated efficiency trajectory as a cost-effective and necessary strategy to manage India's growing cooling demand, reduce peak electricity loads, and enhance consumer benefits. Proactive policy interventions—aligned with global best practices—can enable India in achieving its goal of becoming a global leader in sustainable and affordable cooling technologies, ensuring both energy security and economic competitiveness in the years ahead.

# APPENDIX 1: METHODS AND ASSUMPTIONS

## EFFICIENCY TRAJECTORY

We have created two scenarios for how the AC MEPS (one-star level) would be revised in the future:

- **Business-As-Usual (BAU)** scenario follows the Bureau of Energy Efficiency (BEE) stipulated star labels through 2028 and assumes that efficiency improvements continue at the historical rate of one-star ratchet every three years (e.g., the previous cycle's 2-star label becomes the new 1-star standard), translating to a 2–3% annual efficiency increase. By 2033, the one-star level is projected to reach an ISEER of 4.3. This scenario serves as the reference case for our analysis.

- **Accelerated Efficiency Improvement** scenario assumes that starting in 2027, MEPS are revised at an ambitious rate, in line with India's commitment to double the historical rate of energy efficiency improvement and the vision of becoming a global leader in sustainable and affordable cooling technologies. double the historical rate, with a fivetwo-star ratchet jump every three years. For example, the 3-star level from the previous cycle becomes the new 1-star standard. MEPSUnder this trajectory looks like the following:

  » **2027**: Set 1-star at ISEER 5.0 - equivalent to the 5-star level today. **600+ AC models** (20% of the models offered in the market) already exceed this level.

  » **2030**: Set 1-star at ISEER 6.3 - on par with the most efficient AC sold in India today, similar to a top-runner program, used widely and successfully in Japan. Leading **domestic and international manufacturers** (e.g., Godrej, Voltas, Blue Star, Hitachi, Daikin etc.) offer such super-efficient models at competitive prices, signalling supply chain readiness.

  » **2033**: Set 1-star at ISEER 7.4 **-** (equivalent to on-par with the today's most efficient commercially available AC sold globally). This will need several supporting measures such as bulk procurement programs for ultra-efficient ACs, revising test procedures to account for dehumidification etc.

  This Accelerated Efficiency Improvement scenario implies over 8% annual efficiency improvement, more than double the rate under the BAU scenario.

Table A1 shows the room AC MEPS (one-star levels) up to 2035 for the two scenarios: BAU and accelerated efficiency improvement.

**TABLE A-1:** BAU and Accelerated Efficiency Improvement One-Star MEPS Levels

| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BAU | 3.3 | 3.3 | 3.3 | 3.5 | 3.5 | 3.5 | 3.8 | 3.8 | 3.8 | 4.3 | 4.3 | 4.3 | 4.3 |
| Accelerated Efficiency | 3.3 | 3.3 | 3.3 | 3.5 | 5.0 | 5.0 | 5.0 | 6.3 | 6.3 | 6.3 | 7.4 | 7.4 | 7.4 |

## AC PRICES

To know the incremental price paid by the consumers, we first have to estimate what the price would have been in the absence of efficiency improvement (counterfactual price). We base it on the detailed engineering cost estimates of efficiency improvement from Abhyankar et al (2017), combined with actual retail prices in India. Table A2 shows our estimated retail AC prices for a select range of ISEER levels, and compares them with actual retail prices.

**TABLE A-2:** Estimated 1.5 ton AC Prices for a Range of ISEER Levels

| ISEER | Median actual retail price 2025 (Rs) | Estimated AC price (Rs) |
|---|---|---|
| 3.5 | 26,750 | 29,379 |
| 3.8 | 36,495 | 35,744 |
| 4.0 | 37,990 | 37,486 |
| 4.2 | 39,789 | 39,380 |
| 4.5 | 37,695 | 39,824 |
| 4.6 | 40,495 | 41,722 |
| 5.0 | 37,490 | 42,209 |
| 5.2 | 44,245 | 46,580 |
| 5.4 | 59,990 | 55,448 |
| 5.6 | 56,990 | 54,942 |
| 5.8 | 55,190 | 55,037 |
| 6.2 | 64,229 | 61,546 |

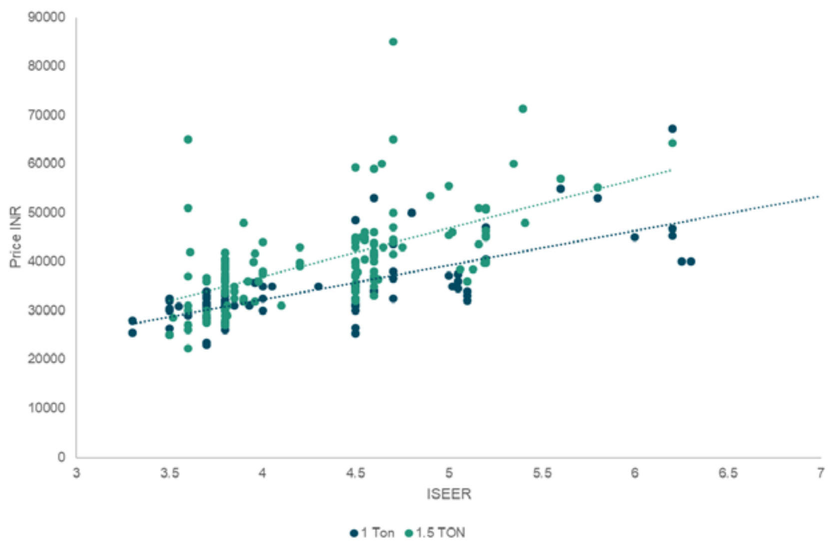


**FIGURE A-1:** Regression analysis showing over 200 room AC models marketed in India in March 2025

## CONSUMER YEARLY SAVINGS

Consumer yearly savings for a given level of cooling service is of the electricity bill savings estimated as the difference of the electricity consumption of a baseline AC efficiency of ISEER 3.3 and the energy consumed by an efficient AC multiplied by the electricity price. AC incremental cost for improving ISEER is based on the Updated cost model. The simple payback is estimated as the number of years required for the electricity bill savings to surpass the cost of improving ISEER. Table A3 shows our assumptions.

**TABLE A-3:** Assumptions for Calculating Net Consumer Benefit

| Parameter | Assumption | Units |
|---|---|---|
| Cooling capacity | 3.5-5.3 | kW Ref |
| AC hours of use/yr | 1250 | hours/yr |
| AC Life (median) | 7.3 | Years |
| Marginal Electricity Tariff (Rs/kWh) | 8.9 | Rs/kWh |

## STOCK TURNOVER MODEL

Room AC sales have been growing at a compound annual growth rate (CAGR) of more than 10% over the last 15 years. In the future, rising incomes, urbanization, and falling appliance prices are expected to support the continuation of the same trend. Sales CAGR was modeled linearly decreasing from 13.5% (2014-2023 average) to 10% in 2035.

For the AC stock turnover model, we use a Weibull survival function with a median expected life of about 7.3 years (figure A2).

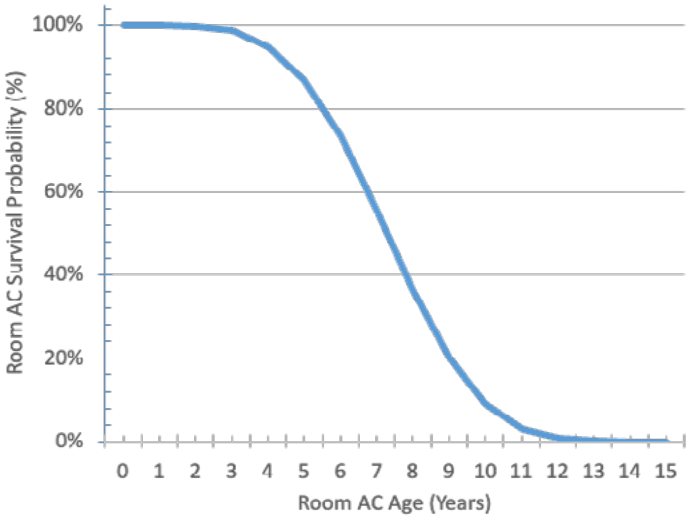


**FIGURE 1:** Room AC Survival function

## TOTAL ENERGY CONSUMPTION AND PEAK LOAD

For estimating the total energy consumption at the bus-bar, we assume the transmission and distribution loss would be 15% in 2010, linearly decreasing to 12.5% in 2035. Because ISEER is a seasonal energy-efficiency metric, it cannot be directly used for estimating the kW rating of an AC or the AC's peak load contribution. Based on the temperature distribution and seasonal test conditions in India and the engineering options available for efficiency improvement, we estimate the equivalent EER level (Shah et al 2016). This EER value (W/W) is then used to estimate the kW input rating of the AC. Based on (Phadke et al., 2013), we use a peak coincidence factor of 60% in 2010, linearly decreasing to 55% in 2035. Tables A4 and A5 summarize the key assumptions and results.

**TABLE A-4:** Assumptions for Calculating Peak Load

| Parameter | Assumption |
|---|---|
| AC Sales growth CAGR | 13.5%-10% |
| AC life | 7.3 years (median) |
| Transmission and Distribution Losses | 15%-12.5% |
| Peak Coincidence factor | 0.60-0.55 |
| AC input rating (kW) | AC Cooling Size (kW R)/EER* |
| AC peak load (bus-bar) | (AC input rating * peak coincidence factor) / (1 - transmission and distribution loss) |

* EER is different from ISEER and would not measure part-load performance unlike ISEER

**TABLE A-5:** Summary of Sales, Stock, Energy, and Peak-Load Projections

| Parameter | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|
| Room AC sales (Millions/y) | 7 | 14 | 23 | 34 |
| Room AC live stock (Millions/y) | 45 | 72 | 126 | 202 |
| Total room AC consumption at bus-bar BAU Scenario (TWh/y) | 103 | 148 | 238 | 342 |
| Total room AC peak load at bus-bar BAU Scenario (GW) | 48 | 72 | 122 | 183 |
| Total room AC consumption at bus-bar Accelerated Efficiency Scenario (TWh/y) | 103 | 148 | 195 | 224 |
| Total room AC peak load at bus-bar Accelerated Efficiency Scenario (GW) | 48 | 72 | 99 | 119 |

# APPENDIX 2: LITERATURE REVIEW ON ROOM AC EFFICIENCY IMPROVEMENT IN INDIA

Rising incomes, rapid urbanization, and intensifying heat waves are driving the exponential growth in cooling demand in India. Room air conditioners (ACs) have emerged as a key contributor to peak electricity demand, and their proliferation has major implications for energy security and climate goals. Over the past decade, India has implemented a range of policies and programs to improve AC energy efficiency, with notable success in technological transformation and market shifts. However, challenges remain in ensuring equitable access, sustained compliance, and achieving the ambitious targets laid out in the India Cooling Action Plan (ICAP). This literature review synthesizes academic, policy, and think-tank research on room AC efficiency improvements in India over the last 10 years, covering policy evolution, technological progress, market adoption, consumer economics, grid and climate implications, and implementation barriers.

## EVOLUTION OF STANDARDS AND LABELING

India's efforts to improve room AC efficiency have largely been led by the Bureau of Energy Efficiency (BEE), which introduced mandatory star labeling in 2009 and Minimum Energy Performance Standards (MEPS) shortly thereafter (BEE, 2018). The program transitioned from a constant-load efficiency metric (EER) to a seasonal metric (ISEER) in 2015 to better capture part-load performance in India's diverse climate (Karali et al., 2020). Between 2010 and 2023, the 1-star MEPS improved from an EER of 2.7 to an ISEER of 3.3, and the 5-star level rose to 5.0 (BEE, 2023; Abhyankar et al., 2017a).

Several studies note that BEE's progressive label revisions and tighter standards have helped eliminate the least efficient models and nudged the market toward better performance (Shah et al., 2015; Park et al., 2021). However, India's MEPS still lag behind those of countries like Japan and South Korea, where average efficiencies are significantly higher (IEA, 2018).

## TECHNOLOGICAL ADVANCEMENTS AND EFFICIENCY TRENDS

A key shift in India's AC market has been the widespread adoption of inverter technology, which offers 20–30% higher seasonal efficiency than fixed-speed models by adjusting compressor speed to cooling load. Inverter models constituted over 75% of new AC sales by 2022 (AEEE, 2023; LBNL, 2023). This transition was aided by the introduction of the ISEER metric and voluntary inverter-specific labels (BEE, 2018).

Efficiency gains have also stemmed from improved refrigerants (e.g., HFC-32 replacing HCFC-22), larger heat exchangers, and better expansion valves (Kalanki et al., 2025). Prototypes from the Global Cooling Prize demonstrated radical improvements, using low-GWP refrigerants and novel thermodynamic cycles to achieve over fivefold reduction in climate impact (RMI, 2021).

Despite these advances, several studies caution that real-world efficiency can vary due to poor installation, high ambient temperatures, or inadequate maintenance (CLASP, 2020; NRDC, 2022). Moreover, humidity control remains under-addressed, prompting calls to revise test procedures to reflect latent cooling performance (Kalanki et al., 2025).

## MARKET ADOPTION AND CONSUMER BEHAVIOR

The Indian AC market has expanded from 4.7 million annual units in 2015 to over 10 million by 2023 (Statista, 2023). However, market adoption remains skewed toward mid-efficiency (3-star) models due to affordability concerns and limited consumer awareness (Prayas, 2020; CEEW, 2021). Surveys find that consumers prioritize upfront cost over lifecycle savings, and that dealers often promote lower-efficiency units due to higher turnover or margins (Chunekar et al., 2021; Shah et al., 2015).

Yet, the supply side shows readiness for higher standards: more than 600 models already exceed the 5-star level, with ISEERs above 5.6 (BEE, 2023). Bulk procurement programs by EESL and rebate schemes by utilities (e.g., Tata Power Delhi) have demonstrated that efficient ACs can be made cost-competitive through aggregation (EESL, 2019; AEEE, 2020).

Behavioral factors also affect outcomes. Users often set ACs to 20–22°C, significantly lower than the recommended 24–26°C, leading to overcooling and energy waste (CEEW, 2020). Government efforts to mandate 24°C default settings and promote thermostat awareness are promising but under-evaluated (PIB, 2018).

## ENERGY SYSTEM AND CLIMATE IMPACTS

Abhyankar et al (2017) find that room ACs are expected to contribute over 140 GW to India's peak load by 2030 if efficiency improves at slow historical rates. This could necessitate vast investments in peaking capacity and energy storage. They also show that doubling AC efficiency could reduce peak demand by 40-50 GW by 2030, saving ₹5 trillion in avoided generation and grid infrastructure (Abhyankar, et al 2017a).

From a climate perspective, efficient ACs also reduce indirect emissions from electricity use and support India's commitments under the Kigali Amendment and Paris Agreement. IEA (2018) projects that improving global AC efficiency could halve cooling-related $CO_2$ emissions by 2050. For India, this equates to 100+ TWh/year of savings and tens of millions of tonnes of $CO_2$ avoided by 2030 (IEA, 2018; Shah et al., 2015).

## IMPLEMENTATION AND COMPLIANCE CHALLENGES

Despite robust policy design, compliance and enforcement remain weak links. The Comptroller and Auditor General (CAG, 2020) flagged limited check-testing, inadequate lab capacity, and delays in updating standards. Label accuracy and field performance discrepancies have also been observed (CLASP, 2020).

Stakeholder coordination is another challenge. Multiple agencies—BEE, BIS, MoEFCC, MNRE, and state DISCOMs—oversee different aspects of cooling efficiency, leading to regulatory fragmentation (AEEE, 2021). Researchers advocate for a permanent inter-agency task force to oversee cooling policy integration (CEEW, 2022).

## COMPLEMENTARY POLICIES

To augment MEPS and labeling, India has piloted cooling demand response (DR) programs, with Tata Power Delhi demonstrating peak reductions via smart thermostat setbacks (RMI, 2022). The India Cooling Action Plan also promotes passive strategies like cool roofs and natural ventilation (MoEFCC, 2019). On the finance front, EESL's leasing model and proposals for on-bill financing and green GST discounts aim to overcome affordability barriers (Shakti Foundation, 2020).

Bulk procurement, innovation prizes (e.g., GCP), and policy incentives for R&D are highlighted as effective levers to accelerate transformation (Kalanki et al., 2025; Abhyankar et al., 2017a & 2017b).

India has made significant progress in improving room AC efficiency through policy innovation, market transformation, and technological upgrades. However, to meet the dual challenge of growing cooling demand and decarbonization, further acceleration is essential. Key areas for future work include revising dehumidification metrics, strengthening enforcement, expanding demand response, and addressing affordability for low-income households. The convergence of policy, industry, and consumer engagement will be critical in shaping India's cooling future.

# APPENDIX 3: HOW DO INDIA'S ROOM AC MEPS COMPARE GLOBALLY?

Figure A3 shows an interregional comparison of room AC efficiency, based on a normalized standard, the ISO CSPF. We show the MEPS (the most stringent efficiency label), and the most efficient AC model available in each region, revealing insights into the potential for further efficiency gains. These comparisons suggest that there is considerable scope for improving AC efficiency in India using commercially available technologies. The most efficient models sold in each region and worldwide often surpass the efficiency levels recognized by the most stringent regional energy standards and labeling (S&L) programs. This implies that significant energy savings could be achieved if more rigorous labeling or standards programs were implemented in India. Compared to other selected regions, India currently lags in terms of the stringency of its MEPS labels and the efficiency levels of its most efficient available models.

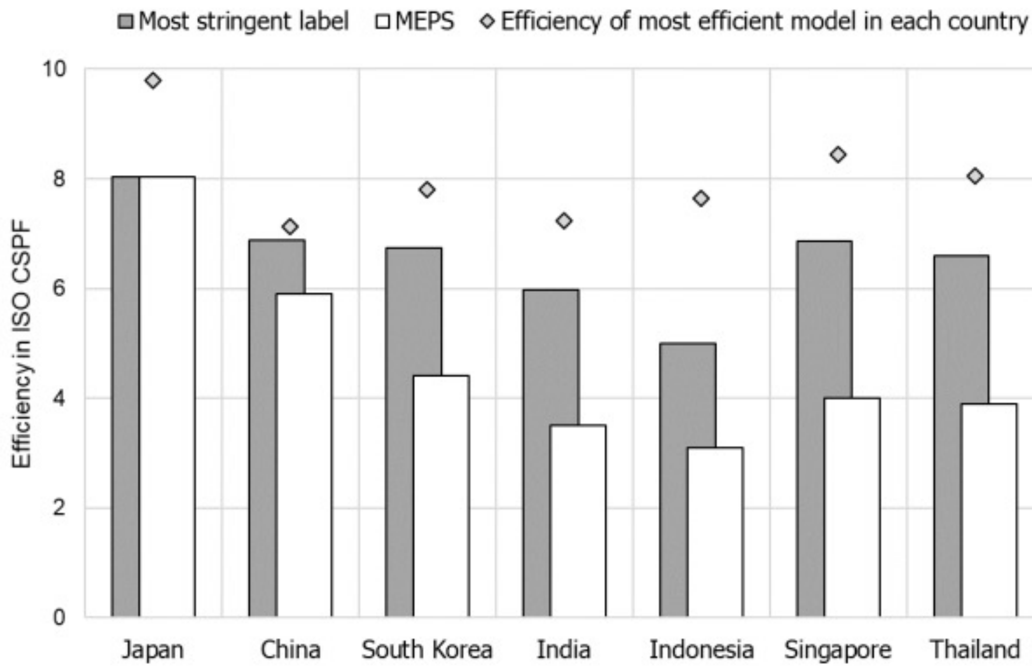


**FIGURE A-2:** presents a comparative analysis of room air conditioner efficiency across India and six other major markets: China, Japan, South Korea, I`ndonesia, Singapore and Thailand.

Source: (Park, 2021)

# APPENDIX 4: REBOUND EFFECT

The rebound effect is a common concern when evaluating the accuracy of cost-benefit estimates for appliance efficiency improvements. The direct rebound effect occurs when increased energy efficiency effectively raises consumers' disposable income, leading to higher energy consumption. In developed countries, this effect is typically 8-12% for most appliance efficiency improvements in the short and medium term (Borenstein, 2013; Gillingham, Rapson, & Wagner, 2016). However, in emerging economies, direct rebound effects on electricity consumption tend to be higher, ranging between 12% and 46% (Gillingham et al., 2016). These variations arise due to rapidly evolving consumption patterns, making short-term demand elasticity and rebound effect estimates particularly challenging.

It is important to note that the rebound effect represents increased access to cooling services and improved consumer welfare. The indirect rebound effect—where energy savings lead to increased consumption of other goods—is generally small and difficult to predict (Borenstein, 2013; Gillingham et al., 2016). Moreover, the rebound effect is unlikely to impact peak-load savings, as increased AC usage does not necessarily change the timing of peak demand.

Abhyankar et al. (2017a, 2017b) analyzed the impact of varying direct rebound effect values (10% to 50%) on net consumer financial benefits in developing countries. Their findings indicate that while an increase in AC operating hours reduces total electricity bill savings, the net consumer benefits remain significant. Even under a high direct rebound effect of 50%, net consumer benefits could still reach Rs 87,000 Cr ($10 billion).

Additionally, higher net consumer benefits from efficiency improvements could drive greater AC adoption, particularly among households that might not have purchased an AC under a business-as-usual (BAU) scenario. While this may reduce overall energy and peak-load savings, it substantially enhances consumer welfare by expanding access to cooling. For a deeper discussion on the welfare benefits of cooling and improved indoor environments, refer to Fisk (2000a, 2000b).

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