

INDIA ROOM AIR CONDITIONER MARKET ANNUAL STOCKTAKE 2025

Market And Technology Transitions,
Efficiency Derating, and Peak-Demand Implications



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Prepared by: Alliance for an Energy Efficient Economy (AEEE)

Alliance for an Energy Efficient Economy (AEEE) is a not-for-profit policy support and implementation organisation working to advance energy efficiency in India. AEEE collaborates with government, industry and other stakeholders to accelerate the adoption of energy-efficient products, services and solutions and support India's energy security and climate goals. With a vision to "catalyse the responsible use of energy for a climate-resilient and energy-secure future," AEEE works across the ecosystem, building a culture where efficiency becomes the default, powering India's transition to Atmanirbhar and Viksit Bharat. Discover more through our flagship initiatives featured at www.aeee.in.

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Disclaimer

This report is intended for informational purposes and is based on the best available evidence as of October 2025. The report presents central estimates that are subject to an overall uncertainty of approximately $\pm 10\text{--}15\%$, reflecting limitations in available data and modelling assumptions. While reasonable efforts have been made to ensure the accuracy and reliability of the information presented, AEEE does not guarantee its completeness or accuracy and accepts no liability for consequences arising from its use. The views expressed are those of AEEE and do not necessarily reflect the positions of the reviewers or supporting organisations.

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Acronyms and Abbreviations

BEE	Bureau of Energy Efficiency
BLDC	Brushless Direct Current (motor)
CAC	Commercial Air Conditioner
CEAMA	Consumer Electronics and Appliances Manufacturers Association
COP	Coefficient of Performance
DISCOM	Distribution Company (electricity)
ECSBC	Energy Conservation and Sustainable Building Code
EER / ISEER	Energy Efficiency Ratio / Indian Seasonal Energy Efficiency Ratio
FS	Fixed-Speed (air conditioner)
GHG	Greenhouse Gas
GW	Gigawatt
GWh	Gigawatt-hour
ICAP	India Cooling Action Plan
Inv / VS	Inverter / Variable Speed (air conditioner)
kW / kWh	Kilowatt / Kilowatt-hour
MEPS	Minimum Energy Performance Standards
MoEFCC	Ministry of Environment, Forest and Climate Change
MW / MWh	Megawatt / Megawatt-hour
NBC	National Building Code of India
OEM	Original Equipment Manufacturer
PWM	Pulse Width Modulation
RAC	Room Air Conditioner
SPIM	Single-Phase Induction Motor
TR	Tonne of Refrigeration
TWh	Terawatt-hour
VFD	Variable Frequency Drive
VRF	Variable Refrigerant Flow
UR	Urban
RU	Rural

Glossary of Key Technical Terms

Term	Definition
Bottom-Up Modelling	Building aggregate energy-demand estimates by summing granular, component-level inputs (unit stock, efficiency ratings and operating hours) rather than scaling from high-level national averages.
Climate-Weighted Operating Hours	Adjusted annual compressor runtime for each climatic zone, combining cooling-degree hours, occupancy profiles and duty cycles into a representative operating duration per technology–zone combination.
Co-incidence (Diversity) Factor	The fraction of total installed RAC capacity assumed to operate simultaneously at the system peak hour. A 25% rate is applied throughout this study, calibrated from utility load data.
Derating	Progressive deterioration in a unit's real-world performance below its factory-rated specification, due to mechanical wear, refrigerant leakage or heat-exchanger fouling accumulated over years of operation.
Deep-Decay Fleet	Legacy Fixed-Speed 1-3 Star units aged seven years or more - the most severely degraded cohort, imposing the highest per-unit grid penalty.
Efficiency Death Spiral	A compounding feedback loop in Fixed-Speed compressors: clearance widening raises current draw, accelerating thermal degradation, which widens clearances further, cumulatively inflating energy waste over 7–10 years.
Hydrodynamic Lubrication	A regime in which a continuous oil wedge separates moving surfaces. Inverter compressors sustain it through near-continuous rotation, unlike Fixed-Speed units that lose the oil film at every stop-start cycle.
Inverter (Variable-Speed) RAC	An air conditioner whose compressor speed is modulated by a VFD/PWM drive, matching cooling output to room load and substantially reducing energy waste and mechanical stress relative to Fixed-Speed designs.
Avoidable Derating Load	Excess electrical power drawn by degraded appliances above an equivalent unit operating at rated efficiency – power that yields no additional cooling benefit.
Star Rating (BEE)	A 1–5 star energy-efficiency classification assigned by the Bureau of Energy Efficiency; higher stars denote superior efficiency, minimum performance periodically revised upward via MEPS.
Vintage Stock	The cohort of RAC units in service, stratified by year of manufacture, enabling age-based analysis of fleet efficiency and grid impact.
Worst-First Strategy	A prioritisation principle for scrappage or maintenance that targets the oldest, lowest-efficiency, most-degraded units first, maximising grid relief per rupee of expenditure.

This Report and the Cooling-Sector Publication Series

This report is the inaugural edition of AEEE's India Cooling Sector Study Series, an annual evidence base tracking country's cooling transition. The series will comprise two companion reports, released annually, covering the residential Room Air Conditioner (RAC) and the Commercial Air Conditioning (CAC) segments respectively, offering a recurring read on India's cooling transition.

This first edition focuses on the RAC segment across two dimensions: (i) market trends and technology transition; and (ii) efficiency derating of the ageing AC stock, its implications for peak electricity demand, and an investment-backed roadmap for targeted replacement. The companion CAC report, applying the same analytical framework, is under development and will follow.

From the next edition onward, the scope of both reports will broaden to incorporate greenhouse-gas (GHG) emission associated with both electricity consumption and refrigerants. Through consistent year-on-year tracking, the series aims to give policymakers, regulators, DISCOMs and industry an integrated, continuously updated basis for understanding the market, energy and climate dimensions of India's cooling transition.





Executive Summary

Market

India's space cooling sector is a INR30,000+ crore market sitting at the intersection of energy security, grid reliability, consumer welfare and national climate targets. Its Room Air Conditioner (RAC) sub-segment, worth roughly INR19,000 crore (an industry-reported, OEM/ex-factory value; the retail market is materially larger once trade margin and GST are added), comprises 81 million installed units (~108 million TR) as of end-2024, and is growing by 10–15 million units a year. This study presents a bottom-up analysis of the RAC market across four themes: market structure and technology transition; climatic-zone demand profiles; efficiency derating and its grid consequences; and replacement-policy design.

The Technology Transition

The most significant structural shift over 2015–2024 has been the decisive adoption of inverter (variable-speed) technology. Inverter RACs now make up around 75% of new annual sales, up from about 1% in 2015, and account for approximately 53% of the installed base in 2024. Within new inverter sales, 3-Star models lead at 70%, with 5-Star units at 30%, concentrated in metropolitan markets. This shift has lifted the efficiency of new equipment but has left a large legacy stock of ageing Fixed-Speed units that impose a disproportionate burden on the grid.

The Derating Problem

A central finding is the quantification of efficiency derating in the ageing FS stock. By the end of 2024, age-related mechanical degradation, compressor wear, motor-winding deterioration and heat-exchanger fouling, had pushed the real-world performance of legacy FS units well below their rated specifications. The aggregate consequence is substantial: the RAC stock consumed ~121 TWh in end of 2024 against an ideal (no-derating) baseline of ~94 TWh, a systemic penalty of 27 TWh a year. On a peak-demand basis, derating adds ~11 GW of avoidable load (49 GW actual vs. 38 GW ideal), equivalent to the entire estimated cooling Demand of Maharashtra.

The Replacement Opportunity

The study identifies a clear priority, with around 27 million legacy 1–3 Star fixed-speed (FS) units aged five years or more accounting for most of the derating-related energy waste. Replacing these units could reduce peak demand by around 7 GW and annual electricity consumption by 16 TWh. A smaller group of around 22 million units aged seven years or more, where performance deterioration is more pronounced, could deliver greater savings per unit, reducing peak demand by around 5.5 GW and annual consumption by 13.5 TWh.

~27 TWh	~11 GW	~27 Million	98,000 Cr
Annual energy penalty from the ageing stock (FS+Inverter), end of 2024)	Total avoidable peak demand from derating	Units targetable (1-3 Star FS, aged ≥5 years) for nation-wide replacement	Economic value of a replacement programme

Geographic Concentration and Policy Asymmetry

Vintage RAC stock and grid vulnerability are highly concentrated. The top five urban states, Maharashtra, Tamil Nadu, Gujarat, Delhi and Uttar Pradesh, hold the majority of legacy stock and grid penalty. A uniform nationwide replacement programme would be capital-inefficient: policy should be executed asymmetrically, channelling more than half of resources into these five corridors, where reverse-logistics density, consumer concentration and grid-relief potential are the highest.

Policy Recommendations

Three immediate priorities are proposed for 2027–2029: (i) launch targeted buy-back and scrappage programmes for 1–3 Star FS units manufactured before 2020, with incentives gated on verified appliance retirement; (ii) establish reverse-logistics infrastructure, including refrigerant recovery and recycling hubs, in the top five urban states, co-ordinated with state designated agencies (SDAs, SERCs, etc.) and DISCOMs; and (iii) evolve MEPS and BEE labelling from point-of-sale regulation toward lifecycle regulation, addressing in-service degradation through mandatory maintenance standards and periodic field-efficiency testing.



01

Introduction

1.1 Context: India's Cooling Imperative

By 2025, India's space cooling sector had undergone a fundamental transformation driven by three converging forces: rising mean temperatures accelerated by climate change; rapid urbanisation that concentrates heat-island effects and disposable income; and an expanding middle class with growing aspirations for thermal comfort. What was once a luxury has become a near-essential appliance across multiple climatic zones, reshaping electricity demand curves and posing significant planning challenges for grid operators. The RAC sector is moving swiftly toward inverter-driven units, which now account for 75% of new sales.

These demand-side pressures coincide with an ambitious supply-side policy environment. The BEE Star Labelling programme has progressively raised minimum efficiency thresholds, incentivising inverter adoption; the India Cooling Action Plan (ICAP) has set a long-term trajectory toward dramatically lower cooling-energy intensity; and the electrification of the economy, alongside Net-Zero commitments under the Paris Agreement, requires that cooling-demand growth be decoupled from emissions. This study supplies the granular demand intelligence needed to navigate these competing imperatives. Its findings speak directly to three intersecting mandates: ICAP (2019), targeting a 25–40% reduction in cooling-energy requirements by 2037–38 (against a baseline in which cooling demand is projected to grow around eightfold); the BEE Star Labelling programme, which drives minimum standards and consumer awareness; and MoEFCC guidance on appliance lifecycle regulation.

1.2 The Space Cooling Market Landscape

India's overall space cooling market exceeded INR30,000 crore in 2024, spanning residential RAC and commercial air-conditioning (CAC) segments. The RAC segment, at roughly INR19,000 crore, is the larger and faster-growing component. As Figure 1 illustrate, the 2024 RAC revenue distribution is led by Voltas (20%), Daikin (18%) and Blue Star (14%), together 52% of the market, with the remainder spread across a fragmented set of domestic and international brands.

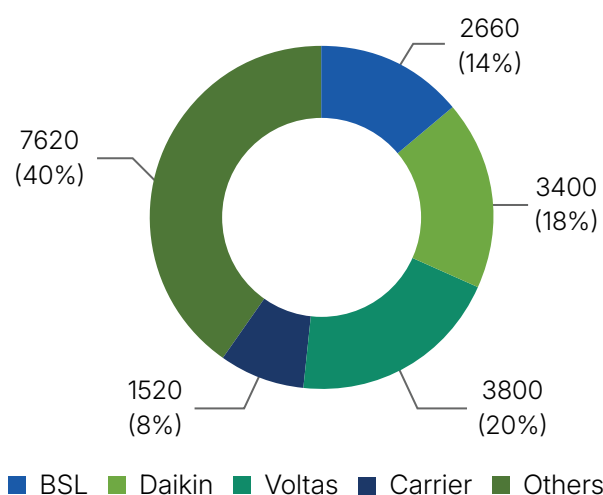


Figure 1: RAC 2024 Revenue Share by Manufacturerⁱ

The installed RAC base reached 81 million units (108 million TR) by end-2024, with annual additions of 10–15 million units expected from both new installations and replacements. Figure 2 traces the installed-stock trajectory from 2015 to end of 2024 and the inflection at which inverter technology crossed the 50% penetration threshold in the stock, around 2023–24. The accelerating substitution of Fixed-Speed units by inverter models from 2015 onward is visible in the widening Green band.

ⁱ Source: CEAMA reference data; OEM financial reports. Figures are indicative of best-available estimates.

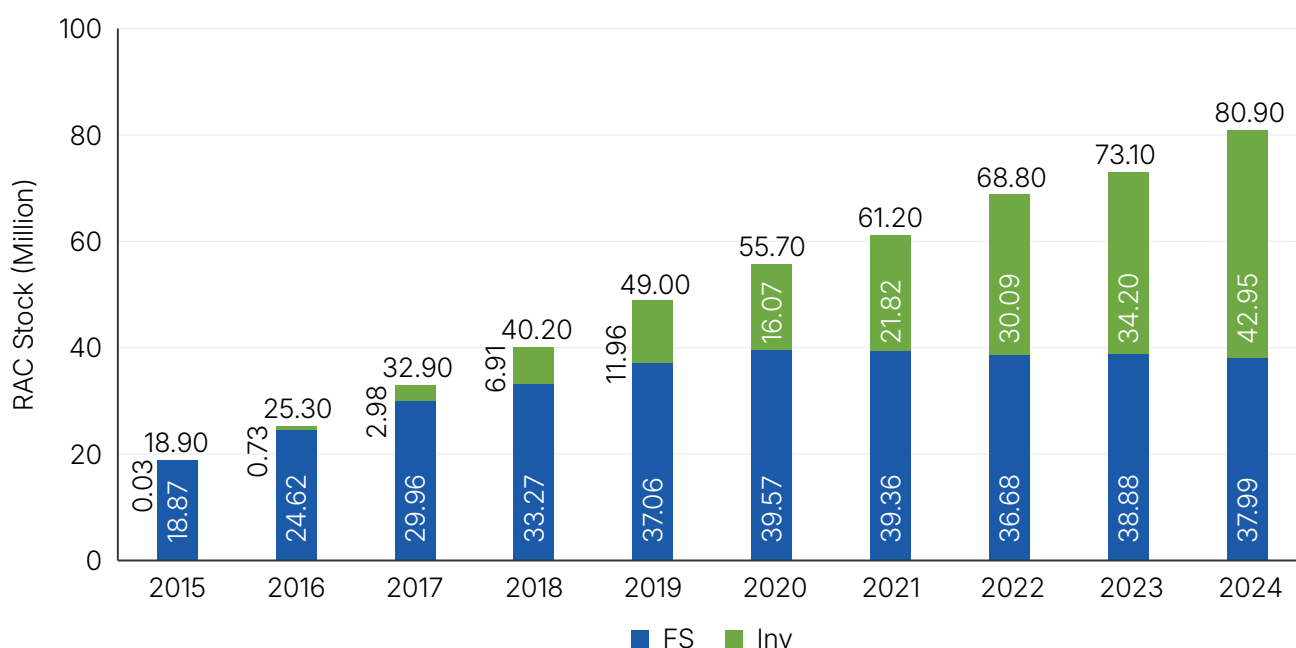


Figure 2: RAC Installed Stock Movement, 2015 to end of 2024 (Million units) Technology Wiseⁱⁱ

Technology distribution has shifted sharply: inverter share of new sales rose from 1% in 2015 to 75% in 2024. In new sales 3-star models lead to 60-65% and 5-star units makeup 20-25%. This shift improves new-equipment efficiency and creates headroom for further gains, but the benefit accrues only gradually to the installed base.

1.3 Significance for Energy Planning

Space cooling has become the single largest driver of peak-electricity-demand growth in India, with summer-afternoon loads dominated by RAC compressors operating simultaneously across urban agglomerations. Without co-ordinated intervention, cooling could account for as much as 45% of national peak demand by 2050, up from around 10% in 2016 (IEA 2018). The significance extends beyond grid management: India's supply mix remains heavily coal-dependent, so every kilowatt-hour wasted through inefficient or degraded operation translates directly into incremental greenhouse-gas emissions. This study quantifies that nexus and proposes a targeted response.

1.4 How This Report Is Structured

To navigate directly to a section of interest, the remaining chapters are organised as follows:

Chapter 2 – Methodology and Data Sources: sets out the methodology and modelling framework underpinning all quantitative findings. It establishes the assumptions, data sources and validation approach that give the numbers their credibility.

Chapter 3 – Market Structure and Segmentation: Profiles the RAC market by manufacturer, technology and star rating, and quantifies the installed base's shift toward inverter technology.

Chapter 4 – Climate Zone Analysis: Breaks down usage patterns, operating hours and set-point preferences across India's five climatic zones, and each zone's contribution to national energy demand.

ⁱⁱ Source: AEEE bottom-up stock model, back-cast from CEAMA annual sales and BEE registration data

Chapter 5 – Energy Demand and Peak Load Implications: Quantifies the 2024 national grid penalty from derating, disaggregates it by technology, star rating and geography, and identifies the age-based replacement opportunity and its economic value.

Chapter 6 – Policy Relevance and Recommendations: Maps the findings onto ICAP, the BEE Star Labelling Programme and DISCOM priorities, and sets out a sequenced set of policy actions for 2027–2029.

Chapter 7 – Key Findings and Insights: Synthesises the report's central conclusions on market transformation, the derating problem, and what the bottom-up methodology reveals that top-down analysis cannot.

Chapter 8 – Limitations and Future Research: States the study's data and modelling limitations candidly, including the sensitivity of key results to the co-incidence factor and derating assumptions, and outlines directions for future research.

Chapter 9 – Conclusions: Draws the findings together into a closing statement on the derating problem and the case for coordinated action.



02

Methodology and Data Sources

This chapter presents the analytical framework, data sources and modelling approach behind all quantitative findings. Placing the methodology upfront allows readers to assess the robustness of the evidence base before engaging with the results and to calibrate their interpretation of specific figures against the model's assumptions.

2.1 Research Design: Multi-Source Data Reconciliation

To maximise the reliability of market estimates and energy projections, the study integrates two data streams:

- **Primary data:** structured interviews with OEMs, industry associations (including CEAMA), dealers, distributors and end-users across multiple cities and climatic zones.
- **Secondary data:** BEE Star Labelling registration and sales data; ICAP (2019) baseline documentation; ECSBC and NBC building standards; academic publications from Herrick Laboratories (Purdue), LBNL and other Scopus-indexed venues; CEAMA industry reports; and Prayas Energy Group household-survey data for rural-urban stock allocation (state-level allocation uses CEAMA regional sales and Census urbanisation as the primary basis; where national totals are apportioned to states, the Prayas PIER model's state-wise peak-demand shares serve as the apportionment key, and the diurnal peak-timing profile is likewise taken from PIER), CLASP reports; response-enabled room air conditioners, residential energy consumption survey, AEEE's report on consumer surveys of set-point preferences and usage patterns.

Key market parameters are validated against at least three independent sources before acceptance. Where sources disagree, weighted averages are applied with qualitative justification based on source credibility and recency.

2.2 Bottom-Up Energy Modelling Framework

Energy demand is estimated through a bottom-up model that disaggregates the national RAC fleet into defined sub-populations and computes electricity consumption for each. This approach is preferred over top-down scaling because it preserves the fleet heterogeneity, differences in technology, star rating, age and climatic zone, that is critical to quantifying derating impacts and identifying replacement targets. The core relationship is:

$$\text{GWh} = \text{Stock (Million TR)} \times \text{kW/TR} \times \text{Operating Hours} \times 10^6 / 10^9$$

Figure 3 sets out the framework as a four-layer flow. The model assembles six data inputs (unit stock, star ratings, operating hours, technology mix, geographic allocation, and vintage profile), processes them through a two-stage computation engine, base consumption followed by an age-specific derating adjustment, and produces paired outputs for annual energy (TWh) and peak demand (GW), each reported on an "ideal" (rated) and "actual" (derated) basis. A final validation layer cross-checks every output against utility billing, manufacturer volumes, historical trends and international benchmarks, feeding back into recalibration where discrepancies arise.

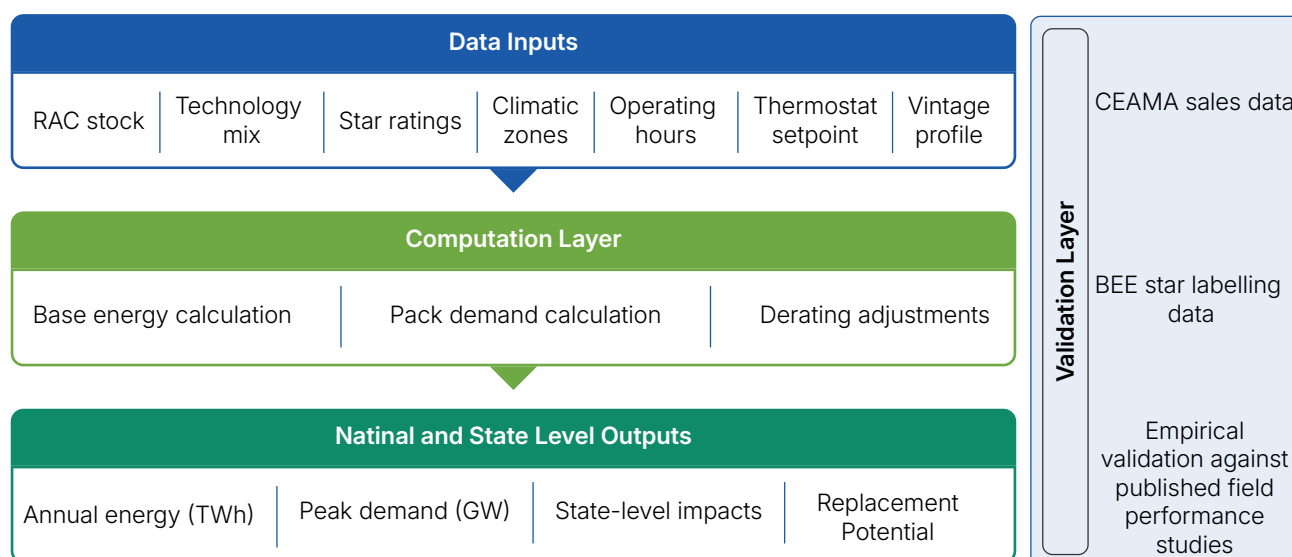


Figure 3: Bottom-Up Energy Modelling Framework: Data Inputs, Computation Layers and Validation Checks

Table 1 summarises the key model parameters, their central values, plausible uncertainty ranges, and data sources. All values are central estimates unless otherwise noted; sensitivity ranges are documented in Chapter 8.

Table 1: Summary of Key Model Parameters, Central Values, Uncertainty Ranges and Data Sources

Parameter	Definition / Role in Model	Central Value(s) Used	Plausible Range / Uncertainty	Primary Evidence / Source	Remarks
Unit capacity per RAC	Nominal TR per residential split RAC used for converting units to TR and GW	1.31 TR per unit	1.1–1.5 TR depending on room-size segment	CEAMA product mix, OEM catalogues, ICAP baseline	Central value reflects weighted average of 1.0–1.5 TR units sold since 2015
RAC stock by technology, star, vintage	Installed units disaggregated by fixed-speed/inverter, BEE star rating, and year of manufacture	See Table 2 (technology/star mix) and Figure 14 (vintage distribution)	±10–15% on vintage split and FS/inverter share	CEAMA annual sales, BEE registration, CLASP report, and OEM interviews	Back-cast from sales and registrations; reconciled with ICAP baseline and DISCOM load growth.
Rated efficiency (kW/TR)	Factory-rated power per tonne of refrigeration under standard test conditions specified by BIS (IS 1391) and applicable BEE S&L requirements	Star-wise BEE values	±3–5%	BEE Star Label database, OEM spec sheets	Treated as deterministic; uncertainty enters mainly through the derating curve rather than nameplate EER/ISEER.

Parameter	Definition / Role in Model	Central Value(s) Used	Plausible Range / Uncertainty	Primary Evidence / Source	Remarks
Derated efficiency (kW/TR vs age)	Age-specific multiplier applied to FS kW/TR to reflect real-world degradation	Curve fitted to Kim & Groll (2014), Ishii et al., Siegel et al. (ASHRAE 2002); central degradation reaching ~20–25% by year 10	±20% on the degradation factor, e.g. 15–30% at 10 years	Purdue Herrick compressor tests; LBNL field study (Eto & Moezzi, 1966); ASHRAE	FS degradation is a motor+pump-based parametric curve; inverter curve is constrained to a much lower slope per Bell & Groll (2011). Note: Table 9's FS sensitivity run tests ±10%.
Climate-weighted operating hours	Annual AC runtime by climatic zone, building type, and technology	as in Figures 5–6	±10%	AEEE publications and CEEW's IRES survey findings	Central values are chosen to match observed billing data and cooling-degree-day envelopes; sensitivity is typically at ±10%.
Thermostat setpoint distribution	Zone-wise distribution of household thermostat settings	Warm-Humid 24–25°C mode; Moderate 26–28°C; others per Figure 4	Behavioural spread included implicitly; not varied separately		Setpoints enter via duty-cycle and operating-hour estimation.
Geographic stock allocation	RAC stock split by five climatic zones and by state (urban/rural)	As per Table 3 and Figures 14–16	±15–20% for rural share; lower for urban metros	CEAMA regional sales; Census urbanisation; PIER peak-demand shares as apportionment key	Reconciled across three sources; uncertainty is acknowledged in Chapter 8.
Peak coincidence factor	Fraction of installed capacity assumed to operate at the system peak hour	25% national coincidence	Sensitivity at ±10% (See Table 9's FS sensitivity)	Utility load curves; ICAP	Central value is calibrated to DISCOM load traces; explicit sensitivity bands are reported in Chapter 8.
Annual sales growth	Growth in RAC units sold per year	10–15 million units annually	±10% around central growth trajectory	CEAMA annual sales reports; OEM investor presentations	Used for forward-looking replacement potential; not central to the 2024 penalty estimates.
Technology mix of new sales	Share of inverter vs FS units in annual sales by star rating	Inverter 75% of new sales; 3-star 60–70%; 5-star 20–30%	±5 percentage points on technology shares	CEAMA, BEE registrations, OEM data	Drives forward shift in installed-base mix; interacts with replacement policy scenarios.

2.3 Derating Model

Age-specific derating factors are applied to Fixed-Speed efficiency values using a degradation curve derived from Purdue Herrick Laboratories data (Kim & Groll, 2014; Ishii et al.) and validated against LBNL field findings (Eto & Moezzi, 1996). The function raises the effective kW/TR of each FS unit as a function of years in service, capturing three compounding failure mechanisms, compressor volumetric-efficiency loss, electromechanical decay and heat-exchanger fouling, whose physical basis is detailed in Chapter 5. Inverter units are assigned a substantially lower derating rate, consistent with the peer-reviewed evidence on variable-speed resilience (explained in Section 5.2). This FS-inverter derating differential is a central result, quantified throughout Chapter 5.

A further share of real-world derating is maintenance-related rather than purely age-driven: dust and particulate fouling of condenser and evaporator coils, refrigerant undercharge from poor servicing, and clogged filters all raise the effective kW/TR of a unit in operation. Unlike irreversible mechanical wear, much of this maintenance-related loss is recoverable through servicing; it is therefore carried within the aggregate derating curve rather than modelled as a separate term. Isolating the maintenance-recoverable fraction and the derating attributable to coil quality and servicing practices over the equipment lifecycle requires more rigorous field investigation and sectoral inputs and will be examined in future work, as outlined in Section 8.

2.4 Peak Demand Modelling

Peak demand (GW) is estimated by applying the 25% co-incidence factor to installed capacity (in TR) and converting to GW using technology-specific kW/TR values that incorporate age-related derating. The co-incidence rate represents the fraction of the installed base operating simultaneously during the peak hour. The 25% co-incidence factor is consistent with ICAP planning assumptions; the diurnal timing of the peak is taken from the PIER bottom-up hourly demand model, which places peak-season (May) residential AC demand in the late afternoon to early evening, peaking around 18:00 and remaining elevated into the night, so cooling contributes strongly to the emerging evening net-peak, when solar output has fallen. Sensitivity at 20% and 30% co-incidence is reported in Chapter 8. The 25% co-incidence is treated as a scenario assumption rather than a fixed empirical value, and peak-demand figures should be read across this 20–30% range.

2.5 Validation Framework

Model outputs pass through three parallel checks before acceptance:

- **Manufacturer volume reconciliation:** annual sales volumes implied by the stock model reconciled with CEAMA-reported shipments.
- **Historical trend consistency:** year-on-year changes in modelled peak demand and TWh checked against historical grid-operator load data.
- **International benchmarking:** per-unit consumption estimates compared against LBNL and IEA benchmarks for comparable climate–technology combinations.

Given data limitations, particularly for pre-2015 vintages, rural installations and small commercial sites, all key figures are central estimates carrying an inherent $\pm 10\text{--}15\%$ uncertainty range, documented for critical parameters in Chapter 8.

With the framework established, the following chapters present the substantive analysis in sequence: Chapter 3 characterises market structure and technology composition; Chapter 4 examines regional demand across the five climatic zones; and Chapter 5 applies the derating model to quantify grid vulnerability and the replacement opportunity.





03

Market Structure and Segmentation

This chapter characterises the current composition of India's RAC market by technology, star rating, manufacturer and installed base, drawing on the reconciliation methodology of Chapter 2. The fleet's technology mix and vintage distribution directly determine the scale and distribution of the derating-related grid penalties quantified in Chapter 5, making this structural picture a prerequisite for the energy analysis that follows.

3.1 RAC Market Overview

The RAC market generated about INR19,000 crore in revenue in 2024, serving primarily residential consumers with a growing footprint in small commercial establishments. The decisive structural shift has been toward inverter technology, now 75% of new annual sales. Table 2 sets out the sales breakdown by technology and star rating, showing how thoroughly the 3-Star inverter unit has come to define the new-sales market.

Table 2: Sales Breakdown: RAC Market by Technology and Star Rating (2024)ⁱⁱⁱ

Technology Category	Star Rating	Share of Segment	Share of Total Sales
Inverter AC - Total	All	100%	75%
Inverter AC	3-Star	70%	52.5%
Inverter AC	5-Star	30%	22.5%
Fixed-Speed AC - Total	All	100%	25%
Fixed-Speed AC	3-Star	95%	23.75%
Fixed-Speed AC	5-Star	5%	1.25%

3.2 Installed Base and Technology Penetration

The installed base reflects the cumulative layering of a decade of annual sales, so its technology mix lags new-sales composition. Of the 81 million units installed by end-2024, inverter penetration in the stock stood at roughly 53% (about 43 million units), with the remaining 47% Fixed-Speed models of varying vintages. The top three manufacturers, Voltas (20%), Daikin (18%) and Blue Star (14%), hold 52% of revenue share, with the balance distributed across a fragmented competitive set.

This composition is decisive for the derating analysis in Chapter 5: the older FS units concentrated in the installed base, particularly the 3-Star tier that dominated sales through 2015, inflate system-wide peak demand and energy consumption disproportionately relative to their share of the current fleet. The next chapter establishes how that stock is distributed across India's climatic regions, setting the operating-hour and usage-intensity parameters that translate unit counts into energy demand.

ⁱⁱⁱ Reconciliated from CEAMA sales records, BEE registration data and primary OEM interviews. Figures are indicative best-available estimates.



04

Climate Zone Analysis

India's geographic diversity, from arid desert to humid tropics and temperate highlands, creates fundamentally different cooling demands. The NBC and ECSBC formalise this into five climatic zones. For RAC energy analysis the zone framework is foundational: it determines annual compressor operating hours, set-point preferences, technology suitability and the intensity of derating-driven efficiency loss.

4.1 India's Five Climatic Zones

Table 3 characterises the five NBC climatic zones based on monthly mean temperature and relative humidity, along with their thermal attributes, representative cities and cooling-season duration. These durations represent the typical active mechanical-cooling months in each zone, informed by the ECBC 2017 Design Guide (BEE) and consistent with a cooling-degree-day characterisation using the standard 18°C base (World Bank CCKP; ASHRAE 169-2013). Under this approach, the Hot-Dry, Warm-Humid, Composite and Cold zones exceed the base for roughly nine, twelve, eight and four months, respectively. The mild Moderate zone's ~6 months reflects actual usage rather than degree-day exposure. The RAC energy analysis focuses on the three cooling-dominant zones – Composite, Warm-Humid and Hot-Dry – which account for most of the stock and demand. Moderate and Cold zones have a smaller role in room-AC cooling, while Warm-Humid and Composite are particularly important given their high energy intensity and large installed stock. The zone-wise usage hours in Figure 4 are drawn directly from AEEE's nationwide residential RAC-usage survey (Sachar et al. 2018), while the set-point preferences and household temperature-band distribution by zone in Table 4 are based on AEEE's residential usage and behavioural studies (Sachar et al. 2019; Kaur et al. 2022) together with CEEW's India Residential Energy Survey (IRES 2020). Table 3's durations serve only as a reference for validation. The survey-based usage hours are then weighted by temperature-band compressor-on factors to derive the compressor running hours in Table 5.

Table 3: India's Five Climatic Zones: Key Characteristics and Cooling Demand Months^{iv}

Zone	Representative Cities	Cooling Season	Key Thermal Characteristics
Hot-Dry	Jaipur, Ahmedabad, Nagpur	9 months	High temperatures, low humidity, intense solar radiation; sensible cooling dominant; high compressor load but low dehumidification demand
Warm-Humid	Mumbai, Chennai, Vizag	Year-round	High temperature and humidity; significant latent (dehumidification) load; prolonged runtimes that accelerate mechanical wear and derating
Composite	Delhi, Lucknow, Indore, Bhopal	8 months	Hot dry summers transitioning to humid monsoon; wide seasonal variation; highest annual cooling-degree-days nationally
Moderate	Bengaluru, Pune, Hyderabad	6 months	Moderate temperatures; lower cooling intensity; higher penetration of premium 5-Star products
Cold	Shimla, Srinagar, Gangtok	4 months	Cool conditions; minimal cooling requirement; market is primarily heating-focused

^{iv} Zone classifications follow NBC definitions

4.2 Usage Patterns, Operating Hours and Set-Point Preferences

Annual compressor operating hours vary substantially across zones and building types. Figures 4 to 6 present, respectively, set-point preferences, zonal running hours and climate-weighted annual usage hours by technology. Figure 4 shows that Warm-Humid consumers favour lower set-points (24-25°C) because of higher latent loads, whereas Moderate-zone consumers more commonly set 26-28°C, reducing duty cycles and energy use. These are observed preference bands; separately, a 24°C factory-default set-point has been mandatory for star-labelled room ACs since 1 January 2020 – a regulatory baseline distinct from the temperatures consumers actually select.

Table 4: RAC Consumer Set-Point Temperature Preferences by Climatic Zone^v

Climate	Op Temp range (below 24°C)	Op Temp range (24-26°C)	Op Temp range (26-28°C)
% Households preference			
Composite	45%	33%	22%
Warm & Humid	60%	25%	15%
Hot & Dry	37%	33%	30%

Figure 4 depicts estimated annual running hours, weighted across residential and small-commercial building types: the Composite zone leads at 1,635 hours, ahead of Warm-Humid (1,421) and Hot-Dry (1,355). These are AC usage hours (the hours the unit is switched on); the corresponding compressor running hours – obtained by weighting these usage hours by a temperature-band compressor-on factor for fixed-speed units and a part-load running-speed factor for inverters – are set out in Table 5.

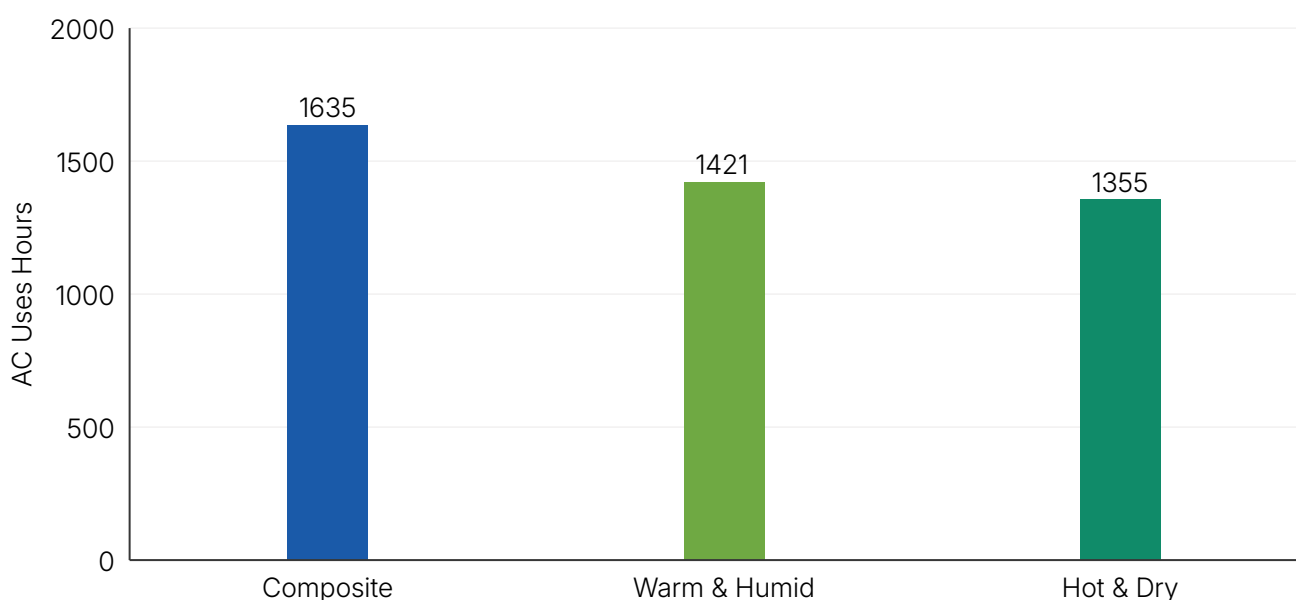


Figure 4: Estimated Annual Usage Hours by Climatic Zone^{vi}

^v Source: AEEE studies and IRES survey

^{vi} Source: AEEE primary surveys and analysis

Table 5 presents the resulting compressor running hours by technology and set-point band, obtained by weighting each zone's usage hours by a temperature-band compressor-on factor for fixed-speed units and a part-load running-speed factor for inverters. Because inverters modulate at part load rather than cycling on and off at full power, their full-load-equivalent running hours fall below those of fixed-speed units – the source of their energy advantage – most pronounced at lower set-points. These figures are direct inputs to the energy model of Chapter 2.

Table 5: Climate-Weighted Annual Compressor Running Hours - Fixed-Speed vs. Inverter

Climate-wise, weighted annual usage hours			
Climate	Operating set point temprange	Fixed speed	Variable speed
Composite	< 24°C	1063	981
	24-26°C	818	654
	26-28°C	572	491
Warm & Humid	< 24°C	924	853
	24-26°C	711	568
	26-28°C	497	426
Hot & Dry	< 24°C	881	813
	24-26°C	678	542
	26-28°C	474	407

4.3 Zonal Contribution to National Energy Demand

The Composite zone hosts the largest share of installed cooling capacity at 33.4% of national RAC stock, driven by population concentration in Delhi NCR and the Indo-Gangetic Plain. The Warm-Humid zone accounts for 26.1%, encompassing coastal megacities. Together these two zones hold 59.5% of installed capacity but contribute 69.4% of total RAC energy consumption, a disproportionality reflecting longer operating seasons, lower set-points and higher dehumidification loads.

This asymmetry matters for derating. The Warm-Humid zone's prolonged compressor runtimes accelerate mechanical wear, so 3-Star FS units in coastal cities degrade faster than equivalent units in the Moderate zone, a finding that motivates the zone-specific MEPS thresholds discussed in Chapter 6. With market composition (Chapter 3) and climatic demand profiles (Chapter 4) now established, the next chapter applies the bottom-up and derating models to quantify the energy and peak-demand consequences of the ageing FS fleet and to define the precise parameters of the replacement opportunity.



05

Energy Demand and Peak Load Implications

This chapter presents the core analytical contribution of the study. It translates the market inventory (Chapter 3) and climatic demand profiles (Chapter 4), through the modelling framework of Chapter 2, into grid-level consequences: national peak demand, aggregate energy consumption, technology and star-tier disaggregation, spatial mapping and the economic valuation of the replacement opportunity. It opens with the physical science of derating, the “why”, before the quantitative results, so the findings remain interpretable in light of their underlying mechanisms.

5.1 The Fixed-Speed Efficiency Death Spiral

The deterioration of Fixed-Speed (FS) performance over time is a compounding, multi-physics process documented extensively in the peer-reviewed literature. Three interlocking failure mechanisms drive it:

- **Volumetric efficiency loss:** Tribological wear on compressor moving parts — scroll tips, vanes and rollers, progressively widens internal clearances, enabling high-pressure refrigerant blow-by. The compressor must work harder to maintain the same mass-flow rate, drawing more electricity without delivering additional cooling. (Kim & Groll, 2014; Ishii et al., Purdue.)
- **Electromechanical decay:** The single-phase induction motor (SPIM) endures repeated high-inrush start-stop cycles, each subjecting windings to thermal micro-shocks at 500–800% of rated current, progressively degrading insulation and raising resistive (I^2R) losses. Bearing wear introduces air-gap eccentricity that further increases power demand. (Luo et al., 2017; Staton et al., IEEE.)
- **Thermal resistance surcharge:** Particulate fouling accumulates on heat-exchanger surfaces, raising airside pressure drops and thermal resistance by up to 44% over seven years and forcing operation at higher pressure ratios. (Siegel et al., ASHRAE; Bell & Groll, 2011.)

Table 6 summarises these mechanisms, their physical drivers, grid consequences and supporting evidence.

Table 6: Fixed-Speed Compressor Derating: Failure Mode and Peer-Reviewed Impact

Failure Mode	Physical Mechanism	Grid / Energy Consequence	Supporting Evidence
Volumetric leakage	Clearance widening via compressor wear	Increased power draw per TR of cooling delivered	Kim & Groll (2014); Ishii et al. (Purdue)
Motor resistance increase	Winding insulation decay from thermal micro-shocks at start-up	Rising I^2R losses raise unit kW at rated load	Luo et al. (2017); Staton et al. (IEEE)
Heat-exchanger fouling	Particulate accumulation on coils raises pressure drop	Higher pressure ratio; increased fan and compressor power	Siegel et al. (ASHRAE 2002); Bell & Groll (2011)

5.2 Why Inverter RACs Resist Derating

In contrast to the FS death spiral, inverter (variable-speed) RACs are structurally resistant to the primary derating mechanisms. This resilience flows from the Brushless DC (BLDC) motor and Pulse Width Modulation (PWM) control architecture:

- **Tribological preservation:** Near-continuous rotation at variable frequency sustains a persistent hydrodynamic oil film between moving surfaces. The absence of repeated dry starts prevents the boundary-lubrication wear that widens clearances in FS units, preserving volumetric efficiency over 7–10 years. (Ooi, 2005; Kerpicii et al., Purdue 2012.)
- **Electromechanical superiority:** Permanent-magnet BLDC motors carry no induced rotor current, eliminating rotor copper (I^2R) losses. Soft-start protocols ramp frequency from 0 Hz upward, removing the 500–800% current spikes that degrade induction-motor windings. (Staton et al., 2005; Jahina et al., Purdue 2018.)

- **Pressure-ratio optimisation:** By modulating compressor speed to match real-time room load, inverter units operate at the minimum necessary pressure ratio, reducing stress on valves, seals and bearings across the appliance's life. (Tassou & Qureshi, 1998; Schwedler, ASHRAE 2014.)

Table 7 contrasts the two architectures feature by feature and links each to its consequence for derating.

Table 7: Comparative Summary: Inverter vs. Fixed-Speed Derating Characteristics

Feature	Fixed-Speed (FS)	Inverter (Variable Speed)	Consequence for Derating
Start-up profile	High inrush current (thermal shock)	Soft-start (linear frequency ramp)	Prevents motor-winding insulation decay
Lubrication regime	Boundary lubrication (high wear at each start)	Hydrodynamic film (continuous, low wear)	Prevents clearance widening and refrigerant blow-by
Rotor heat generation	High (I^2R losses in induction rotor)	Near-zero (permanent magnets carry no induced current)	Extends electromechanical service life substantially
Operating pressure ratio	Constant maximum stress	Variable, optimised to instantaneous load	Reduces valve and seal fatigue over the unit's life

5.3 Quantifying the End of 2024 National Grid Penalty

Applying the age-adjusted derating curves (Section 2.3) to the end of 2024 installed fleet yields the national baseline in Table 8. The gap between the "ideal" scenario (all units at rated efficiency) and the "actual" scenario (the fleet operating with age-related degradation) defines the systemic penalty imposed by the ageing stock.

Table 8: End of 2024 Baseline: Cost of Inaction from RAC Derating (Peak demand and energy Penalty)^{vii}

Metric	Without Derating (Ideal Rated)	With Derating (Actual end of 2024)	Systemic Penalty
Peak demand at 25% co-incidence	~38 GW	~49 GW	~11 GW of avoidable derating load
Aggregate annual consumption	~94 TWh	~121 TWh	~27 TWh of wasted energy per year

The 11 GW avoidable derating load equals the entire cooling demand of Maharashtra, India's most populous state, borne entirely by degraded appliances that return no additional cooling. The 27 TWh annual penalty matches the residential electricity consumption of a major Indian city. On a coal-heavy grid, (assumed at roughly 70% coal and 30% renewables), this thermodynamic friction drives substantial excess GHG emissions and inflated consumer bills. The implication is direct: point-of-sale Minimum Energy Performance Standards (MEPS) are necessary but insufficient; policy must extend to lifecycle regulation, maintenance incentives and mandatory legacy scrappage.

A second, complementary mechanism compounds this picture and is not captured in the derating analysis assumptions above. The rated capacity and efficiency of RACs fall sharply at high ambient temperatures, yet neither is required to be disclosed at such conditions, and in practice rarely is. Under IS 1391, nominal capacity and efficiency are rated only at the ISO T1 (mild-climate) condition of 35°C outdoor, and ISEER is evaluated across a 24-43°C temperature bin; the standard's only engagement with the T3 (hot-climate) 46°C mark is a Maximum Operating Conditions test that checks a unit can run without tripping – not how efficiently it cools there. With no rated high-ambient performance to design to, users and installers routinely oversize equipment as a hedge, inflating connected load and peak demand during the very summer periods when the grid is most

^{vii} The 25% co-incidence factor is applied uniformly; see Chapter 8 for the sensitivity discussion.

stressed. This ambient-temperature derating is distinct from the age- and wear-based derating quantified here; it is treated qualitatively in this edition and flagged for measurement in future work (Section 8).

Figure 5 traces peak demand year by year. The gap between the two curves widens markedly from 2018 onward as the installed base ages, reaching the 11 GW avoidable load by the end of 2024.

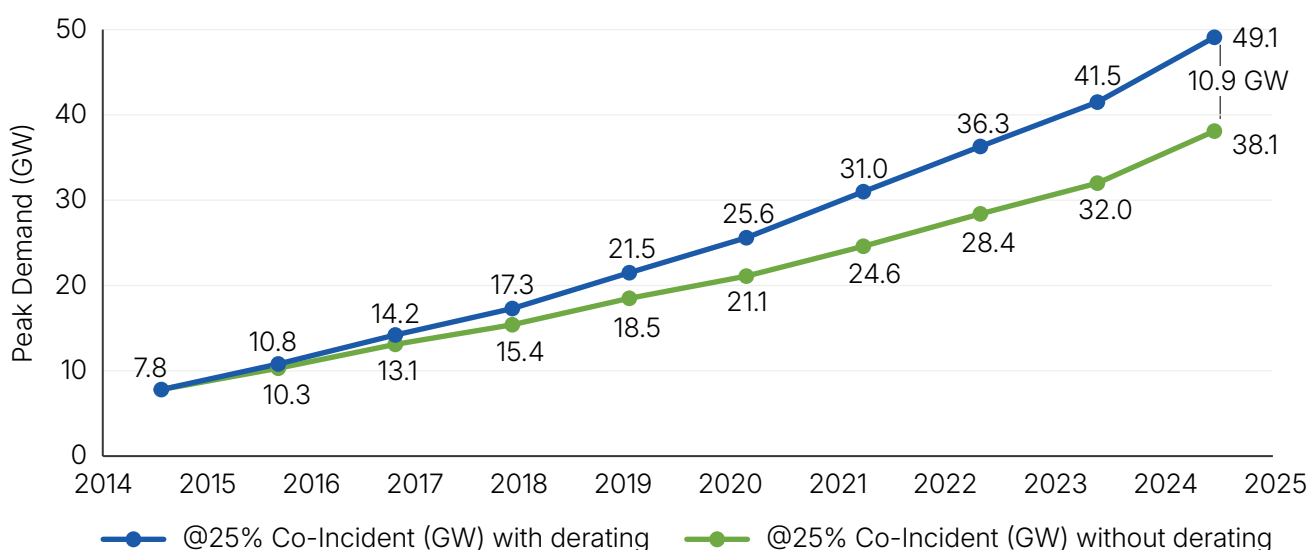


Figure 5: Peak Demand (GW) at 25% Co-Incidence: With and Without Derating, 2015–2024^{viii}

Figure 6 shows the same divergence in energy terms: the end of 2024 derating penalty of 27 TWh has grown from near-zero in 2015, tracking the maturation of the legacy FS fleet.

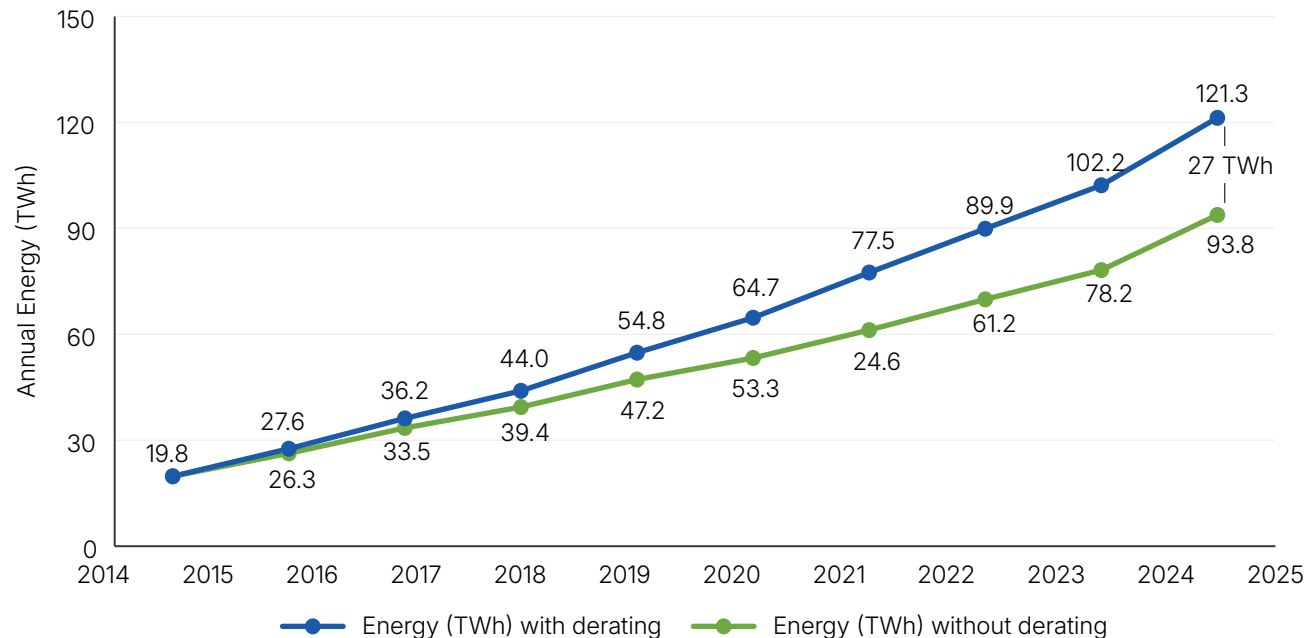


Figure 6: Annual RAC Energy Consumption (TWh): With and Without Derating, 2015–2024^{ix}

^{viii} Source: AEEE analysis. “with derating” applies age-specific FS degradation curves to the installed fleet.

^{ix} The widening gap is the cumulative derating-load penalty from ageing stock.

5.4 Technology and Star-Rating Disaggregation

Disaggregating the penalty by technology and star rating reveals both the concentration of the problem and the precision of the opportunity. As context, the vintage-stock trajectory (Figure 2) shows inverter stock overtaking Fixed-Speed around 2024, reaching ~43 million units by end 2024 against ~34 million legacy FS units. Figure 7 then resolves the 2024 stock by star rating. The 3-star tier dominates at 65% (52.5 million units), classified under the BEE star-rating thresholds in force in 2024, slightly weighted towards inverters (26.6 million units) over fixed speed (25.9 million units). Legacy 1 and 2-star units have shrunk below 4 million (~5% of stock), conforming the effectiveness of progressive MEPS. It might be pertinent to review the ageing of derated 1-3-star FS ACs as they will have huge impact on peak power and energy.

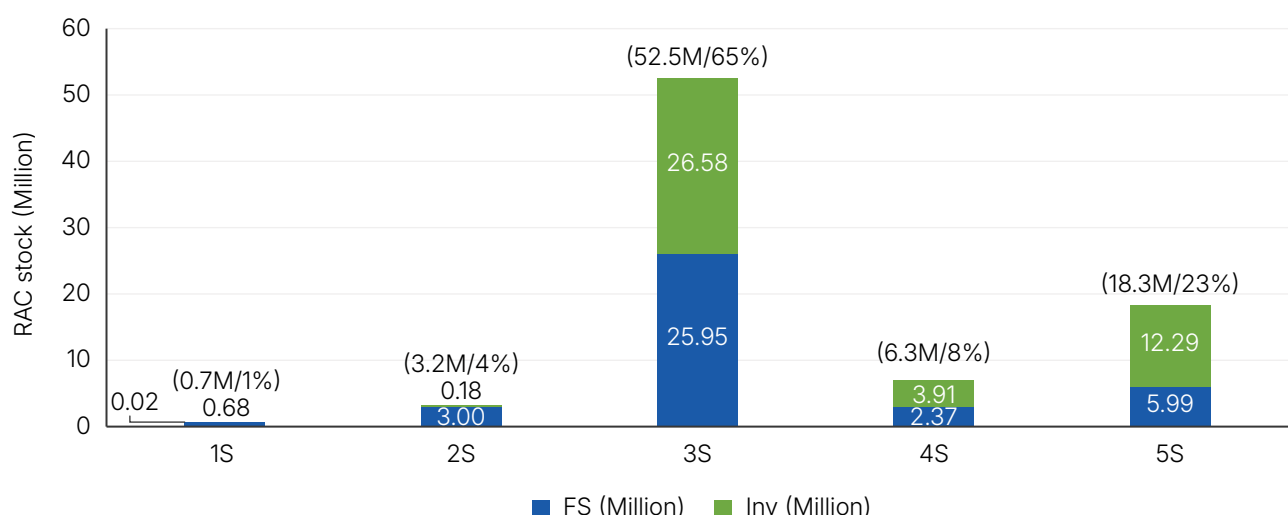


Figure 7: RAC Installed Stock Composition by Technology and Star Rating, End of 2024^x

Figures 8 and 9 apply the 25% co-incidence model to peak demand by star rating. The contrast is stark. For Fixed-Speed units (Figure 8) the 3-Star tier alone generates ~5 GW of avoidable derating-related load, over 58% of the FS fleet's aggregate grid burden. Because the lower-tier penalty is so concentrated, retiring or upgrading just these units can shed roughly 1.5 GW of peak load, a far cheaper lever than fleet-wide replacement.

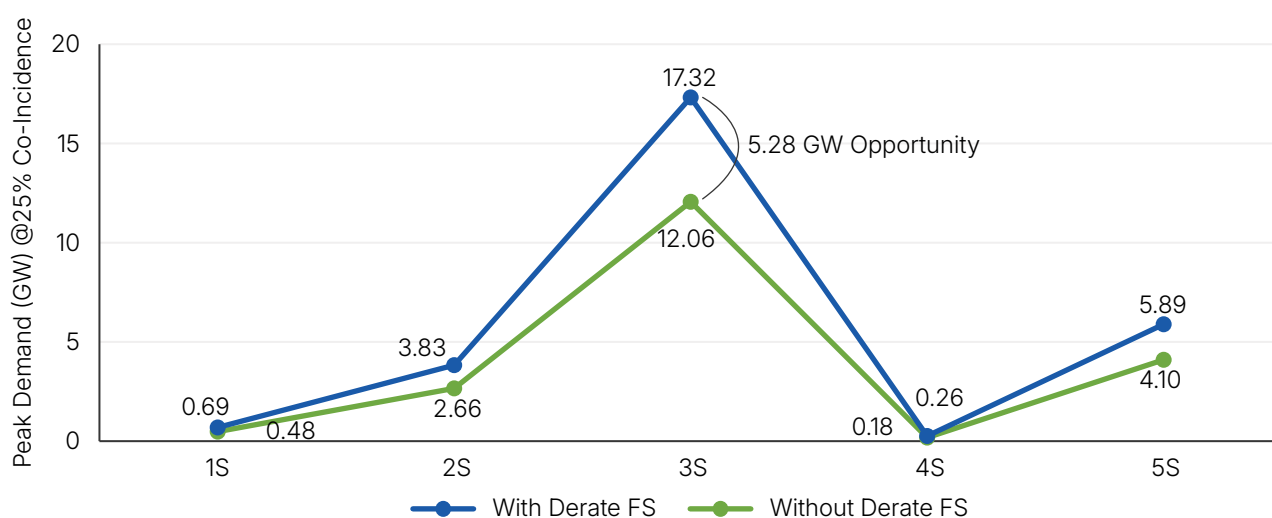


Figure 8: Fixed-Speed RAC: Star-Wise Peak Demand (GW) at 25% Co-Incidence, End of 2024^{xi}

^x Source: AEEE analysis. Bars show million units by star tier, split Fixed-Speed vs. Inverter.

^{xi} Derating penalty = (with derating - without derating) peak GW per star tier)

Figure 9 shows the inverter equivalent. Despite the 3-Star inverter tier being the largest single cohort nationally, its derating penalty is only 1.8 GW, less than half the Fixed-Speed figure, validating the grid-protection value of variable-speed architecture. Premium 4- and 5-Star tiers derate minimally, and the near-zero 1- and 2-Star inverter demand reflects manufacturer positioning well above the MEPS floor (1-Star being the MEPS level) rather than MEPS alone removing such models from the market.

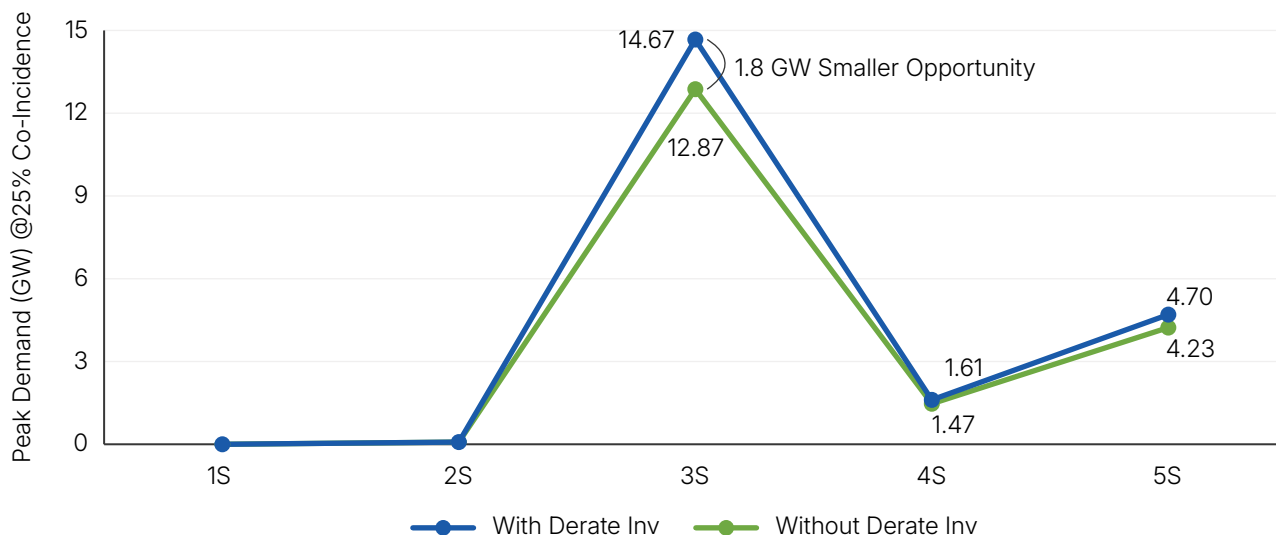


Figure 9: Inverter RAC: Star-Wise Peak Demand (GW) at 25% Co-Incidence, End of 2024^{xii}

The annual-energy view reinforces the point. The 3-Star FS tier (Figure 10) carries a 13.5 TWh derating penalty against the 3-Star inverter tier's 4.28 TWh (Figure 11), a 3-fold reduction, despite the inverter cohort being nearly twice as large by unit count. The 3-Star FS excess is the single largest target for the proposed scrappage programme, while the uniformly low inverter penalties make the strategic case for preserving the inverter fleet through subsidised maintenance rather than replacement.

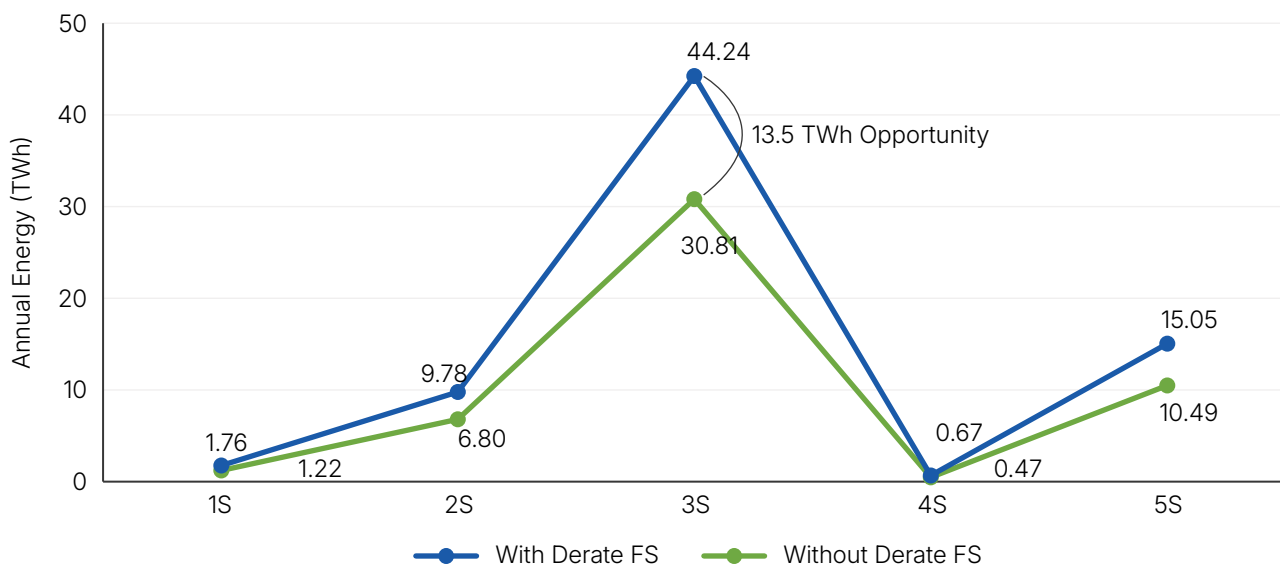


Figure 10: Fixed-Speed RAC: Star-Wise Annual Energy (TWh) Consumption, End of 2024^{xiii}

^{xii} Inverter derating penalties are uniformly lower than the FS equivalents in Figure 10

^{xiii} Ideal vs. actual annual energy by star tier; the gap is the derating penalty

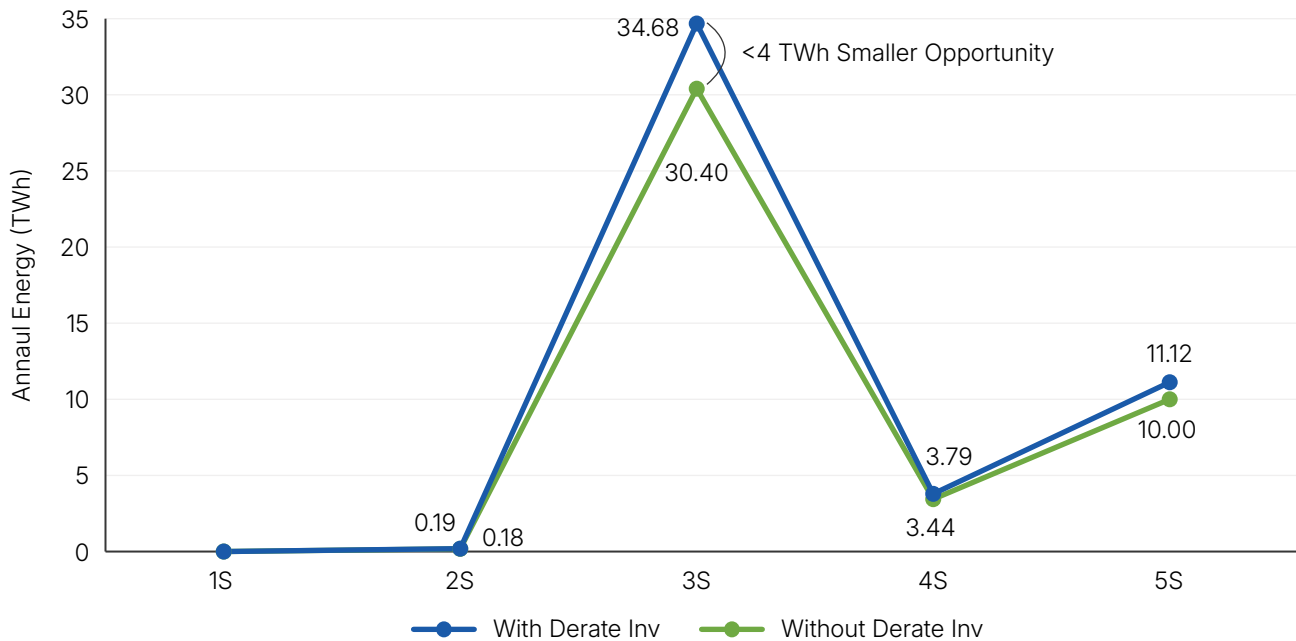


Figure 11: Inverter RAC: Star-Wise Annual Energy Consumption (TWh), End of 2024^{xiv}

5.5 Geoclimatic and State-Level Distribution

Figure 12 resolves the end of 2024 stock by climatic zone, star rating and technology. The Warm-Humid and Composite zones each host roughly 28 million units, ahead of Hot-Dry at 24 million. Inverters dominate every zone, but the 3-Star tier forms the vast majority throughout. The Warm-Humid zone's prolonged dehumidification loads accelerate derating even in inverter units, creating localised efficiency risk.

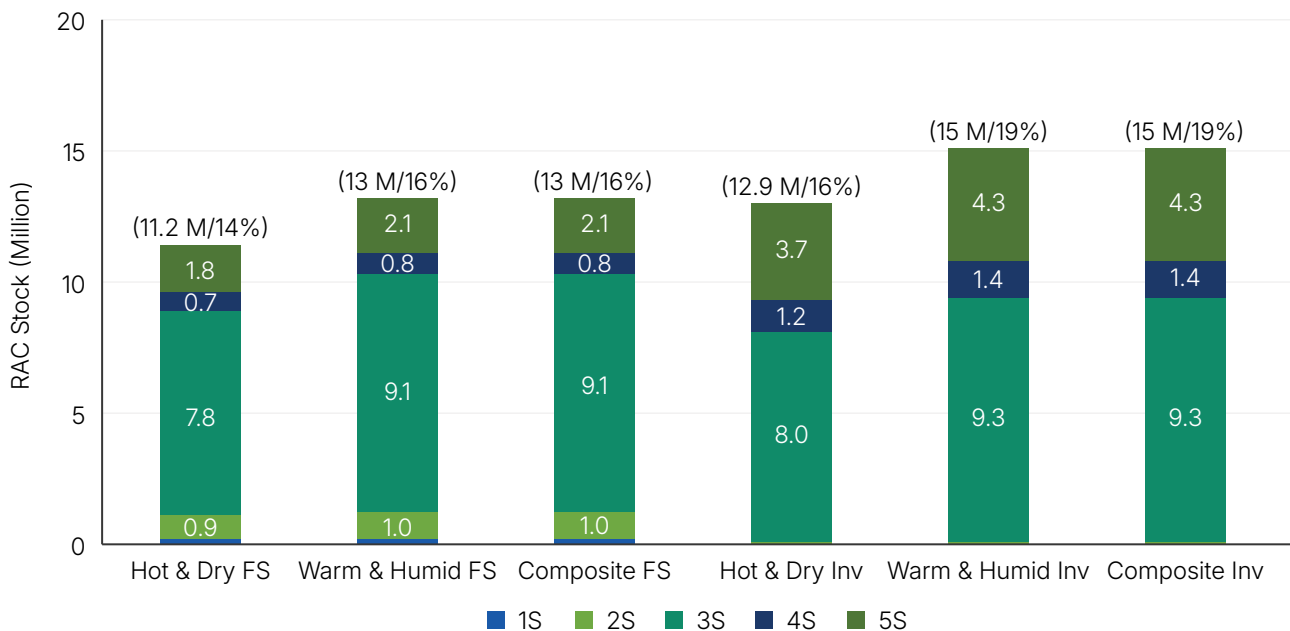


Figure 12: Star Rating and Technology-Wise Geoclimatic RAC Stock Distribution, End of 2024^{xv}

Figure 13 applies the peak-demand model across zones for the combined fleet and returns a counter-intuitive result: the derating-related grid penalty is nearly uniform in the range of 2.4-3 GW. This near-uniformity

^{xiv} Inverter energy penalties are a fraction of the FS equivalents in Figure 12

^{xv} Stock allocated to zones via CEAMA regional sales, Prayas model and Census data

supports a standardised national scrappage policy rather than complex zone-specific schemes for the worst-degraded units.

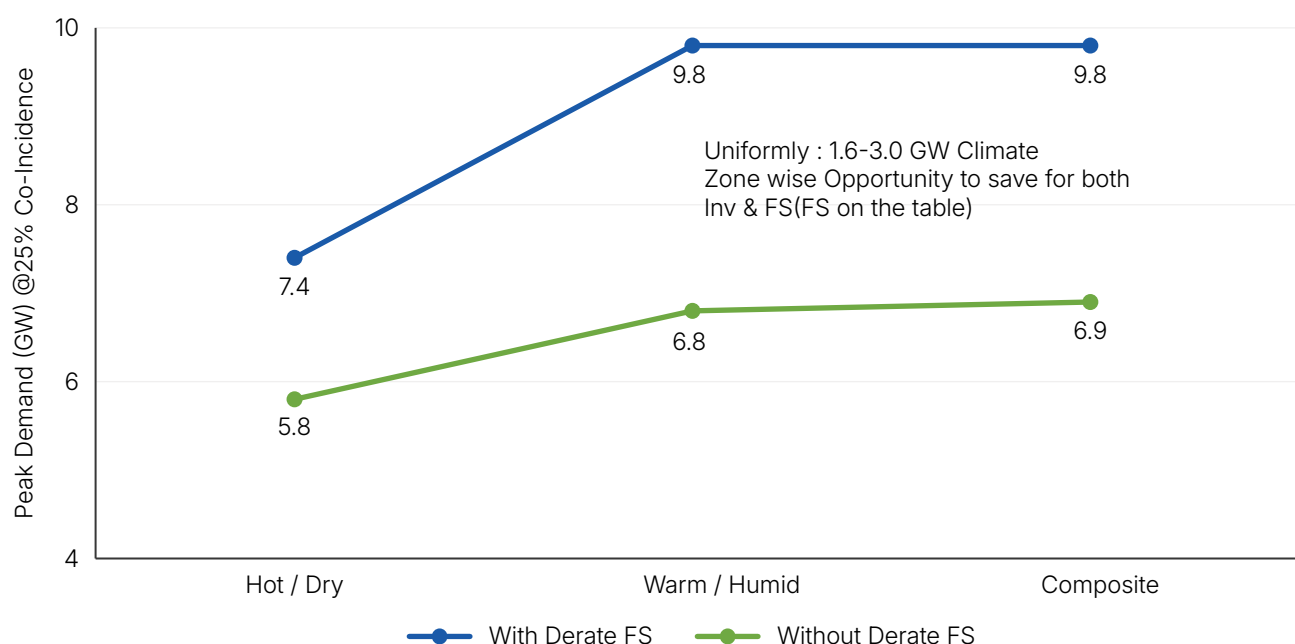


Figure 13: RAC (FS + Inverter): Climatic Zone-Wise Peak Demand (GW) at 25% Co-Incidence, End of 2024 ^{xvi}

Figures 14 and 15 translate the national picture into state-level diagnostics. The top five states, Maharashtra (10.3 M), Tamil Nadu (7.9 M), Gujarat (7.6 M), Delhi (6.0 M), and Uttar Pradesh (5.5), hold the majority of national legacy stock and are the primary targets for replacement. On a peak demand basis, urban Maharashtra leads at 6,265 MW, ahead of Tamil Nadu (4,798 MW) and Gujarat (4,577 MW).

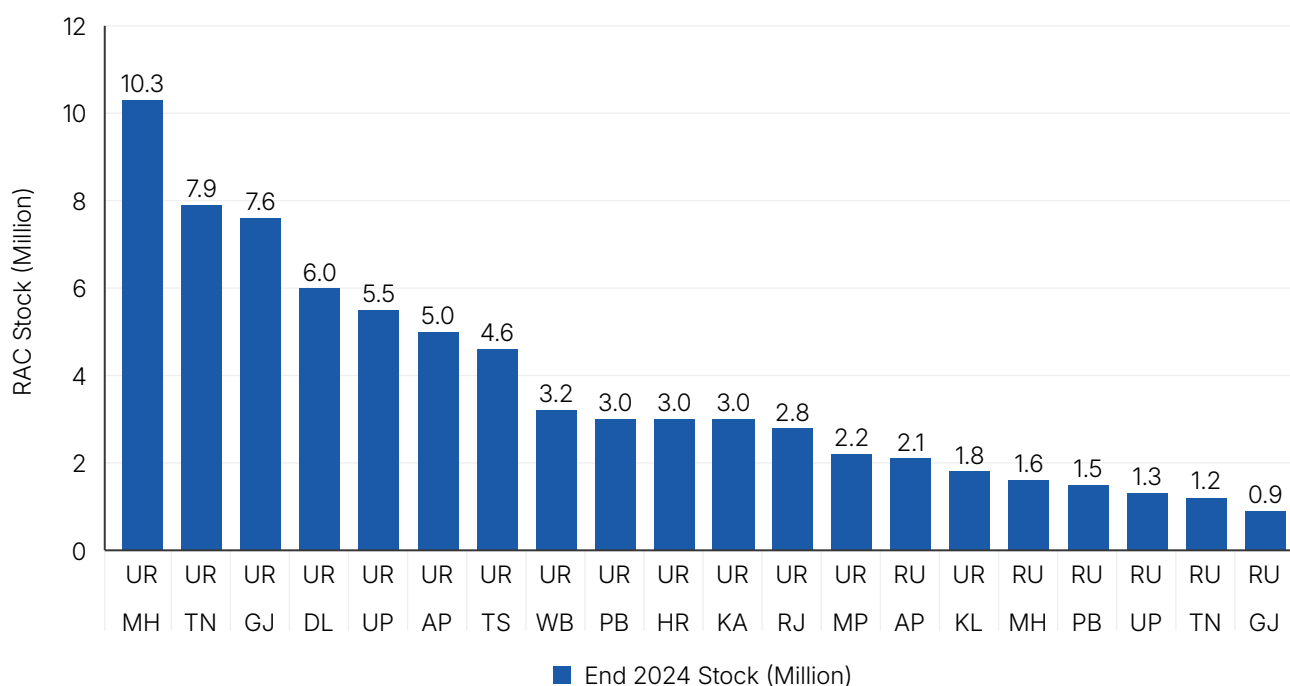


Figure 14: State-Wise RAC Stock Distribution, Urban and Rural, in Million units, End of 2024 ^{xvii}

^{xvi} Derating penalty per zone is the gap between with- and without-derating curves.

^{xvii} Split from Census urbanisation and Prayas model

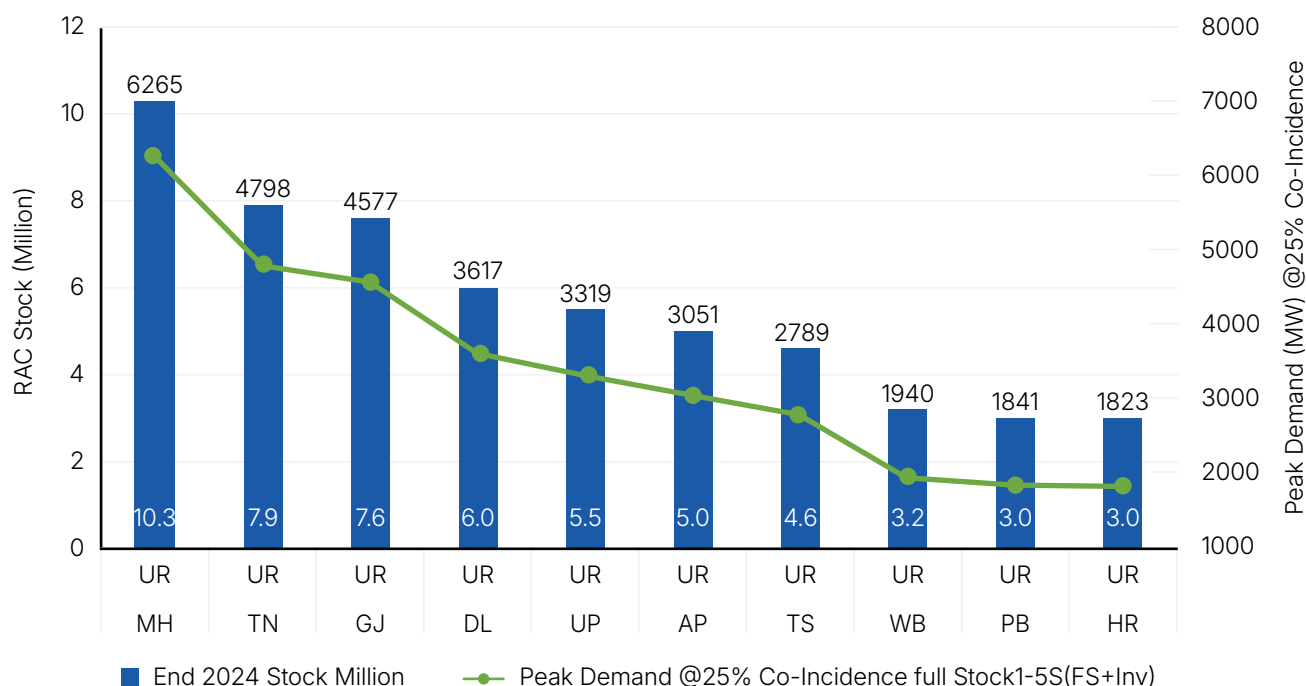


Figure 15: Top 10 States: Highest Peak Demand (GW) from RAC, End of 2024^{xviii}

5.6 The Phase-Out Trigger: Age-Based Replacement Potential

Figures 16 and 17 present the most actionable output of the study: the peak-demand and energy savings achievable by targeting legacy 1-3 Star FS units at two age thresholds. Retiring the 27.5 million units aged ≥ 5 years recovers 6.21 GW of peak demand (Figure 18) and eliminates 15.84 TWh of annual electricity consumption (Figure 19). The 22.2 million “deep decay” units aged ≥ 7 years deliver the highest return per unit replaced, 5.29 GW and 13.50 TWh, making them the priority “worst-first” cohort.

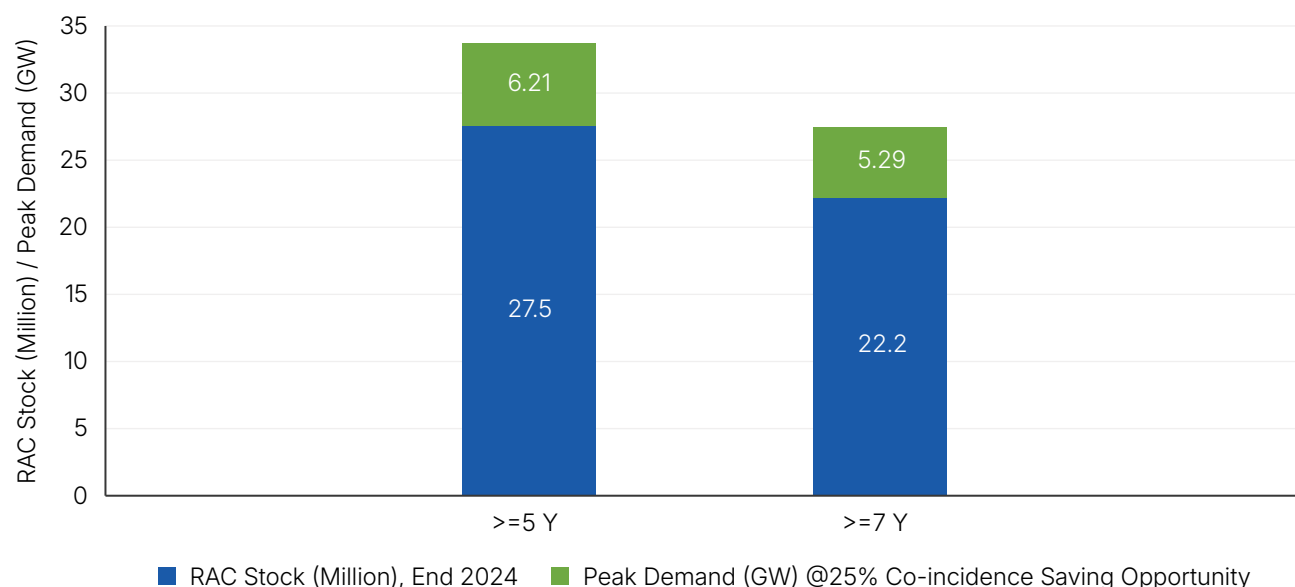


Figure 16: Peak Demand Savings (GW) Potential, 1-3 Star FS Units ≥ 5 Years and ≥ 7 Years^{xix}

^{xviii} Peak demand at 25% co-incidence, full stock (1-5 Star, FS + Inverter)

^{xix} Bars show targetable stock (million units) and recoverable peak GW at 25% co-incidence

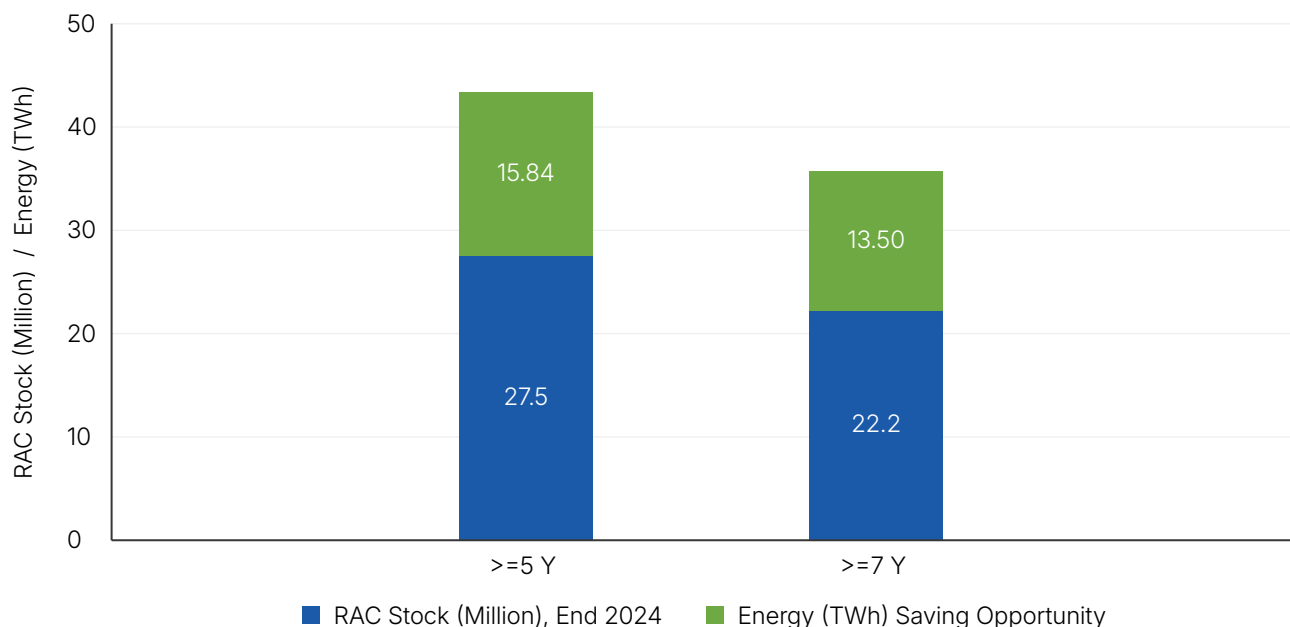


Figure 17: Annual Energy Savings (TWh) Potential, 1-3 Star FS Units ≥5 Years and ≥7 Years^{xx}

Figures 18 to 22 disaggregate the replacement potential by state across both peak power (MW) and annual energy (TWh) metrics, at both age thresholds. Maharashtra, Tamil Nadu and Gujarat consistently rank as the primary intervention zones, each offering on the order of 0.6-0.8 MW of peak savings and 1.5-2 TWh of annual energy savings. Maharashtra heads every ranking with highest peak demand and energy recoverable from its ≥5-year cohort alone.

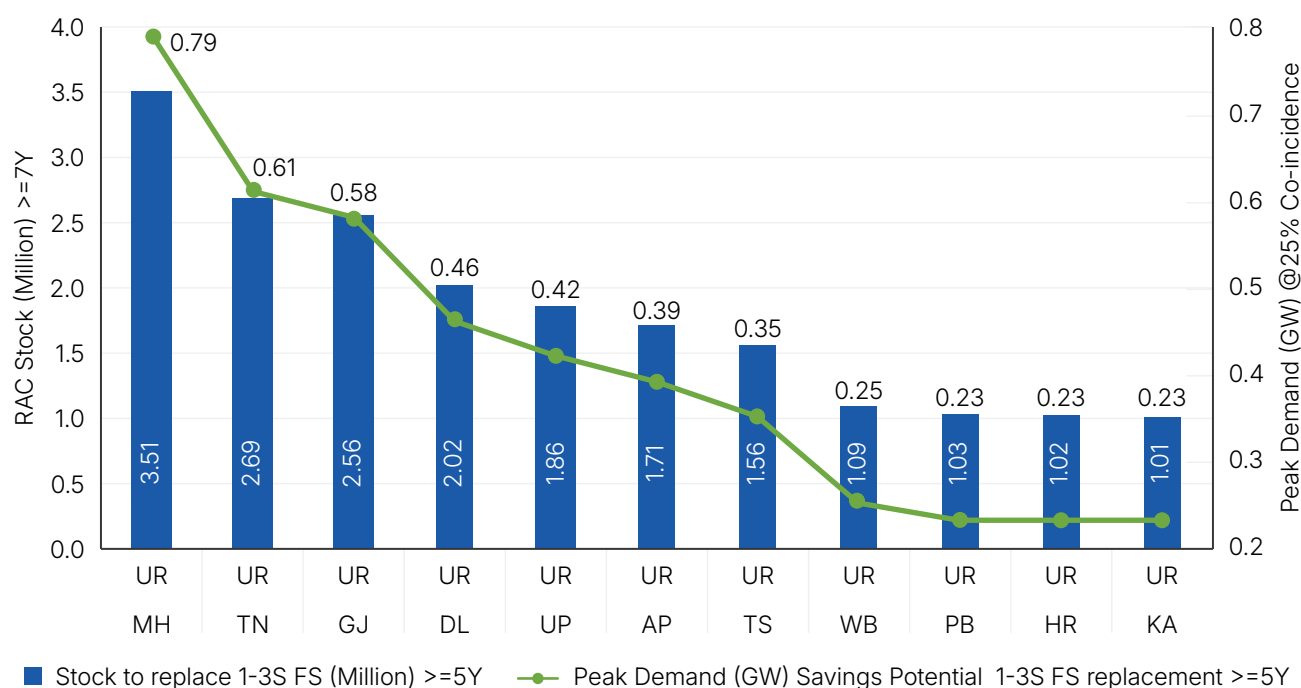


Figure 18: Top 10 States: Replacement Potential for 1-3 Star FS Units ≥5 Years, Peak Demand Savings (GW) per State^{xxi}

^{xx} ≥7-year cohort yields a disproportionate share of savings per unit retired

^{xxi} Targetable stock (million units) and peak MW savings at 25% co-incidence

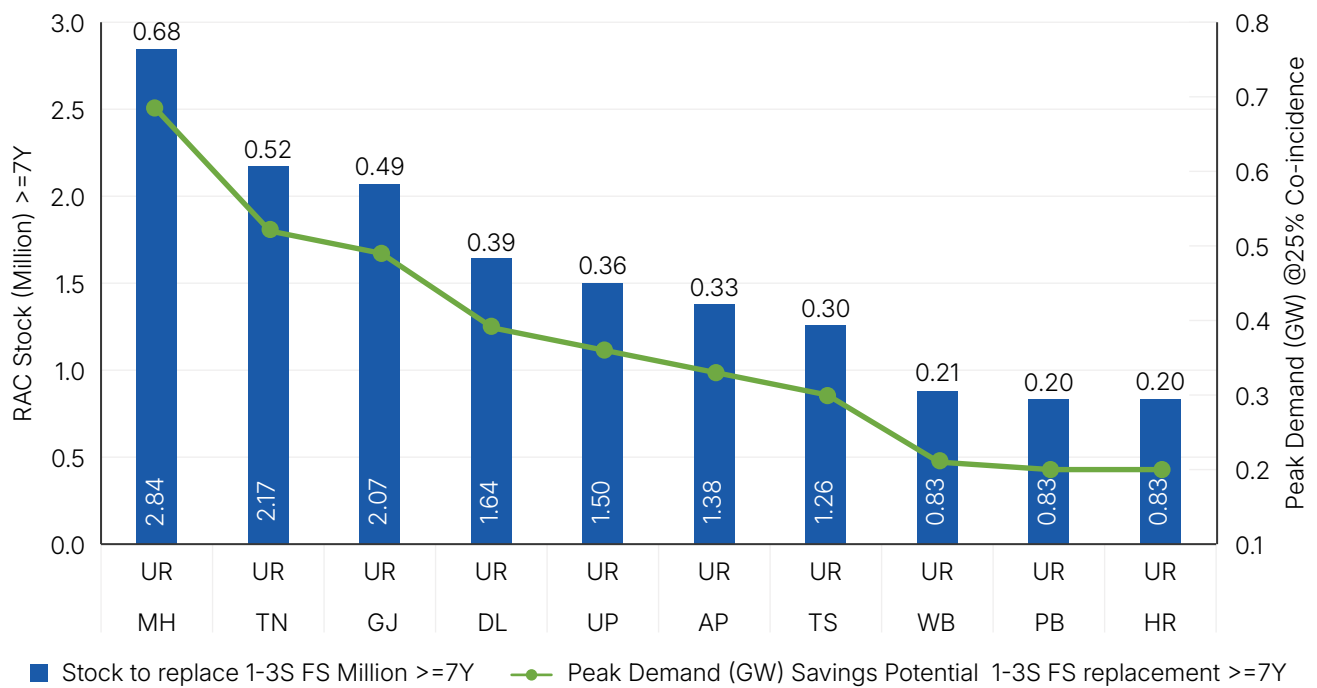


Figure 19: Top 10 States: Replacement Potential for 1-3 Star FS Units ≥ 7 Years, Peak Demand Savings (GW) per State^{xxii}

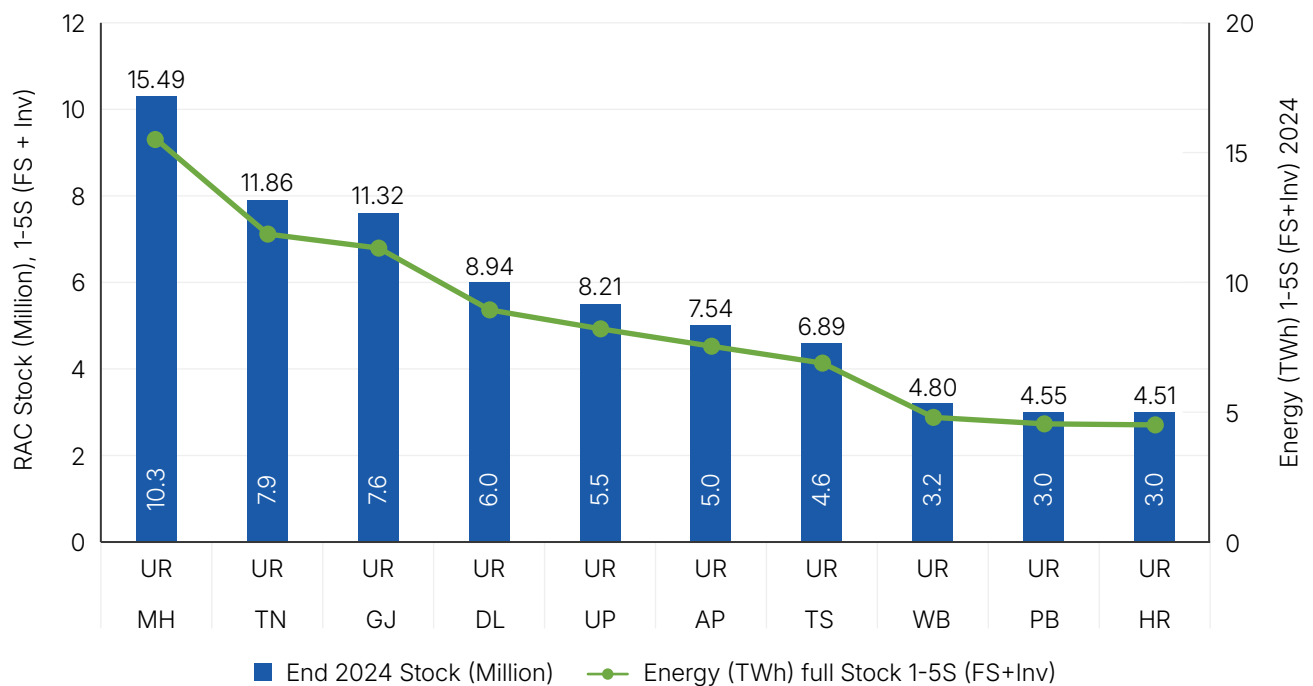


Figure 20: Top 10 States: Total RAC Energy Consumption (TWh), End of 2024,^{xxiii}

^{xxii} The deep-decay cohort concentrates the highest per-unit grid relief

^{xxiii} Full-stock annual energy (1-5 Star, FS + Inverter) by state

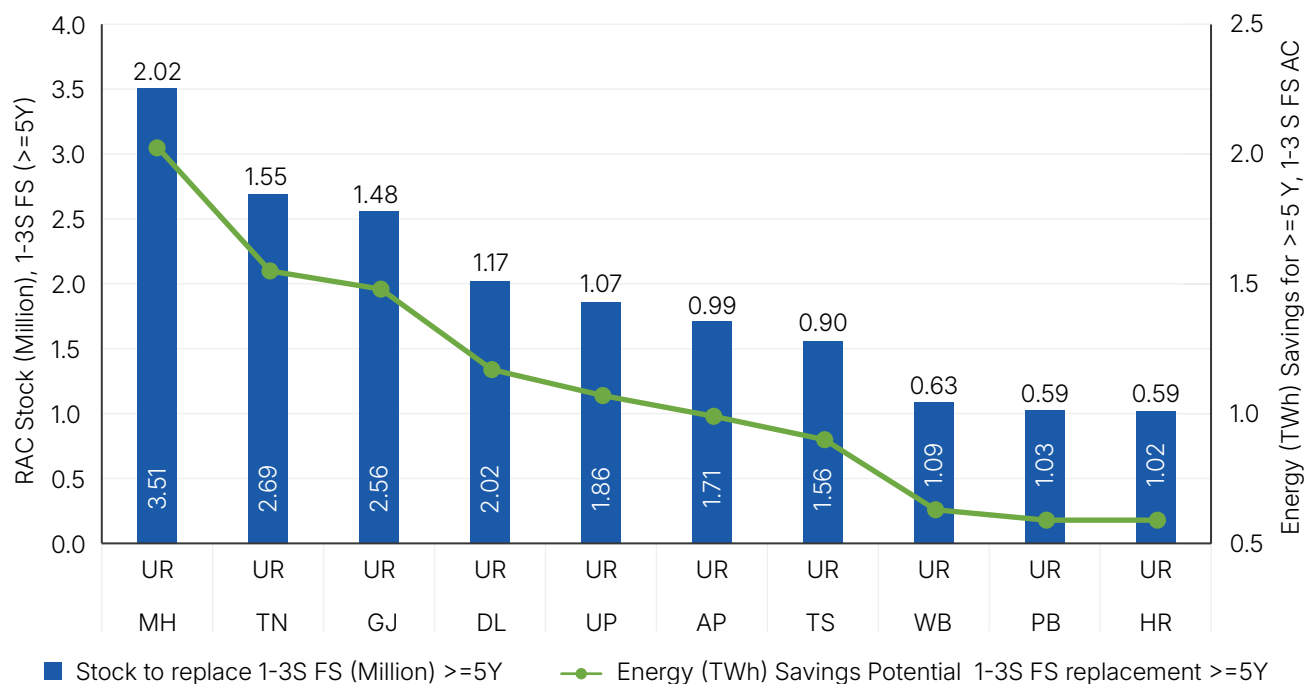


Figure 21: Top 10 States: Energy Savings (TWh) from Replacing 1-3 Star FS Units ≥5 Years^{xxiv}

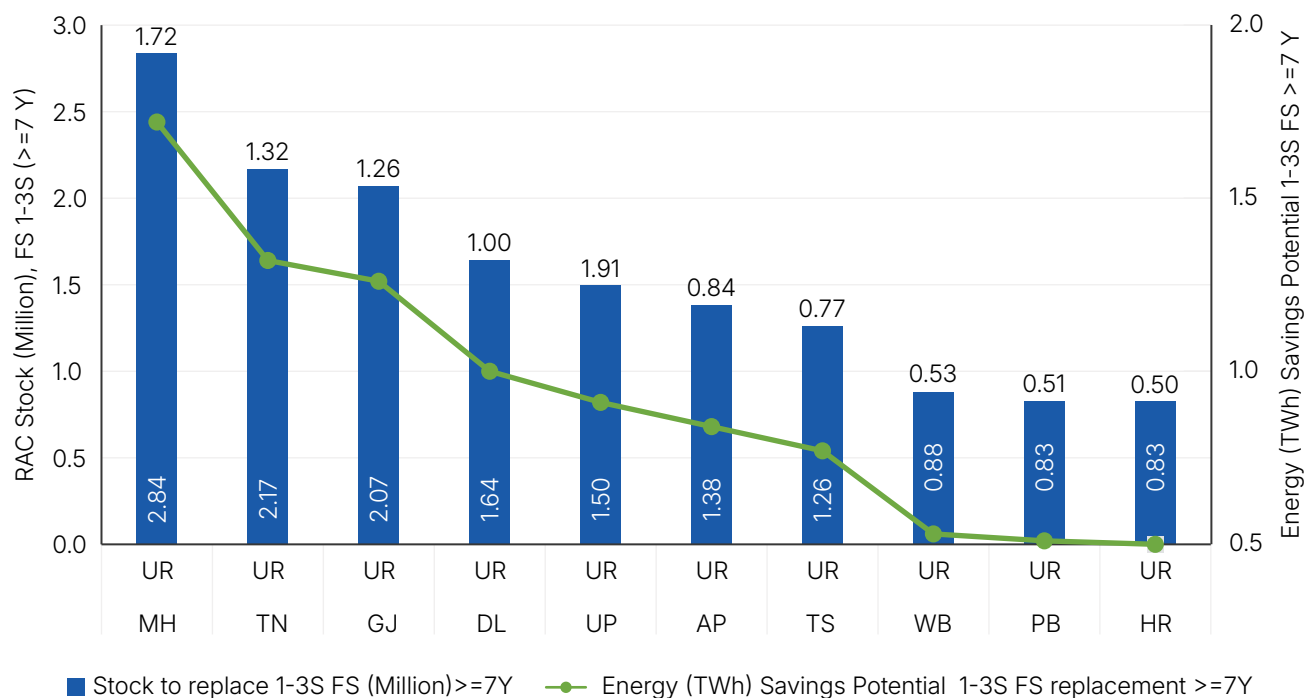


Figure 22: Top 10 States: Energy Savings (TWh) from Replacing 1-3 Star FS Units ≥7 Years^{xxv}

^{xxiv} Annual energy savings from retiring the ≥5-year legacy FS cohort

^{xxv} Annual energy savings from the priority deep-decay cohort

5.7 Economic Valuation

Replacing the ~27 million legacy 1-3 Star FS units aged five years or more generates an estimated (~ INR35,000 crore) in aggregate economic value over a three-year programme horizon. These benefits are distinct and non-overlapping: the utility saving (~ INR63,000 crore) is the avoided cost of the peak generation capacity that derating necessitates plus its fixed O&M with no avoided energy (power-purchase) cost included while the consumer saving (~ INR35,000 crore) is the avoided energy cost of running derated appliances. Because one is a capacity cost and the other an energy cost, the two do not overlap. Per-unit consumer savings average (~ INR23,000) over three years for the ≥5-year cohort, rising to ~ INR26,000 for the ≥7-year cohort owing to greater cumulative derating losses. Table 9 sets out the split between grid operators and households.

**Table 9: Economic Value of Replacing Legacy 1-3 Star FS Units Aged ≥5 Years
(INR Crore, 3-Year Horizon)**

Savings Category	Economic Beneficiary	Three-Year Value (INR Crore)
Avoided peak power purchase / generation costs	DISCOMs and grid operators	63,000
Direct utility-bill reduction for households	Consumers	35,000
Total economic value	National economy	98,000

Figures 23 and 24 distribute the power-company (grid) savings across states for the ≥5-year and ≥7-year cohorts respectively, while Figures 25 and 26 decompose the combined consumer-and-utility economics into capital, operating and maintenance components. The state distribution mirrors the stock concentration: Maharashtra, Tamil Nadu and Gujarat capture the largest absolute savings, reinforcing the case for an asymmetric, top-five-states delivery model.

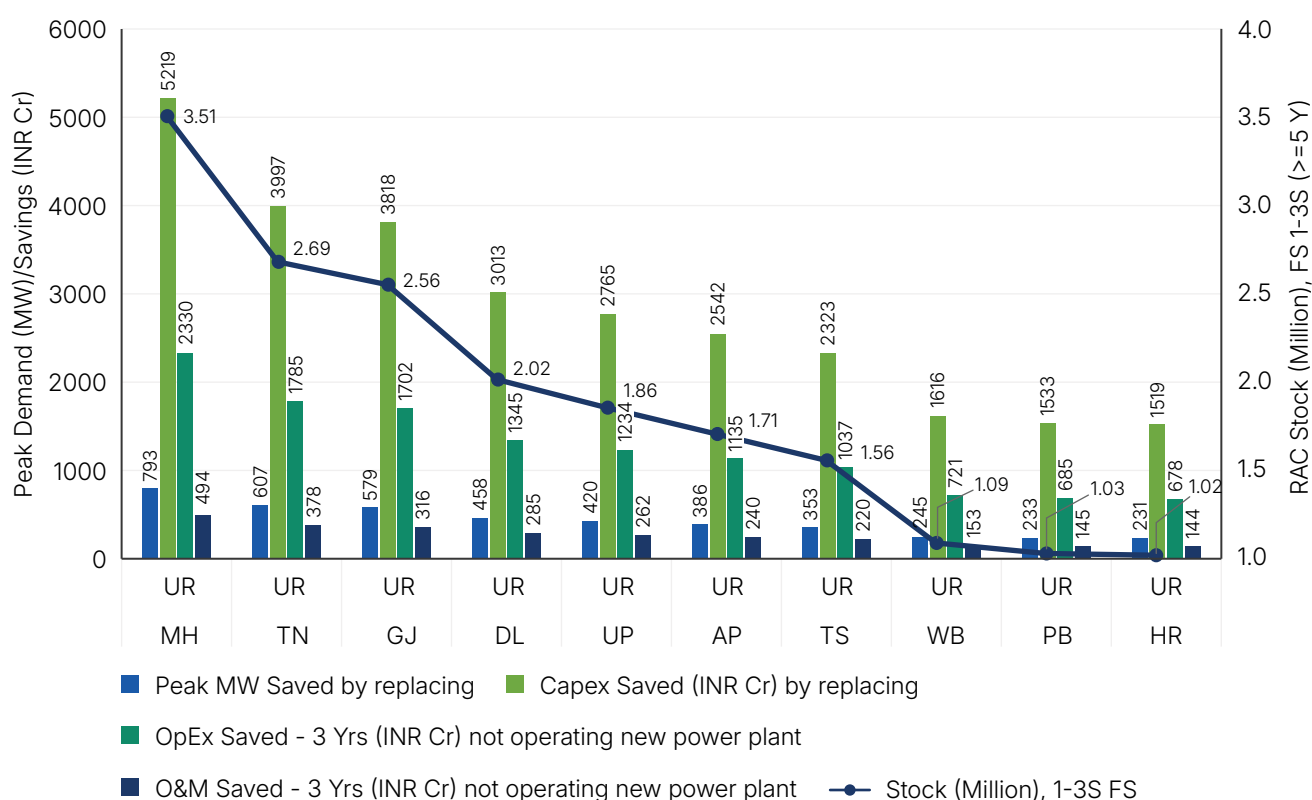


Figure 23: Power Company Savings from Replacing ≥5-Year 1-3 Star FS Units, by State

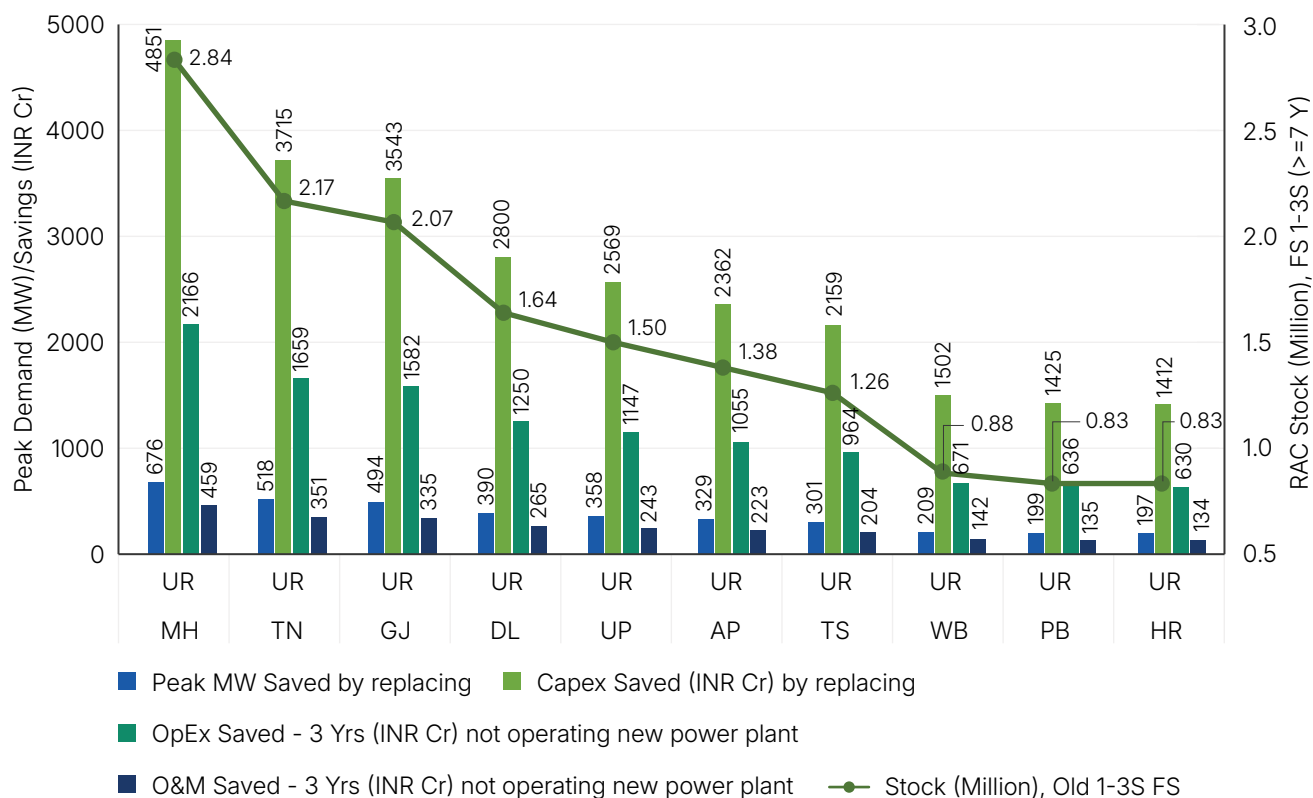


Figure 24: Power Company Savings from Replacing ≥7-Year 1-3 Star FS Units, by State

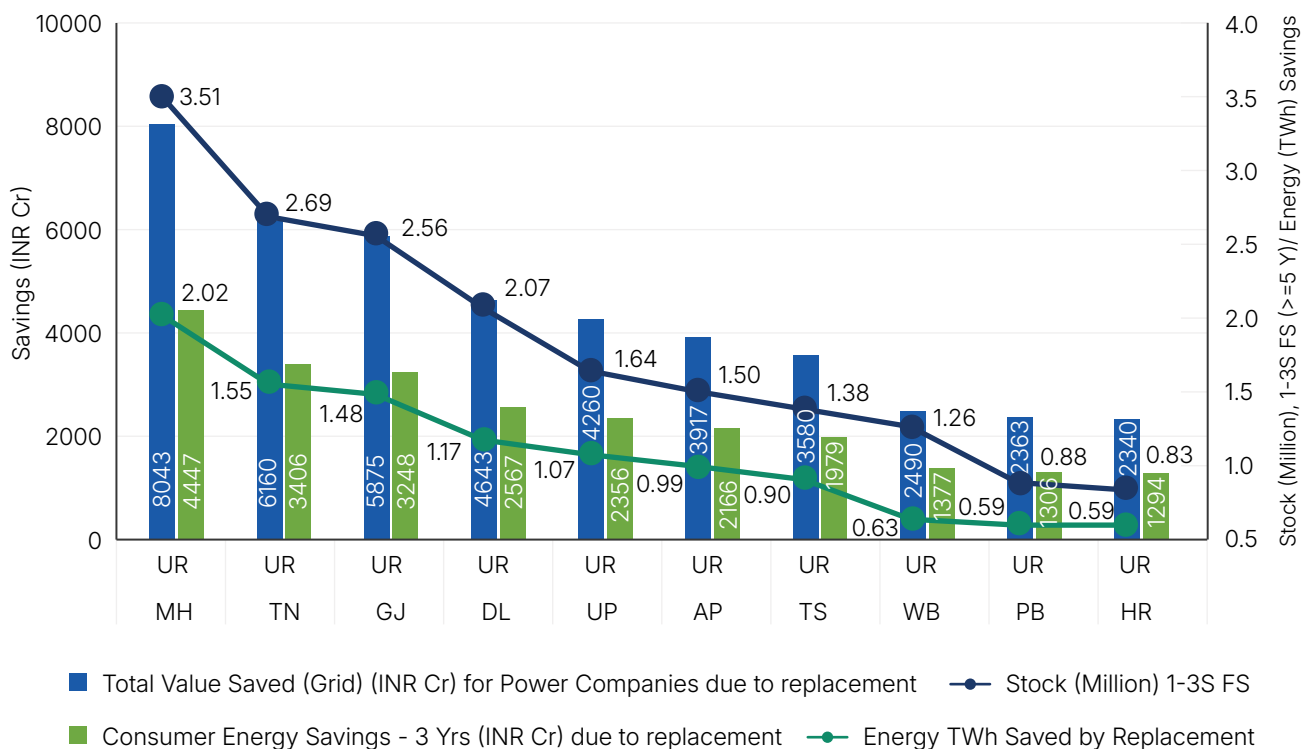


Figure 25: Consumer and Power Company Economics: ≥5-Year Replacement^{xxvi}

^{xxvi} Decomposition of three-year economics into capital, operating and maintenance components

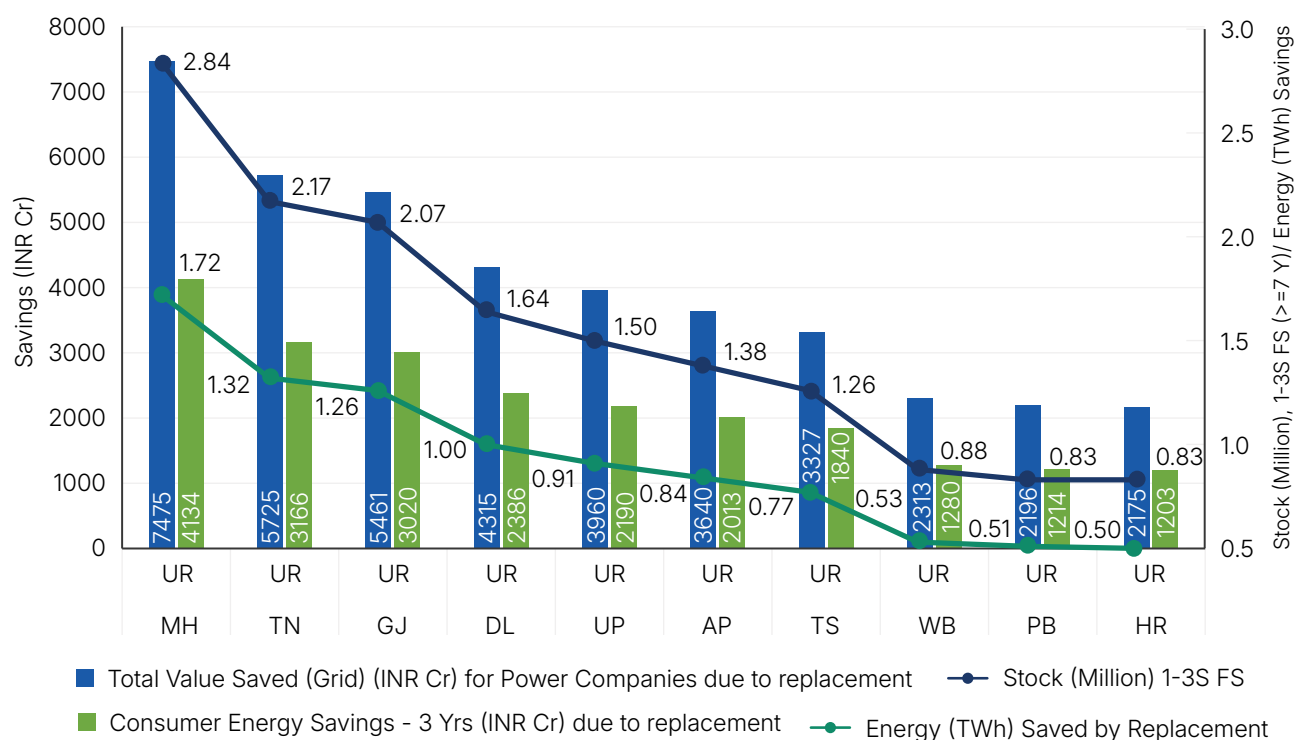


Figure 26: Consumer and Power Company Economics: ≥7-Year Replacement^{xxvii}

The evidence assembled here, ~27 TWh of annual energy waste, 11 GW of avoidable derating load and INR98,000 crore of recoverable value, concentrated in five urban states, provides the foundation for the policy framework set out in the next chapter.

^{xxvii} Higher per-unit derating losses raise the opex-saving share for the deep-decay cohort





06

Policy Relevance and Recommendations

This chapter frames the findings of Chapters 3–5 within India’s policy architecture and translates them into sequenced, actionable recommendations. It identifies the key stakeholders that can drive implementation, including national and state-level policymakers and regulators (Sections 6.1–6.2); distribution utilities and load-dispatch centres, for whom the state-level peak and cost outputs are directly actionable (Section 6.3); and industry stakeholders, including manufacturers, servicing professionals, and programme implementers (Section 6.4). The sequenced recommendations that follow (Section 6.5) translate these into a phased programme.

6.1 Relevance for the India Cooling Action Plan (ICAP)

ICAP (MoEFCC, 2019) targets reductions of 20–25% in cooling demand and 25–40% in cooling-energy requirements by 2037–38, against a baseline in which cooling demand is projected to grow around eightfold. This study contributes to ICAP implementation on four fronts:

- **Baseline establishment:** A rigorously validated 2024–2025 baseline of RAC stock, energy consumption, peak-demand contribution and technology penetration by zone, a prerequisite for measuring progress toward ICAP targets.
- **Technology-transition monitoring:** Year-by-year inverter-adoption data (1% of new sales in 2015 to 75% in 2024) quantifies the pace of transformation and supports projection of future stock composition under alternative MEPS scenarios.
- **Efficiency-gap quantification:** The derating analysis measures the gap between MEPS-rated and real-world in-service performance, providing the evidence base for extending MEPS beyond point-of-sale standards.
- **Regional demand intelligence:** Climatic-zone disaggregation supports ICAP’s call for region-specific cooling solutions, supplying data for differentiated standards and targeted incentives.

6.2 Relevance for the BEE Star Labelling Programme

The BEE Star Labelling programme is India’s primary market-transformation instrument for appliance efficiency. The findings offer it both intelligence for standards revision and opportunities to extend the label beyond the point of sale:

- **Market intelligence for standards revision:** Current technology shares, star-rating distribution by zone and regional adoption patterns provide the context for setting the next MEPS thresholds at levels both ambitious and achievable.
- **In-service performance data:** The derating analysis provides the empirical basis for an “in-service label” or field-efficiency verification scheme, extending the framework from the point of manufacture to the point of actual consumption.
- **High-ambient performance disclosure:** RAC capacity and efficiency at high ambient (ISO T3, 46°C) are never disclosed – only the T1 (35°C) rating and the 24–43°C ISEER bin – which drives the oversizing that inflates connected load. Because IS 1391 already tests units at 46°C for survivability, the label is well placed to carry a reported high-ambient performance metric at low cost, giving buyers, DISCOMs and programme designers a truer basis for equipment selection.
- **Consumption feedback at the point of use:** The findings also point to scope for the framework to give users direct feedback on their set-point and usage choices – through in-device real-time power or running-cost display – complementing the label beyond the point of sale and supporting demand-side response.

6.3 DISCOM and Grid Operator Relevance

For distribution companies and State Load Despatch Centres, the most actionable outputs are the state-level peak demand savings (Figures 20-21) and the associated economic valuation (Table 7). These let utilities weigh the cost of scrappage subsidies against procuring short-term peaking power or reinforcing the network. For states like Maharashtra, Tamil Nadu, Gujarat, the avoided cost of peak power during a heat wave, at typical short run marginal costs of Indian peaking generation, substantially exceeds the subsidy cost of retiring targetable units over three years, making a buy-back programme financially self-justifying from the utility's perspective.

6.4 Relevance for Industry and Delivery

For manufacturers, the servicing trade and programme implementers, the findings point to a sizeable near-term delivery opportunity. The ~27 million unit replacement pool is an addressable market for efficient inverter models; realising it depends on the reverse-logistics, refrigerant-recovery and unit-destruction capacity that a scrappage programme requires, and on a servicing workforce equipped to handle recovery and the shift to lower-GWP refrigerants. Aligning manufacturer incentives, dealer networks and the servicing trade with the phased programme below is therefore a precondition for delivery, not an afterthought.

6.5 Sequenced Policy Recommendations

Table 10 sets out a sequenced programme for 2026-2028. Priorities 1-3 address immediate grid relief; Priorities 4-5 build the regulatory architecture for long-term lifecycle efficiency management.

Table 10: Policy Directives Summary

Priority	Directive	Target / Scope	Timeline
1	Launch a "worst-first" national scrappage buy-back: gated incentives for 1-3 Star FS units made before 2020, conditional on verified refrigerant recovery and unit destruction	~27M ≥5-year units; prioritise the 22.2M ≥7-year deep-decay cohort first	By the end of 2027
2	Establish reverse-logistics hubs in the top five urban states: refrigerant recovery, component separation, recycling, SLDC co-ordination	MH, TN, GJ, DL, UP; cover >50% of national vintage stock	2027 - 2028
3	Align DISCOM incentive structures with MW / TWh savings; set data-backed cash rebates using avoided-peaking-cost methodology	All top-10 state DISCOMs	2027 - 2028
4	Strengthen the labelling and MEPS framework: (i) Low-cost, near-term additions - a) encouragement of in-device real-time power / running-cost display, b) voluntary declaration of high-ambient (ISO T3) performance; and (ii) Evolve MEPS toward lifecycle regulation i.e., in-service efficiency testing for units >5 years, maintenance certification and periodic field audits, and zone-specific MEPS floors (e.g. a 4-Star minimum in Warm-Humid coastal zones).	National; BEE-administered	2028 - 2029
5	Redirect inverter support from purchase subsidies (market self-sustaining at 75% of sales) to subsidised maintenance: PCB diagnostics, refrigerant top-up, voltage stabilisation	National; OEM dealer network	2027 onwards





07

Key Findings and Insights

- **The Market Transformation: Inverter Technology Has Arrived:** The most consequential development of the past decade is the decisive market shift to inverter technology, which rose from about 1% of new sales in 2015 to roughly 75% by 2024 – a trajectory consistent with BEE's production-share series (1% in 2015-16, 62% by 2020-21 and about 77% by 2022-23), with 75% adopted here as a rounded 2024 figure. Driven by BEE Star Labelling incentives, falling inverter-component costs and consumer education on long-term savings, this transition has raised average new-equipment efficiency. It is a template for future efficiency programmes, demonstrating the power of co-ordinated minimum standards, consumer-facing labels and technology cost reduction.
- **Derating Is a National Infrastructure Problem:** The 11 GW avoidable derating load and 27 TWh annual penalty for the end of 2024 are not abstract statistics. They represent real power plants generating real emissions to supply electricity that delivers no additional cooling. Reframing appliance inefficiency as an infrastructure deficit is essential to elevating it to the appropriate policy priority, on a par with grid reinforcement and transmission investment.
- **The Replacement Opportunity Is Precisely Identifiable:** The age-based analysis shows the opportunity is concentrated, not diffuse. Over 80% of the FS fleet's grid penalty comes from 3-Star units; over 75% of sector energy waste originates in pre-2020 hardware; and over 60% of potential savings is recoverable by targeting just the 22 million deep-decay units aged seven years or more. This precision enables policy that is proportionate, targeted and defensible in cost-benefit terms.
- **Regional Diversity Demands Differentiated Policy:** The climatic-zone analysis confirms that India's cooling challenge is not geographically uniform. The Composite and Warm-Humid zones together hold 59.5% of installed capacity but 69.4% of energy consumption, driven by longer seasons, lower set-points and dehumidification loads. A uniform national policy that ignores these differentials would under-invest in high-impact areas and over-invest in low-impact ones; coastal zone-specific MEPS floors are warranted by the evidence.
- **Inverter Technology Shields the Grid - Policy Must Reflect the Asymmetry:** A critical insight is that the FS and inverter fleets require fundamentally different responses. For FS units the evidence supports scrappage and replacement; for inverter units, which derate far more slowly and already dominate new sales, the optimal intervention is maintenance preservation. Conflating the two in a single undifferentiated programme would waste public resources and risk removing well-functioning equipment from service prematurely.
- **The Bottom-Up Methodology Reveals What Top-Down Analysis Cannot: A meta-finding is methodological:** The precision of the opportunity, ~27 million specific units in specific states generating specific grid penalties, could only be surfaced through bottom-up modelling. Top-down analysis at the national aggregate would reveal that a derating problem exists, but not its location, its magnitude by star tier, or its optimal targeting parameters. This argues for sustained investment in granular, asset-level data infrastructure to support ongoing programme design.



08

Limitations and Future Research

8.1 Research Limitations

8.1.1 Data Limitations

- Utility billing data available for validation is aggregated at sub-regional levels insufficient for granular cross-checking; finer-grained advanced-metering-infrastructure (AMI) data would materially improve calibration.
- Equipment registration records before 2015 are incomplete, requiring extrapolation of vintage stock for older cohorts and adding uncertainty to the ≥ 7 -year deep-decay estimates.
- Building-stock quality data varies substantially across states and urban tiers, affecting climate-zone allocation for smaller cities.

8.1.2 Coverage Gaps

- Small commercial establishments may be incompletely captured, as CEAMA data primarily tracks residential and declared commercial channels.
- Rural RAC adoption, accelerating in peri-urban and tier-3 markets, is likely underestimated given limited rural survey data.
- The model treats humidity as a driver of cooling demand and of wear-based derating at the climatic-zone level (Sections 4 and 5) but does not represent latent load thermodynamically; nor does it assess the matching of system type to the predominant climatic load, or the comfort and health effects of dry-bulb-only control, which can drive over-dehumidification and indoor dryness. These lie beyond this edition's energy and peak-load boundary.

8.1.3 Modelling Assumptions and Sensitivity

- The 25% co-incidence factor is calibrated from limited metering data. At 20% co-incidence the peak penalties fall by about 20%; at 30% they rise by about 20%. Core policy conclusions are robust across this range.
- Technology distribution within star-rating categories is assumed uniform within zones; intra-zone diversity in building type and occupancy creates heterogeneity not fully captured.
- Derating curves are calibrated primarily from Purdue/LBNL data; India-specific long-run field measurements remain scarce and would improve calibration.
- All central estimates carry an inherent ± 10 –15% uncertainty range. Findings for the top five states, where stock density and data quality are highest, carry lower uncertainty than estimates for smaller states and rural areas.

The consolidated sensitivity analysis below is scoped to the Fixed-Speed (FS) segment of the RAC stock, roughly 38 million units instead of the 81 million units total installed base by end-2024 reported in Figure 2. Holding per-unit capacity and efficiency at baseline values (≈ 1.7 – 2.0 kW per unit; 1,085–1,310 kWh per year), the FS fleet's full rated capacity implies roughly 78 GW of peak demand and 50 TWh of annual consumption by 2024 before any derating is applied; incorporating vintage-based derating raises these to roughly 112 GW and 71 TWh respectively (Table 11)^{xxviii, xxix}.

^{xxviii} These figures represent gross installed (100%-co-incident) capacity and consumption and are not directly comparable to the 25%-co-incidence system-peak estimates in Table 8; they isolate the sensitivity of the fleet-and-derating layer of the model from the co-incidence-factor sensitivity addressed above.

^{xxix} This sensitivity analysis is presented only for the Fixed-Speed segment. Inverter (variable-speed) units are not run through a parallel derating-sensitivity exercise because, per Section 5.2, inverter compressors are constrained to a materially shallower degradation slope than fixed-speed units. Perturbing that shallower slope by the same $\pm 10\%$ applied here would move inverter-segment peak demand and energy by a proportionally smaller amount, since the coefficient being perturbed is itself smaller. On this basis, the FS-segment percentage ranges in Table 11 can reasonably be treated as an outer bound, inverter-segment sensitivity to the same assumptions would not be expected to exceed these percentage swings, though the absolute GW/TWh magnitudes involved are smaller given inverter units' lower baseline derating.

Table 11: Consolidated Sensitivity Analysis of Peak Cooling Demand and Electricity Consumption under^{xxx}

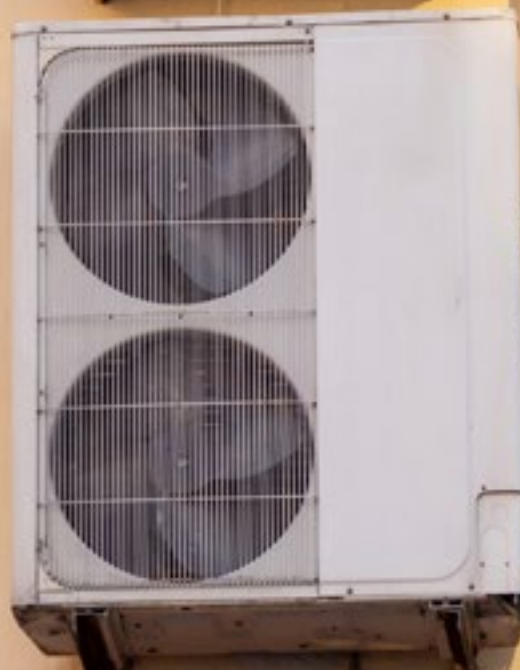
Scenario	Fleet Stock Assumption	Derating Assumption	Peak Demand (GW)	Δ Peak vs Base	Annual Energy (TWh)	Δ Energy vs Base
Reference (without derating)	Baseline	No Derating	77.93	–	49.78	–
Reference (with derating)	Baseline	Vintage-based Derating	111.95	–	71.49	–
Optimistic Derating	Baseline	–10% kW/machine Derating	96.99	–13%	61.95	–13%
Pessimistic Derating	Baseline	+10% kW/machine Derating	125.89	+12%	75.71	+6%
Low Stock Scenario	Fleet (–10%)	Reference (with derating)	107.77	–3.7%	68.83	–3.7%
High Stock Scenario	Fleet (+10%)	Reference (with derating)	114.45	+2.2%	73.09	+2.2%

Fleet-stock sensitivity scales the results nearly linearly: a $\pm 10\%$ change in installed units shifts peak demand and annual energy by a proportional $\pm 2\text{--}4\%$. Derating sensitivity is more consequential: a further 10% worsening in per-unit derating raises the 2024 peak from 111.95 GW to 125.89 GW (+12%) and annual energy from 71.49 TWh to 75.71 TWh (+6%); conversely, a 10% improvement in derating reduces peak demand to 96.99 GW (–13%) and annual energy to 61.95 TWh (–13%). Operational changes, such as raising the average thermostat set-point by 2°C, can cut cooling energy by 10–12% (on BEE guidance of up to ~6% per °C) with a comparatively smaller effect on coincident peak. Taken together, an ageing, low-efficiency fleet materially worsens both energy and peak-demand outcomes, while inverter penetration and higher set-points offer a comparably sized lever in the opposite direction, reinforcing the case, made in Chapter 5 and Chapter 6, for accelerating replacement of the legacy fixed-speed stock.

8.2 Directions for Future Research

- **Longitudinal field-efficiency measurement:** Structured in-service testing across a statistically representative sample by age, star rating and zone would sharpen derating-curve calibration and strengthen the case for lifecycle MEPS.
- **Rural cooling-adoption dynamics:** Dedicated survey research on rural penetration, usage patterns and efficiency preferences would address a significant and growing data gap.
- **DISCOM avoided-cost modelling:** State-specific avoided-cost calculations, incorporating grid mix, time-of-use pricing and DISCOM financial positions, would enable more precise scrappage-subsidy design.
- **Consumer-behaviour research:** Studies on consumer acceptance of, and optimal incentive structures for, buy-back programmes would support design and uptake projections, drawing on precedents from Japan, China and the EU.
- **Latent load and controls:** thermodynamic treatment of dehumidification demand by climatic zone, climate-matched system specification (cooling-only versus cooling-and-dehumidification), and the energy, comfort and health implications of dry-bulb-only versus humidity-aware control.
- **High-ambient performance derating:** field measurement of RAC capacity and efficiency loss at 40–45°C, to quantify the oversizing and connected-load penalty that undeclared high-ambient performance now produces, and to inform a high-ambient (T3) declaration requirement.

^{xxx} Baseline represents the reference fleet composition considering the vintage distribution of fixed-speed and inverter air conditioners. Optimistic and pessimistic scenarios represent $\pm 10\%$ variation in machine derating (kW/machine); stock sensitivity represents $\pm 10\%$ replacement within the ≥ 10 -year vintage population. Annual energy incorporates the corresponding variation in operating hours and thermostat settings under the derating framework.





09

Conclusions

India's room-air-conditioner sector in 2025 is simultaneously a story of remarkable success and a source of urgent, actionable concern. The success is the technology transition: inverter RACs have moved from a minority product to the market standard in four years, demonstrating the power of co-ordinated BEE labelling, industry investment and consumer education. This shift has materially improved the efficiency trajectory of new equipment and will progressively improve the installed base over time.

The concern is equally clear: a large cohort of ageing Fixed-Speed units, entrenched in the installed base and accumulating mechanical degradation each year, now imposes a quantifiable and growing burden on the grid and the carbon budget. The ~11 GW avoidable derating load and ~27 TWh annual energy penalty documented for the end of 2024 are present-tense consequences of policy inaction on the lifecycle regulation of appliances already past their useful efficiency life.

The solution is precisely identified and analytically grounded. Targeting ~27 million 1-3 Star Fixed-Speed units aged five years or more, concentrated in five urban states, with a well-designed, gated scrappage programme can recover ~7 GW of peak demand, eliminates ~16 TWh of annual waste and generate ~INR35,000 crore of economic value over three years. This is not a speculative projection: it is a bottom-up accounting of every unit in the targetable cohort, validated against multiple independent sources and grounded in peer-reviewed derating science.

The strategic imperative is to shift from a regime focused on the point of sale, which leaves ageing in-service units unaddressed, toward a comprehensive lifecycle approach spanning installation, in-service monitoring, maintenance and end-of-life replacement. The evidence makes the case compelling, and the implementation tools, DISCOMs, SLDCs, BEE labelling infrastructure and existing ICAP frameworks, are already in place.

Securing India's energy future requires treating the retirement of inefficient legacy air conditioners not as a consumer choice but as a national infrastructure priority, on a par with grid reinforcement and renewable deployment. The bottom-up framework developed here, and the data it has surfaced, provide the foundation for that reframing and for the targeted, evidence-based action that must follow.



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