Bringing Super-Efficient Air Conditioners to the Market

Insights from field testing in India and the path forward

Developed by the Global Cooling Efficiency Accelerator | April 2025

Authors and Acknowledgments

Authors

Ankit Kalanki
Yash Shukla, Centre for Advanced Research in Building Science and Energy, CEPT University, India
Srilekhya Vennamaneni

Authors listed alphabetically. All authors from RMI unless otherwise noted.

Contact

Ankit Kalanki, akalanki@rmi.org

Acknowledgments

The authors thank the following individuals for their insights and perspectives on this work (*names listed alphabetically*):

Aun Abdullah, Lodha
Chao Ding, Lawrence Berkeley National Laboratory
Tarun Garg, RMI India Foundation
Charlotte Matthews, RMI
Ian McGavisk, RMI
Won Young Park, Lawrence Berkeley National Laboratory
Sneha Sachar, Clean Cooling Collaborative
Nihar Shah, Lawrence Berkeley National Laboratory
Laurie Stone, RMI

This work was conducted in partnership with Lodha, one of the largest real-estate developers in India. The authors express their gratitude to the supporters of this work.

About Global Cooling Efficiency Accelerator

The Global Cooling Efficiency Accelerator is a coalition of scientists and cooling experts working to establish the necessary preconditions and scientific data-based evidence to pave the way for bringing super-efficient air conditioners (ACs) to the marketplace. The Global Cooling Efficiency Accelerator consists of partners with deep technical and policy expertise and brings together policymakers, manufacturers, industry and market experts, and buyers to shape the market for commercialization and adoption of super-efficient ACs.

About RMI

Rocky Mountain Institute (RMI) is an independent, nonpartisan nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to secure a prosperous, resilient, clean energy future for all. In collaboration with businesses, policymakers, funders, communities, and other partners, RMI drives investment to scale clean energy solutions, reduce energy waste, and boost access to affordable clean energy in ways that enhance security, strengthen the economy, and improve people's livelihoods. RMI is active in over 60 countries.

Table of Contents

Executive Summary

Record-breaking temperatures, rapid urbanization, and a growing middle class are creating a significant increase in demand for air conditioning. Currently, space cooling accounts for nearly 20% of global building electricity use worldwide,[1] and it is projected to be the second largest single-use driver of electricity demand growth between 2023 and the end of the decade (only behind electric vehicles).[2] Adopting today's air conditioning systems worldwide would create enormous stress on the grid and generate more than 100 gigatons of CO_2 equivalent emissions by 2050 — more than double today's annual global emissions.[3] Addressing this challenge is a matter of human health, comfort, and equity, and is crucial for our ability to adapt to the changing climate.

Nowhere is this challenge — and opportunity — more pronounced than in India. Already the world's fastest-growing air conditioning market, India is projected to have over 1 billion room air conditioners (ACs) in operation by 2050, increasing its electricity demand for cooling ninefold compared with 2022. Widespread adoption of current AC technology could jeopardize both the power grid and the environment. Therefore, India has an urgent need and a great opportunity to be a pioneer in the innovation of cooling technologies.

In 2021, the Global Cooling Prize — an innovation challenge focused on identifying the best possible residential cooling technology — successfully demonstrated prototypes that had a five times lower climate impact than typical units in the market and delivered greater comfort at a significantly lower life-cycle cost. This is possible through ACs that use highly efficient components, are optimized for managing humidity, and incorporate low global warming potential refrigerants. These super-efficient ACs use many-times less energy than conventional products and have the potential to substantially reduce peak demand and neutralize the climate impacts of the exponential air-conditioner growth anticipated across the globe.

However, the limitations of current testing standards in measuring real-world AC performance — particularly in relation to measuring performance in dealing with humidity — leaves a major opportunity for efficiency improvements. And to improve the visibility of super-efficient ACs, it is critical that standards are revised to measure key performance indicators of real-world operation.

Therefore, in 2022, a broad-based coalition of scientists and cooling experts — the Global Cooling Efficiency Accelerator (GCEA) — was founded to build a pathway to support the commercialization of super-efficient ACs. The group initiated the work in partnership with CEPT University, India, to help develop an AC test methodology and performance metric that accurately reflects the real-world performance of room ACs.

Additionally, in October 2023, the GCEA, in collaboration with Lodha, one of India's largest real-estate developers, began nine-month field testing of ACs in Palava City near Mumbai, India.[i] The testing was led by a team of scientists and experts from CEPT University, India and RMI. This location was chosen due to its warm and humid climate, conditions experienced by a large percentage of India's population. This climate poses specific challenges for ACs in managing both temperature and humidity. We tested seven AC units from

---

i Palava City — a greenfield development near Mumbai — serves as a "living laboratory" for the Net Zero Urban Accelerator, a partnership between Lodha and RMI India, to test and implement sustainable urban solutions at a city scale, aiming for a net-positive environmental impact. See **https://www.lodhagroup.com/blogs/sustainability/palava-city-blueprint-for-sustainable-urban-living-in-india**.

market-available typical and high-efficiency room AC models to super-efficient room AC prototypes that are optimized for real-world conditions and can manage humidity efficiently.[ii]

The testing compared the difference in performance between super-efficient AC prototypes and market-available ACs when operated in the real world. The tested units were required to achieve a target temperature of 27°C and 60% relative humidity. The field testing also established the limitations of the current testing standard and highlighted how units that are optimized to achieve higher performance rating have much higher energy use in the field than what is predicted by these standards today. The testing proved that adopting super-efficient ACs will enhance occupant comfort, decrease energy usage, reduce peak demand, and lower greenhouse gas emissions.

This report presents the key findings from the field testing.

- **Super-efficient ACs used 60% less energy** than a typical AC in real-world testing conditions over the nine-month testing period. Unlike typical ACs, the super-efficient ACs were able to consistently achieve the target temperature and relative humidity conditions for optimal comfort.
- **The current testing standard underestimates the real-world energy use of ACs**, especially in warm and humid climates. This is largely due to **extra energy used by typical ACs to control humidity, which is not measured by today's test method or reflected in AC performance metrics**. Our testing, including a full-year lab simulated test, validated that **up to 25% more energy is used just to manage humidity** in typical AC units.
- **Super-efficient ACs reduce peak electricity demand by 50%** compared with typical ACs, helping prevent power outages by lowering stress on the grid and avoiding the need for costly infrastructure upgrades to meet peak demand.
- **Super-efficient ACs represent a step-change in efficiency,** and in combination with the use of low global warming potential refrigerants, they have a **4.9 times lower climate impact** (compared to the Global Cooling Prize baseline unit), proving that the five-times-lower climate impact goal set by the Global Cooling Prize is well within reach.
- Over their lifetime, **super-efficient ACs can save consumers over 50% on energy bills**. This leads to a substantially lower total cost of ownership compared with typical ACs.

Allowing super-efficient ACs to successfully commercialize and access the market could reduce India's peak load by approximately 400 gigawatts in the year 2050 — equivalent to India's total installed power capacity today. This would significantly reduce pressure on power grids, save US$380 billion in new infrastructure investments, and support India's climate goals.

---

ii In this report, a typical AC is defined as the one most commonly used for residential cooling — a 1.5 tons of refrigeration (TR) inverter AC with an Indian Seasonal Energy Efficiency Ratio (or ISEER) corresponding to a three-star label (ISEER 3.8–4.3) sold in the Indian market in 2023. A high-efficiency AC is a 1.5 TR inverter AC with an ISEER corresponding to a five-star label (ISEER 5.0 and above) sold in the Indian market in 2023. The Global Cooling Prize baseline unit was the most common unit in the Indian market in 2017 — a 1.5 TR fixed-speed AC unit slightly less efficient than today's typical AC.

But this impact is not just limited to India — super-efficient ACs also present an opportunity to change the trajectory of global energy use and emissions. Globally, deploying super-efficient ACs for the 3 billion more ACs expected to be installed worldwide by 2050 would avoid 68 gigatons of cumulative emissions — more than current annual global emissions.

However, this transformation will require government leaders, policymakers, manufacturers, and large buyers to unite and demonstrate their leadership at this critical juncture to drive change. By setting new test standards and performance rating systems, fostering market demand, and taking actions to improve affordability, India can unlock the potential of super-efficient ACs. These actions are key to improving lives, strengthening grid resilience, and addressing the climate crisis.

This report is intended to raise the awareness of key stakeholders — such as government leaders, policymakers, AC manufacturers and industry players, and financial institutions — and garner their support for the development, commercialization, and adoption of super-efficient ACs in India and globally.

Introduction: The Cooling Challenge

With 2024 now the warmest year on record, cooling has become a defining issue of our time.[4] Record-setting temperatures coupled with rapid urbanization and a warming planet mean significantly greater demand for indoor cooling globally, particularly in cities. Without concerted action, by 2030, 4 billion people (almost 50% percent of the projected global population) will be exposed to deadly heat conditions, mostly in low-income and lower-middle-income countries. Extreme heat also creates enormous financial hardship. By 2030, the accumulated global financial loss due to heat stress is expected to reach **US$2.4 trillion**.[5]

Access to cooling is critical for human health, education, productivity, and economic development. But current cooling technologies come with a significant environmental cost. Space cooling already accounts for nearly 20% of building electricity use worldwide,[6] and is projected to be the second largest single-use driver of electricity growth between 2023 and 2030.[7] RMI analysis indicates that global adoption of today's air conditioners (ACs) would contribute over 100 gigatons of CO_2 equivalent emissions by 2050 — more than twice current worldwide emissions.[8]

ACs primarily cool the air through "sensible cooling," which lowers the air temperature. To a lesser extent ACs also dehumidify the air in a process called latent cooling. However, today's ACs are primarily designed to manage temperature, not humidity, and their dehumidification capabilities are limited. Most of an AC's energy input goes toward sensible cooling, leaving very little energy available for latent cooling. This energy allocation is largely fixed, leaving users little control over improving the balance between cooling and dehumidification. As a result, today's ACs are inefficient at managing humidity, leading to either discomfort or high energy bills for people in hot humid climates.

In India, the world's fastest-growing AC market, this issue is especially pressing due to the large population living in warm and humid zones. A room AC with the lowest first cost is increasingly the choice for many urban consumers due to the affordability and ease of maintenance; however, these are also the most inefficient units when it comes to providing cooling and dehumidification. Many of these units also rely on refrigerants with high global warming potential (GWP), contributing to further environmental harm.

When ACs fail to manage humidity, users tend to overrun the AC and overcool the room to achieve comfort. This results in significantly more energy consumption, straining electricity grids and increasing costs for customers. Current AC testing standards do not capture this excess energy use when rating ACs for efficiency. So, while consumers seek to make conscious, cost-advantageous purchasing decisions by looking at the star label, they do not get accurate information on lifetime energy use and costs associated with today's AC products.[iii]

In 2024, India estimated record sales of approximately 14 million new AC units — a 30% increase from the previous year.[9] This growing AC demand will substantially contribute to peak electricity demand, which is projected to rise from the current 243 gigawatts (GW) to 366 GW by 2030.[10] The increased load, especially during peak hours, will require an investment of at least US$120 billion in new power plants and significant investments in grid infrastructure to prevent outages and maintain stability.[11] This surge in energy consumption not only poses a significant challenge to India's carbon neutrality goals set for 2070 but also escalates greenhouse gas (GHG) emissions and perpetuates a cycle of rising temperatures and increased cooling demand. **There is an urgent need, therefore, to greatly increase the efficiency of ACs.**

India is in a unique position to turn this challenge into an opportunity and lead the transition to next generation super-efficient air conditioning technologies. India has already demonstrated leadership by launching the India Cooling Action Plan in 2019 — the first comprehensive national strategy of its kind. The country has recognized that transforming the cooling sector is an economic, social, and environmental necessity. By advancing super-efficient air conditioning technologies, India has the potential to become a global leader in lower climate impact cooling while continuing its journey toward achieving carbon neutrality by 2070.

---

iii India's Bureau of Energy Efficiency implements a star rating system for air conditioners to promote energy efficiency. The rating, ranging from one to five stars, reflects the unit's energy consumption; higher ratings indicate better energy efficiency. The system is intended to help consumers make informed decisions while encouraging manufacturers to adopt more energy-efficient technologies.

Laying the Groundwork for Super-Efficient ACs

The Global Cooling Prize

Recognizing the growing demand for cooling — and the need to meet this demand while reducing grid stress and neutralizing emissions — RMI, in partnership with India's Department of Science and Technology and Mission Innovation, launched the Global Cooling Prize (the Prize). The goal was to identify residential cooling technology that can provide comfort in hot and humid conditions while achieving a five-times-lower climate impact — through a combination of electricity reduction and refrigerant GWP reduction, using assigned weighting of 80% and 20%, respectively — than most typical products sold on the market in India in late 2017.

The Prize received an overwhelming response from startups, universities, research labs, major industry players, and AC manufacturers worldwide. In April 2021, two global AC manufacturers emerged as the winners of the Prize; each manufacturer developed a prototype that exceeded the five-times-lower climate impact criteria, as demonstrated through extensive testing within an actual apartment building and through testing in a lab by simulating conditions that people would experience over a full year in India.

The winning solutions exceeded the five-times-lower climate impact criteria through smart design and high-efficiency components. They designed compressors that adjust to low cooling needs, improved coil design to better manage sensible and latent cooling loads in the space, and added advanced sensors and control algorithms to sense these loads and optimize the coil operation to ensure efficient dehumidification and achieve target indoor conditions (i.e., at or below 27°C and 60% relative humidity). And they did all this while using refrigerants with a low GWP. These innovations ensured the solutions consumed dramatically less energy, lowered lifetime cost of ownership, and had significantly lower life-cycle emissions.

RMI calculated that if by 2040 nearly all the units sold globally met the contest parameters, the technology could prevent up to half a degree Celsius of global warming by the end of the century.[12] In India, the commercialization and wide adoption of the winning AC technologies could reduce the country's estimated peak loads by around 400 GW and avoid 16 gigatons of GHG emissions by 2050. This would significantly reduce pressure on power grids, save US$380 billion in new infrastructure investments, and support India's climate goals.[13]

The Global Cooling Efficiency Accelerator

While the Prize successfully demonstrated that next-generation ACs with five-times-lower climate impact than typical products are technically possible, it was clear that much work is needed to bring these solutions to the market and jump-start their sales.

The Indian government, through the Bureau of Energy Efficiency and with the AC industry's support, has made notable progress over the years to improve efficiency levels. The energy efficiency ratings have been ratcheted up regularly and efforts have been made to advance the market toward adoption of inverter ACs. However, as the demand for ACs in the country grows exponentially, switching entirely to today's high-

efficiency ACs (corresponding to the five-star label available in the market) will not be sufficient to reduce the grid stress and neutralize the climate impacts.

Fortunately, the AC industry is increasingly aligned with the goal of stepping up efficiency. This is India's moment to lead the way in producing affordable super-efficient ACs and bringing them to millions of homes both domestically and globally. By doing so, India can set the global standard for lower climate impact, high-efficiency cooling technologies.

Recognizing this opportunity and building off the learnings and the promise of super-efficient AC technologies demonstrated through the Prize, the Global Cooling Efficiency Accelerator (GCEA) was launched. The GCEA, which includes a broad base of partners with deep technical and policy expertise and industry know-how, is working to establish the necessary preconditions and scientific data-based evidence to pave the way for bringing super-efficient ACs to the marketplace.

GCEA identified four intervention areas necessary to make super-efficient ACs a market reality:

1. **Update AC performance metrics and testing standards** to accurately characterize the real-world performance of super-efficient ACs. This involves:

    - Identifying the gap in current testing standards through scientific experiments and measured data. This means highlighting the additional energy use for overcooling due to inefficient dehumidification and making a case for incorporating it in standards.

    - Updating the test methodology and performance metric to be adopted by standard-setting bodies and policymakers. This means recognizing efficient dehumidification performance in future standards and performance rating systems.

2. **Partner with the AC industry ecosystem** — including manufacturers, industry associations, and supply chain actors. It is crucial that multiple manufacturers design and develop products that are optimized for real-world conditions.

    - GCEA offers vital testing support and actionable feedback to accelerate the development, production, and commercialization of super-efficient ACs. Additionally, GCEA collaborates with the experts and industry players and garners their support for updates to AC performance metrics and testing standards.

3. **Undertake real-world demonstrations to gather performance data, generate evidence, and build market confidence in super-efficient ACs.** Data and insights from these demonstrations, along with lab testing, support updates to testing standards and the design of market instruments, all of which would facilitate the initial uptake of super-efficient AC products.

    - GCEA engages with the buyer community to generate critical evidence and insights on energy savings and peak load reduction benefits of super-efficient ACs at scale, which is key to building consumer and policymaker confidence and helping secure future demand signals for these products.

4. **Raise consumer awareness** to help end-users understand that operating ACs that fail to manage humidity effectively can lead to discomfort and health issues all while increasing their energy bills due to the need for overcooling. This awareness is also essential for policymakers and key market actors — namely, those responsible for policies that shape the industry's future. These decision makers ultimately shape the market's approach to cooling.

    - To support these efforts, GCEA actively conducts outreach to engage stakeholders, ensuring they are informed and supportive of the necessary changes needed for super-efficient ACs to successfully access the market.

The rest of this report discusses GCEA's work on real-world demonstration. Since the Prize concluded four years ago, the Indian market has evolved significantly. While the Prize initially used a fixed-speed AC as the baseline, the industry has shifted to inverter ACs, which feature a variable-speed compressor. A nine-month field test was conducted in Palava, India — a region that typically experiences a warm and humid climate — with three primary goals: (1) to reinforce the performance benefits of super-efficient ACs against today's typical ACs or the current baseline (i.e., inverter ACs); (2) to generate rigorous evidence to update AC performance metrics and testing standards; and (3) to demonstrate to market actors and policymakers that super-efficient ACs are technically feasible, scalable, and can become commercially viable with the right market mechanisms.

Field Testing of Super-Efficient ACs

In 2023, GCEA partnered with Lodha, one of India's largest real-estate developers, to conduct field testing of room ACs in Palava, India. The testing was led by a team of scientists and experts from RMI and CEPT University, India. The study, which spanned nine months, compared the real-world performance of super-efficient AC prototypes against room ACs sold in the Indian market today.

Testing methodology

The field testing was conducted from October 2023 to June 2024. The testing methodology involved the installation of AC units in residential apartment homes, but without occupants, to ensure a controlled comparison of performance under real-world conditions. The study compared the real-life performance of super-efficient AC prototypes with market-available ACs that were installed and tested concurrently and continuously, ensuring that they operated under similar conditions during the testing period.

The apartments used in the study were carefully selected to have identical sizes along with similar envelope characteristics and solar heat gain profiles, allowing for an accurate assessment of performance of the selected AC units. Internal load profiles were simulated based on typical daily sensible and latent gains observed in a home, incorporating factors such as lighting, appliances, and occupants. Electric resistance and humidifiers were used to replicate real-world conditions.

The testing was conducted on seven AC units — two Prize baseline units, one typical AC (three-star, inverter AC), two high-efficiency ACs (five-star, inverter AC), and two super-efficient AC prototypes. The AC units were assessed for their ability to achieve both indoor temperature control (at or below 27°C) and relative humidity management (at or below 60%) in alignment with thermal comfort conditions under the ASHRAE 55 standard.[iv] Exhibit 1 shows pictures from the field-testing site.

---

iv Indoor conditions of at or below 27° and 60% relative humidity are in alignment with thermal comfort conditions under the ASHRAE 55 standard, "Thermal Environmental Conditions for Human Occupancy." The standard specifies the combinations of reasonable indoor environmental factors (air temperature and relative humidity) and personal factors (metabolic rate and clothing level) to achieve acceptable thermal comfort for occupants in buildings.

Exhibit 1

Test setup in apartment units selected for field testing in Palava, India

RMI Graphic

Testing conditions

The testing period saw a wide range of outside air temperatures and humidity levels, with outdoor temperatures (dry-bulb or air temperature) varying between 16.5°C and 40.8°C and relative humidity levels fluctuating between 20.3% and 90%. Exhibit 2 shows the breakdown of the weather conditions for each group of air temperature and relative humidity in 15-minute intervals throughout the field-testing period.

An approximately three-month equivalent of the testing period coincided with India's warmest and most humid climate; this corresponded to temperatures between 24°C and 33°C and relative humidity between 60% and 90%, typically observed between June and September. These conditions were needed to reinforce

the critical role of humidity control in AC performance. Such conditions are commonplace today even outside India, especially for AC users living in a warm and humid place such as Singapore or Florida in the United States.

By ensuring that the AC units operated under such diverse climatic conditions, the study was able to assess and compare their effectiveness in delivering cooling comfort.

Exhibit 2

Outdoor air temperature and relative humidity during the testing period (recorded in 15-minute intervals)

Relative humidity (%)	Dry bulb temperature (°C)							
	<21	21-24	24-27	27-30	30-33	33-36	36-39	39-42
20-29		10	34	62	114	153	11	
30-39	94	276	435	302	167	105	119	71
40-49	426	718	1,051	1,777	2,396	1,829	241	
50-59	555	1,112	1,526	1,404	960	282	2	
60-69	434	1,355	**1,539***	**1,429***	**473***			
70-79	26	410	**1,040***	**1,504***	**24***			
80-89		197	**1,877***	**182***				
90-100		8	54					

*Temperatures and relative humidity coinciding with the three-month period coinciding with India's warmest and most-humid climate.

RMI Graphic. Source: RMI analysis

Testing units

Baseline unit (typical AC)

We compared the performance of the super-efficient AC prototypes against the typical ACs. In this context, this refers to a 1.5 ton of refrigeration (TR) inverter AC with an Indian Seasonal Energy Efficiency Ratio (or ISEER) corresponding to a three-star label (ISEER 3.8–4.3) sold in the Indian market in 2023 (hereafter referred to as "typical AC"). The 1.5 TR, three-star inverter ACs are the most commonly sold AC products in India today with two-thirds of the market share. The typical AC unit was operated to control indoor conditions via internal controls at a setpoint of 27°C, with no overcooling to achieve the desired indoor relative humidity conditions.

In addition to the typical AC, we also (re)tested the Prize baseline unit, which was a fixed-speed, single-split-type room AC unit with an ISEER of 3.5 that used R22 refrigerant. Throughout the testing period we operated two of the Prize baseline units. One was operated to control indoor conditions with internal

controls with a setpoint of 27°C; and the second was operated to control indoor conditions with an external thermostat to adjust the setpoint to maintain both indoor temperature and relative humidity conditions (at or below 27°C and 60% relative humidity). Simply put, the second Prize baseline unit was externally controlled to overcool the indoor space to ensure it always achieved the target relative humidity conditions.

Super-efficient AC

Both Prize winners supported the field testing by providing super-efficient AC prototypes inspired by the winning Prize technologies. The units integrated smart design and high-efficiency components to deliver breakthrough performance. This included compressors that adjusted to low cooling needs, improved coil design to better manage sensible and latent cooling loads in the space, and advanced sensors and control algorithms to sense these loads and optimize the coil operation to ensure efficient dehumidification and achieve target indoor conditions (i.e., at or below 27°C and 60% relative humidity). At the same time, these second-generation prototypes eliminated some of the high-cost components from the first-generation winning prototype designs that had a limited impact on performance as assessed through Prize testing; however, it is not expected that these changes will result in a material reduction in the first cost of these super-efficient AC prototypes.

Additionally, while the benchmark refrigerants used in the winning Prize technologies — R1234ze and R152a — helped achieve a five-times-lower climate impact, the super-efficient prototypes tested in this field testing used R32 and R152a as refrigerants. We anticipate that the choice of refrigerant in the early stages of super-efficient AC technology will be driven by national regulations and commercial availability in individual markets. In the short-to-medium term in India, R32 is likely to be the refrigerant of choice due to its proven performance, reliability, and wide acceptability, making commercializing super-efficient ACs with this refrigerant a viable option. We may also see the adoption of hydrocarbons like R290, as its use has been demonstrated in the Indian market.

For the purposes of this report, we present the performance of the super-efficient prototypes in aggregate.

Testing results

Performance of super-efficient ACs against key criteria

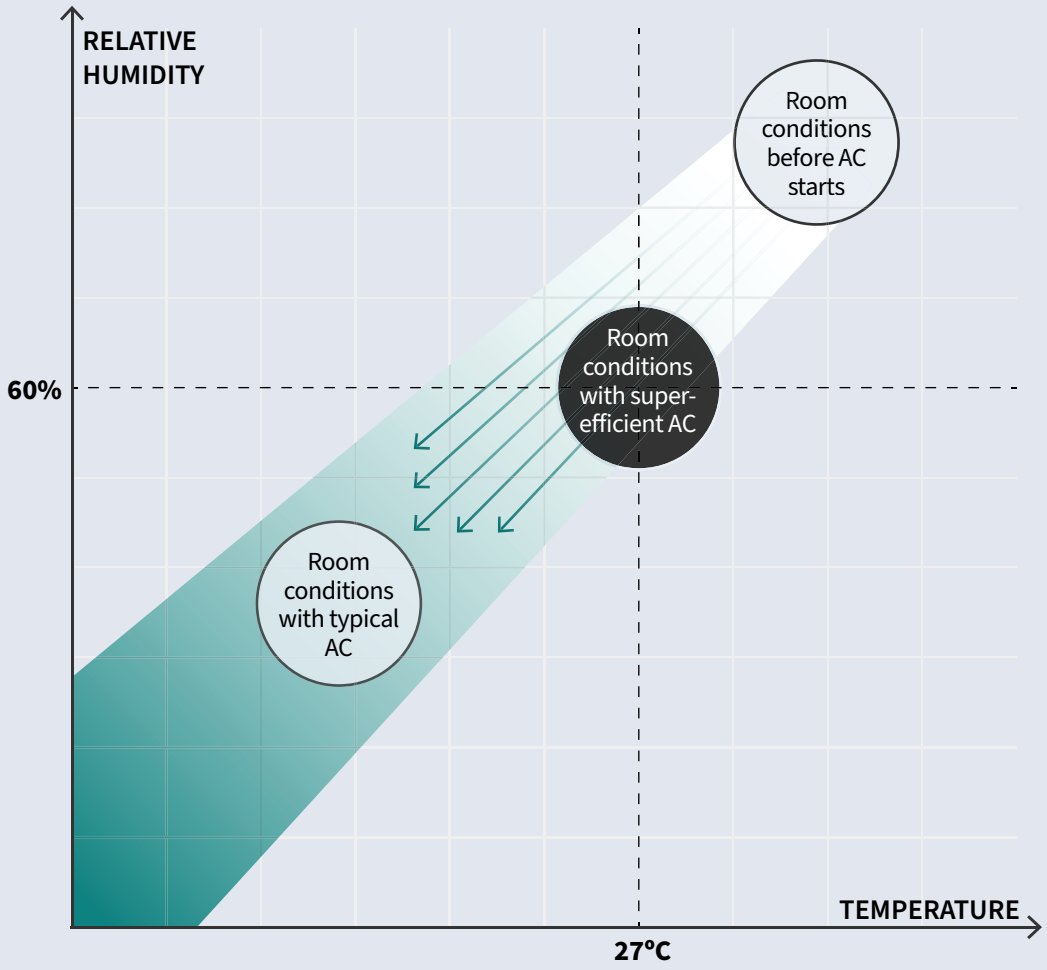
Throughout the testing period, the super-efficient AC prototypes showed that they were able to handle sensible and latent cooling loads and achieve occupant comfort conditions much more efficiently than the Prize baseline unit, typical AC unit, and other high-efficiency market-available ACs. Sensible cooling loads refer to the loads that result from the difference in temperature between the indoor and outdoor environment; latent cooling loads are the loads that result from change in moisture (or humidity) in the space.

Electricity Consumption. Super-efficient ACs used 60% less energy than a typical AC over the nine-month testing period. This represents a scenario where both super-efficient and typical ACs were operated to achieve target indoor comfort conditions at or below 27°C and 60% relative humidity. To achieve target comfort conditions, particularly in warm and humid climates or in spaces where indoor humidity is high, it is common to turn down the thermostat or the AC setpoint significantly to manage humidity in the air. This results in “overcooling” of the air and consequently significantly higher energy consumption. Therefore, one of the Prize baseline units was externally controlled to overcool the space to more closely simulate real-world conditions. This data was then used to estimate the additional energy consumption associated with overcooling in a typical AC (see Exhibit 3).

Exhibit 3

Energy use and cooling strategy of a typical AC versus a super-efficient AC

Although modern ACs are highly effective at cooling, they often fall short in terms of managing humidity, a crucial factor in comfort. Many users compensate for this by lowering the thermostat to manage humidity levels, thus overcooling their space and leading to discomfort and excess energy consumption. This issue even occurs with the high-efficiency ACs currently available on the market. While the AC industry has made significant strides to improve efficiency in managing temperature, less attention has been paid to managing humidity. Focusing on both temperature and humidity could result in significant energy savings and improved comfort.



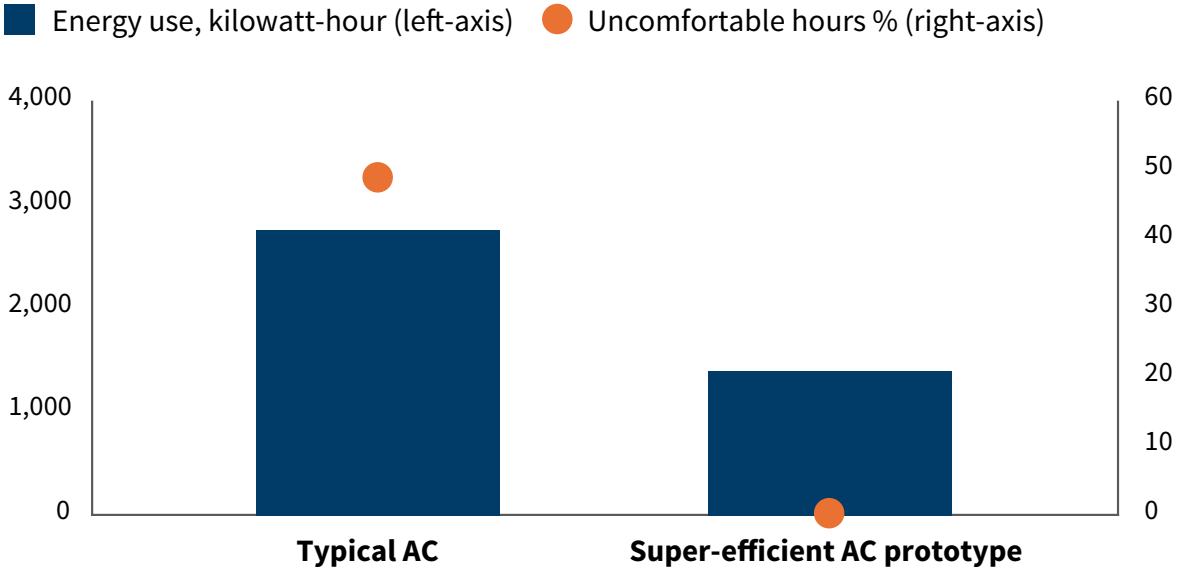
Typical ACs use extra energy to achieve the target condition of 60% humidity, leading to overcooling the space past the target condition of 27°C.

RMI Graphic. Source: RMI analysis

When the typical AC is operated using its internal controls and there is no overcooling, the super-efficient AC still used 50% less energy than the typical AC. But in this scenario, the typical AC does not achieve the targeted relative humidity level (at or below 60%) during several hours of its operation, leading to what we define as "uncomfortable hours." The super-efficient AC, in contrast, had zero uncomfortable hours (see Exhibit 4).

Exhibit 4

Energy use and uncomfortable hours (%) of ACs during nine-month field testing



Note: Energy use does not account for the energy impact due to overcooling.
RMI Graphic. Source: RMI analysis

We also compared the performance of the super-efficient AC against a sample of high-efficiency ACs available in India today. The testing revealed that the super-efficient AC, on average, used 30% less energy than the high-efficiency AC. The high-efficiency AC had a similar fraction of uncomfortable hours as the typical AC.

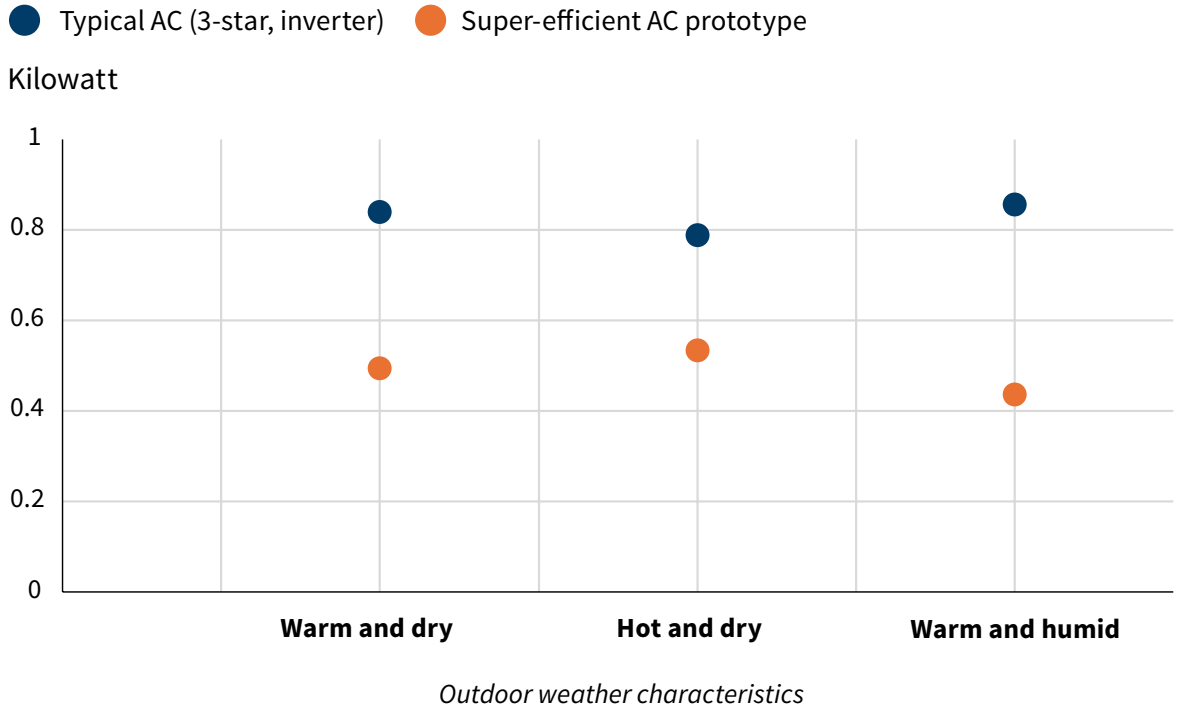
The field testing thus confirmed the fundamental challenge with today's AC units — namely, that ACs (including typical and high-efficiency models available on the market) are designed to meet only the temperature setpoint and do not adjust their operation to control indoor relative humidity. While overcooling the space by lowering the temperature setpoint — a common practice among users of most AC units — can reduce discomfort from high humidity, it leads to a significant increase in energy consumption.

Building on this, when comparing the performance of ACs based on the current testing standard followed in India, we identified that the standard underestimates the real-world energy use of ACs, especially in warm and humid climates. This is largely due to extra energy used by typical ACs to control humidity, which is not measured by today's test method or reflected in AC performance metrics. Our testing, including a full-year lab simulated test, validated that up to 25% more energy is used just to manage humidity in typical AC units. In short, it highlights the fact that the AC performance metrics and testing standards are not aligned with real-world operation; in particular, they are inadequate in assessing dehumidification performance (or ability to remove moisture efficiently).

Peak Demand. Super-efficient ACs significantly reduce peak demand due to their high-efficiency components and effective dehumidification capabilities. Their peak power draw is **up to 50% less than the typical AC**, particularly on warm and humid days. This significantly alleviates stress on the electrical grid and lowers the risk of blackouts, particularly during high-demand periods (see Exhibit 5). This translates to significant cost savings for the government on new grid infrastructure — savings that can be used for other social and developmental priorities — while ensuring the cooling needs of the population are met.

Exhibit 5

Peak power draw of a super-efficient AC versus a typical AC for the field-testing period



Note: Testing period included warm and dry, hot and dry, and warm and humid days. The data shows up to a 50% reduction in peak demand.

RMI Graphic. Source: RMI analysis

Climate Impact. The substantially reduced electricity consumption of super-efficient ACs, combined with the use of low-GWP refrigerants, results in a dramatically lower climate impact and a significant reduction in GHG emissions over the AC's lifetime. In the context of the Prize's technical criteria, the winning solutions — which used very low-GWP refrigerants — reduced the climate impact by five times compared with the Prize baseline unit. While R32 is likely to be the refrigerant of choice for commercializing super-efficient ACs in the short to medium term, a future transition to ultralow-GWP refrigerants (including natural refrigerants like R290) is possible.

To evaluate the climate impact reduction of super-efficient ACs and where they stand compared with the winning Prize solutions, we compared a super-efficient AC's performance with the Prize baseline unit during field testing, in addition to the typical AC. The climate impact of a super-efficient AC was calculated

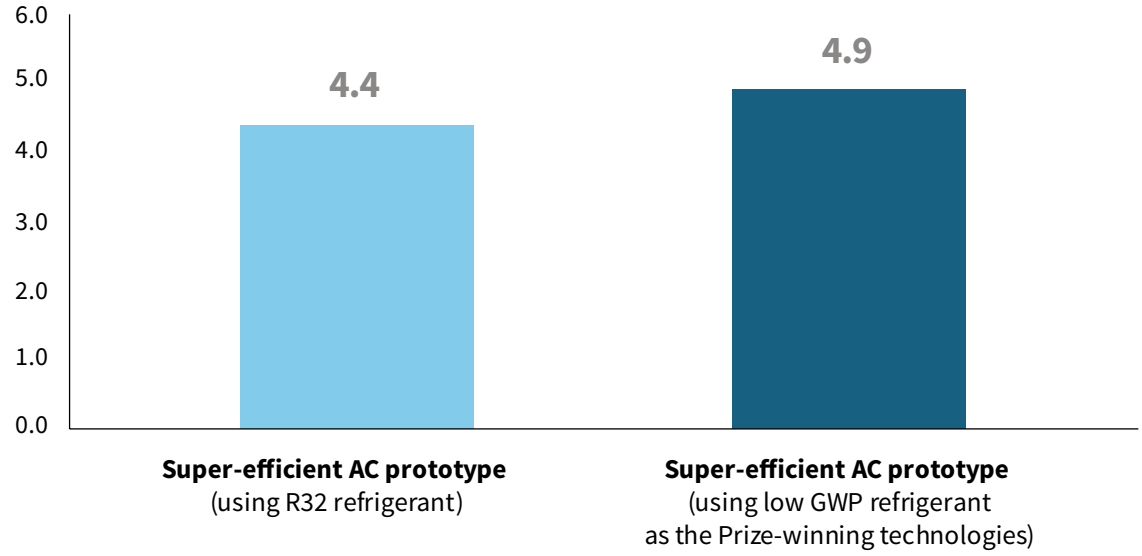
by combining the electricity reduction and refrigerant GWP reduction, using a weighting of 80% for electricity reduction and 20% for refrigerant GWP reduction, relative to the Prize baseline unit.

The testing revealed that the super-efficient AC used 72% less energy overall relative to the Prize baseline unit (factoring in the additional energy use of overcooling to achieve desired humidity levels). Combined with the GWP of R32 refrigerant, it still achieved a 4.4-times-lower climate impact relative to the Prize baseline. However, when normalized for refrigerant GWP of the winning Prize solutions, the super-efficient AC achieved a 4.9-times-lower climate impact relative to the Prize baseline (see Exhibit 6). When compared with high-efficiency ACs available in India today, the climate impact reduction of the super-efficient AC using R32 refrigerant is 2.4 times (or 50% less).

These performance insights suggest that super-efficient ACs are capable of reaching the five-times-lower climate impact target (as demonstrated by the winning Prize units), likely making that target a reality in the future.

Exhibit 6

Lower climate impact of a super-efficient AC, relative to Prize baseline unit, combining energy use reduction and refrigerant GWP



RMI Graphic. Source: RMI analysis

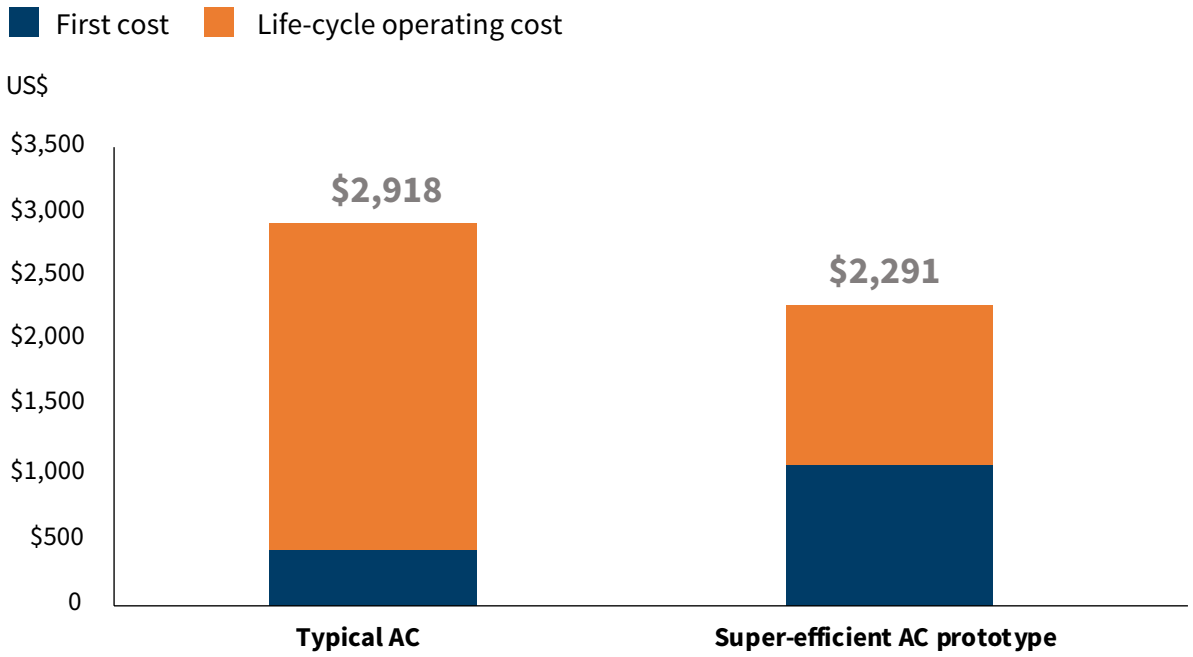
Total Cost of Ownership. When evaluating the total cost of ownership or payback period for super-efficient ACs, it is essential to consider both the first cost (sticker price) and the operating costs over their lifetime. Because super-efficient AC products are not yet commercially available, multiple factors could influence their first cost. These factors include procurement volumes, warranties, brand, and specific buyer requirements. Pricing is typically negotiated between the buyer and manufacturer or supplier based on these variables. Therefore, each buyer should conduct an economic analysis tailored to their specific situation. It is crucial for buyers to perform a thorough analysis, considering all relevant factors, to make informed procurement decisions.

It is also important to note that, in the Indian market (but mostly true worldwide), demand for ACs in the residential sector is traditionally driven by low first cost, which has led the industry to focus on high

volumes of sales through lower-priced models. In contrast, super-efficient ACs — when they become commercially available — are expected to carry a premium when first introduced to the market. However, the field testing demonstrated that adopting a super-efficient AC results in a substantially lower total cost of ownership over the appliance's lifetime for the consumers. Based on the learnings through extensive lab and field testing as well as consultations with experts from industry, our analysis reveals that even at a first cost of two times the average sticker price of today's high-efficiency AC in India, the substantial lifetime operating cost savings of super-efficient ACs, projected to exceed 50% as seen in Exhibit 7, will support a target simple payback period of less than four years.

Exhibit 7

Projected lifetime cost of a typical AC and a super-efficient AC, accounting for first cost and operating costs associated with electricity bills



Note: Key assumptions include AC lifetime of 10 years; average residential electricity tariff of INR 10 (US$0.12) per kilowatt-hour and increase at 4% per year; and total operating hours of 5,774 based on ISEER standard for temperature greater than 24°C, which is indicative of when AC is typically expected to operate.

RMI Graphic. Source: RMI analysis

Super-efficient ACs can provide significant cost savings for consumers through reduced electricity bills and for the Indian government through avoided investments in new grid infrastructure to meet the growing demand for cooling. The government can support development and production as well as incentivize adoption of super-efficient ACs by channeling the savings from avoided grid investments to lower the first cost for consumers. Our analysis indicates that, even in typical Indian cities with limited AC usage, super-efficient ACs can reduce energy consumption for consumers by more than 50%. Leveraging grid investment savings and employing innovative financing mechanisms like bulk procurement — proven to lower costs by up to 30%[14] — as well as demand aggregation, manufacturers commitments, and updated testing standards, create a pathway to reduce first cost of super-efficient ACs, making them more affordable and delivering favorable returns on investment for users.

The Path Forward

The nine-month field testing conducted by GCEA clearly demonstrated the significant energy savings, reduction in peak demand, and lower energy bills and life-cycle emissions achieved by super-efficient ACs. India's rapidly growing demand for AC makes the need for such solutions not just urgent, but essential. Scaling these solutions has the potential to transform not only India's economy and its citizens' lives, but also the global market.

Advancing super-efficient ACs from the prototype stage and bringing them closer to commercialization requires a deep collaboration among several market actors. To bridge this gap, GCEA calls on government leaders, policymakers, manufacturers, and large buyers to unite and demonstrate their leadership at this critical juncture in the fight against climate change:

1. **Policymakers responsible for writing testing standards and designing labeling programs have a key role to play in prioritizing revision of AC performance metrics and testing standards that support production of super-efficient ACs.** This will help bring innovative technologies to bear and guide consumer choices.

2. **Large buyers can play a key role as anchor buyers to spur market demand for super-efficient ACs.** Relevant stakeholders within their organizations — procurement teams, engineers, contractors, and consultants — should prioritize products that reduce energy use, lower total cost of ownership, cut life-cycle emissions, and enhance comfort, rather than focusing solely on current performance metrics that are inadequate.

3. **AC manufacturers are encouraged to commit to developing and commercializing cost-effective super-efficient AC products.** This should be done in parallel with supportive policies and market signals that enable manufacturers to continue their product development.

4. **Governments can explore innovative strategies, including tax concessions, to boost the supply ecosystem, and support financial mechanisms, such as rebates and low-interest loans, to accelerate the market shift toward super-efficient ACs.**

This is India's moment to lead the way in producing affordable super-efficient ACs, ensuring they reach millions of homes both domestically and around the world. To accelerate the market transition and make these solutions accessible, all stakeholders must come together and take bold, decisive action. With rising urbanization, increasing incomes, and growing heat, the urgency of shifting to super-efficient ACs has never been greater. The enormous economic, grid resilience, and climate benefits India and the world stand to gain from commercializing this technology and making it accessible to people is clear. By doing so, we can provide access to cooling for all, without further warming the planet.

Endnotes

1 *The Future of Cooling,* IEA, 2018, **https://www.iea.org/reports/the-future-of-cooling**.

2 "Air Conditioning to Be Major Driver of Electricity Demand, Says IEA," *Financial Times*, October 12, 2024, **https://www.ft.com/content/de175bfd-aaf1-4adc-b4b5-3e9973aed522**.

3 Iain Campbell, Ankit Kalanki, and Sneha Sachar, *Solving the Global Cooling Challenge: How to Counter the Climate Threat from Room Air Conditioners,* RMI, 2018, **https://rmi.org/wp-content/uploads/2018/11/Global_Cooling_Challenge_Report_2018.pdf**.

4 *Temperatures Rising: NASA Confirms 2024 Warmest Year on Record,* NASA, 2024, **https://www.nasa.gov/news-release/temperatures-rising-nasa-confirms-2024-warmest-year-on-record**.

5 *Heat Stress and Climate Change: An Urgent Challenge for Workers and Employers,* ILO, 2021, **https://www.ilo.org/global/topics/working-conditions/heat-stress/lang--en/index.htm**.

6 *The Future of Cooling,* 2018.

7 "Air Conditioning to Be Major Driver of Electricity Demand, Says IEA," 2024.

8 Campbell, *Solving the Global Cooling Challenge,* 2018.

9 "AC Sales May Touch New Record of 14 Million Units Annual Sales in 2024: CEAMA," *Economic Times*, June 6, 2024, **https://economictimes.indiatimes.com/industry/cons-products/electronics/ac-sales-may-touch-new-record-of-14-million-units-annual-sales-in-2024-ceama/articleshow/110768479.cms**.

10 Colin Tang, "India's Leapfrogging Energy Transition: Sustaining Economic Expansion, Enhancing Grid Reliability, Flexibility, and Achieving Net Zero Policy Goals," *Corinex*, February 12, 2024, **https://www.corinex.com/articles/india-leapfrogging-energy-transition**.

11 Elizabeth O'Grady and Saarthak Narsipur, "The AC Industry Conundrum: Cooling Is Warming the Planet, but Market Failures Are Preventing the AC Industry from Innovating," *RMI,* September 17, 2018, **https://rmi.org/ac-industry-conundrum/**.

12 Ankit Kalanki, Caroline Winslow, and Iain Campbell, *Global Cooling Prize: Solving the Cooling Dilemma*, RMI, 2021, **https://rmi.org/wp-content/uploads/dlm_uploads/2021/04/GlobalCoolingPrize_SolvingtheCoolingDilemma.pdf.**

13 "India's Cooling Challenge: The Unprecedented Opportunity to Save Energy and Money," *World Economic Forum*, May 15, 2019, **https://www.weforum.org/stories/2019/05/india-heat-cooling-challenge-temperature-air-conditioning/**.

14 1.5 TR Super Efficient 5 Star Split AC, Energy Efficiency Services Limited, **https://eeslmart.in/seac-15-tr**.

Ankit Kalanki, Yash Shukla, and Srilekhya Vennamaneni, *Bringing Super-Efficient Air Conditioners to the Market: Insights from field testing in India and the path forward*, RMI, 2025, **https://rmi.org/insight/bringing-super-efficient-air-conditioners-to-the-market**.

All images used are from iStock.com unless otherwise noted.

RMI Innovation Center
22830 Two Rivers Road
Basalt, CO 81621

www.rmi.org