Response-enabled room air conditioners:

A call to action on scaling demand

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Acronyms and abbreviations

BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
CO_2	carbon dioxide
CEMS	customer energy management systems
CEUD	critical energy use data
CPP	critical peak pricing
DOE	Department of Energy
DR	demand response
DR-RAC	demand response ready air conditioner
IEC	International Electrotechnical Commission
IoT	internet of things
LBNL	Lawrence Berkeley National Laboratory
LoRa	long-range radio frequency
PII	personally identifiable information
PMS	power management system
RAC	room air conditioners
RTP	real-time pricing
ToD	time-of-day
ToU	time of use

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Executive summary

A Call to Action on Scaling Demand Response–Enabled Room Air Conditioners (RAC)

HEAT STRESS IS DRIVING UNPRECEDENTED GROWTH IN AC OWNERSHIP

Air conditioners (AC) have emerged as an essential cooling solution due to rapidly rising heat stress. This is especially true in India, which is projected to become one of the largest contributors to global cooling demand. Only 8% of Indian households own a room air conditioner (RAC), but ownership levels are rising, with RAC sales growing by 12–17% annually.[1] Approximately 130–165 million RACs will be sold between 2025 and 2030, almost doubling India's existing stock.

GROWING RAC OWNERSHIP IS CAUSING ELECTRICITY DEMAND TO SURGE

Room air conditioners are projected to account for approximately 11% of India's annual peak demand by 2030. However, this figure understates their true impact. In dense urban areas such as Delhi and Mumbai, cooling already accounts for 40%–60% of the peak demand during hot summer days. This seasonal strain is likely to worsen with rising ownership and climate-induced heat extremes.

Under a business-as-usual trajectory, RACs could contribute up to 120 GW to national peak demand by 2030, representing nearly 30% of the projected total peak load.

Rising RAC ownership will also result in sharper peaks in the electricity load pattern. RAC-driven demand typically peaks between 18:30 and 19:30 IST and then again between 22:00 and 23:00 IST. During this time, overall residential demand is already high, and renewable energy such as solar power is largely unavailable.

Consequently, India's peak demand of 335 GW in 2030 will exceed 300 GW for only 88 hours in a year or roughly 1% of the time. Meeting these brief demand surges will require utilities to make major investments in power plants and grid infrastructure, which will divert investments away from other priorities such as decarbonization and expanding reliable power supply.

This rapid growth in cooling is already straining the power system. If left unattended, it will increase costs for consumers, reduce access to cooling, increase grid vulnerability, and undermine efforts to address the impact of a growing cooling load.[2]

DR-RAC IS A POWERFUL SOLUTION TO MANAGE PEAK DEMAND

Demand response (DR) is a set of technologies and methods that enable consumers to adjust their electricity load in response to grid conditions. It is widely recognized as an effective strategy to manage peak demand. Demand response initiatives—primarily targeting larger commercial and institutional loads—are already being explored and implemented in several countries.

By enabling DR in RACs, real-time demand response functions can be integrated into individual RACs. Demand response-enabled RACs can help reduce electricity use during peak demand periods in two ways:

- **shimmy,** which raises the RAC temperature setting for about 60 minutes
- **shed,** which turns off the unit for about 15 minutes

Both shimmy and shed initiatives cut energy use without compromising the RAC end-user's thermal comfort. In the short term, DR-RACs can ease grid congestion and prevent power outages. In the long term, they can be integrated into power systems planning as a reliable mechanism for managing peak load and reducing the need for new power infrastructure.

DR-RAC IS ALREADY TECHNICALLY AND COMMERCIALLY FEASIBLE

DR-RAC units will need to be equipped with communication modules (e.g., Wi-Fi or LoRa), sensors (for for controlling temperature, humidity, and power use), data recorders, and processors. These components will allow the RAC to record and transmit data about its settings, operations, and environment and receive and execute DR commands without the end-user's intervention.

The components required to integrate DR in a RAC are mature technologies. Many manufacturers are already selling smart RACs that offer several DR features, such as the ability to program dynamic settings or remotely control the unit through a digital mobile application or dashboard. Given that a range of smart RACs are already available on the market, manufacturers appear well-positioned to rapidly scale up the production of DR-RACs once the market is ready.

In India, where smart RACs currently constitute less than 2% of the market, the incremental costs of incorporating full DR functionalities into a base, bare-bones RAC could range up to $30. In markets where smart RACs are more widely available, such as in China, the incremental costs will be significantly lower. External companion sockets, which can be used to retrofit a traditional RAC to transform it into a smart device, are readily available for about $10 in several markets globally.

For demand response to be effective, utilities or DR operators must have a high level of confidence that DR-RACs will perform exactly as needed when required. The components currently used to create smart RACs will need to be marginally enhanced to provide additional reliability, redundancy, privacy, and safety. Even with these incremental enhancements, due to the widespread availability of smart RACs and the ubiquitous prevalence of the Internet of Things (IoT), the incremental costs for integrating DR in an RAC in India will likely remain at the lower end of the $10–$30 range.

The incremental cost of integrating DR in RACs will not be a barrier to their production or an additional burden for consumers. As DR-RAC production and IoT integration increases across appliances, DR-RACs are likely to become a regular product offering in India, with no discernible cost difference compared to units without these capabilities.

DR-RAC CAN REDUCE PEAK LOAD AND DELIVER SIGNIFICANT COST SAVINGS

Our analysis suggests that India will be market-ready for DR-RACs by 2028, with approximately 53–67 million units deployed by 2030. We assume that 27–37 million DR-RAC owners (or 50% of the total) will participate in DR programs, with each unit participating in 30 shed and 88 shimmy events annually. Such a DR program will reduce peak demand by 8–10 GW—equivalent to erasing the entire peak demand of Delhi in 2024—and save 563–709 GWh of electricity in 2030.

DR-RACs could potentially address all of India's power demand flexibility requirements. The Maharashtra Electricity Regulatory Commission, for example, introduced a demand flexibility portfolio obligation (DFPO) in 2024.[3] This requires utilities to meet a share of their peak demand through demand-side flexibility—starting at 1.5% of the previous year's peak demand in FY 2025–2026 and rising to 3.5% by FY 2029–2030. If similar targets are implemented nationally, demand flexibility requirements could reach approximately 11 GW[4] by 2030. DR-RACs can help avoid peak demand of 8–10 GW, or 70–90% of the national demand flexibility target, underscoring the large and critical role that DR-RACs could play.

These peak demand savings from DR-RACs could help avoid $12.8 billion in grid investments by 2030—equivalent to $473 per participating DR-RAC owner—which is enough to effectively offset the cost of the unit. These avoided costs could be used to fund customer incentives, ranging from $49 to $24 annually over 10 to 20 years, respectively.

If DR-RACs are made available in 2025 instead of 2028 as estimated above, the reduction in peak demand would approximately double to 16 GW in 2030. Avoided generation would increase almost fivefold to 2,719 GWh in 2030. Every year that DR-RACs are not readily available is a year of lost opportunity, indicative of the clear and urgent need for this technology.

TECHNICAL STANDARDS ARE A CRITICAL PREREQUISITE FOR SCALING DR-RAC DEPLOYMENT

The use of DR-RACs as a dispatchable grid resource requires the development of supportive regulations and policies, increased availability of DR-RACs, a wider range of business models and utility DR platforms, and greater consumer awareness. Technical harmonization through the creation of DR-RAC standards is a critical prerequisite that will help kick-start action on all these fronts.

DR-RAC standards must define technical requirements for units and provide a common technology framework for DR initiatives. Technical standardization would make it possible to aggregate DR-RACs across brands, models, and manufacturers. It ensures that DR-RACs will reliably deliver consistent performance during DR events, providing utilities the confidence they need to utilize DR-RACs to manage peak loads.

In 2024, the Bureau of Indian Standards (BIS) began evaluating options for national DR standards. The BIS's initiative offers India a unique opportunity to accelerate the development and deployment of DR-RACs and trigger a global DR movement. We call on stakeholders to tap into this unique opportunity to lay the groundwork for managing the impact of India's growing cooling demand.

CALL TO ACTION

1. **RAC manufacturers, consumers, and utilities must support BIS in developing DR-RAC standards**
   - **Technical standardization is essential:** Establishing technical standards for DR-RACs is a critical prerequisite and will help build confidence in DR-RACs as a reliable resource option for the grid.
   - **India should develop DR standards by leveraging global best practices:** BIS should draw from examples of other countries and relevant international standards to develop robust DR-RAC standards that are contextualized to India's needs and conditions.
2. **Stakeholders must begin to build the basis for DR-RACs within their own segments**
   - **Appliance manufacturers:** Support the development of standards, incorporate DR-RAC-compliant components into RAC designs, and collaborate with policymakers to advance DR regulations.
   - **Utility (or DR aggregators-operators):** Quantify the benefits of DR-RACs, explore different business models, conduct pilot programs, and educate consumers about cost-saving opportunities.
   - **Technology and testing labs:** Support the development of DR-RAC standards, develop appropriate test methods, and invest in DR-RAC testing and certification.
   - **Researchers and policymakers:** Investigate economic incentives, behavioral drivers, policies, and regulatory mechanisms to accelerate DR-RAC adoption.
3. **Investors must catalyze funding to scale DR-RAC deployment**
   - **Public- and private-sector investments:** Mobilize investments to support research and development and manufacturing of DR-RACs, scale business models, implement demonstration projects, and support grid modernization to integrate DR.
   - **Financial institutions:** Develop innovative financing models such as risk-sharing mechanisms or green bonds to incentivize DR-RAC adoption and implement DR programs.
   - **Government support:** Introduce subsidies or tax incentives to lower the upfront cost of DR-enabled RACs, encouraging manufacturers to integrate DR capabilities.

A. Context

HEAT STRESS AND THE RISING NEED FOR COOLING

Heat stress is the world's leading cause of weather-related deaths and can exacerbate illnesses such as cardiovascular disease, diabetes, mental health disorders, and asthma.[5] Researchers estimate that approximately 489,000 heat-related deaths occur each year, with 45% occurring in Asia and 36% in Europe.[6]

In India, the areas experiencing heat stress have grown by 30%–40% over the past 70 years.[7] The summer of 2024 saw a severe heatwave, with temperatures soaring past 50°C in some regions. By the end of July 2024—just before the monsoon rains provided relief—374 fatalities and 67,637 suspected heatstroke cases had been reported nationwide.

Air conditioners (ACs) have emerged as an essential cooling solution for ensuring thermal comfort. According to the International Energy Agency (IEA), sustained average daily temperatures of 30°C or above typically boost AC sales by around 16%.[8] Currently, over two billion ACs are in use worldwide, and that number is expected to triple to approximately six billion by 2050.[9]

India is poised to become one of the largest contributors to global cooling demand, accounting for 32%—approximately 1 billion—of the 3.2 billion new room air conditioner (RAC) units projected to be sold between 2025 and 2050.[10] During this period, new RAC sales in India will be twice that of the next largest market, China, where RAC stock is projected to grow by 514 million units. Currently, only about 8% of Indian households own an AC, compared to 90% in some high-income countries such as Japan or the US.

RAC sales in India are already growing at an average annual rate of 12%,[11] and some forecasts suggest that this growth might accelerate to 16–17%.[12] Approximately 130 to 165 million RAC units are likely to be sold between 2025 and 2030,[13] which would almost double the country's existing stock. This rapid growth in cooling demand is already straining the power system, and, if left unattended, will undermine efforts to mitigate the climatic impact of cooling loads (Figure 1).

Rising temperatures, affordable ACs, and aspirational lifestyles are fueling India's rapidly rising adoption of RACs. While AC ownership can provide a respite from increasingly intense heatwaves for millions across India, exponential adoption can exacerbate other challenges.

India's electricity generation depends heavily on coal, which accounted for 74% of the generation mix in 2024.[14] The increased electricity production required to meet this demand will result in higher emissions and increased air pollution. RAC use disproportionately occurs in the evening, when solar energy generation declines, leading to further increases in fossil-fuel generation.

Without interventions, increased RAC ownership and usage could lead to severe grid instability and higher energy costs, setting back India's plans to reduce its greenhouse gas (GHG) emissions. This paper explores how DR-RACs offer grid-responsive cooling solutions that contribute to India's efforts toward building demand-flexible assets. DR-RACs can also supplement energy efficiency efforts to reduce the climatic impact of cooling.

This paper urges India to take the global lead in launching DR-enabled cooling and issues a call to action to accelerate the development of technical standards for DR-RACs.

The number of new ACs added by 2050 will exceed the number of people born in Southeast Asia over the same period.

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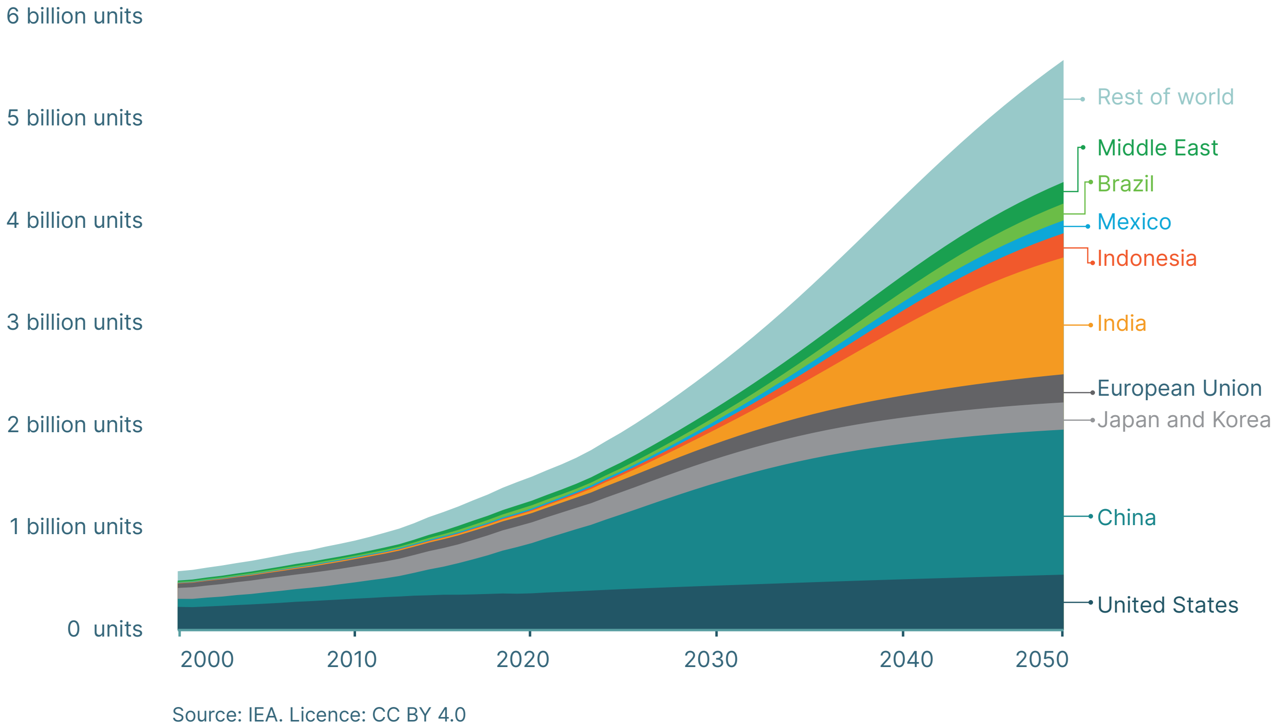
FIGURE 1: PROJECTED NUMBER OF AIR CONDITIONING UNITS

Figures from 2017 onwards are projections from the International Energy Agency, based on estimated changes in population and income.



Source: International Energy Agency (IEA). Future of Cooling.

ENERGY REQUIREMENTS FOR COOLING

The IEA estimates that "space cooling"—primarily air conditioning but also fans—consumed around 2,100 terawatt-hours (TWh) of power in 2022, which is around 7% of the world's electricity use. The electricity demand from ACs has more than doubled since 2000 and is expected to contribute nearly 40% of the growth in electricity demand worldwide by 2050. In 2022, AC use resulted in approximately 945 million metric tons (Mt) of CO_2 emissions, nearly equivalent to the 1 billion tonnes of CO_2 emissions that India is seeking to reduce by 2030.[15]

The impact of rising temperatures and growing RAC ownership on India's electricity demand has become more pronounced. In 2019, for instance, an increase of 1°C in the average daily temperature led to a 4 GW rise in the average maximum power demand. By 2024, the same temperature increase resulted in a 7 GW rise.[16]

Table 1 summarizes the key impacts of rising RAC ownership on India's electricity demand.

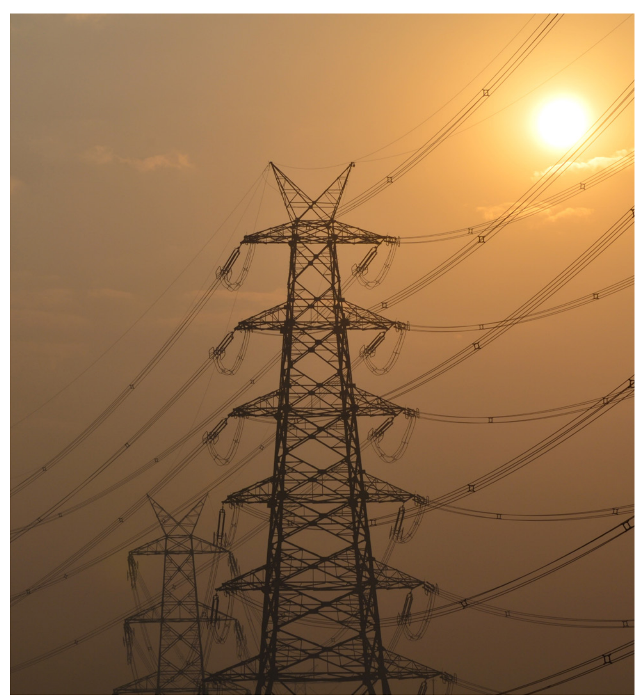


TABLE 1: IMPACT OF RISING RAC OWNERSHIP ON INDIA'S ELECTRICITY DEMAND

	2024	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE
Stock of RAC (millions)	84	143	165	70	96
Stock of RAC in the residential sector (millions)[17]	58.8	100.1	115.5	70	96
RAC contribution to residential peak demand (GW)	31.5	47.5	54.8	51	74
Residential peak demand (GW)	82.5	100.0	107.3	21	30
Residential AC electricity consumption (TWh)	92	122	140	32	53

Source: Authors' analysis

Increased RAC ownership and use will continue to drive India's electricity demand. RACs are projected to account for approximately 61% of the growth in residential electricity demand, contributing 35 TWh to the increase from 413 TWh in 2024 to 470 TWh in 2030.[18]

The contribution of RACs to peak demand growth will be equally significant. In 2024, they contributed 19 GW or 7.5% of the total peak demand. Even with annual RAC sales growing at the current rate of 12%, air cooling's contribution to peak demand is expected to nearly double to 36 GW or 10.7% of the peak demand by 2030. During this period, RACs will account for nearly all residential sector peak demand growth, contributing to 17 GW of the 18 GW increase.[19]

IMPACT OF COOLING ON PEAK DEMAND PROFILE

Rising RAC ownership and usage are also altering the load profile, resulting in sharper peaks. RAC-related peak demand typically occurs between 18:30 and 19:30 IST, which coincides with the peak periods for cooling and overall residential energy demand. India's peak demand of 335 GW in 2030 will exceed 300 GW for only 88 hours—about 1% of the total time for that year.[20] This means that roughly 35 GW of generation capacity—plus an additional 10–15% in reserves—will need to be kept on standby only to serve those brief peak demand hours.

The peak demand for RACs occurs during the evening, when renewable sources (particularly solar energy) are unavailable. As a result, the increased demand must be met predominantly by fossil-fired power plants, primarily using coal or gas, leading to higher emissions. In addition, utilities will need to make substantial investments in new peaking power plants and transmission and distribution infrastructure to meet the increased demand for power during peak times.

These capital-intensive investments will be spent on establishing infrastructure designed for use only during critical peak demand periods. Without such expensive peak management infrastructure and grid enhancements, power demand growth from cooling can lead to grid congestion, increased losses, and deterioration of power quality, collectively resulting in a less resilient and more vulnerable grid.

India's emphasis on decarbonization, and its ambitious target of installing approximately 500 GW of renewable energy (RE) capacity by 2030, will significantly increase the share of RE in its energy mix. A greater reliance on RE generation will require a more flexible grid, with steeper ramps (the rate at which dispatchable generation must increase or decrease to match demand fluctuations), deeper turndowns (operating dispatchable generators at minimal possible levels of operation to ensure they remain available for rapid scaling), and shorter peaks to manage the variability in electricity generation from renewable sources.[21]

ADDRESSING PEAK DEMAND WITH DR-RACS

Efforts to address the impact of India's growing cooling demand have thus far focused on improving RAC energy efficiency and decarbonizing the grid. India's minimum energy efficiency performance standards for RACs have increased by 52% in 2009–2026, delivering approximately 130 GWh of avoided energy use and 100 million tonnes of avoided CO_2 emissions.[22] On the grid decarbonization front, India's renewable energy capacity is projected to increase to approximately 450 GW or about 58% of the total installed power capacity by 2030.[23]

However, energy efficiency improvements and grid decarbonization measures alone cannot address the impact of peak demand growth induced by growing cooling needs. Investments in peak power infrastructure will divert scarce resources away from more pressing needs, such as expanding the baseload electricity supply, which India urgently needs to broaden its reliable supply. Additionally, India is seeking to establish a base of demand-flexible assets that can help manage its peak demand and support increased integration of intermittent RE generation into the grid.

The use of DR-RACs in peak demand periods is one of the most cost-efficient ways to establish a large base of demand-flexible assets while simultaneously addressing the impact of a growing cooling load. While DR-RACs specifically target cooling demand, they can also open the door to other DR strategies for managing flexible loads, such as water heating, refrigeration, and electric vehicle charging.

SUITABILITY OF DR-RACS IN INDIA

India is well-positioned to pursue DR-RAC initiatives. DR-RACs can help reduce peak demand growth, lower costs, and improve affordability. Many elements of the ecosystem that are needed to enable the development of DR-RACs are already in place and aligned with the power sector's need for demand flexibility.

Many parallel developments in India's power sector support the growth of the DR-RAC sector.

- India intends to deploy 250 million smart meters by 2025 under the Smart Meter National Programme. These meters enable time-of-day pricing and remote load management, making large-scale DR implementation feasible.
- Indian utilities are increasingly recognizing the need for demand-side management (DSM) strategies, including DR, to reduce peak loads and defer costly infrastructure upgrades. The Maharashtra Electricity Regulatory Commission, for example, has introduced Demand Flexibility Portfolio Obligations that establish a minimum threshold for demand-responsive assets in the state. If that same minimum threshold were applied nationally, approximately 11 GW of demand-flexible assets would be required by 2030.
- India's goal of developing 500 GW of RE capacity by 2030 will need flexible demand-side solutions such as DR to balance the grid and optimize intermittent RE generation.
- The Bureau of Energy Efficiency (BEE) has a well-established energy labeling initiative for RACs, which could integrate DR requirements in the future.

RACs are particularly well-suited for DR because of a few important characteristics.

- RACs already offer integrated digital controls and communication features, and they provide excellent system interoperability
- Compared to many other residential and commercial appliances, RACs are relatively simple to configure for DR due to the rapid adoption of smart meters and expanding digital infrastructure
- RACs can have a significant impact on peak load because they have the quickest growth rate among appliances in India's residential market.
- A well-planned DR event that utilizes RACs can reduce or shift energy use with minimal discomfort to the user, increasing the likelihood of sustained customer participation.

These elements work together to make RACs the perfect place to start building India's portfolio of demand-flexible assets.

B. Fundamentals of demand response

UNDERSTANDING DEMAND RESPONSE

Demand response refers to a set of strategies and technologies designed to enable consumers to adjust their electricity use in response to grid conditions in real time. DR can be achieved through load control by power DR aggregators (typically, utilities) or by aggregating consumers through DR initiatives. Usually, DR is accomplished by offering customers incentives to participate in DR interventions. These incentives could include time-based pricing, variable peak pricing, and peak-load rebates.

DR initiatives are being implemented in several nations worldwide. Some countries are conducting pilot projects to determine the effectiveness and efficiency of this approach. Others have created sophisticated DR frameworks, incorporating them into their power supply systems. Globally, these initiatives have reported tangible benefits in terms of lower electricity costs, avoided investments in new generation capacity, reduced GHG emissions, enhanced grid reliability, and improved power generation and transmission systems.

Technological developments are making it easier to apply demand-side solutions. Advances in communication protocols, smart metering, software control systems, sensors, and device control systems are making it easier and more affordable to monitor and control real-time electricity use. Importantly, industrial and domestic appliances and equipment are getting smarter; they are Wi-Fi-enabled, have sensors that can be programmed to respond in specific ways, and can be operated remotely. Advanced demand management is possible through the combination of smart grids, real-time data analytics, and the Internet of Things (IoT). These strategies enable appliances to automatically respond to grid conditions and optimize energy use.

Demand flexibility and demand response

Demand response refers to a set of strategies and technologies designed to enable consumers to adjust their electricity use in response to grid conditions in real time. Over the long term, DR offers a strategic approach that can help avoid capacity and transmission and distribution additions or enhancements. In the immediate and short term, DR is a critical real-time mechanism that enables electricity grids to respond rapidly, helping them balance demand and supply and integrate intermittent generation, thus reducing transmission congestion and improving power quality.

Dispatchability

Demand response can be both dispatchable and non-dispatchable.

Dispatchable DR refers to DR initiatives where utilities or DR aggregators directly communicate with a consumer or the appliance to reduce electricity usage at a specific time. Dispatchable DR can be quickly activated to address grid conditions and help balance supply and demand or reduce grid congestion.

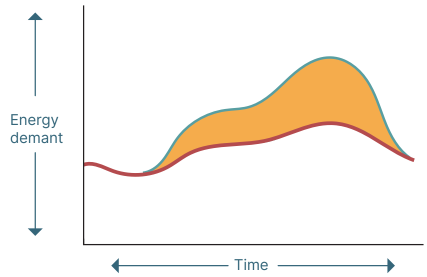
Non-dispatchable DR refers to DR initiatives where consumers voluntarily reduce their electricity consumption based on price signals or other incentives, without direct instructions from the utility at any specific time. The consumer can decide when and how much to reduce their consumption based on time-of-use (ToU) pricing or other incentives. However, this approach may not provide the same level of immediate and reliable responses when compared to dispatchable DR initiatives.

TYPES OF DEMAND RESPONSE INITIATIVES

Demand response initiatives[24] can broadly be divided into four different categories: shape, shift, shed, and shimmy (modulate), as described in Table 2.

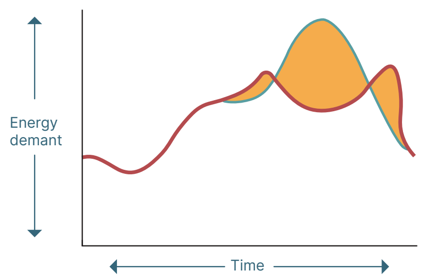
TABLE 2 Typical types of DR initiatives

Shape initiatives result in **seasonal demand shifts.**



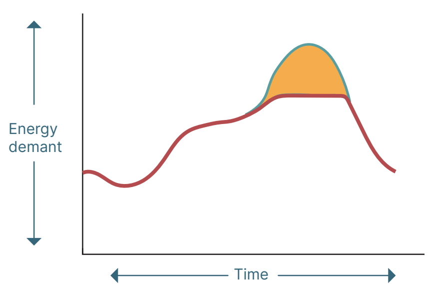
Shape is a demand resource category that refers to long-term and persistent alterations in the demand pattern. In DR terms, this relates to changes in consumer behaviour. Any change in the end-use consumption patterns in response to a Time-of-Use or dynamic energy rate is a classic example of a shape resource. Although incentive-based mechanisms are commonly classified as a DR resource, any lasting consumer behavioural change is, in essence, DR. Actions from an empowered consumer to alter his or her energy usage can contribute to the shape resource. For example, actions taken by energy-aware residential energy consumers based on behavioural energy campaigns such as Home Energy Reports, when aggregated, serve as an easily exploitable DR resource.

Shift initiatives result in **daily demand shifts.**



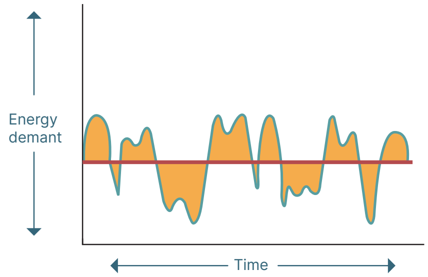
Shift refers to the DR resource associated with shifting the load without any net reduction in energy consumption. The shift from the peak time period to another is typically done to balance the load curve in response to the incremental cost of power procurement and defer the investment needed to meet peak demand. In a grid with a high share of RE, Shift DR encourages the shifting of demand to a period of a surplus solar or wind generation. Shift can be considered a type of storage resource from the supply-side perspective and can mitigate the frequent ramping of power plants [10]. Customers could also participate in incentive-driven programmes to shift energy consumption to a time window that falls outside the DR event—for example, running a washing machine outside of the DR event period or, in the case of industrial facilities, shifting forklift battery charging to outside the peak demand period. Shift DR is also a method to encourage EV charging during the day to coincide with high solar generation.

Shed initiatives result in **hourly and sub-hourly demand shifts.**



The most traditional and easily identifiable value from DR is associated with load reduction programmes. The shed resource is quantified in terms of the aggregated potential to reduce demand at the time of peak demand or a system emergency through individual load curtailment by end-use consumers. The ability of consumers to curtail their loads in response to signals received from grid operators has direct implications on peak capacity reduction and reliability improvement. Shed is considered a type of generation capacity resource from the supply-side perspective and can be used to manage contingency events or economic events (e.g. when wholesale procurement costs go above the normal range or the marginal cost of power procurement is too high).

Shimmy initiatives result in **hourly and sub-hourly demand shifts.**



Shimmy is a very versatile DR resource linked to flexibility, i.e. the ability of a load to dynamically adjust demand. This constitutes fast-acting DR measures that operate on shorter timescales of seconds/minutes or an hour. Shimmy is critical for flexible grid operation, as it is used to provide ancillary services like frequency regulation. This resource is extremely handy in tackling intermittent demand-supply mismatches in a grid with a high share of renewables and is therefore valuable for the future grid, as it can assist in handling sudden fluctuations in solar generation due to changing cloud cover.

Source: Authors' analysis

Note: Shed, shift are at day, hourly, and sub hourly level, shimmy is at hourly and sub hourly level, and shape is generally applicable at yearly, seasonal and day level.

For RACs, the most relevant DR methods are

i. shed initiatives, which turn the unit off

ii. shimmy initiatives, which adjust the temperature settings

These approaches are dynamic and reliable and offer temporary flexibility to the grid without having a significant impact on the customer's thermal comfort. This report focuses on shed and shimmy DR strategies.

GLOBAL SURVEY ON DEMAND RESPONSE INITIATIVES

Several countries around the globe have established technical standards and protocols to support the integration of DR-enabled appliances. Australia, Japan, Singapore, and the United States offer some of the best examples of these standards. However, most global DR initiatives focus on commercial equipment, where each appliance is large enough to trigger a meaningful change in electricity demand. DR-RACs are smaller and require standards to aggregate units across brands and makes, receive centralized commands, and remotely control the performance of individual units. A more detailed discussion of these initiatives is presented in Appendix 1.

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C. Demand response in India

OVERVIEW

The legal framework governing India's power sector is anchored in the Electricity Act, 2003. At a broad level, it establishes regulatory bodies—the Central Electricity Regulatory Commission and state electricity regulatory commissions—and enables them to formulate power regulations. A key regulatory mechanism for demand-side interventions in India is the Demand Side Management (DSM) regulations, where DSM is defined as "a set of initiatives undertaken by the utility on the consumer side of the meter to bring about a desired change in consumer demand and/or demand profile maintaining, or even enhancing the service provided to the consumer in terms of quality, reliability and cost of service."[25]

Maharashtra was the first state to adopt the DSM regulations in 2010, followed by 30 other states and union territories. However, the implementation of these regulations has been nominal.

In addition, Maharashtra *Demand Response Regulations, 2024,* Issuing Authority: Maharashtra Electricity Regulatory Commission (MERC) and Assam *Draft Assam Electricity Regulatory Commission (Demand Response) Regulations, 2024,* Issuing Authority: Assam Electricity Regulatory Commission (AERC) have issued DR regulations, whose key provisions are summarized in Table 3.

TABLE 3 Key highlights of the demand response and demand flexibility regulations released by Assam (draft) and Maharashtra (notified) in 2024

ELEMENTS	REGULATION SUMMARY
Define demand response	Demand response is defined as the process of balancing the electricity demand managed by power grids by encouraging consumers to shift their electricity usage to times when the supply is abundant or the demand is lower. This is typically achieved through price incentives or monetary rewards.
Demand response targets	The Assam regulations list provisions to set DR targets based on a potential assessment of the licensee, focusing on: • Percentage of reduction in overall demand • Percentage of reduction in peak demand • Percentage of reduction in peak demand across different seasons • Percentage of reduction in short-term power procurement through DR The regulations allow DISCOMs to design, develop, and implement pilot DR initiatives targeting different consumer categories with smart meters. In Maharashtra, the regulations propose that DISCOMS increase flexible demand annually to enable the quick ramping up and ramping down of the load based on system requirements, including the need to maximize RE integration. The annual target, or demand flexibility portfolio obligation (DFPO), is set as a percentage of peak demand from the previous financial year, gradually increasing from 1.5% in FY 2025–2026 to 3.5% in FY 2029–2030. If Maharashtra's DFPO requirements are applied nationally, a base of approximately 11 GW of demand-flexible assets would have to be created.

ELEMENTS	REGULATION SUMMARY
DR systems	■ System standards must comply with the regulations set by the CEA ■ Where applicable, CEA or BIS guidelines should be followed for all DR-related system and network operations ■ In the absence of CEA/BIS standards, IEC, IEEE, or ANSI standards should be followed
DR equipment	■ BIS standards should be followed for DR-related equipment and technology, where available ■ In the absence of BIS standards, IEC, IEEE, or ANSI standards should be used
Network and communication standards	■ If interoperability or cybersecurity standards are established by CEA or BIS, they must be adopted ■ If such standards are unavailable, IEC (International Electrotechnical Commission), IEEE (Institute of Electrical and Electronics Engineers), and ANSI (American National Standards Institute) should be used instead
Data protection	■ Consumer data should be classified as personally identifiable information (PII) and critical energy use data ■ Strict access controls must be enforced, and third parties must sign non-disclosure agreements ■ PII data must not be shared with third parties
Customer participation and incentives	Consumers can "opt in" or "opt out" depending on the initiative. Incentive types: ■ **Enrollment-based incentives**: Rewards for signing up for DR initiatives ■ **Participation-based incentives**: Payments for active participation in DR events ■ **Performance-based incentives**: Additional rewards for meeting specific performance targets during DR events
Tariff regimes	Specific tariff regimes may be implemented for DR initiatives, including: ■ ToU tariffs ■ Real-time pricing ■ Critical peak pricing

Source: Authors' analysis

DEMAND-RESPONSE PILOTS

Over the last decade, several Indian utilities have implemented pilot initiatives to demonstrate peak management, capacity avoidance, and grid flexibility. Figure 2 summarizes these pilots.[27]

FIGURE 2: DEMAND RESPONSE PILOTS IN INDIA

Source: Sasidharan et al., 2021[26]

Over the past decade, Indian utilities have implemented multiple DR pilots to explore their potential in managing peak demand, avoiding capacity expansion, and enhancing grid flexibility. Initially, these pilots focused on commercial and industrial consumers due to their significant and predictable electricity loads. However, recent initiatives include residential consumers and smart appliances.

The following case studies highlight two significant initiatives—one from India and another from China—illustrating different approaches and outcomes in DR implementation. The case studies demonstrate diverse approaches to DR implementation. BSES Rajdhani Power Limited's initiative in Delhi highlights how utilities can leverage DR to manage peak demand in urban environments, while Midea's initiative in China showcases the role of smart applications in enabling automated demand-side flexibility (Boxes 1 and 2).

Midea's role in developing DR-RACs

Midea Group, a Fortune 500 company headquartered in China, has integrated DR capabilities into its smart AC systems. It offers a model for other markets, including India.

Key learnings from Midea's DR initiatives

1. **R&D in smart RAC and system integration**
   - Since 2019, Midea has invested in the development of smart RACs with internet connectivity and DR functionality.
   - It launched cloud-based RACs that support 5G and Narrowband-IoT communications, enabling remote control and integration with grid platforms.
   - It introduced a smart home energy management system that optimizes appliance energy usage through IoT.
2. **Retrofit solutions for existing RACs**
   - Midea developed a renovation project that allows conventional RACs to be upgraded to DR-enabled devices using a gateway terminal.
   - This approach extends the product lifecycle and enhances participation in DR initiatives.
3. **Advanced load modeling and DR optimization**
   - Leveraging its proprietary "Cloud-to-Cloud" IoT platform, Midea collects real-time operational data from over 20 million connected RACs.
   - It developed machine learning–based load models to optimize control strategies for peak demand management.

© Source: Shutterstock

BSES Rajdhani Power Limited (BRPL)—Behavioral energy efficiency pilot project

About the pilot: This pilot was jointly launched by BRPL and Oracle Utilities in 2018. It targeted residential customers and aimed to influence their behavioral energy efficiency (EE). Behavioral EE interventions utilize proactive, personalized feedback and peer comparisons to effect changes in energy consumption. These pilots provide relevant, visually appealing, and actionable insights into energy use, motivating consumers to change their energy consumption patterns. A key feature of behavioral EE campaigns is the use of home energy reports (HERs) as a feedback mechanism. These reports include a summary of a home's recent and historical energy use, personalized energy-efficiency tips (including links to existing energy efficiency offerings), and a normative comparison of a household's energy use with that of its neighbors.

Modality: The pilot employed a randomized controlled trial to evaluate the impact of software generated HERs on customer energy savings. A total of 260,000 residential customers participated, with 200,000 assigned to the treatment group and 60,000 to the control group. The treatment group received HERs by paper or email, while the control group did not, providing baseline energy consumption data.

To measure the intervention's effect, the energy consumption of the treatment group was compared to that of the control group. The HERs were personalized with energy usage insights, comparisons with peer group customers, and conservation tips, encouraging behavioral changes without installing any physical hardware at the customers' premises. Customers in the treatment group could also log into their accounts on the DISCOM website to access personalized analytics and additional energy-saving recommendations.

Benefits for the grid: In addition to lowering energy costs for consumers, the initiative prioritized enhancing energy literacy and fostering engagement with other DSM initiatives. It attempted to empower consumers to reduce consumption by 1–3% annually, which helped reduce their energy bills and grid congestion. Special care was taken in selecting customers for the pilot. The customers were chosen from areas with overloaded distribution transformers that would benefit from reducing network congestion. This pilot has since been converted to a full-scale DR program by the DISCOM, making it a rare scale-up success story.

Key points

- DR was implemented using HERs
- A total of 260,000 residential customers participated: 200,000 in the treatment group (receiving the intervention) and 60,000 in the control group (no intervention)
- HERs were sent to the treatment group as part of the behavioral intervention; the control group did not receive any reports and served as the baseline
- The intervention's impact was measured by the deviation in demand of the treatment group from the baseline demand of the control group
- Annual energy savings of 1–3% were observed as result of the HERs

A snapshot of the HERs distributed by BRPL DISCOM to influence household electricity consumption:

UtilityCo

1515 N. Courthouse Road, Floor 8
Arlington, VA 22201-2909

0014837 0023-C10-I -P14851 -730905

***********AUTO**5-DIGIT 12345
PLUGGIE
1515 N COURTHOUSE ROAD
8TH FLOOR
ARLINGTON,, VA 22201

Home Energy Report
May 20, 2015
Account number 8249865991

We've put together this report to help you understand your energy use and what you can do to save.

Find a list of rebates and energy-saving products and services you can buy.
www.utilityco.com/rebates

Introducing a new energy report—designed for you.

Here's how you compare to neighbors

You	402 kWh
Efficient neighbors	465 kWh
Average neighbors	602 kWh

Apr 21, 2015 - May 20, 2015

This is based on 87 similar homes within approx. 4 miles. Efficient neighbors are the 20% who use the least amount of electricity. See back for details.

Great
Good
Using more than average

14% less electricity
than efficient neighbors

Neighbor comparison over time

Over the last 6 months, you used less than your efficient neighbors.
$58 saved

Tips from efficient neighbors

Unplug electronics when they're not in use
Save up to $75 per year

Program your thermostat
Save up to 10% a year on heating and cooling bills.

Turn over

18586857- UTILITYCO-20141126-195-(UTILITYCO_000_N10_STD)-(GEN_0000_NO_INSERT)-STANDARD-1-2-3577

1189-24-00-0008574-001-0008682

BENEFITS OF IMPLEMENTING DR-RAC IN INDIA

DR-RAC initiatives modeled

We modeled two types of DR initiatives (shed and shimmy) to quantify the benefits of a DR-RAC policy for India.

Initiative type 1: shed-based DR-RAC events

In shed-based DR initiatives, utilities turn off RACs remotely during peak hours in line with pre-signed contracts with customers. Based on the projected load profile for 2030, RAC peak demand is most likely to occur between 18:30 and 19:30 IST.

We assume that the utility will divide the one-hour DR event into four 15-minute intervals, with each customer participating in only one of these intervals on a rotational basis. This approach limits the duration of time over which a customer is affected during a DR event, thus ensuring that their comfort is not compromised.

Another key consideration is the number of hours that the DR events will be operational in a year. We assume that shed-based DR initiatives will be run for no more than 30 hours a year. On average, a customer participating in a shed-based DR-RAC initiative will be subjected to 30 events of 15 minutes each, totaling 450 minutes a year.

Based on the typical RAC in India, a single DR-RAC unit participating in a shed event will contribute to an average demand reduction of 1 kW.

Initiative type 2: DR-RAC in shimmy-based events

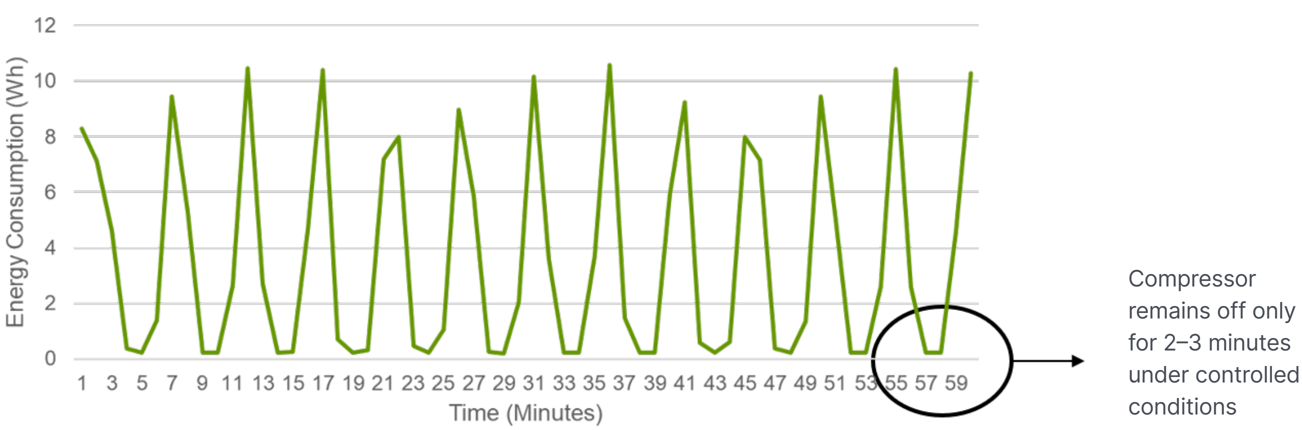
In shimmy-based DR initiatives, RAC set-point temperatures are adjusted to reduce their energy consumption. During peak hours (18:30 to 19:30 IST), we expect utilities to use DR action to increase the temperature set point of RACs by 2°C. This intervention is expected to lower the energy usage for each RAC by roughly 12%, making it an effective strategy to reduce energy consumption while also maintaining customer comfort.[27]

This approach reduces energy consumption but may not substantially lower peak demand, as the modest temperature increase may lead to frequent compressor cycling. This limitation occurs because ACs quickly revert to cooling mode to maintain comfort levels, limiting the duration of compressor shutdown. Figure 3 illustrates the energy consumption pattern (compressor cycling) of an RAC operating at a set point of 24°C.

A shimmy-based DR initiative targeting a 2°C temperature increase for 60 minutes is unlikely to reduce the customer's comfort. For this reason, we assume that shimmy-based DR initiatives can be implemented throughout the entire 88-hour critical peak demand period.

The approach, methodology, and peak demand management strategy for shed- and shimmy-based DR-RAC initiatives are summarized in Table 4. The analysis assumes that DR-RACs will be fully available to customers by 2029. We expect 2025–2026 will be devoted to the development of standards, while 2027–2028 will be spent getting the DR market ready.

FIGURE 3: ENERGY CONSUMPTION OF AN RAC OPERATING AT 24°C



Source: Bohra et al., 2023[28]

TABLE 4: SUMMARY OF CASES

DR INITIATIVE TYPES	TYPE 1: SHED	TYPE 2: SHIMMY
Peak hour	18:30–19:30	18:30–19:30
Intervention	DR-RACs of distinct batches of customers are switched off for 15 minutes on a rotational basis over the one-hour period	The temperature set point of the RAC is increased by 2°C for the entire 60-minute period
No. of DR-RAC events in a year	30	88
A customer's total annual participation in DR	30 events of 15 minutes each, totaling 450 minutes in a year	88 events of 60 minutes each, totaling 5,280 minutes in a year

Source: Authors' analysis

Shed and shimmy DR initiatives are designed to operate independently. Shimmy is utilized to ease grid disturbances and smooth the load through modulation (e.g., managing voltage fluctuations and frequency management). Shed DR events contribute to actual load curtailment. Triggering both shed and shimmy interventions simultaneously within the same time block is not anticipated, as customers participating in a shed event would have zero potential to participate in shimmy events at the same time.

In our analysis, we modeled customer participation in the DR-RAC initiative by estimating 30 shed events and 88 shimmy events in a year. The total peak and energy savings and associated avoided investments resulting from both shed and shimmy DR initiatives are aggregated and reported in the sections below.

CUSTOMER PARTICIPATION SCENARIOS

We assume that all 53–67 million RAC units sold in 2029 and 2030 will be DR-enabled. This baseline of available DR-RACs is used to estimate DR benefits by 2030. However, not all customers will participate in a DR initiative. The scenarios used to simulate customer participation in DR events are illustrated in Table 5 below.

IMPACT OF DR-RAC INITIATIVES

Avoided peak and energy demand impacts

In the short or immediate term, DR-RACs can instantaneously lower demand, reduce grid congestion, and address other stresses on the grid. In the long term, DR can be integrated into power systems as an alternative to generation, thus avoiding the need for new power plants, transmission expansion, and distribution additions or enhancements.

Each RAC in a shed DR event contributes to a 1 kW reduction in demand at the consumer end. There will be additional savings as transmission and distribution losses will also be avoided. The total avoided generation capacity will be approximately 15% higher than the demand reduction at the consumer level, or around 1.15 kW for each RAC participating in a shed DR event. When aggregated, the total peak demand reduction in 2030 from shed-based DR events will range between 5–6 GW and 8–10 GW for 30% (scenario 1), 40% (scenario 2), and 50% (scenario 3) participation, respectively, compared to a projected total peak demand of 335 GW in 2030.[29]

TABLE 5: CUSTOMER PARTICIPATION SCENARIOS IN DR-RAC INITIATIVES

	Scenario 1	Scenario 2	Scenario 3
Total customers with DR-RACs by 2030 (in millions)		53–67	
Share of total DR-RAC customers (%)	30	40	50
Total customers by 2030 (in millions)	16–20	21–27	27–34

Source: Authors' analysis

The peak demand savings of up to 10 GW from DR-RACs would meet up to 90% of the national demand flexibility target, illustrating the critical role that DR-RACs could play in providing demand flexibility.

In shimmy-based DR initiatives, the temperature set points of RACs are increased by 2°C, leading to an estimated 12% reduction in energy consumption. By 2030, shimmy-based DR-RAC initiatives could avoid electricity demand of approximately 197–246 GWh to 329–415 GWh annually, for participation rates of 30% (scenario 1) and 50% (scenario 3), respectively.

The peak and energy demand reductions from shed- and shimmy-based DR-RAC initiatives are summarized in Table 6.

Every year that DR-RACs are not readily available represents a lost opportunity. The savings listed in Table 6 assume that RACs sold in India will only be DR-ready by 2029. As a result, the peak and energy demand savings are estimated only for DR-RACs purchased in 2029 and 2030. However, if DR-RACs are made available for purchase as early as 2025, peak demand savings in 2030 will approximately double to 16 GW with 50% DR-RAC participation, while avoided energy demand would increase almost fivefold to 2,719 GWh.

The scenarios in Table 6 model outcomes for varying participation levels and highlight the importance of customer involvement. For example, peak and energy demand savings would double to approximately 16 GW and 400 GWh if all customers participated in the initiative, assuming DR-RACs become available in 2029. If DR-RACs are made available from 2025, and all customers participate, these savings could quadruple to around 32 GW and 800 GWh by 2030.

Reductions in peak and energy demand will help avoid the need for new generation capacity and transmission and distribution enhancements, leading to significant cost savings. The avoided cost impact associated with these savings is outlined in Table 7.

TABLE 6: PEAK AND ENERGY DEMAND SAVINGS FROM DR-RACS IN 2030

		CUSTOMER PARTICIPATION SCENARIOS		
		Scenario 1	Scenario 2	Scenario 3
Total DR-RACs in 2030 (millions), assuming DR-RACs become fully available by 2029		53–67		
DR-RAC customers participating in the DR initiative (%)	Percent (%) of total	30	40	50
	Total customers (millions)	16–20	21–27	27–34
Peak demand savings inclusive of avoided transmission & distribution losses (GW) in 2030		5–6	6–8	8–10
Total energy demand savings (GWh) in 2030		337–404	450–579	563–709
From shed DR events		140–175	187–240	234–295
From shimmy DR events		197–246	263–337	329–415

Source: Authors' analysis

TABLE 7: IMPACT OF AVOIDED COSTS AND REDUCED DEMAND DUE TO A DR-RAC STRATEGY IN 2030

		CUSTOMER PARTICIPATION LEVELS		
		Scenario 1	Scenario 2	Scenario 3
Total DR-RACs in 2030 (millions), assuming DR-RACs become fully available by 2029		53–67		
DR-RAC customers participating in the DR initiative (%)	Percent (%) of total	30%	40%	50%
	Total customers (millions)	16–20	21–27	27–34
Peak demand savings inclusive of avoided transmission & distribution losses (GW) in 2030		5–6	6–8	8–10
Total energy demand savings (GWh) in 2030		337–404	450–579	563–709
From shed DR events		140–175	187–240	234–295
From shimmy DR events		197–246	263–337	329–415
Avoided investments ($ millions) by 2030		7,648–9,560	10,198–13,108	12,747–16,045
Avoided transmission & distribution		2,716–3,395	3,621–4,653	4,527–5,697
Avoided new power plant capacity		4,889–6,111	6,519–8,382	8,148–10,263
Avoided fuel purchases	From shed DR events	18–23	24–31	30–38
	From shimmy DR events	25–31	34–44	42–53
Avoided emissions (thousand-tons of CO_2) in 2030		241–301	322–413	402–506
From shed DR events		100–125	134–172	167–210
From shimmy DR events		141–176	188–242	235–346

Source: Authors' analysis

Although the emissions reduction benefits are relatively minor, DR-RACs are a powerful tool for reducing the peak demand resulting from growing cooling needs. As outlined in Table 7, our analysis concludes that by 2030, reductions in peak demand will lead to cost savings from avoided investments, ranging from $7.6–9.5 billion to $12.8–16 billion for the 30% and 50% customer participation scenarios, respectively.

Of these savings, avoided investments of approximately $2.7–3.3 billion to $4.5–5.6 billion in transmission and distribution capacity will come from the resource adequacy value that DR-RACs provide. Avoided investments in new generation capacity are more of a notional estimate. We acknowledge that in some cases, there may not be a one-to-one relationship between a reduction in peak demand and avoided new generation capacity. Providing a more precise estimate of avoided new generation capacity will require detailed long-term power system modeling, which could be sensitive to several other dynamics that influence the decision to build new power plants. This detailed modeling analysis is outside the scope of this study. Nonetheless, the estimated savings from avoided investments in new power plants represent a reasonable addition to the potential benefits DR-RAC.

These avoided investments will translate directly to cost savings for consumers and could also be used to finance the scale-up and adoption of DR-RACs. For example, consider the fact that the approximate savings from avoided investments, if translated into an average per DR-RAC participant cost, would range from $478 to $485. This could fully offset the initial cost the participant would incur to acquire a DR-RAC.

In practice, however, customers are more likely to opt for incentives that accumulate as they participate in DR-RAC initiatives. The avoided investments could be used to finance incentives ranging from $24 annually over 20 years to $49 annually over 10 years. The actual incentive offered to a participating customer will depend on the scheme design used by the utility or DR operator. In addition, DR-RAC participants will benefit from electricity savings during shed and shimmy DR events. On average, a customer may be able to reduce their electricity bills by $1–2 by participating in 30 shed and 88 shimmy DR events.

The estimated electricity demand savings and the associated avoided investment costs highlight how DR-RACs can be used to lower energy prices for consumers and enhance grid reliability. These benefits establish the urgent need to support comprehensive efforts to standardize and commercialize DR-RACs, accelerate their adoption, and encourage consumer participation in DR initiatives.

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D. DR-RAC architecture and technology

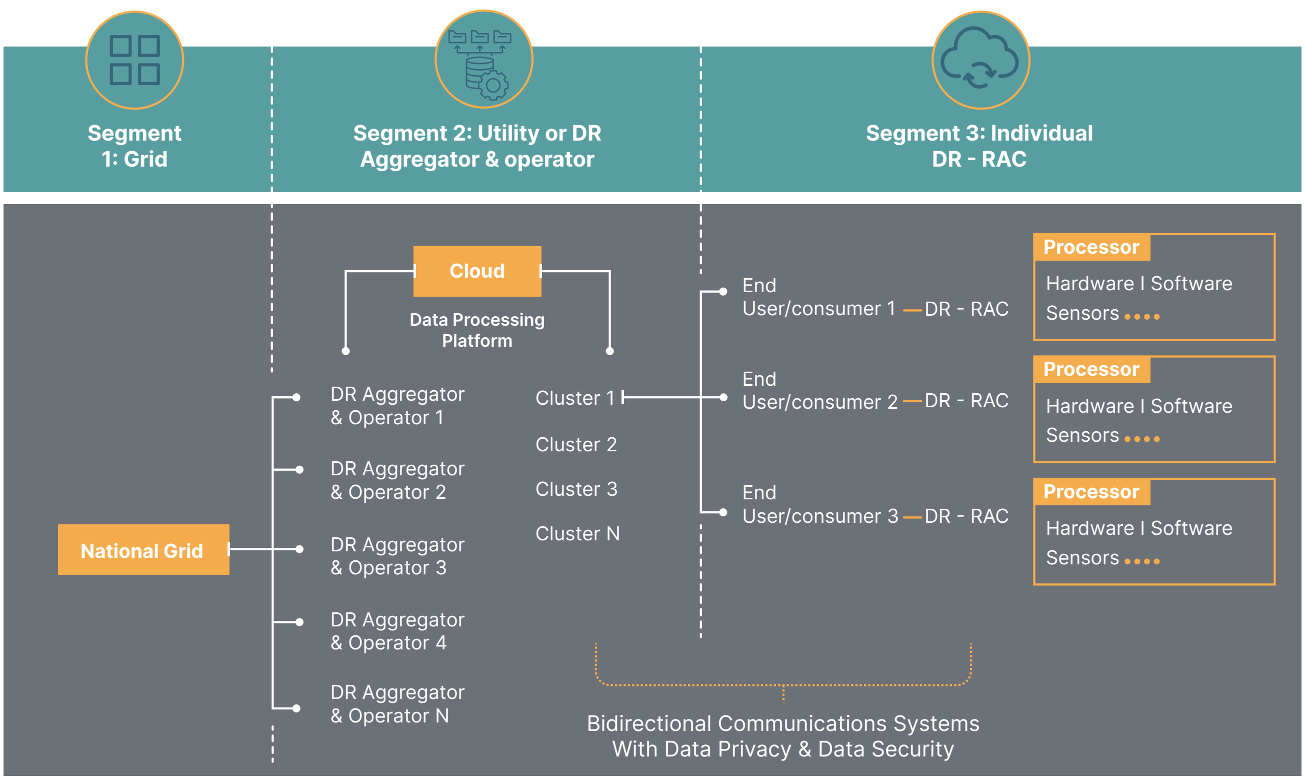
This section discusses the potential architecture of the DR-RAC system in India and the technologies that need to be integrated into RACs to make them DR-ready.

DR-RAC SYSTEM ARCHITECTURE

At the individual level, DR actions are small and dispersed across many RACs, with each action having little impact on the grid. However, when such individual responses are aggregated, they offer a response block that is large enough to have a positive material impact on grid operations. For DR-RACs to be recognized as a dispatchable grid resource, it must be feasible to aggregate many RACs and reliably deliver their estimated demand reductions. The aggregation of RACs and the reliability of their aggregated responses are the two key factors shaping the architecture of DR-RAC systems within the power sector.

The integration of DR-RACs into the power sector will depend on the structure, regulations, and market design of the power system, which may vary across states in India. Despite design variations, the architecture for integrating DR-RACs into the power system will generally involve three layers: (a) the grid, (b) the utility or DR aggregator and operator (DR-AO), and (c) individual DR-RACs, as illustrated in Figure 4.

FIGURE 4: EXPECTED SYSTEMS ARCHITECTURE FOR INTEGRATING DR-RACS IN INDIA'S POWER SECTOR



Source: Authors' analysis

Grid: The grid is where the interplay between electricity supply and demand takes place. All actors in the DR system architecture respond to real-time grid conditions.

Utility (or DR-AO): Utilities serve as the intermediaries between the grid and individual RACs. Each utility will have multiple individual RACs under its control, which can be aggregated in various ways to achieve the desired DR.

The utilities will likely utilize a cloud platform that processes real-time data from RACs, tracks grid conditions, employs algorithms to determine optimal DR strategies, and transmits instructions to RACs under their control. The design of these cloud platforms and algorithms will vary across utilities, as each approach will be tailored to its business model and core to its intellectual property.

Individual DR-RAC: The individual DR-RACs will be located at the site of the end user (or consumers). Several individual DR-RACs will be aggregated by the utility, and further, the utility may have multiple aggregated groups or clusters. Each DR-RAC must be equipped with built-in sensors and hardware as well as processors and software that enable it to collect and transmit data, receive commands, and alter its performance according to the instructions received from the utility.

DR-RACs should ideally work across different aggregation platforms. Establishing common standards will ensure a unified framework for data transfer, interoperability, and RAC operation and control. This report focuses on the technology and specifications of DR-RACs rather than the broader DR system architecture, which may take various forms.

DR-RAC TECHNOLOGY COMPONENTS

DR RACs must include built-in hardware and software to continuously monitor settings and operational parameters, send and receive data, process remote DR commands, and adjust RAC settings in accordance with DR instructions. Most RACs in use today already have built-in sensors and processors that monitor and provide real-time data on operational parameters such as energy consumption, temperature, humidity, mode of operation, usage duration, and clock time. Additionally, existing RACs offer users an interface to adjust these settings and, in some cases, allow them to create presets for different conditions.

The central nerve cell of the DR-RAC is its command unit. This is the core hub within which all the components, software, and hardware are housed. It serves as the hub that passes information and instructions between components.

Although the specifics of the components may vary across brands and RAC types, in general, the technology used in DR-enabled RACs involves the following key components.

- **Communication channel:** The RAC connects to a cloud-based system through a reliable communication network, such as Wi-Fi, Zigbee, or cellular networks. Remote monitoring and control are made possible through this channel. It allows the utility or DR-AO to seamlessly and reliably send and receive data from the RAC and issue real-time instructions.
- **Sensors:** The RAC's integrated sensors gather various data, including performance parameters, power usage, temperature, and humidity. This data must be available for real-time analysis to enable swift DR responses when needed.
- **Data recorders**: These devices save data gathered by sensors and send it to the cloud for processing. This ensures that historical data is also retained for analysis, performance evaluation, and system enhancements.
- **Processor:** The RAC's processor (typically located within the command unit) implements the commands received from the utility or the DR-AO. It makes local modifications while preserving operational efficiency by regulating compressor cycles or altering temperature settings.
- **Software:** Every DR-RAC has built-in software that controls how information is transferred from one component to another and between the RAC and the utility's digital platform. Many manufacturers are likely to use software that is specific to the components of the DR-RAC they produce.

In most cases, standards will not define the specific components to be used, leaving those decisions to manufacturers. For DR-RACs, however, standards will have to define their expected functionality, operational requirements, speed and lag times, and contingency.

COSTS OF INCLUDING DR IN RACS

The components required to integrate DR in RACs are mature technologies. Many manufacturers are already selling smart RACs that incorporate several DR features, such as the ability to program dynamic settings or remotely control the unit through a digital mobile application or dashboard. Based on the range of smart RACs available, manufacturers appear well-positioned to rapidly scale up the production of DR-RACs once the market is ready.

In India, where smart RACs currently constitute less than 2% of the market, the incremental costs of adding full DR functionalities to a base, bare-bones RAC could range up to $30. In markets where smart RACs are more widely available, such as in China, the incremental costs will be significantly lower. External companion sockets that can be used to retrofit a traditional RAC to transform it into a smart device are readily available for about $10 in several markets globally.

TABLE 8: INCREMENTAL COSTS OF MAKING RACS DR READY

COMPONENT	COST (USD)	COST (INR)
Wi-Fi or Zigbee module	$5	₹425
Temperature, humidity, and power sensors Simplified command unit and data recorder (basic)	$20	₹1710
Embedded system processor	$5	₹425
Total additional cost	**$30**	**₹2,560**

Source: Authors' analysis

However, at this stage, most manufacturers expect the incremental cost of integrating DR into RACs to be below $30 (₹2,560), which is less than 10% of the average retail price of RACs in India. Details about the incremental costs for making RACs DR ready are listed in Table 8.

Utilities or DR operators will require high levels of reliability and must be confident that DR-RACs will perform exactly as required. The components currently used to make an RAC smart will need to be marginally enhanced to improve reliability, redundancy, privacy, and safety. Even with these incremental enhancements, the widespread availability of smart RACs and the ubiquitous prevalence of IoT suggest that the incremental costs for integrating DR in an RAC in India will remain at the lower end of the $10–30 range.

The incremental cost for integrating DR in RACs will not be a barrier to their production or an additional burden for consumers. As production of DR-RACs increases, and IoT integration increases in various appliances, DR-RACs are likely to become the default product offering in India with no visible cost difference compared to units that do not have those capabilities.

Economies of scale: As DR-RACs proliferate, component costs are likely to decrease due to increased production and the development of more effective technologies, facilitating their broader adoption. We expect that more competitive pricing for these components will emerge as the DR industry expands, especially if widespread implementation results in further standardization. In the future, this might significantly lower the incremental cost of DR-enabled RACs.

Infrastructure costs: In addition to RACs, there could be other expenses associated with the need for cloud-based platforms or communication networks to handle DR signals, collect data, and transmit DR instructions. However, these costs are likely to be absorbed by the utility or the DR-AO as part of their business operations.

E. Technical standards for DR-RACs

Standards are the essential starting point

Scaling DR-RAC initiatives requires a multifaceted approach supported by an enabling regulatory environment, diverse business models, technology development, and high levels of customer awareness. Standardizing DR-RAC technologies is the crucial first step and a key prerequisite for advancing regulations, policies, new technologies, business models, and customer choices.

Standards define the essential technical specifications and features required for an RAC to be DR-ready. These standards will help ensure that RACs produced by varied manufacturers can participate in DR initiatives, enabling the aggregation of DR across many RACs, and reliably delivering consistent demand reductions. They must outline the functional requirements for communication protocols, remote operations, monitoring processes, response times, data privacy, and security.

It is crucial to distinguish between regulatory requirements and technological standards. In India, technical standards are developed by the BIS, which also oversees compliance to ensure that all RACs fulfil the established requirements. To ensure uniformity and interoperability among various DR systems, the BIS guidelines specify how RACs should respond to DR signals.

In India, the development of BIS standards for DR-RACs could be supplemented by enabling regulatory actions from other agencies. For example, the BEE could integrate DR-readiness standards into energy efficiency initiatives such as the Standards & Labeling (S&L) initiative. In this way, the technical standards established by the BIS could lay the foundation for the development of technologies, regulations, communications, awareness, and consumer incentives, driving the adoption and deployment of DR-RAC.

Standards are the prerequisite to unlocking demand response using RACs

Standards define the essential technical specifications and features that an RAC will need to have to be DR-ready. Standardization in DR-RAC technology is the essential starting point, the key prerequisite that opens the pathway to action on regulations, policies, technology development, business models, and customer choices. Standards provide a common technical framework and then help to overcome challenges associated with coordination, communication, and technology integration. This, in turn, builds confidence in the reliability of DR whenever needed.

Standards help with the following:

- Consistency in implementation: Standards offer a clear set of instructions for carrying out DR initiatives. A common technical framework reduces the risk of delays in initiative deployment and participation, which in turn will enhance overall confidence in the technology.
- Streamlined communication: With standards, communication between DR aggregators, grid operators, and consumers is secure, reliable, and improved. This facilitates quicker decision-making and increases the reliability of DR initiatives in generating the required result.
- Interoperability: Standards ensure that different technologies and systems can work together seamlessly. Interoperability is critical for aggregating DR resources from various participants, enhancing overall initiative effectiveness, and reducing technical delays.
- Enhanced measurement and verification: Standardized methods for measuring and verifying DR performance help identify and address inefficiencies quickly, leading to faster adjustments, improvements in response strategies, and increased confidence in the technology.
- Risk reduction: By following commonly agreed standards, organizations can better manage the risks associated with DR initiatives, including participant engagement and the reliability of DR in enhancing grid stability, thus enhancing overall confidence in DR-RACs.

Increased participation: A common framework of clear standards can make it easier for consumers to acquire DR-enabled RACs and understand and participate in DR initiatives, thus expanding the pool of available DR resources and increasing the impact on the grid.

OVERVIEW OF RELEVANT GLOBAL STANDARDS

DR standards in other countries

Several countries have established standards for DR technologies and have begun testing or, in some cases, have fully implemented DR initiatives. In most countries, these standards cover a wider range of appliances and equipment beyond RACs. Nonetheless, global experiences and learnings in DR provide a rich base of insights that can help accelerate the development of DR-RAC standards in India.

Table 9 summarizes the key standards from other countries that have begun implementing DR initiatives and are relevant to the Indian context.

TABLE 9: DEMAND RESPONSE STANDARDS IN SELECT COUNTRIES

COUNTRY	STANDARD NAME	SCOPE	DEVICES COVERED	CAPABILITY	GAPS
Australia	AS/NZS —DR standard	Enable DR for domestic appliances	Standard interface (usually an RJ45 socket) on an AC to connect to an external “demand response enabling device” (DRED)	DR modes (DRM) 1—“Turn OFF”; DRM 2 or 3 – “operate at reduced load”; DRM 4 – “Turn ON over user-set controls”	The standard primarily relies on one-way communication, where signals are sent **from the utility or DR service provider to the appliance without a feedback mechanism** to confirm execution or status. Additionally, the **lack of a user-override option** limits consumers’ control over their appliances once a DR event is triggered.
Japan	ECHONET Lite protocol with AIF specifications	Communication protocol to enable IoT in home energy management services	Devices including air conditioners (ACs) under a HEMS	Supports multiple DR modes or “operation states” that appliances can switch to during DR events	**Compatibility constraints:** While the protocol supports multiple DR modes, its effectiveness depends on the integration with Japan’s **Home Energy Management Systems (HEMS)**, which is not universally available outside Japan. This creates challenges in deploying the system in markets with different smart home infrastructures. **Market scalability limitations:** Due to the country-specific nature of the standard, expanding its use in other markets would require significant modifications or additional adaptations, hindering seamless global implementation.

COUNTRY	STANDARD NAME	SCOPE	DEVICES COVERED	CAPABILITY	GAPS
Singapore	Green Mark Scheme	Buildings and Construction Authority (BCA)	Commercial buildings' performance	Air conditioning and mechanical ventilation system	**Lack of standardized DR communication protocols:** Unlike other DR standards that define specific **communication interfaces** between utilities and appliances, the Green Mark Scheme does not mandate the use of **specific DR protocols (e.g., OpenADR, CTA 2045).** This limits its interoperability with broader DR initiatives. **Focus on commercial buildings only:** The scheme applies mainly to commercial buildings and **does not extend to residential appliances**, overlooking a key sector with significant potential for demand-side flexibility.
USA	Energy Star connected	Energy Star certified by the Environmental Protection Agency (EPA)	Enable DR for domestic appliances	More than 14 appliances and equipment, including RACs	**Reliance on external standards:** The Energy Star Connected initiative does not establish its own detailed **DR communication framework** but instead relies on other standards (e.g., **CTA 2045, OpenADR**). This creates inconsistencies in implementation across different appliances and manufacturers. **Limited enforcement of DR capabilities:** While Energy Star certification encourages DR functionality, **there is no mandatory requirement** for appliances to participate in DR initiatives, leading to varied adoption.
	AHRI-1430	AHRI	Communication, infrastructure, and system functionality for DR	Water heaters	These standards focus on **specific appliance categories (e.g., water heaters, HVAC systems)**, making them less applicable to a **broader range of household and commercial devices**.
	AHRI-1380	AHRI	Communication, infrastructure, and system functionality for DR	Variable capacity HVAC in residential and small commercial applications	

COUNTRY	STANDARD NAME	SCOPE	DEVICES COVERED	CAPABILITY	GAPS
	Open ADR	Open ADR	Non-proprietary, open DR interface	Multiple	**OpenADR is the most advanced DR standard**: It serves as a **global reference for DR implementation**, offering **automated, real-time response capabilities**. However, its adoption depends on **the availability of smart grid infrastructure** and **utility readiness**.
	ANSI/CTA 2045	Consumer Technology Association (CTA)	Modular communication interface for energy management standards	Multiple	CTA-2045 **bridges the gap between appliance manufacturers, consumers, and utilities** by offering **a cost-effective, flexible, and scalable DR solution**. While its effectiveness depends on compatibility between appliance and grid systems, **wider adoption of smart grid infrastructure** and **alignment with OpenADR** will help its broader implementation across markets. Thus, this is also an important standard that will be referred to when building on the Indian standard.

Source: Authors' analysis

Most of the current DR standards and initiatives globally relate to commercial equipment, where each equipment by itself is large enough to trigger a meaningful change in electricity demand. Consequently, these standards primarily address the interface between equipment and the gird. In these types of large commercial applications, the equipment is likely to be able to directly sense grid conditions and respond to grid signals (such as frequency and voltage).

Unlike most existing global DR initiatives, which target C&I applications, DR-RACs are typically smaller and one of many appliances within an end user's circuit (e.g., an RAC in a household alongside other appliances). RACs often have buffers or filters between them and the grid (for example, inverters with battery storage or voltage stabilizers) which alter the true grid signals before they reach the DR-RAC. In these settings, DR-RAC actions will need to rely on instructions that are remotely sent rather than automatically responding to grid conditions. Therefore, DR-RAC standards will need to establish common methods for how RACs receive centralized commands and how those instructions remotely control the performance of the RAC.

Another area where standards for DR-RACs will need to fill a gap is aggregation. Unlike existing global DR initiatives, which target larger C&I applications, DR-RACs are much smaller and far more diffuse. Several RACs must be aggregated to generate any meaningful DR. Consequently, standards for DR-RACs must establish how an individual RAC can be clustered within the centralized command framework of the utility or DR aggregator.

INTERNATIONAL STANDARDS

The IEC standards are voluntary, consensus-based standards for electrical and electronic technologies aimed at ensuring global conformity in quality, safety, and compatibility. They also form the basis for testing and certification and are also often adopted, in whole or with minor modifications, by countries or regions as national or regional standards. BIS, India's standards-setting body, often builds from IEC's methods and approaches when developing national standards.

A wide range of existing IEC standards are relevant to DR-RACs. These are listed in Table 10.

TABLE 10: IEC STANDARDS RELEVANT FOR DR-RAC

STANDARD NAME	DEVELOPED BY	SCOPE
IEC 62746 series	IEC	This series defines the system interface between customer energy management systems (CEMS) and the power management system (PMS). It covers protocols and standards for the communication and integration of smart appliances, including RACs, with grid management systems for DR. It also includes **OpenADR** (Automated DR), which enables the automated communication between grid operators and energy-consuming devices to facilitate DR events.
IEC TS 62950	IEC	This standard outlines the smart capabilities required for household and similar electrical appliances. It defines the functional requirements necessary for energy efficiency, ensuring interoperability, and enabling communication with energy management systems—all of which are crucial for effective participation in DR initiatives.
IEC 63510 series	IEC	This series focuses on the data models and communication layers required for the interoperability of connected household appliances. It ensures that devices like RACs can communicate seamlessly within a smart home or smart grid ecosystem. The series defines the standards for device interaction, ensuring that appliances can effectively respond to DR signals and work in coordination with other devices and grid management systems.

Source: Authors' analysis

IEC standards can be broadly divided into two categories:

- Standards for the Reference Framework (e.g., IEC TS 62950): According to them, an appliance is considered "smart" or "DR-ready." They list the essential functionalities that appliances should include, such as communication capabilities, energy efficiency features, operating modes, and compatibility with energy management systems. In essence, they outline the requirements that an appliance must fulfill.
- Standards Defining Communication Protocols and System Interfaces (e.g., **IEC 62746 series** and **IEC 63510)**: These outline the protocols and communication channels needed for safe information sharing between appliances and energy suppliers. To enable real-time load adjustments during DR events, they help ensure that household appliances (such as thermostats, RACs, and batteries) can "talk" to the grid or an energy management system.

While communication protocols and system interface standards (e.g., IEC 62746) can be directly adopted, specific standards for DR-enabled RACs have yet to be developed. A targeted approach specifically covering DR-RACs will ensure their effective integration into DR frameworks. To read about the details of some countries in terms of their standards related to DR capabilities and the interoperability of appliances, focusing on air conditioners and their role in energy management systems, refer **to Appendix 3.**

ELEMENTS FOR DR-RAC STANDARDS

Specific elements critical to the development of DR-RAC standards are outlined below.

- **Communication protocols:** For real-time adjustments, the communication route between RACs and the grid operator or DR aggregator must be clearly established. For DR-enabled RACs to successfully receive and respond to DR signals, standardized communication protocols (e.g., Wi-Fi, Zigbee, or other IoT-enabled networks) must be developed. To ensure that the equipment from various manufacturers is compatible, standard data interchange formats and communication interfaces must be established.
- **Response times**: To guarantee that the DR is reliable and dependable, the speed with which RACs react to DR signals needs to be standardized. This includes the amount of time it takes for RACs to react to remote commands (or grid signals) and the time it takes to modify RAC temperature set points, adjust cooling loads, or shut down the RAC. Coordinating the activities of several RACs during times of high demand requires standardized response times.
- **Capabilities for load-shedding:** RACs should be able to shed a certain amount of load as needed during periods of high demand or when directed. All RACs can contribute equally to grid balancing efforts if load-shedding capabilities are standardized across devices. Determining the lowest and highest load reduction that RACs are capable of achieving must be established as part of the standards.
- **Data privacy and security**: Standardization of data privacy and security procedures is crucial because RACs will gather and send sensitive data, such as energy use and user behavior. Standards must specify how private information about RAC users is safeguarded, how information will be encrypted while being transmitted, and the safeguards that must be established to guarantee that the access provided to the utility (or any third party) does not violate the data privacy or security of RAC end users.
- **User interface and mechanisms for opting in and out**: Standards must establish a common framework for RAC user interfaces, ensuring users can easily opt in or out of DR initiatives without navigating complex processes.
- **Interoperability with grid management systems**: The communication between DR-enabled RACs and grid management platforms, smart meters, and demand response aggregators must be standardized. This guarantees that the DR signals supplied by the grid operator are consistently and effectively received and that the RAC responds to those commands.
- **Energy efficiency and performance metrics**: Standardization is required to set performance metrics for DR-enabled RACs, such as their capacity to save energy during periods of peak demand, in accordance with energy efficiency targets. This makes it possible for DR initiatives to effectively manage grid loads while simultaneously lowering overall energy use and carbon emissions.
- **Additional customer safeguards:** Standards must provide a high level of safeguards that protect the safety, comfort, and interests of RAC end users. These safeguards include:
    - Override capabilities: DR-RAC end users must be able to override DR signals in specific circumstances for their comfort, safety, or other individual factors. Standards should balance user control with the need for a reliable DR response that is not entirely dependent on individual user decisions.
    - Safety: Standards must ensure that DR modifications do not compromise the RAC's performance or safety.
    - User opt-in or opt-out: RAC end users must have the ability to make decisions regarding their participation in DR initiatives and to opt out when needed. Standards do not need to govern the commercial agreements between utilities (or DR aggregator–operator), but they must provide a common mechanism for customers to opt in and out of DR initiatives.

Technical standards that provide a common framework for these elements are essential to developing the entire DR ecosystem, including policies, technology, consumer experience, awareness, markets, and business models, and in generating confidence in the ability of DR to serve as reliable option for managing load growth. In short, technical specifications are a critical first step in making RACs "DR-ready."

Developing DR-RAC standards in India

CURRENT STATUS

The process of developing a national standard for DR devices in India is in its early stages. Industry players, utilities, appliance manufacturers, the BIS, and civil society partners are working together to create these standards.

BEE India and the U.S. Department of Energy (DOE) organized the Space Cooling Efficiency Enhancement and Demand Response Workshop on June 24–25, 2014. Utilities, grid operators, regulators, and AC manufacturers participated in this workshop.[30] During the event, Lawrence Berkeley National Laboratory (LBNL) presented a paper and analysis on DR-ready RACs in India.

In 2024, the BIS, India's national standards body, began considering options and proposals to formulate a national standard for DR devices. Once this standard is published, the respective appliance committee will consider how to integrate it into the standards for that appliance. This means that the development of a specific DR-RAC standard will begin only after the DR device standard is finalized. During the process, the involvement of utilities, appliance manufacturers, and DR device manufacturers will be crucial to ensure that the development of the standard moves forward briskly and in collaboration with all relevant stakeholders.

In the interim, many manufacturers are already implementing plug-and-play DR technologies, which are simple to install and can be applied to already-existing RACs. During periods of high demand, these devices enable utility providers to remotely control or communicate with the RACs to redistribute or lower the load. The plug-and-play option simply requires the installation of a smart module that connect to the AC and enables two-way communication between the appliance and the utility grid.

These modules frequently make use of communication protocols that enable utilities to issue directives based on real-time grid conditions, such as lowering the cooling capacity or modifying the temperature. For older RACs not originally designed for DR, this technology is an easy and cost-effective way to enable DR features without requiring complex retrofitting or making major changes to the device.

Despite the absence of an official BIS standard, manufacturers are increasingly employing this strategy to meet the growing demand for DR-enabled appliances in the Indian market.

Additionally, some manufacturers are using proprietary solutions by integrating DR capabilities into their smart home ecosystems or cloud-based platforms. This strategy entails creating a specialized control and communication infrastructure, where appliances are outfitted with cloud-based communication capabilities to interact with energy management systems. Even if a formal national standard does not yet exist, these technologies enable appliances to accept remote signals from utilities or grid operators to shift or reduce consumption during peak times. This cloud-based control system could also be part of a broader home energy management system (HEMS) that allows users to manage energy consumption more efficiently.

Cooperation among utilities, appliance manufacturers, and DR device manufacturers is essential to the development of a national DR-RAC standard. India is already taking steps toward formulating standards for DR-RACs in part by drawing upon international standards.

APPROACHES FOR ADDRESSING TECHNICAL GAPS IN DR-RAC STANDARDS

India's national standard for DR devices is likely to be based on IEC TS 62950, which defines the testing of smart capabilities and operating modes in appliances incorporating DR or smart functions. It also describes how such products respond to instructions and conditions that arise in the operation of smart grids. It also describes various approaches for measuring how products respond to specific smart operating modes. This standard will be used to address smart capabilities and smart operating modes in various products, including RACs.

IEC Technical Standard 62950 outlines testing protocols for the smart features and modes of operation of appliances that include DR or smart functions. It specifies how appliances should respond to specific guidelines and circumstances that frequently occur in smart grid operations. Additionally, it offers ways to gauge how well items perform when they switch to particular smart operating modes.

While drawing upon IEC 62950 and relevant standards from other countries, India's national standard for DR-RACs aims to address two key technical gaps that have been identified:

- **Lack of a unified communication protocol:** The lack of a defined communication protocol that guarantees smooth interoperability across various appliances, manufacturers, and utilities is one of the main shortcomings in the current framework for DR devices in India. International standards like IEC TS 62950 offer a foundation for DR device operation, but they do not cover the intricacies of communication protocols, which are still dispersed.

- **Limited interoperability of DR-enabled appliances:** Manufacturers currently rely on proprietary communication protocols or third-party solutions. The lack of a widely recognized protocol raises questions regarding device compatibility and data security during two-way communication between appliances and the utility grid, and manufacturers are left to develop their own communication infrastructure solutions, which may lead to inefficiencies and increased costs. However, it is worth noting that IEC standards for communication protocols, including interoperability, are currently under development.

Our analysis offers several recommendations to address these gaps which could then help advance the development of DR-RAC.

- By creating a single communication protocol under its own DR standards, India could close this gap. One crucial first step could be integrating international standards by adopting protocols like OpenADR. Strong security features must also be included in these protocols to safeguard customer information and guarantee system dependability.
- DR modes (DRMs), such as DRM 1 (compressor OFF), DRM 2 (which operates at 50% load), and DRM 3 (which operates at 75% load), are required for appliances under the AS/NZS 4755 (Australian standard). The standard does not, however, include customer override choices, which has sparked worries about end users' lack of flexibility. It's critical to strike a balance between grid management requirements and customer comfort and control. Customers may get dissatisfied and perhaps stop participating in DR initiatives if they are unable to control how the device operates during a DR event. User override options, which allow users to modify their appliances in the event of an emergency or discomfort, should be incorporated into India's DR standard. DR initiatives may be more popular if customer participation is voluntary and they are offered incentives for participate. Manufacturers can think about including smart home systems that let users conveniently operate their appliances from a distance using mobile applications or other interfaces.
- India can take inspiration from Australia's approach and create a testing and certification process for DR appliances that is in line with both national and international standards. Collaborating with organizations such as BIS, BEE, and IEC, India can establish a robust certification framework that provides manufacturers with clear testing protocols and ensures that only certified DR appliances are sold in the market. This will help enhance product quality and reliability while also increasing consumer trust in DR technologies.

STAKEHOLDERS INVOLVED

Several stakeholders from the public and private sectors must work together to create and implement DR-RAC standards in India. To guarantee that DR-enabled appliances are dependable, compatible, and compliant with international best practices, a coordinated strategy is necessary. The roadmap for standards development involves multiple phases, from initial consultations to adoption and enforcement.

Key stakeholders in the DR-RAC process include government agencies, standards groups, utilities, appliance producers, IT companies, and customers. These stakeholders must engage at different stages of the process to develop, create and implement DR-RAC standards successfully, as outlined in Table 2.

TABLE 11: STAKEHOLDER ROLES IN DR STANDARDS DEVELOPMENT AND IMPLEMENTATION

STAKEHOLDER	ROLE	RESPONSIBILITIES
Bureau of Indian Standards (BIS)	Lead the national standardization process for DR	- Develop national DR standards - Establish a National DR Standards Committee - Collaborate with international bodies (e.g., IEC, ISO) - Ensure compliance with and enforcement of DR standards
Ministry of Power (MoP)	Formulate energy policies that promote DR and grid stability	- Create policies supporting DR adoption - Adopt DR standards developed by BIS - Introduce regulatory mandates for DR compliance

STAKEHOLDER	ROLE	RESPONSIBILITIES
Bureau of Energy Efficiency (BEE)	Facilitate DR integration into energy efficiency initiatives and grid operations.	- Support BIS in standard development - Encourage DR adoption through energy efficiency initiatives - Develop regulatory frameworks for integrating DR into energy systems
State electricity regulatory commissions (regulators and policymakers)	SERCs are responsible for framing regulations and guidelines that enable DR initiatives within their respective states. They ensure alignment with national policies—such as the Electricity Act 2003, the National Electricity Policy, and the National Tariff Policy—while integrating DR into state-specific electricity policies and demand-side management (DSM) strategies.	- Formulate policies, design, tariffs, manage the grid, and consumer engagement - Design time-of-use (ToU) tariffs, real-time pricing (RTP), and critical peak pricing (CPP) structures to incentivize consumer participation in DR initiatives
Indian Power Utilities (DISCOMs)	Implement and test DR systems in the grid	- Provide real-world data and grid load profiles - Conduct pilot initiatives using DR-enabled appliances - Establish communication protocols between the grid and appliances - Explore scaling up DR initiatives based on pilot results.
Appliance and DR device manufacturers	Develop DR-enabled appliances and comply with national standards	- Incorporate DR capabilities into appliances - Participate in standards discussions and testing - Ensure interoperability of appliances with grid systems
Technology Providers (Smart Grid, IoT, and Communication Providers)	Provide communication technologies and smart devices for DR.	- Develop communication protocols for DR (e.g., OpenADR, using the IS standard when it is established) - Provide smart modules and support aggregators in the cloud-based storage
Testing and calibration laboratories	Provide testing and certification services for compliance of the standard.	- Provide third-party testing and calibration services to ensure appliances and DR devices meet standards - Conduct compliance audits and ensure product quality

Source: Authors' analysis

PATHWAY FOR THE DEVELOPMENT OF DR-RAC STANDARDS IN INDIA

India is well-positioned for large-scale development and adoption of DR-RAC. With the right emphasis and coordinated action from all relevant stakeholders, India could well be one of the pathbreaking adopters of DR-RACs. The following section outlines a pathway for the development of DR-RAC standards in India.

1. **Development of technical specifications**

   BIS, in collaboration with manufacturers and other stakeholders, could develop technical specifications for DR-ready RACs, including communication protocols, energy consumption reduction mechanisms, and performance requirements.

2. **Public consultations and feedback**

   Conduct public consultations with stakeholders, including RAC manufacturers, utilities, and end-users, to gather feedback on the proposed technical specifications and make necessary revisions.

3. **Pilot initiatives and testing**

   Launch pilot projects to test the performance of DR-enabled RACs in real-world conditions. This will help identify any gaps in the standards and provide valuable data for refinement.

4. **Regulatory measures and policy support**

   The BEE should incorporate DR readiness into its existing energy efficiency initiatives (e.g., Standards & Labelling) and encourage regulatory measures that incentivize the adoption of DR-enabled RACs.

5. **Finalization of standards**

   Once the technical specifications are refined and pilot initiatives are successfully completed, the BIS can finalize the DR-RAC standards and issue them for industry-wide adoption.

6. **Market adoption and continuous monitoring**

   Post- standardization, the market can begin to adopt DR-enabled RACs. Regular monitoring and updates to the standards will be necessary to keep pace with technological advancements and market developments.

7. **Public awareness and consumer engagement**

   Launch educational campaigns to inform consumers about the benefits of DR participation and encourage them to adopt DR-ready RACs.

   By following this roadmap, India can effectively develop and implement DR-RAC standards, ensuring the widespread adoption of DR technologies, improving energy efficiency, and enhancing grid stability.

A call to action

Scaling demand response-enabled room air conditioners

DR-RACs can help lower peak demand, reduce energy costs, and support the transition to sustainable cooling. In India, DR-RAC can help to meet almost all the entire requirement for demand flexible assets. Enabling utilities (or DR aggregators and operators) to adjust cooling loads through DR-RACs could help reduce the electricity demand, provide the grid with greater flexibility in balancing supply and demand, enhance grid stability, and reduce energy costs for consumers by avoiding investments in generation, transmission, and distribution.

STANDARDS AS THE ESSENTIAL STARTING POINT FOR DR-RAC INITIATIVES

Technical standards for DR-RAC technologies are an essential starting point and a key prerequisite that will open the pathway to broader action on regulations, policies, technology development, business models, and customer choices. Standards provide a common framework that will help spur the entire ecosystem to develop and scale adoption of DR-RACs.

LEADERSHIP OPPORTUNITY FOR INDIA

India is in a strong position to take the lead in creating and implementing DR-enabled RAC technical standards. Beyond energy savings, DR-RACs can help address urgent challenges in India's power sector such as peak demand management and grid congestion, while reducing costs for consumers. India is well-positioned to roll out DR-enabled RACs and establish itself as a global leader in a new type of DR-enabled cooling.

COORDINATED ACTION ACROSS STAKEHOLDERS

Coordinated action across policymakers, RAC manufacturers, technical experts, consumers, investors, and regulators is required to spur action in the DR-RAC sector. **This call to action on DR-RAC aims to crowd in coordinated stakeholder action to accelerate the development of technical standards for DR-RACs—an essential first step toward building a pathway for sustainable cooling in India.**

© Source: Shutterstock

CALL TO ACTION

1. **Support technical standardization as the critical first step to scaling DR-RAC deployment**
   - Technical standardization is essential: Establishing technical standards for DR-enabled RACs is a crucial prerequisite to ensuring effective implementation and scalability. Standards provide a common technical framework for the functional requirements of DR-RACs related to communication, response times, and aggregation. They also help build confidence in DR-RACs as a reliable resource option for the grid.
   - India must develop DR standards leveraging global best practices: India's BIS, responsible for developing product standards, must draw from examples from other countries and relevant international standards to develop robust DR-RAC standards contextualized to India's needs and conditions.
2. **Unlock the potential of DR-RAC: All relevant stakeholders must support the development of DR-RAC technical standards and begin to prepare for its implementation.**
   - Appliance manufacturers: Support the development of standards, incorporate DR-RAC compliant components into RAC designs, and collaborate with policymakers to advance DR regulations.
   - Utility (or DR aggregators–operators): Quantify the benefits of DR-RAC, explore different business models, conduct pilot initiatives, and educate consumers about cost-saving opportunities.
   - Technology and testing labs: Support the development of DR-RAC standards, develop appropriate test methods, and invest in DR-RAC testing and certification.
   - Researchers and policymakers: Investigate economic incentives, behavioral drivers, policies, and regulatory mechanisms to accelerate DR-RAC adoption.
3. **Call for investments: Catalyze funding to scale DR-RAC deployment**
   - Public- and private-sector Investments: Mobilize investments to support R&D and manufacture of DR-RACs, scale business models, implement demonstration projects, and support grid modernization to integrate DR.
   - Financial institutions: Develop innovative financing models, such as risk-sharing mechanisms or green bonds, to incentivize the adoption of DR-RACs and implementation of DR initiatives.
   - Government support: Introduce subsidies or tax incentives to reduce the upfront cost of DR-enabled ACs, encouraging manufacturers to integrate DR capabilities.

Endnotes

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Annex

Appendix 1

Status of national DR programs in select nations

DR-RAC programs are at different stages of development across several countries. While some nations have well-established DR frameworks integrated into their energy markets, others are in the early phases of testing and piloting DR-enabled RAC programs. This section summarizes the key aspects of leading global programs.

UNITED STATES

While some states, such as New York and Pennsylvania are beginning to explore DR potential, several states like Florida, Texas, and California already have strong programs in place. DR initiatives in the US since 2021 have achieved estimated peak demand savings of 29 GW and reduced 1,154 GWh.

In the US, DR programs operate mainly as voluntary opt-in systems. Legislative developments have expanded DR capabilities by requiring new appliances to be grid-connected. For example, new water heaters in Oregon and Washington must include communication ports for real-time grid interaction. Some states have mandated that utilities provide DR alternatives; for instance, California's Title 24 energy code requires lighting systems to incorporate DR functionality. Reliability-driven projects such as direct control of home RACs and industrial loads have been a focal point, with such programs in place for over three decades, forming a solid foundation for DR expansion.

SINGAPORE

Singapore's DR programs require participants to have at least 100 kW of load reduction capacity. Several load aggregators exist, primarily targeting commercial and industrial customers through programs like the base interruptible program, demand bidding program, and scheduled load reduction program. The electricity market in Singapore is based on real-time wholesale trading, with half-hour auctions and an Open Electricity Market (OEM) that allows consumers to choose their retailers and load aggregators to sell demand reductions into the OEM. Residential DR participation, however, remains limited.

EUROPE

The potential for DR in Europe is significant, particularly in Norway and Sweden, where DR programs could reduce peak loads by 18.6% by 2050. However, existing DR programs are limited, with pilot programs aimed at understanding DR's impact and identifying barriers such as consumer data privacy concerns.

DR implementation across European Union

Member States fall into two categories:

- **Group 1 & 2**: Countries yet to engage in serious DR reforms or those enabling DR through retailers and distributors.
- **Group 3**: Countries such as Belgium, France, Ireland, and the UK, which have enabled both DR and independent load aggregation.

Belgium and France have made progress in defining independent aggregation roles and adjusting market entry requirements. Belgium's Transmission System Operator (TSO) initiated a pilot in 2016 to test DR participation in its Secondary Reserve. France has also outlined a structured approach to DR application in network codes. In contrast, the UK's capacity market design has made it challenging for demand-side resources to compete.

CHINA

China introduced DR in 2000, launching pilot projects across major cities. The government later implemented policies to guide local load management and stabilize grid operations. In 2015, China set a target for DR to contribute approximately 3% of peak electricity load. DR is recognized as a tool to integrate renewable energy and support China's "Dual Carbon" goals, which aim to boost non-fossil fuel energy consumption to over 80% by 2060.

China has set several ambitious policies designed to integrate and expand use of DR in the power sector. In 2021, the State Council's Action Plan for Carbon Dioxide Peaking set a goal for provincial grids to achieve at least 5% DR capacity by 2030. The following year, **a** follow-up policy required grids to meet 3-5% of maximum load DR capacity by 2025, with higher targets in East, Central, and South China. In 2023, The National Development and Reform Commission (NDRC) and five ministries issued revised measures for electricity demand-side management, prioritizing DR as a key tool for grid stability

By mid-2022, 23 provinces had introduced policies supporting DR pilot programs. Projections indicate that China's grid will need to manage a peak-to-valley load difference of up to 36% by 2025 and 40% (400 GW) by 2030. To address these challenges, China is strengthening its grid management, load control, and renewable energy integration capabilities. The executive summary of DR in China is presented in **Annex 2 of this report.**

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Appendix 2

Executive summary of China report

Demand response (DR) refers to actions taken to address short-term imbalances between the electricity supply and demand or challenges in integrating renewable energy. It primarily relies on economic incentives that encourage electricity users to voluntarily adjust their consumption behaviors based on the power system's needs, achieving peak shaving and valley filling[31] through load shifting, shedding, shaping, or shimmying. DR has been developing in China for over 30 years and is increasingly vital in the electricity system. The Chinese government has introduced policies to encourage DR development to achieve a response capacity of 5% or more of the grid's maximum load by 2030.

Air-conditioning (AC) load accounts for a significant portion of China's electricity consumption, especially during peak periods. Effectively managing the AC load is critical to ensuring a secure power supply. In the residential sector, room air-conditioners (RACs) are typically high electricity consumption appliances, offering greater load flexibility and adjustment capabilities than other household appliances. The integration of intelligent functions enables RACs to interact with power grids, creating opportunities to participate in DR initiatives. AC load reduction serves as a form of DR shedding, leading to load shifting to later hours as the system recovers from the DR event.

With precise DR control strategies, RACs, combined through load aggregation, can play a significant role in peak shaving and energy savings. DR-RACs are predominantly deployed in the industrial and commercial sectors, while residential DR remains in the pilot phase. This study aims to quantify the benefits of adopting DR- RACs in China and introduces the policy and technical requirements necessary for enabling the broad adoption of DR-RAC in China. It explores what it takes to make RACs DR-ready and illustrates these concepts through two pilot cases of DR-RAC development in China: one focusing on a localized implementation model and the other driven by the RAC industry. These pilots highlight the key pathways to making DR-enabled RACs a reality, including policy incentives, industry collaboration, and technological innovation.

Standardization is essential to promote the broad adoption of DR-ready RACs. Standardization is required to unify aspects such as the terminology and definitions, system structures, essential functions, performance indicators, interfaces and communication protocols, operating environments, and security requirements.

KEY RESULTS

- China's DR-RAC system is built on a load aggregation framework, involving grid enterprises from the central and local levels, major RAC manufacturers, ICT service providers, and end users. However, challenges remain for large-scale DR deployment in the residential sector: power market reforms are required, accurate DR control strategies need to be developed, and end-user participation needs to increase.
- The market for DR-ready products is growing aggressively, with the rapid development of ICT technologies. Among the sampled 2,500 RAC products, across several major RAC manufacturers, 47% can be operated from pre-connected mobile phones. This allows users to remotely turn their RACs on or off, adjust the temperature, monitor the operational status from anywhere, and possibly participate in a DR event through an aggregation mechanism.
- Smart RACs were initially developed to enhance user comfort, but these functions also enable interaction with the power grid for DR purposes. These additional functions, acting as a built-in DR capability, do not significantly increase the overall cost of RACs. A socket-connected approach costs approximately $10 USD, which is an affordable option for most residential users.
- In addition, the market is expected to see an upward trend in the sale of affordable RACs with mobile control, driven by the increasing demand for intelligent RAC features and heightened competition among manufacturers for market share and new business opportunities as a load aggregator. All of these will benefit large-scale RAC involvement in DR deployment.
- China implemented a DR-RAC pilot initiative in Huzhou in 2022, where 300 volunteer households joined a DR-RAC initiative. According to estimates by the project team, half a billion Chinese households participated in DR events by increasing their RAC temperature by

1°C for 10 hours; by doing so, they saved 294 GWh of electricity and reduced CO_2 emissions by 0.4 million tons—equivalent to 60% of the emissions produced by a coal power plant with a rated capacity of 100 MW.

China's DR standards are being gradually refined alongside the adoption of new technologies and products, including systems, terminals, interfaces, testing and measurement technologies, and management. However, the creation of unified DR-RAC standards is still in its preliminary stage, and multi-lateral cooperation and collaboration are fundamental for standardization. A number of DR-related standards, most of which are voluntary, have been proposed to promote and regulate the growth of RACs, with the involvement of key stakeholders.

RECOMMENDATIONS

Implementing DR is a complex process that involves multiple dimensions, including product technologies, system solutions, testing methodologies, and close collaboration among various stakeholders. Each of these aspects requires careful planning and execution to ensure the seamless integration of DR into existing frameworks.

At the same time, RACs, as pioneers in DR adoption, can serve as a reference for expanding DR to other household appliances. This approach can help not only broaden the scope of energy-efficient DR initiatives but also enhance user experience. Furthermore, by optimizing energy usage and reducing peak demand, such initiatives can play a crucial role in addressing climate change.

- **Standardizing RACs for DR deployment.** When proposing standards for integrating DR into RACs, it is essential to consider not only technical specifications related to integrating DR into smart grids but also the specific characteristics of RACs as residential appliances. This includes considering systems, terminals, interfaces, inspection and testing procedures, and management practices, across a large number of units as well as end users.
- **Broadening standards from RAC products to systemic solutions.** Systematic research is needed to evaluate the potential opportunities and roles of RACs in DR. This also involves expanding RAC-related standards to other smart appliances in the same apartment to enhance DR aggregation.
- **Innovating new test methods to benefit smart RACs.** The current RAC testing method lags behind the development of RACs, particularly for intelligent functions. An innovative measurement, *Dynamic Test Methods for Energy Performance of Smart Air Conditioners,* aims to enhance RAC energy efficiency testing standards and presents an opportunity to incorporate DR into testing scenarios.
- **Driving major stakeholders' exchange and cooperation.** Successful implementation of DR requires close collaboration between various stakeholders, including policymakers, manufacturers, grid and energy service companies, as well as end users, ensuring they are aligned with the evolving needs of smart grids and residential appliances. Furthermore, cooperation—not only domestically but also internationally—will play a pivotal role in advancing the integration of RACs into DR systems. Engaging in best practices, technical exchanges, and collaborative research can facilitate the creation of international standards and benchmarks for DR-RACs.
- **Expanding pilot mechanisms into a national DR-RAC policy.** It is essential to build on the successful experiences of pilot projects that have optimized DR locally through technological and fiscal measures. These mechanisms cover taxation, green finance, and subsidies and should be easily scalable under similar conditions. Furthermore, it is crucial to design more innovative pilot mechanisms to address China's diverse geographical conditions. By accumulating experience from various DR pilot cases, a comprehensive national policy can be formulated to effectively and efficiently meet DR-RAC requirements nationwide.

To know more read the full China report.

Appendix 3

DR capabilities and interoperability of appliances

Below are the details of some countries in terms of their standards related to DR capabilities and interoperability of appliances, focusing on air conditioners and their role in energy management systems.

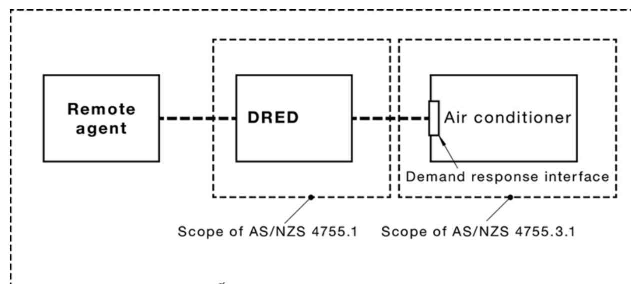
DR STANDARD IN AUSTRALIA

The wider adoption of behind-the-meter Distributed Energy Resource (DER) installations and the resultant uncertainty in power demand have motivated the Australian Energy Market Operator (AEMO) to turn to demand response. AEMO has identified incorporating demand response capabilities into appliances as a key tool to address this new demand and supply challenge. The AS/NZS 4755 is a series of standards that requires selected appliances to have 'demand response modes' that can shift or reduce load. The series was prepared by the Joint Standards Australia/Standards New Zealand Committee EL-054, Remote Demand Management of Electrical Products. The standard aims to improve the security of the energy system and marketplace, ensure reliable energy supply and reduce the cost of energy in Australia.

This series of standards establishes a framework where a range of appliances and manufacturers are all connected and respond to remote signals. A demand response system using an air conditioner that complies with AS/NZS 4755 shall include at least the following, as illustrated in Figure A.1:

- A demand response enabling device (DRED) complying with AS/NZS 4755.1
- A means by which the DRED receives commands from a remote agent
- An air conditioner complying with AS/NZS 4755.3.1 and having a standard interface to connect to an external DRED
- Cabling or other means of transmitting Operational Instructions (OIs) between the DRED and the electrical product.

FIGURE A.1: Scope of AS/NZS 4755



Although the series of standards deal with various documents, the following two documents come under the scope of this report (Figure A.1):

1. AS/NZS 4755.1, Demand response capabilities and supporting technologies for electrical products, Part 1: Framework for demand response capabilities and requirements for demand response enabling devices (DREDs)
2. AS/NZS 4755.3.1, Demand response capabilities and supporting technologies for electrical products, Part 3.1: Interaction of demand response enabling devices and electrical products—Operational instructions and connections for air conditioners

An Air conditioner adhering to the AS/NZS 4755.3.1 standard can be capable of three possible demand response modes (DRMs) - DRM 1 (Compressor OFF), DRM 2 (Operate but at maximum 50% load) and DRM 3 (Operate but at maximum 75% load). Compliance with DRM 1 is mandatory under this standard. The standards provide for physical connection with DRED via either a terminal block or an RJ45 socket. The standard also mandates a standardized set of OIs along with required responses to these instructions. It also includes specifications for labeling and marking compliant products, as well as guidelines for testing and verifying demand response capability.

The two standards work in tandem with several other standards in the region including *Performance of electrical appliances (AS/NZS 3823.2)* and *Testing and rating for performance (ISO 5151)*.

In November 2019, Australian Energy Ministers required that four domestic appliances, including air conditioners (ACs), sold in the country must support demand response by 2023. Additionally, the Government of South Australia mandated that from July 1, 2023, all single and three-phase air conditioners with a cooling capacity of up to 19kW, connected to the South Australian electricity distribution network, must comply with demand response capability requirements as specified in the new Technical Regulator Guideline. These requirements can be met by complying with any listed standards - AS/NZS 4755.3.1:2014, AS/NZS 4755.2 or the equivalent of AS/NZS 4755.3.1.2012. Although appliances must have demand response capabilities, consumer participation in DR programs remains voluntary.

While Australia has been a forerunner in introducing standards for demand response capabilities in air conditioners, several opines that the mandatory adoption of the standard will restrict the demand response market in Australia[3]. The one-way communication requirement and absence of a user override option provided for in the standard may hinder the AC's compatibility and interoperability for modern demand response programs. Moreover, the standard fails to define an independently certified common communication protocol, which is imperative for data-driven intelligent, responsive, and verifiable DR programs.

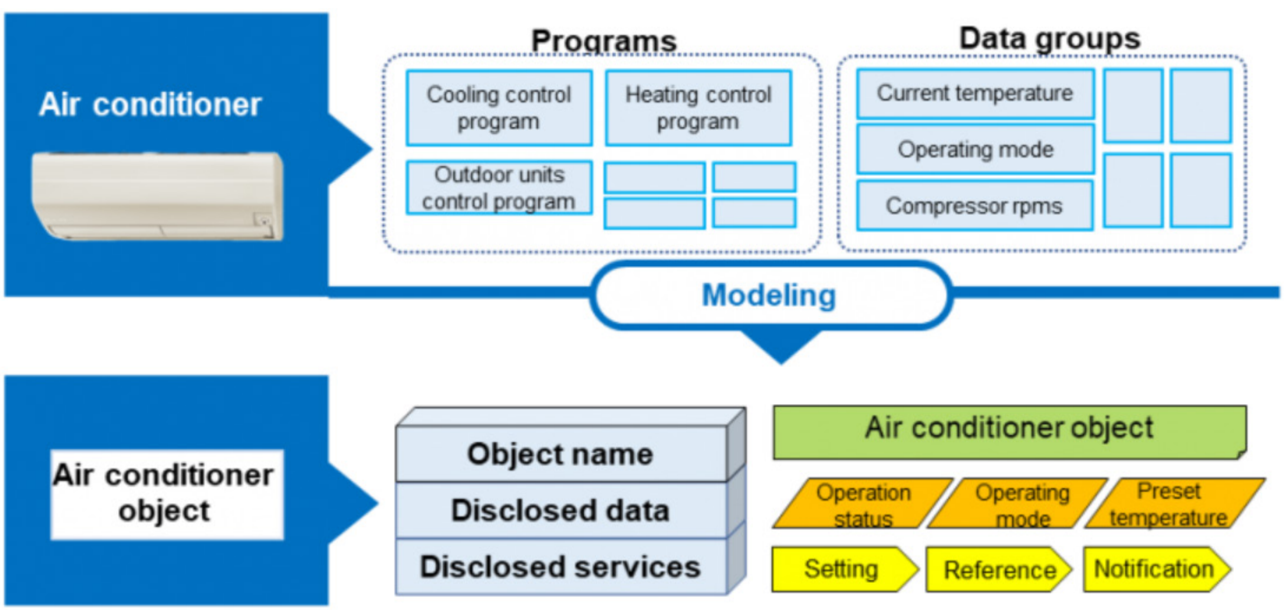
DR STANDARD IN JAPAN

Japan has explored a standard for communication specifications known as Echonet Lite specifications. The open standard network protocol enables resource-saving devices such as sensors and smart home appliances, to support IoT and Home Energy Management Systems (HEMS). The Echonet lite tested and certified appliances claim a high level of interoperability especially for designated "key devices" including air conditioners. Communication can utilize various existing standard transmission media, which possess an IP address or a MAC address. To enhance high interoperability for the key devices including air conditioners, the application communication interface specifications (AIF specifications) are formulated. The AIF specifications define the specific usage of ECHONET Lite at the application level of each device including,

- Installed device objects
- Combination of supported properties
- Timeout after sending a request until receiving a response
- Sequence assuming concrete use case

ECHONET Lite defines control commands that model the diverse programs and data groups of various devices as device objects (Figure A.2). Over 120 device objects ranging from sensors to energy saving devices such as air conditioners and energy-storing devices such as batteries have been defined.

FIGURE A.2: Modeling and data structure of air conditioners in ECHONET lite protocol



Specification documents that make up the ECHONET Lite are provided below:

1. For AIF: ISO/IEC 14543-4-301 Application protocols for home air conditioners and controllers
2. For ECHONET device object: IEC 62394:2022 Service diagnostic interface for consumer electronics products and networks
3. ECHONET Lite communication middleware: ISO/IEC 14543-4-3 Application layer interface to lower communications layers for network-enhanced control devices of HES Class 1

The reliability of AIF specification certification testing is ensured by conducting standard conformity tests by a third party approved by the ECHONET Consortium. ECHONET Consortium is an organization that promotes ECHONET Lite standards and ECHONET Lite AIF specifications for smart home appliances in Japan. The ECHONET Consortium itself has about 260 members, from the home appliances, electricity, electronics, energy, residential, and IT industries, as well as from academic and research fields. Its managing members are Mitsubishi Electric Corporation, Panasonic Holdings Corporation, Sharp Corporation, Tokyo Electric Power Company Holdings, Inc., and Toshiba Corporation. The ECHONET Lite-certified products have compatibility across installations and link devices from different manufacturers. The support of appliance manufacturers along with the recommendation by the Japanese as a communication standard for HEMS (Home Energy Management System) equipment ensures a high level of interoperability for the devices.

The "ECHONET Lite communication middleware" and "device object detailed specifications", which are the main parts of the ECHONET Lite Specifications, have been certified as international standard specifications by IEC and ISO/IEC. ECHONET Lite enables two-way communication between smart appliances and energy management systems (EMS) or utility providers. It also allows energy providers or DR aggregators to remotely control or adjust appliance settings during peak demand periods.

ECHONET Lite is predominantly used in Japan and has a limited global presence, which restricts its adoption and reach in other regions. As a result, the ecosystem of compatible devices, services, and support is smaller, and its interoperability with devices from manufacturers outside Japan is constrained. While ECHONET Lite supports a seamless plug-and-play experience, its security framework is often considered weaker than newer protocols. However, the protocol being open and royalty-free increases its possibility of wider adoption as smart homes are becoming more popular. There have also been studies exploring bridging ECHONET Lite with other communication protocols such as OpenADR and Matter, especially in Japan.

DR STANDARDS IN SINGAPORE

In Singapore, DR is an essential component of the country's strategy to optimize energy usage and enhance grid reliability, particularly in the face of increasing energy consumption and renewable energy integration. The Energy Market Authority (EMA) of Singapore has implemented several initiatives and regulatory frameworks to encourage DR programs across residential, commercial, and industrial sectors. Guidelines for the implementation of demand response in the nation are provided by the Singapore Standards (SS) series, namely SS 600, which sets the requirements for technologies and systems that allow customers to shift or reduce their electricity demand during peak hours, frequently in exchange for credits or reduced electricity rates. The framework described in SS 600 comprises technical specifications for measurement systems, communication protocols, and the integration of DR with grid operations, guaranteeing that participating devices can efficiently respond to utility signals.

Singapore has created a more specialized set of standards for smart appliances in addition to SS 600. The ability to be remotely managed via smart grids or energy management systems (EMS) is the main focus of the standards for smart appliances, which include air conditioners and other electrical devices. For these devices to function flawlessly within the DR framework, they must adhere to specific interoperability and communication standards.

The EMA oversees Singapore's Demand Response Program (DRP), which encourages commercial and industrial customers to engage in DR by modifying their energy use during peak hours or in the event of a system emergency. Although there are increasing incentives for smart appliances that can be incorporated into home energy management systems (HEMS) to support DR, residential consumers have no obligation to participate.

Singapore's DR strategy heavily relies on the integration of advanced metering infrastructure (AMI) and smart grid technology. Better control of the balance between supply and demand is made possible by these technologies, which allow for real-time monitoring and communication between utilities and customers.

The Singapore Smart Grid Masterplan has advocated for the wider use of DR methods in recent years. As part of these initiatives, standardized communication protocols like OpenADR (Automated Demand Response), which is increasingly used in Singapore's DR programs, are being used to improve the interoperability of smart devices.

Although DR is still emerging in Singapore, the nation's continuing advancement in energy management and DR integration is being facilitated by a number of factors, including well-defined regulatory frameworks, smart appliance standards, and the need for cutting-edge grid technology. DR will become more and more important in balancing supply and demand on the grid as Singapore keeps increasing its usage of smart technologies and renewable energy.

DR STANDARDS IN USA

Progress regulating HVAC/R appliances in the U.S. for FD is limited to the development of a handful of standards, with the exception of residential electric storage water heaters (ESWH - addressed later). In 2019, AHRI published AHRI 1380 for demand response for variable-capacity residential and small commercial HVAC equipment. Recently AHRI initiated the development of a commercial water heater technical standard, AHRI 1530-202X . Currently, we are not aware of any active work in states to consider adopting either of these technical standards in a flexible demand appliance standard. Despite the lack of standards, there are lots of utility AC DR programs in the US.

Two approaches have been employed by states to regulate the communications on demand flexible ESWHs. Washington and Oregon require compliance with the CTA-2045 technical standard, and Colorado requires compliance with the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) 1430-2022 technical standard. The AHRI standard was first published in December 2022, after Oregon and Washington final rules became effective.

Here we are using the term 'technical standard' to refer to a specification of criteria that the communication interface must meet. CTA-2045 includes prescriptive requirements for the connectors (port and plug) and the basic set of signals that can be sent and received. AHRI 1430 incorporates these requirements for ESWHs. The scope of CTA-2045 includes many different devices, including ESWHs. The scope of AHRI 1430 is only residential ESWHs, specifying that the communications interface requires compliance with CTA 2045 level 2b, at a minimum. Importantly, AHRI 1430 also prescribes a method of test and testing requirements. AHRI 1430 and CTA-2045 technical standards are harmonized, but AHRI 1430 requires a further step of testing to verify that DF signals are sent and received as expected by the CTA-2045 port and plug.

Note that state flexible demand appliance standards only regulate the CTA-2045 socket on the ESWH (A in Figure 3). These sockets can pair with CTA-2045 compliant communication modules (B in Figure 3). This module can be swapped out during the lifetime of the equipment, if necessary. Since the current regulations only require the port, the module must be attached before full DF-readiness is accomplished. To complete setup and enrollment, it is likely that utilities will purchase the CTA-2045 modules and provide them to consumers (or else, provide a marketplace for consumers to purchase).

FIGURE A.3: (LEFT) Retrofit DR hardware installed on an electric resistance water heater.

The two black wires are added to monitor the water temperature at the top and bottom of the storage tank Armada Power, "LCS2400 Wifi.". Source: DOE, "Heat Pump Water Heater - Load Shifting.". (RIGHT) A CTA-2045 compliant communications module, denoted as 'B' is plugged into a CTA-2045 compliant port, denoted as 'A', on a heat pump water heater. Note that CTA-2045 ports are also able to be plugged into electric resistance water heaters. Source: Sukow, "Wireless Functions Add Value to Armada Power Water Heater Control."

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