Leveraging an Understanding of RAC Usage in the Residential Sector to Support India's Climate Change Commitment

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ABSTRACT

India is at the cusp of an imminent and exponential growth in the room air conditioner (RAC) market. This will pose severe environmental and societal impacts – strain on the electricity grid, significantly large added power generation capacity, peak load impact causing sharp social inequity, and an enormous carbon footprint. Now is the critical window of opportunity to mitigate these adverse effects. However, existing literature does not give any meaningful insights into usage patterns of the largest RAC user group (i.e., the residential sector). To bridge this data gap, the authors designed a survey to gather a first-of-its-kind nationwide dataset on the current residential RAC stock in India, and particularly on how indoor thermal comfort preferences of RAC users relate with climatic conditions, seasons, run-hours, set points, fan use, and the ingress of solar insolation. The primary objectives of this paper are: (a) to provide a meaningful insight into the residential RAC usage patterns, and (b) to explore the applicability of adaptive thermal comfort as a meaningful strategy towards addressing India escalating cooling energy needs. This paper presents the key outcomes of the survey which can have broad-reaching applicability and relevance for further research and projects related to thermal comfort in residences.

Background

India's cooling energy needs are projected to grow significantly in the near future, with far reaching environmental and societal impacts such as, significant additional power generation capacity, peak load impacts, an enormous greenhouse gas (GHG) footprint, and health and well-being concerns.

The urgency of addressing India's space cooling challenge is further underscored against the backdrop of two recent international climate change agreements: first is the Paris Agreement (2015) within the United Nations Framework Convention on Climate Change (UNFCCC) wherein India, through its Nationally Determined Contribution (NDC), has committed to reduce the emissions intensity of its Gross Domestic Product (GDP) by 33-35% by 2030 over the 2005 baseline (Ministry of Environment, Forest and Climate Change 2015); second is the Kigali Amendment to the Montreal Protocol (2016) wherein India has committed to freeze the use of HFCs by 2028 over the 2024-26 baseline (CEEW 2017).

In this context, the Government of India (GoI) has elevated addressing India's cooling challenge as a national priority and is actively engaged in developing a National Cooling Action Plan (NCAP), scheduled for release in September, 2018. A recent study by Alliance for an Energy Efficient Economy (AEEE), projects that within the next decade, India's cooling energy demand could grow up to 3 times over the current level under the business as usual scenario (AEEE 2018). Of this overall nationwide cooling demand, space cooling, that is, comfort cooling in the building sector, comprises 50% of the total, and also shows the maximum improvement potential in terms of energy saving and carbon emission reduction. Within space cooling, room air conditioners (RACs) contribute ~45% of the energy consumption, and represent a significant share (50%) of the sector's savings potential.

Thus, RAC is a very important part of the dialogue on addressing India's cooling challenge. India currently has a low penetration of RACs (5-7%) but is poised to become one of the largest RAC markets in the world in the next decade or so (LBNL 2015) owing to rapid urbanization and electrification, construction boom, a growing middle class, decreasing RAC prices, and soaring temperatures. Figure 1 depicts the predicted growth in India's installed RAC stock – multiple studies, namely by India Energy Security Scenarios (IESS), Lawrence Berkeley National Laboratory (LBNL), Council on Energy, Environment and Water (CEEW), and AEEE, unanimously project a significant increase, albeit to different degrees. Per a study by LBNL, the peak demand from RACs alone could be 143 GW in 2030, equivalent to 250+ additional power plants of 500 MW capacity each (LBNL 2014).

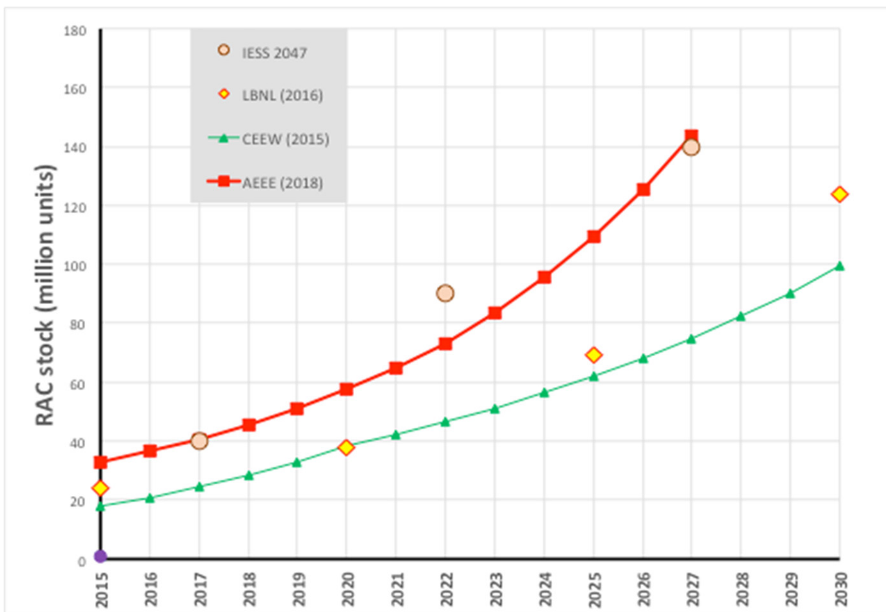

Figure 1. Estimated growth in India's RAC stock. *Sources:* "India Energy Security Scenarios" 2018, LBNL 2014, CEEW 2015 and AEEE 2018.

Objective

With the majority of India's RAC stock ('stock' in this context implies the deployed number of units) yet to come, now is the critical window of opportunity to build in proactive interventions that will have a meaningful impact on the future RAC energy consumption and emission. Given the criticality of what is at stake, all possible levers will have to be pulled to make a collective difference: building energy efficiency, equipment efficiency, alternative cooling technologies, and user behavioral adaptations.

Per Bureau of Energy Efficiency (BEE) inputs, 60% of the existing RAC stock is utilized in the residential sector, and this share is expected to grow to 70% by 2030. However, intelligence on the RAC usage patterns in Indian homes is seriously lacking. More specifically, the authors wanted to explore the feasibility and the potential impact of user adaptation on RAC usage with this underlying question: what is the nationwide energy savings potential through the adoption of adaptive thermal comfort (ATC) standards in the Indian residential sector? However, a careful scanning of relevant literature did not provide any meaningful insights into this, especially the preferred temperature set points (i.e., RAC thermostat settings) in Indian homes. While a 2014 Gujarat-centric study presents some indicators on the RAC stock typology and energy consumption (Garg et al. 2014), there is little information available on the overall usage pattern of RACs in residences. To address this data gap, the authors undertook a first-of-its-kind nationwide survey geared towards understanding the RAC usage pattern in the residential sector: 'Mapping the Use of Air Conditioners (ACs) in Indian Households'. This paper presents the key outcomes of the survey that can have broad-reaching applicability and relevance for further research and projects related to thermal comfort in residences. Some of the outcomes are already being incorporated as an important input towards the development of India's National Cooling Action Plan.

The Residential RAC Survey

In designing the survey questionnaire, the need to keep it quick-paced was balanced with the need to make it comprehensive so that a meaningful dataset could be generated for wide-ranging use. The questionnaire was short, anonymous, easy to fill out, and comprised 13 questions covering geographical location, house & household size, RAC number, type & runtime, set point preference, and fan use.

The primary objectives of the survey were: (a) to provide a meaningful insight into the residential RAC usage patterns, and (b) to explore ATC's applicability as a meaningful strategy towards addressing India escalating cooling energy needs.

Administering the Survey

The survey was constructed on Google Forms and administered online by popularizing it on LinkedIn, Facebook, Twitter, WhatsApp, and email. Although a fairly large number of varied responses were collected by deploying this strategy, the team felt that limiting the survey to an internet-savvy respondent pool may introduce a self-selection bias. Hence, the survey was also physically administered with the help of student-surveyors in the cities of Hyderabad, Chennai, Kolkata, Faridabad, Ahmedabad and Jaipur – these surveys particularly focused on low to mid-income category households (without strictly sticking to definition of these categories) to obtain a holistic overview of RAC users.

Distribution of Indian States by Climate

Per National Building Code (2005) (Bureau of Indian Standards 2005), India is divided into five climate zones i.e. hot-dry, warm-humid, composite, temperate and cold (Figure 2). The temperature and relative humidity (RH) characteristics of these five climates are captured in Table 1. As this study is cooling-centric, the climate types considered were limited to hot-dry, warm-humid and composite; each State (or Union Territory (UT)) was then assigned 1 climate type – the one that is most prevalent in it (Table 2).

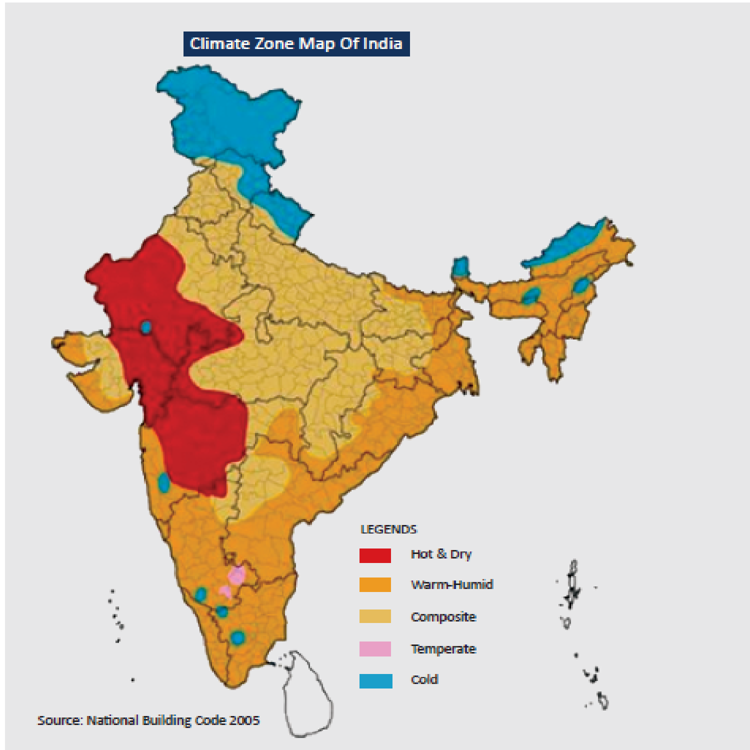

Figure 2. Climate zone map of India. *Source:* Bureau of Indian Standards 2005.

Table 1. Temperature and RH characteristics of India's climate types

Climate type	Summer time temperature	Winter time temperature	RH
Hot-dry	20-45 ºC	0-25 ºC	55%
Warm-humid	25–35 ºC	20–30 ºC.	70-90%
Composite	27-43 ºC	4-25 ºC	20-25% (Dry) 55-95% (Wet)
Temperate	17-34 ºC	16-33 ºC	<75%
Cold	17–30 ºC	-3 ºC to 8 ºC	70-80%

Table 2. Distribution of Indian States by climate

Climate type	State (or UT)
Hot-dry	Gujarat, Maharashtra, Rajasthan
Warm-humid	Andhra Pradesh, Telangana, Assam, Goa, Karnataka, Kerala, Manipur, Meghalaya, Mizoram, Nagaland, Orissa, Tamil Nadu, Tripura, West Bengal
Composite	Bihar, Chhattisgarh, Haryana, Jharkhand, Madhya Pradesh, Punjab, Uttar Pradesh, Chandigarh, Delhi

Extent of the Survey

The survey saw a well-rounded response of 975 households from 100+ towns and cities covering most States and UTs in the three climate zones of interest; the responses were almost equally divided between the climate zones (i.e., hot-dry, warm-humid and composite) – of these, approximately two-thirds were collected online while the rest were from physical surveys.

Outcomes of the Survey and Main Inferences

RAC Distribution by Household Size

The survey covered 1 BHK (bedroom, hall and kitchen) to more than 3 BHK houses. The survey average of household size ('household size' here implies the number of people living as a unit) was 3.7. Per Census of India data, the mean household size has been on a downward trend, sized 5.3 in 2001 and 4.9 in 2011 ("Census of India Website: Office of The Registrar General & Census Commissioner, India" 2018) – it can be inferred that households using air-conditioning are smaller in size than the national average. The survey average of the number of RACs used per household was 1.7 – this can be corroborated by market intelligence that those households which have already installed one air conditioning unit are more likely to purchase additional cooling systems than households that do not have any cooling products (BSRIA 2016). National Sample Survey Office (NSSO) (2001) reports 1.2 RACs/household; market intelligence supports an increase in the number of RACs/household (Prayas (Energy Group) 2010), however, a ~40% increase in less than 20 years can be viewed as aggressive. Figure 3 presents a fairly linear and predictable correlation between house & household size and number of RACs.

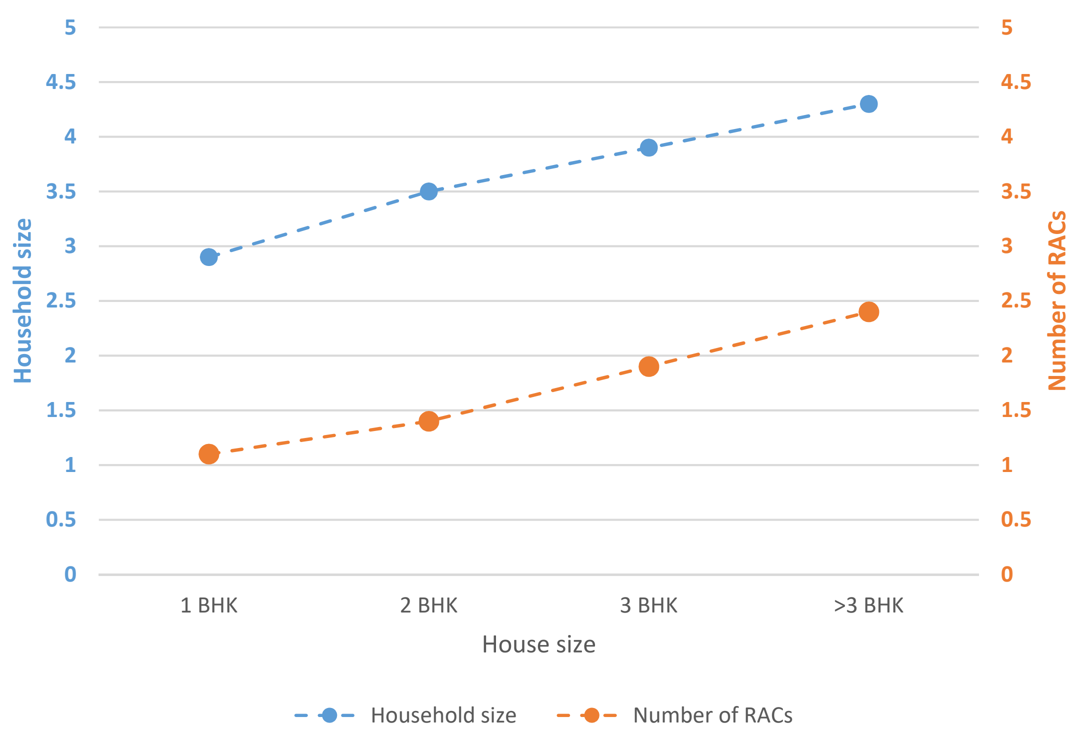

Figure 3. Correlation between house & household size and number of RACs.

RAC Characteristics

The observed characteristics of the surveyed stock are discussed below.

Tonnage. 1.5 tonne of refrigeration (TR) RACs are most widely used in Indian homes, at 61% of the survey dataset (Figure 4).

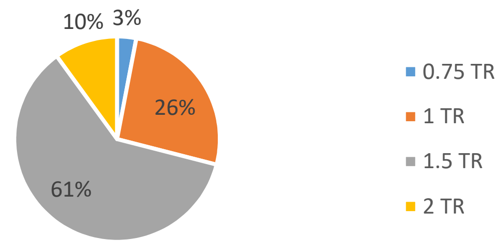

Figure 4. RAC distribution by tonnage.

Configuration. Split RACs are most widely used in Indian homes, at 68% of the survey dataset (Figure 5).

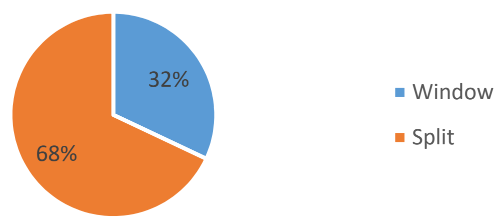

Figure 5. RAC distribution by configuration.

Age. The existing residential RAC stock of India is fairly new in terms of age of the equipment, with nearly half of the stock being less than three years old (Figure 6). Less than 15% of the RAC equipment is greater than 7 years old. This confirms that the equipment lifespan of residential RACs is shorter than that of commercial RACs in India. 7-years seems to be the turnover rate of the residential RAC, beyond which users tend to replace with new equipment. This finding also verifies the notion that with a rising population, a growing middleclass, soaring temperatures, increasing built-up area, and the low existing penetration of RACs in the residential sector, India is poised to witness a larger uptake of RACs in the next decade.

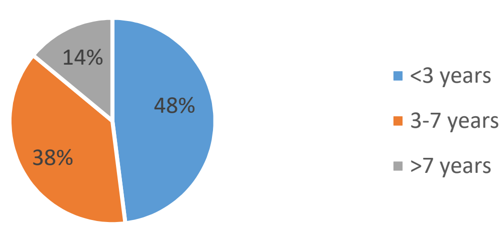

Figure 6. RAC distribution by age.

Star rating. The BEE 3-star RAC is the most common consumer choice (Figure 7), followed by 5-star rated as the next preferred choice. >40% of the stock is 3-star RACs, and ~25% are 5-star RACs. 4-star RAC is a relatively uncommon choice, and perhaps this can be linked with the cost-benefit equation. The cost-benefit ratio of the current 3-star seems optimal in terms of market preference. However, users that do spend above a 3-star's price point go all the way and get the benefits of a 5-star. In Thailand, an aggressive promotional campaign helped move the market average from 3 to above 4 stars. However, for India, where price-sensitivity will continue to play a key role at least in the foreseeable future, the cost-benefit equation will remain the key driver for the consumer choice amongst star-ratings. BEE publishes the number of appliances produced since 2011-12 that fall within its mandatory energy (or star) labelling program (BEE 2018) – our survey results align with BEE's dataset on tonnage and star-ratings.

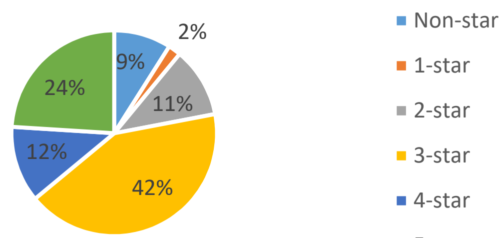

Figure 7. RAC distribution by tonnage star rating.

RAC Operational Preferences

The survey explores three primary operational parameters: the preferred set point, runtime, and fan use concurrent with RAC operation. Preferred set point implies the most widely used thermostat setting for the RAC operation, and runtime implies the annual hours of RAC operation.

There is limited thermal comfort research in India, and as such, the thermal comfort standards are not defined in Indian building codes thus far (though ECBC-Residential, soon to be released in 2018, will likely strive to change that). For now, for all climate and building types, the National Building Code of India specifies the use of two narrow ranges of temperature: summer (23–26°C) and winter (21–23°C). These standards are based on ASHRAE, which are not validated through empirical studies on local subjects (Chandel and Aggarwal 2012). Our survey shows that RAC usage is predominantly limited to summer months. Figure 8 presents the overall distribution of temperature set point preference. The key observations are:

- 24°C is the most preferred set point nationwide, adopted by 20% of the survey population
- 46% of the survey population operates RACs at temperatures below 24°C.

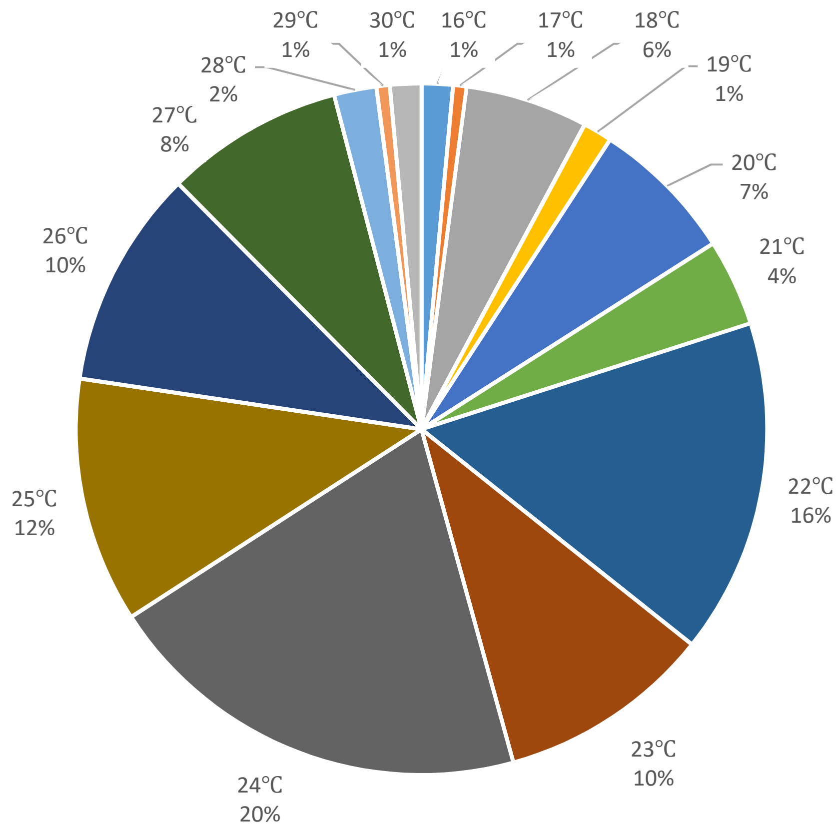

Figure 8. Nation-wide RAC set point preferences.

Through secondary literature review (Dhaka, Mathur and Garg 2012), the neutral temperature range for each of these climate zones was identified as a reference. The responses were aggregated into the three clime zones in order to understand any correlations between these climate zones and the operational parameters. Table 4 summarizes the findings grouped by climate zones.

Table 4. RAC operational preferences presented by climate zone

	Hot-dry	Warm-humid	Composite
Neutral temperature range	23.7 – 28.0°C	25.2 – 27.5°C	24.3 – 27.8°C
Most preferred set point per climate zone	24°C (19%)	24°C (27%)	22°C (20%)
Households that operate RAC below 24°C (most preferred nationwide)	37%	55%	45%
Households that use RAC set point in neutral range	61%	17%	52%
Households that use RAC set point below neutral range	37%	82%	45%
Annual runtime (hour)	1355	1421	1635
Concurrent fan use	65%	59%	77%

Exploring correlation between climate zones and operational preferences. Two observations that stand out are:

- The composite climate zone shows preference for a lower set point at 22°C, has the longest annual run-hours, and also shows the highest percentage of concurrent fan use.
- Warm-humid climate has the highest portion of its population that operates at set points below 24°C.

That said, the survey suggests that the variations, particularly in temperature set points are not significant; we observed that the temperature set point distribution is fairly uniformly scattered across all climate zones. Secondly, we noticed that the percentage households operating within the neutral range is more of a function of the width of the neutral range; since, the neutral temperature zone is the narrowest in the warm-humid climate zone, most users operate RACs outside the neutral zone. Our data set points to a moderate correlation with the climate zones. It appears that set points are more of a psychological preference rather than a direct physiological response; interestingly, we also noted a preference for even set points over odd set points.

RAC runtime is highest in the composite climate zone, where the seasonal disparity in runtime is also most obvious. Figure 9 plots the RAC runtime season-wise for each of the climate types. The survey results also highlighted that those living in houses the roofs of which are exposed to the sun (like those living on the top floor of apartment buildings) operated their air-conditioners up to 10% longer than the average to reach the adequate indoor thermal comfort level. The nation-wide average RAC runtime is 1482 hours/year.

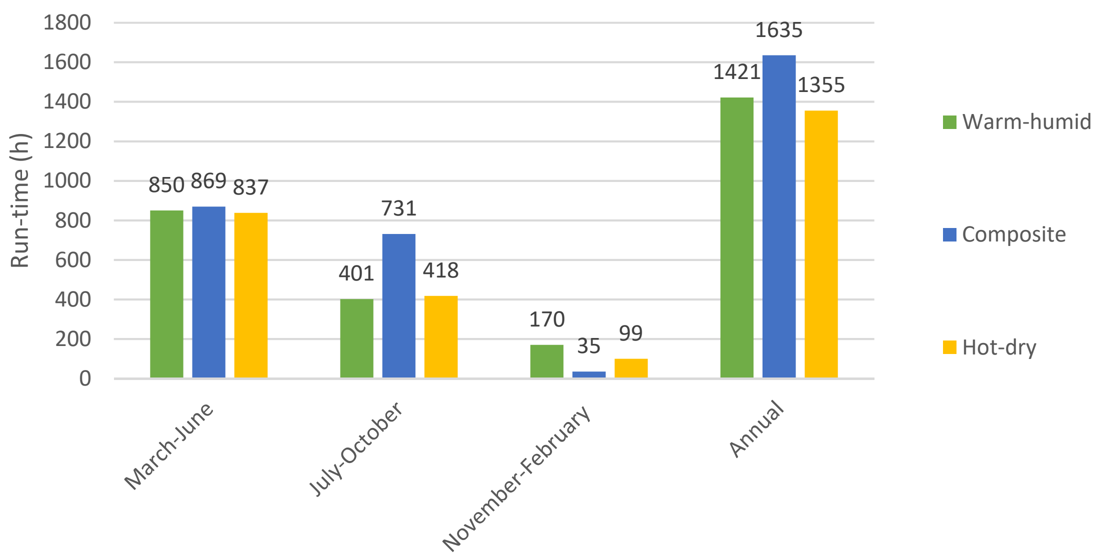

Figure 9. Average annual runtime of RAC per climate-zone and season.

It was observed that a significant proportion of people (66% as an overall aggregate) prefer using a fan in conjunction with air-conditioning. This strengthens the case for the applicability of adaptive thermal comfort in the residential sector, since air movement can help widen the ATC temperature range (Humphreys, Nicol and Roaf 2016): fans are very pervasive in Indian homes and can almost be thought of as a sociocultural element that all houses are fitted with ceiling fans as default.

Exploring correlation with power quality. Premised on the differing quality of power and number of outages in different towns and cities of India ("Prayas-ESMI" 2018), the annual RAC runtime was analyzed separately for Tier-1 cities, i.e. Ahmedabad, Bangalore, Chennai, Kolkata, Mumbai, New Delhi, Pune and Hyderabad, versus the other cities surveyed, where the quality of power is decidedly worse. However, our dataset shows no significant difference between the runtimes – this can likely be attributed to the widespread use of diesel generator sets to power homes during power outages. The population category that currently purchases RACs also typically can afford an infrastructure for continued operations during power outages. As the population pool of RAC purchasers expands to include a wider income group, this correlation may become more apparent and relevant. We suggest that this topic should be further explored as a future study, more specifically designed to understand the RAC market penetration in cities with power supply or quality issues.

Potential Impact of ATC Adoption in the Residential Sector: A Macro View

Applying the above findings from the survey, the authors present a macro-level view of the possible energy and emission reduction potential from the adoption of ATC practices. This macro-level estimate should be further refined with detailed modeling efforts (which is not within the scope of this paper). As aforementioned, the intention of the survey and the paper is to validate ATC's place as a meaningful strategy towards addressing India's escalating cooling energy needs.

The residential RAC usage amounts to ~27 TWh of electricity consumption, and ~32 million tCO2e of carbon emissions. By 2027, in a business-as-usual and moderate growth scenario, this is projected to increase to ~108 TWh of electricity consumption, and ~180 million tCO2e of carbon emissions (AEEE 2018). Upcoming residential buildings can be designed to exploit natural ventilation and mixed mode operations to meet occupants' thermal comfort requirements. The set point can be set above the most preferred set point indicated by the survey, especially when fans are used concurrently to provide assisted air motion. The estimated reduction in Energy Performance Index (EPI) for heating, ventilation and air-conditioning (HVAC) per degree Celsius increase in set point setting is 5-6% (Manu et al. 2016). Per our broad analysis, if ATC standards were to drive for a shift in the preferred set-point (22°C and 24°C) up to 2°C, it could amount to 10-14% savings in India's residential RAC energy consumption in 2027, i.e. savings of up to ~14 TWh of energy.

Conclusion

In the whirlwind of an increasing population, rising temperatures, and an aspirational middleclass, India finds itself in the eye of a perfect 'cooling' storm, against the backdrop of important national developmental commitments and international climate change mitigation targets. Multiple studies unanimously predict a significant increase in the RAC stock in India in the next decade or so with severe societal and environmental bearings. Given the limited understanding of largest RAC consuming sector, i.e. the residential sector, this study aims to bridge the knowledge gap and provides a meaningful and substantial view into the residential RAC stock characteristics and the propensity of RAC usage in Indian homes. This study also validates that ATC is a viable strategy – a proverbial low-hanging fruit – that will help reduce India's growing cooling demand with little capital intervention. Listed below are the key findings detailed out in this paper:

- A significant proportion of the population (46%) tends to operate RACs at temperatures below 24°C. This indicates that the there is a wide band of population that lends itself to the applicability of adaptive thermal comfort standards.
- A large share of RAC users (66%) prefer using a fan in conjunction with air-conditioning. This strengthens the case for the applicability of adaptive thermal comfort in the residential sector, since air movement can help widen the ATC temperature range.
- Our dataset point to only a moderate correlation between climate zones and indoor set point temperatures. It appears that set points may be more of a psychological preference rather than a strictly physiological response.
- With a combination of strong awareness drive and incentivizing lower consumption, the residential sector could be driven towards wider adoption of adaptive thermal comfort practices, thus driving down the energy consumption and emissions from RAC usage.

All in all, this study revisits the dialogue on India's climate change promises and targets from the perspective of thermal comfort and space cooling in the Indian residential sector and presents a robust dataset with a wide-ranging applicability on a carbon-intensive and prevalent cooling appliance.

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