A Nationwide Empirical Study Of Residential Electricity Use In India

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ABSTRACT: Electricity demand from urban residential buildings in India is projected to rise driven by growth in air conditioning (AC). This paper empirically examines the seasonal variation (summer, winter) of residential electricity use in India using statistical analyses of survey data of 1,537 households with AC units (in the form of room AC units) representing four climatic zones and income groups. The survey data includes information on household characteristics, socio-demographics, cooling and non-cooling appliances, electricity use in summer and winter and level of energy awareness. High income households (n: 507) reported the highest mean monthly summer electricity consumption at 349 kWh followed by middle income households (n: 405) at 272 kWh, while low income households (n: 507) experienced the lowest mean monthly summer electricity consumption of 216 kWh. Mean monthly electricity use in summer was lowest in the milder temperate climate zone as compared to the more extreme composite and warm humid zones. When number of AC units increased from one to three or more ACs, residential electricity consumption (REC) almost doubled across summer and winter seasons. In households where the set-point temperature was 19°C, REC was found to be double that of households with 21°C. Based on the statistical method of Least Absolute Shrinkage and Selection Operator (LASSO) method, family size, floor area (m^2) and non-cooling appliances had the biggest influence on electricity use of AC households. It is vital that residential energy policy considers these factors along with the significant seasonal variation in electricity use prevalent in households with AC units.
KEYWORDS: Residential, Electricity, Survey, Household

1. INTRODUCTION

Cooling demand (mainly in the form of room-air conditioners) has been found to be a key driver of residential energy consumption in India, even though India has one of the lowest access to cooling across the world with per capita cooling consumption at 69kWh [1]. India also has the highest distribution of cooling degree-days anywhere in the world [1]. Rapid urbanization, higher incomes, lifestyle preferences and rising temperatures are driving more Indians to buy space cooling appliances. Complementary to this are the air conditioners sales projections in India which are expected to grow sharply from 42 million in 2019 to 240 million units in 2030 which will further increase the residential electricity demand [2]. In anticipation of this increase, Government of India launched the India Cooling Action Plan (ICAP) in 2019 which aims to reduce cooling demand across all sectors by 20-25% by 2037-38. ICAP projects that households with an AC unit would use AC for eight hours every day for five months a year [2]. The ownership and use of air conditioner (AC) was a key factor in determining the household's electricity demand especially during cooling season.

It is vital to explore characterise residential electricity use in India based on air-conditioning (AC). To date most of the studies have used survey-based approach for a particular region or climatic zone in India. Nationwide studies on residential electricity use in India are missing in Literature. Khosla et al., identified that as more people are exposed to ACs at work or school, AC use was expected to increase by 37%; this is especially concerning if more households adopt home-working post-pandemic [3].

The literature review identified a wide array of variables through studies that characterise residential electricity consumption (REC) for an Indian context. The most commonly used variables were cost of electricity per unit, household characteristics (type of dwelling, ownership of dwelling, age of dwelling, BHK, floor area), non-AC appliances and AC characteristics (BEE star rating, tonnage, age, number of units and usage, year of purchase, condition), physical characteristics and socio-economic characteristics (family size, income, age , gender, education of primary householder) [4-7] The literature review also found that electricity demand summer was highest in the summer months despite prices inelasticity, possibly due to higher ambient temperatures [8]. It was also found that there was substantial variation in the usage and pattern of electricity use depending on income levels, climate and geography. Climatic variation is especially important since composite, warm-humid and hot-dry climate zones cover approximately 80% of the total geographical area of India and majority of the population live in these climate zones. The density of population in the cold climate zone is low when compared to other climate zones. Similarly, temperate climate zone covers a small geographical area [9, 10]. Debnath et al., captured the variation in usage of AC and other space cooling devices seasonally and found several interesting behaviours based on AC patterns of the residents in the warm-humid region [11]. It is clear although that there are limited empirical studies in India characterising electricity use of AC households across different climatic zones. This nationwide understanding of electricity use and its key drivers is necessary to curtail the rising demand of the residential sector.

To address these gaps, this paper empirically investigates the magnitude and causes of climatic and seasonal variation of residential electricity use using statistical analyses of survey data gathered for 1,537 urban AC households in India. The study also identifies key drivers of residential electricity consumption in AC households to inform energy policy.

2. METHODOLOGY AND DATASET

This study conducted statistical analyses of survey data gathered by the NEEM-CLASP study. The data was gathered using face-to-face interview based questionnaire survey across during 2018-19. Complete dataset was available for 1,537 households with one or more AC units. The households were located in four climatic zones covering composite, warm-humid, hot-dry and temperate zones.

The survey data were checked for inconsistencies in responses (ex: discontinuity in data), straight-line responses to only required questions (ex: neutral to every environment behaviour awareness), odd responses (ex: Only 32 kids in the dwelling with no adults) and missing responses or partially filled forms. Finally, outlier data were removed from further analysis as including these can skew results. Calculation of annual usage hours from energy use per minute, hour, day and month was calculated for all electrical appliances. The selected variables were then checked for data availability using frequency tables for any missing values. The final filtered variables were then checked again for any outliers and other erroneous data.

The households were categorised into Low (LIG)/medium (MIG)/high (HIG) income groups based on the Pradhan Mantri Awas Yojana. Here the LIG households earn an annual income of less than INR 6 lakhs rupees, MIG were grouped under yearly earnings between INR 6-12 lakhs while HIG earns more than INR12 lakhs per annum. Summer and winter period was defined by the perception of the surveyed residents. The survey data was analysed statistically at the overall sample level, climatic zone, income group and seasons to examine the correlation between variables.

2.1 Data variables used for analysis

Pearson correlation analysis was done to identify correlations among variables. LASSO regression was then used to identify the key drivers of seasonal electricity consumption. The survey variables that were analysed are shown in table 1.

Table 1*:*
Key variables used from the survey

Variable group	Variable name and categories
Physical characteristics	Climatic zone (Composite, Temperate, Warm-humid, Hot-dry)
	Type of house (Flats/Apartment in a society, Flats/Apartment-standalone, Villas (gated community), Independent houses/bungalows)
	House size (1BHK, 2BHK,3BHK,4 or more BHK)
	Built up area (m2)
Household characteristics	Income group (LIG, HIG, MIG)
	Family size (Number of residents)
Cooling appliances: Air conditioners	Number of AC units (1AC,2AC, 3 or more AC)
	AC usage hours per night and day
	AC set point temperature(˚ C)
	Type of AC unit (Window, Split with or without inverter technology)
	Age of AC units (< 1 year, 1-5 years, 5-10 years, > 10 years)
	Cooling capacity of AC units (Ton)
	Condition of AC units (First hand, Second hand)
Cooling appliances: non -AC	Number of Fans [Ceiling fans, Wall/table/mounted fans] and desert coolers
Purchasing behaviours	Very concerned about environment and always purchase star rated appliances
	Prefer to purchase star rated appliances
	Somewhat concerned about environment but no purchases on this
	Importance to cost and performance than environment
Energy awareness of environment	Changed appliance settings with respect to weather
	Switch-off Appliances when not in use
	Neither aware nor concerned on environmental issues
Electricity use	Mean monthly electricity use in summer

	(kWh/month), Mean monthly electricity use in winter (kWh/month)

3. RESULTS

The study sample of 1,537 households was split by income group into 507 HIG households, 625 LIG households and 405 MIG households. About 48% of the household sample occupied independent houses while 52% were based in apartments (standalone or in a society). The mean built-up area was 98 m^2 with a mean of five residents per household. While 37% of the households were located in warm-humid climatic zone and a similar percentage in the composite climate zone, 20% were based in the hot-dry climate zone, and less than 10% of households were in the temperate climate zone. The distribution of households by climate zones broadly represented the distribution of climate zones in India. Across the sample of 1,537 households, the mean monthly summer electricity consumption was found to be 275kWh, which was 32% more than the winter consumption of 186kWh. The distribution of mean monthly electricity consumption in summer and winter at the sample level is shown in Figure 1. The 90th percentile of mean monthly consumption in summer and winter was seven times more than the 10th percentile. Across all percentiles, the mean monthly summer consumption was at least 1.4 times more than the mean monthly consumption in winter.

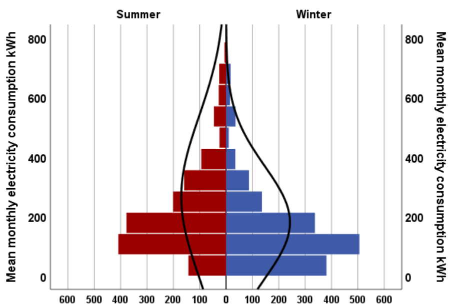

Figure 1:
Distribution of monthly REC across seasons

Across the sample, 90% of the households had one AC unit. Households with three or more AC units consumed around 46% more electricity than households with one AC unit in summer, while households with two AC units consumed 12% more than households with one AC unit. During winter season, households with three or more AC units consumed 57% more than what one AC households consumed. The monthly electricity use almost doubled when number of AC units increased from one or two to three or more AC units irrespective of season.

The highest mean monthly REC for both summer (293kWh) and winter (203kWh) was observed in independent houses/villas and lowest consumption was observed in flats/apartments (standalone or society) (271kWh in summer and 193kWh in winter), since houses are more exposed and wee larger in size. Monthly electricity consumption increased in summer and winter as dwelling size increased from 1BHK to 4 or more BHK, since larger area was cooled. With increase of one bedroom, REC was found to increase by 1.3 times on average in both summer and winter seasons.

3.1 Seasonal electricity consumption across climatic zones

The climatic zones of India as defined by ECBC states that the hot-dry region had the highest mean daily temperature for midday in summer at 42.5°C, followed by composite zone at 37.5°C, warm-humid zone at 32.5°C, and temperate at 32°C and cold zone at 23.5°C. Cold zone had the lowest mean daily temperature in winter at -5°C, followed by hot-dry at 5°C, warm-humid at 7°C, temperate at 17°C and the highest daily mean temperature was observed in composite at 22.5°C. The climatic variation was reflected in the mean monthly electricity consumption across seasons. In summer, highest REC was observed in households located in composite zone (322kWh) while the lowest monthly REC (88 kWh) was in households based in the milder temperate zone. In winter season, mean monthly REC was highest in warm-humid zone (208kWh) and again lowest in the temperate zone (66kWh). The variation in REC across climatic zones was stark - lowest mean monthly REC in the milder climate (temperate zone) was one third of the mean monthly REC in more extreme zones (composite zone/warm-humid).

Despite having highest ambient temperature in summer (45°C) in the hot-dry zone, REC in such households was not higher than households located in the composite or warm-humid zone. This was likely to be due to the fact that households in the temperate zone and hot-dry regions used AC for five hours per day, while households in the warm-humid and composite zones used AC for over six hours per day. Interestingly, more than 90% of all the households in each climatic zones owned only one AC except for temperate zone households where 70% had two AC units.

3.2 Seasonal electricity consumption by income group

Across all income groups, households with less than three AC units, consumed on average 33% more electricity in summer than in winter. However households with three or more AC units showed a 16% rise in summer consumption as compared to winter, indicating a lower influence of ambient temperatures as households got more affluent (represented by 3 or more AC units).

As shown in Table 2, in summer the low income (LIG) households (n: 625) reported a mean monthly electricity consumption of 216 kWh, followed by the MIG households (n: 405) at a mean monthly electricity consumption of 272 kWh, while the HIG households (n: 507) reported the highest mean electricity consumption at 349 kWh. Thus HIG households consumed 1.6 times more than LIG households in both summer and winter. In winter, the usage of AC was expected to fall drastically especially among LIG, however, the REC did not observe a significant difference among these income groups implying that electricity use in winter was determined by other non-cooling appliances and their usage.

Table 2:
Income group variation of REC

Income group	N	Mean (median) of monthly summer REC (kWh)	Mean (median) of monthly winter REC (kWh)
LIG	625	216 (160)	151 (100)
MIG	405	272 (200)	176(130)
HIG	507	349(250)	238(170)

3.3 Characteristics of cooling appliances

Statistical analysis of survey data revealed that all households owned ceiling fans along with an AC unit. Desert coolers were interestingly not very commonly owned or used among households. Other non-AC space cooling appliances such as table fans, pedestal fans or wall mounted fans were owned by 31% of households with more than three AC units. The prevalence of non-AC cooling appliances indicates that Indian households tend to use a combination of cooling devices through a mixed-mode operation.

Table 3:
Ownership of non-AC space cooling appliances

AC ownership type	Ceiling fans	Table Fans/Pedestal/ Wall Mounted	Desert Coolers
1AC (n:1384)	100%	16%	20%
2AC (n:137)	100%	21%	15%
3 or more AC (n:16)	100%	31%	19%

The most common form of AC system was a split system, where 72% of these AC's were relatively new (less than five years) with a capacity of 1-1.5 ton. The average daily use of AC was found to be 5.6 hours per day across the sample although the timing of AC use was not uniform across the sample. The mean daily AC usage varied from 5 hours in LIG households to 5.9 hours for MIG and 6 hours for HIG. The AC use varied from 5.5 hours for households with one AC, 6.8 hours for households with two AC units and 8.6 hours for households with three or more AC units.

Across various income groups, the set point temperature varied widely ranging from 16°C-28°C. The mean set point temperatures of 21-22°C was observed across all income groups. Interestingly, those who set their mean AC temperatures to 19°C or lower (mostly households with more than three AC units) were predicted to have two times higher AC usage than households with set-point temperatures over 21°C. Among all the households, only 56% of the residents used specifically star rated products while less than 50% took energy saving actions, such as changing appliance settings or switching off appliances when not in use to reduce energy use. Although LIG preferred an EE rated product, more percentage of HIG households actually purchased and used an EE rated product. This could be due to the fact that lower income group (40% of all LIG households) prioritised cost and performance more than HIG (25% of all HIG households prioritised cost and performance) due to financial reasons.

3.4 Correlation between variables

The Pearson coefficient or r value was used to find the strength of the correlation between mean monthly electricity consumption (in summer and winter) and survey variables. The value of r between 0.1-0.3 and 0.3-0.5 shows small to moderate correlation and greater than 0.5 shows a strong correlation. All variables were chosen to be significant at the 0.05 level in analysis.

It was observed that BHK and floor area (dwelling size); family size and family structure were strongly correlated with r>0.5. In order to remove multi-collinearity, redundant variables were removed to avoid overfitting into regression. For example, here floor area and family size were used instead of BHK and family structure since these variable correlations were quite obvious. The strength of correlation between number of fans and number of AC appliance with floor area was found to be of moderate strength, implying that as the number of fans and AC units increase with dwelling size.

3.5 LASSO regression

The variables used for LASSO regression were climatic zones (as dummy variables), income group (as dummy variables), family size, floor area (logarithmically-transformed), number of AC units, number of ceiling fans, number of fans (table/pedestal/wall mounted), number of desert cooler, daily AC use and AC set point temperature. The dependent variable was logarithmically transformed in summer and winter to normalize data for regression. In summer, daily AC use influenced the mean monthly summer REC along with floor area, family size and number of ceiling fans. Variables of daily AC use and set point temperatures were be taken as determinants for winter REC as space cooling use was almost nil in this season [12, 13]. In winter, mean monthly REC was influenced by floor area, family size and number of non-AC space cooling appliance (ceiling fans). Overall, the determinants of mean monthly REC were found to be floor area, family size and non-AC space cooling appliances (ceiling fans).

Table 4:
LASSO regression

p<0.05 Standardised coefficients (Beta)	Mean monthly summer consumption kWh	Mean monthly winter consumption kWh
Floor area	0.2	0.1
AC day use	0.1	-
Number of ceiling fans	0.1	0.1
Family size	0.1	0.1
Multiple R	0.5	0.5
R square	**0.3**	**0.2**
Adjusted R square	**0.2**	**0.2**
Penalty	**0.12**	**0.12**

4. DISCUSSION

The analysis shows that in households with AC, there is widespread variation of REC by seasons, climate zones, income group, number of AC units, as well as dwelling size and dwelling form. It was found that main factors that affect REC use were floor area, family size and number of non-AC cooling devices like ceiling fans, while in summer daily AC usage hours influenced REC. Households with more than three AC units used AC for longer hours and thereby contribute to a higher REC. This trend was also observed across income groups with highest income groups contributing to a higher REC use. It is important that residential energy policy in India addresses these highest electricity consumers and ensures that the lowest electricity consumers do not rapidly move to these groups. There is thus a need for policies to be customised to different income groups. While financial incentives to purchase energy efficient appliances may not work for more affluent households, these may be appropriate for the lower income groups. For MIG and HIG households, smart management of AC use in line with occupancy and outdoor weather can be encouraged, along with increasing the set point temperature, given the potential electricity savings this change can bring.

Although the Indian Bureau of Energy Efficiency (BEE) recommends 24°C as the set point temperature for AC units, the set point temperature in the study was found to be 19°C - 21°C. Households with set point temperature of 19 °C consumed 1.6 times more electricity than those with 21°C. Given that with every degree rise in set-point temperature around 6% savings could be achieved, this is a tremendous untapped for reducing electricity use, even though it will be a social challenge given the rapidly rising aspiration of higher thermal comfort in urban Indian households.

Based on data analysis conducted from this study, AC usage varied from 5.6 hours to 8.5 hours depending on the number of AC units. This range is higher that what was found by two other Indian studies that identified average daily usage of AC to be around five hours per day (Khosla et al., 2021, Agarwal et al., 2020). However the two studies were conducted at different periods of the year in different cities. In future studies should aim to establish the average daily household AC use at a national level to inform energy models for estimating savings from a reduction in usage hours.

The study also revealed the wide variation in REC across climatic zones, income groups and seasons**.** Residents in hot-dry (highest mean summer outdoor temperature) and temperate zone (70% households owned two AC units) were thriftier in their summer and winter electricity use than residents in composite and warm-humid zone. Space cooling usage in summer across households located within the composite zone was twice as compared to households located in other climatic zones. This variation across space (climatic zone) and time (season) will need to be tackled through customisation of the recently-launched Residental Energy Code in India, especially as climate warms and more households aspire to reach higher levels of comfort (at lower set point temperatures). The Energy Code will need to consider reducing both annual and seasonal use of electricity and how that varies across climatic zones and income groups.

5. CONCLUSION

This study empirically examined the seasonal variation (summer, winter) of residential electricity use in India using statistical analyses of survey data of 1,537 households with AC units representing four climatic zones (composite, hot dry, warm humid and temperate) and different income groups (low, medium, high). The survey data included information on household characteristics, socio-demographics, cooling and non-cooling appliances, electricity use in summer and winter and level of energy awareness. High income households (n: 507) reported the highest mean monthly summer electricity consumption at 349 kWh followed by middle income households (n: 405) at 272 kWh, while low income households (n: 507) experienced the lowest mean monthly summer electricity consumption of 216 kWh. Mean monthly electricity use in summer was lowest in the milder temperate climate zone as compared to the more extreme composite and warm humid zones. When number of AC units increased from one to three or more ACs, residential electricity consumption (REC) almost doubled across summer and winter seasons. In households where the set-point temperature was 19°C, REC was found to be double that of households with 21°C. The influence of the variables on the electricity consumption was obtained by performing LASSO regression. It was observed that BHK /floor area, family size/number of residents, usage of AC, income group, set-point temperature and number of non-AC cooling appliances were key factors driving the electricity consumption of households.

The study reinforces the need to tackle the growth of AC units among Indian households as climate warms and aspirations for thermal comfort increase. Energy policies should encourage the use of low power consuming space cooling appliances like fans or desert coolers which are also more affordable than AC units. To curtail the rise of residential electricity consumption in India *one size fits all* policy is not likely to work in the Indian context. Instead residential energy policy should address the factors that drive electricity use along with the variation in residential electricity use prevalent across climatic zones, seasons and income groups in India.

ACKNOWLEDGEMENT

We are thankful to the NEEM-CLASP study for providing the survey data for 1,537 households. The analysis in this study is part of the RESIDE project (Residential building energy demand reduction in India), which has received funding from the Department of Science and Technology (DST), India and Engineering and Physical Sciences Research Council (EPSRC), UK grant no: EP/R008434/1.

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