A Residential End Use Energy Consumption and Appliance Ownership Patterns in India

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Abstract

Residential sector in India accounted for 24% of the total electricity consumption in 2016 and is projected to rise more than eight times by 2050. This increased energy demand would primarily be driven by appliances and equipment and attributable to several factors including better access to electricity and rising disposable income. However, at present, there is limited data and understanding of residential energy end-use and its variation with socio-economic strata and climatic zones. As the penetration of appliances and subsequently energy use expands in Indian households, it is becoming pertinent to establish a realistic end-use baseline for formulating informed energy policies and assessing the potential impact of these policies.

A 'first of its kind' comprehensive study was carried out integrating a pan-India survey of residential end-use across 5,000 urban households and a real time appliance energy use monitoring through Non-intrusive Load Monitoring (NILM) of 200 households in 13 cities, spanning different climate zones, socio-economic strata and demographics across the country. The objective of the study was to establish appliance ownership and usage patterns for urban households and develop a framework for collection and analysis of data on energy end-use in the India's residential sector for conducting such surveys in future.

The data indicates that appliance ownership and usage is on the rise significantly. With households shifting towards family nuclearisation, per capita energy use is also increasing. The results also provide good insights on variations in energy consumption across climatic zones, demographic parameters and socio economic strata for the major appliances. This could potentially influence the formulation of customised energy policy interventions to reduce energy consumption. This data can also promote better understanding of future electricity demand, thereby enabling better planning and demand side management programs. The data and the key findings are expected to be beneficial to academicians, think tanks, policymakers, utilities and consumers for research, modelling, planning and future projections.

Keywords: Residential end use survey, appliance ownership, energy consumption, non-intrusive load monitoring, socio economic strata

Introduction

India is the fourth largest energy consumer in the World[1] and will constitute around one quarter of the total global energy demand by 2040[2]. Appliances and equipment will contribute significantly to this increased energy demand.[3] The residential sector constituted 24% of total electricity consumption in

[1] US. Energy Information Administration. International Energy Outlook 2019. September 2019.

[2] International Energy Agency, *India Energy Outlook.* 2015.

[3] https://www.eia.gov/todayinenergy/detail.php?id=33252

India in 2016 (Figure 1) and the energy demand from the sector is projected to rise significantly in the years to come.

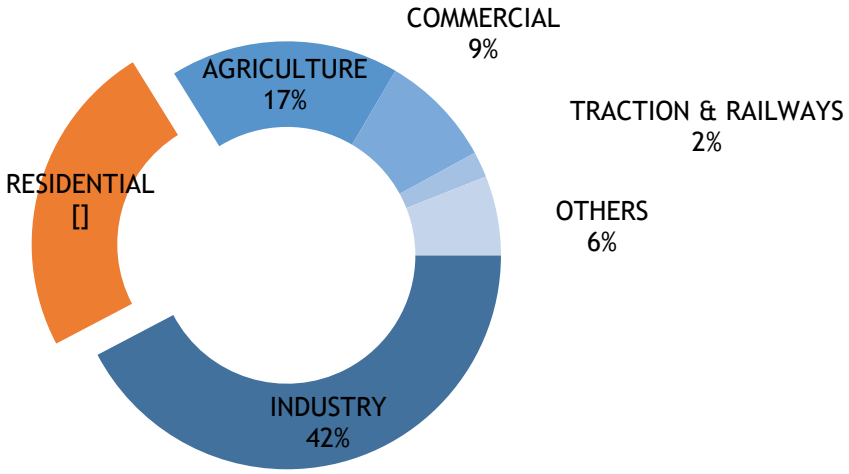

Figure 1: India's sector-wise distribution of electricity consumption in 2016
Source: Ministry of Statistics and Programme Implementation (2017)

India is expected to become one of the fastest growing consumer appliances markets driven primarily by rapid urbanization, household electrification, growing per capita income and female participation in the workforce[4].

Despite the substantial electricity consumption by the residential sector in India, there is no data on the household and appliance energy consumption and variations resulting from socio-economic factors and climatic zones. There is very limited information on appliance ownership and usage patterns. A few countries such as the United States[5] and Australia[6] carry out periodic surveys to understand the residential energy use for forecasting future energy demand, improving energy efficiency measures and developing successful demand side management programs. Thus far, no such surveys or studies have been carried out in India.

The National Sample Survey Office (NSSO) conducts nationwide household consumer expenditure surveys at quinquennial intervals[7]. These surveys provide information on ownership of appliances, however, they do not capture variation across climatic zones or socio economic strata. Also, these surveys do not capture usage pattern or disposal behavior of appliances across households.

It has been established that insight into the human dimension of energy use is key to better understanding future energy trends and to effectively manage them[8]. Therefore, consumer usage data can also promote better understanding of future electricity demand, thereby enabling better planning and demand side management programs. With the growing electricity consumption and a steady progress on the policy development to improve the energy efficiency of the appliances and equipment, it is imperative to understand the trends related to the usage patterns and consumer behaviors. This will not only support formulation of effective energy efficiency policies but also help in establishing a realistic end-use baseline for assessing the potential impact of these policies, and enable better estimation of energy savings.

[4] PricewaterhouseCoopers. Future of consumer durables and electronics in India – the changing landscape. 2018.

[5] https://www.eia.gov/consumption/residential/

[6] Residential baseline Study of Australia, 2000-2030. Government of Australia

[7] Residential Energy Consumer Survey of USA-https://www.eia.gov/outlooks/ieo/india/

[8] Schipper and Meyers, Energy Efficiency and Human Activity. Cambridge: Cambridge University Press, 1993

Objective

The primary objective of the study was to gather data on appliance **ownership** and **usage patterns** for urban households across climatic zones and socio economic strata, aimed at bridging the gap in existing understanding of residential energy end use in Indian households. The study also aimed to develop a **framework to gather data on energy end-use** in the India's residential sector for conducting such surveys in future.

Approach and Methodology

A 'first of its kind' pan-India study was conducted to include a residential electricity consumption survey (RECS) of 5242 urban consumers with electricity end-use monitoring of 200 households. The study was divided into 3 phases as shown in figure below:

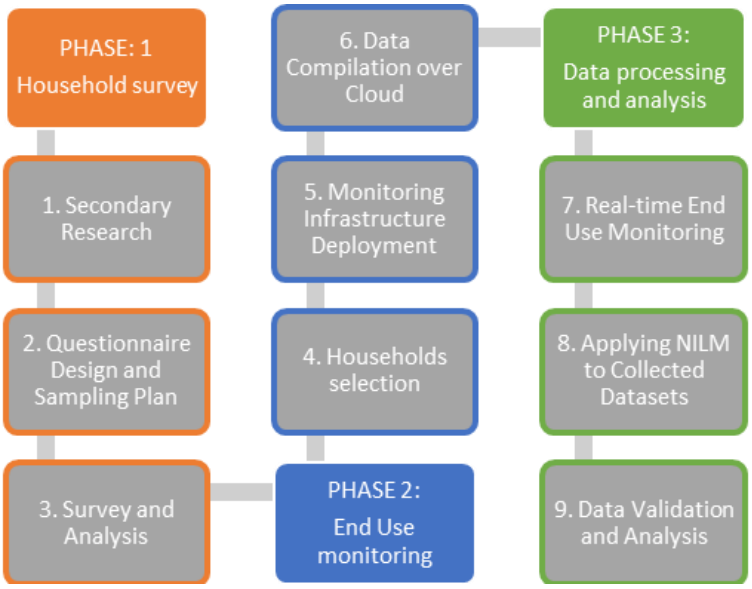

Figure 2: Methodology of the study

Phase 1 - Household Survey
A secondary research was conducted on the methodology from national household census, market reports, journals, articles and government reports to design the survey. A survey questionnaire was designed which aimed to gather following information:

- Demographic characteristics such as household income, family type and size, occupation and educational qualification, socio economic status (SEC)
- Appliance ownership, usage, and disposal behavior
- Electricity usage pattern

A representative sample of 8,448 households was derived from the census data, which included urban and rural households. As the urban sector accounts for almost two-thirds of the consumer durables market[9], the scope of the survey was limited to urban areas and the representative sample was adjusted to 5,242 households.

[9] Indian Brand Equity Foundation. *Consumer Durables,* April 2018.

The distribution of sample size was based primarily on the different climatic zones, followed by urban agglomeration and by socio economic classification (see Figure 3) leading to the selection of 21 representative cities.

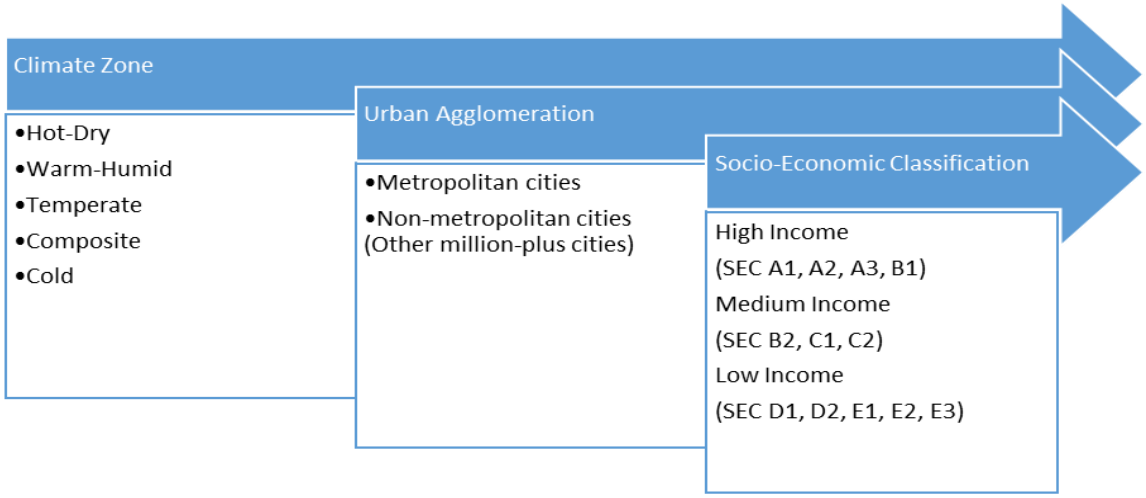

Figure 3: Sample size distribution criteria

The survey was conducted using Computer Assisted Personal Interview (CAPI) technique. The use of an electronic device facilitated data recording while also minimizing recording discrepancies. Willingness to participate in the detailed load monitoring exercise was also assessed during the survey.

Phase 2 - End Use Monitoring

From the large survey, a sample of 200 willing households representing the climatic zones, urban agglomeration, dwelling type and socio economic strata across 13 cities covering 11 states and 2 union territories were selected. Non-Intrusive load monitoring (NILM) devices were installed for real-time electricity consumption across appliances in the household for a period of one year to capture any variations across seasons.

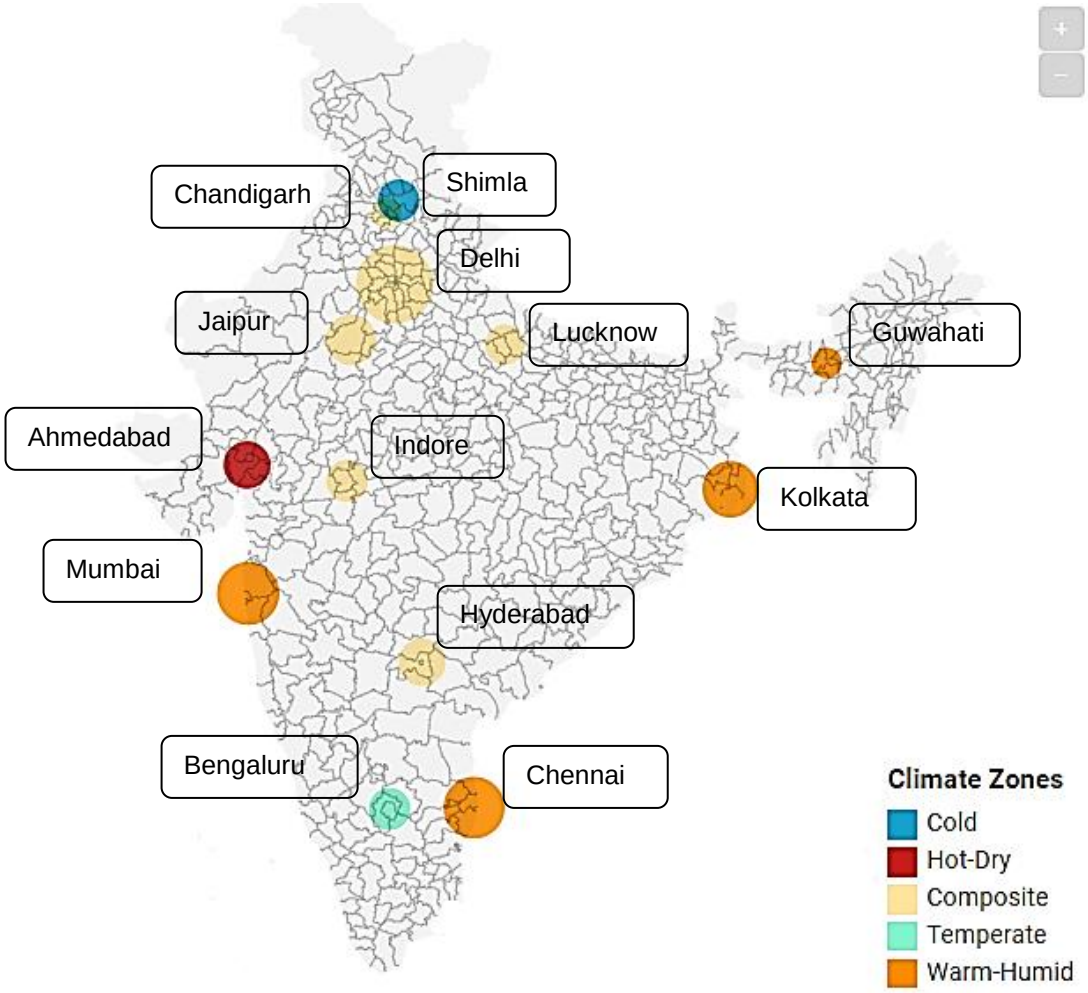

Figure 4: Smart meter deployment across India

Phase 3 - Data Processing and Analysis
Data collected from the survey and the energy metering was processed and analyzed using MySQL database and NILM algorithm, respectively.

The real-time energy use data for all monitored households was collated on a cloud server on electricity consumption, voltage, current, power factor and frequency at 30 seconds interval. This is the first time where data at such fine resolution has been recorded and analyzed for Indian residential sector. The monitored households represent different geographic, climatic, cultural and socio-economic aspects, and the data was aggregated and analyzed for median energy use and peak demand analysis. Considering all households and hourly data points, a representative household was constructed by taking median energy use and peak energy demand at an hourly interval.

This data was analyzed using NILM algorithms to provide detailed analysis of usage and operation of appliances. The NILM algorithms distinguish appliance use and operation by mapping the load signature from trained datasets onto monitored data. The NILM algorithm applied in the study was customized for Indian context and could successfully disaggregate data for air conditioners and water heaters, however for other major appliances such as refrigerator and washing machines, it needs to be further trained on India-specific datasets to identify the load usage signatures.

Key Results

1. Survey Outcomes

A) Ownership and Usage Pattern

The key outcomes from the survey classified into ownership and usage of the respondents across climatic zones, SEC classification and cities are shown in the table below:

Table 1: Ownership and usage pattern of appliances across demography and climatic zones

Category	Family Size	Income	Climate	City	Ownership
Home Appliances[10]	No significant impact.	Ownership increases with income for products such as washing machine, vacuum cleaner. However, for products such as television, cell phone charger and set top boxes it does not vary with income.	No significant impact.	No significant impact.	Cell-phone charger, television, set-top box and washing machine have maximum ownership in the category.
Heating/Cooling[11]	Ownership increases with family size.	Ownership increases with income except for fans, where income does not have any significant impact.	Cold climate has highest ownership of space and water heating devices while ownership of appliances like Air-conditioner (AC) and room-heater is sensitive to climatic variation.	Non-metros have marginally higher ownership while usage is similar except for ceiling fans.	Highest penetration is for ceiling fans followed by desert cooler. Penetration of AC and storage water heater is increasing.
Kitchen Appliances[12]	Ownership increases with family size.	Ownership increases with income for most products except essential ones such as cooktop, refrigerator and mixer grinder. A fifth of high-income respondents own electric cooking appliances, marking a shift to electricity as cooking fuel.	No significant impact.	No significant impact.	Highest penetration is for cooktop, refrigerators followed by mixer grinder.

[10] Includes entertainment systems, IT equipment and some other productivity enhancing appliances

[11] Includes products that provide ventilation, space heating/cooling and hot water

[12] Includes cooking, food processing and storage appliances

Lighting Products[13]	No significant impact	Light emitting diode (LED) penetration increase with income. In lower socio income strata, incandescent lamps are the most used products.	Hot-Dry climate has lowest penetration in all lighting products except LEDs while Cold climate has highest ownership of Incandescent bulbs.	No significant impact.	Highest penetration is for compact florescent lamps (CFL) followed by tubular fluorescent lamps (TFL) and LED. However, LED penetration is expected to take over CFLs.

Across these categories:

- Cell-phone chargers, Television (TV) sets, set-top boxes, cooktops/stoves (fueled by liquid/gas fuel), refrigerators and ceiling fans have penetrated 80% or more market.
- Washing machines, electric cooking products, lighting products, air coolers and air conditioners are expected to grow further and reach higher ownership levels.
- Ownership in percentage of total surveyed households and average annual usage hours for each appliance at the national level were derived from the survey data (see Figure 5)

[13] Includes products that aid illumination (general purpose lighting) in homes

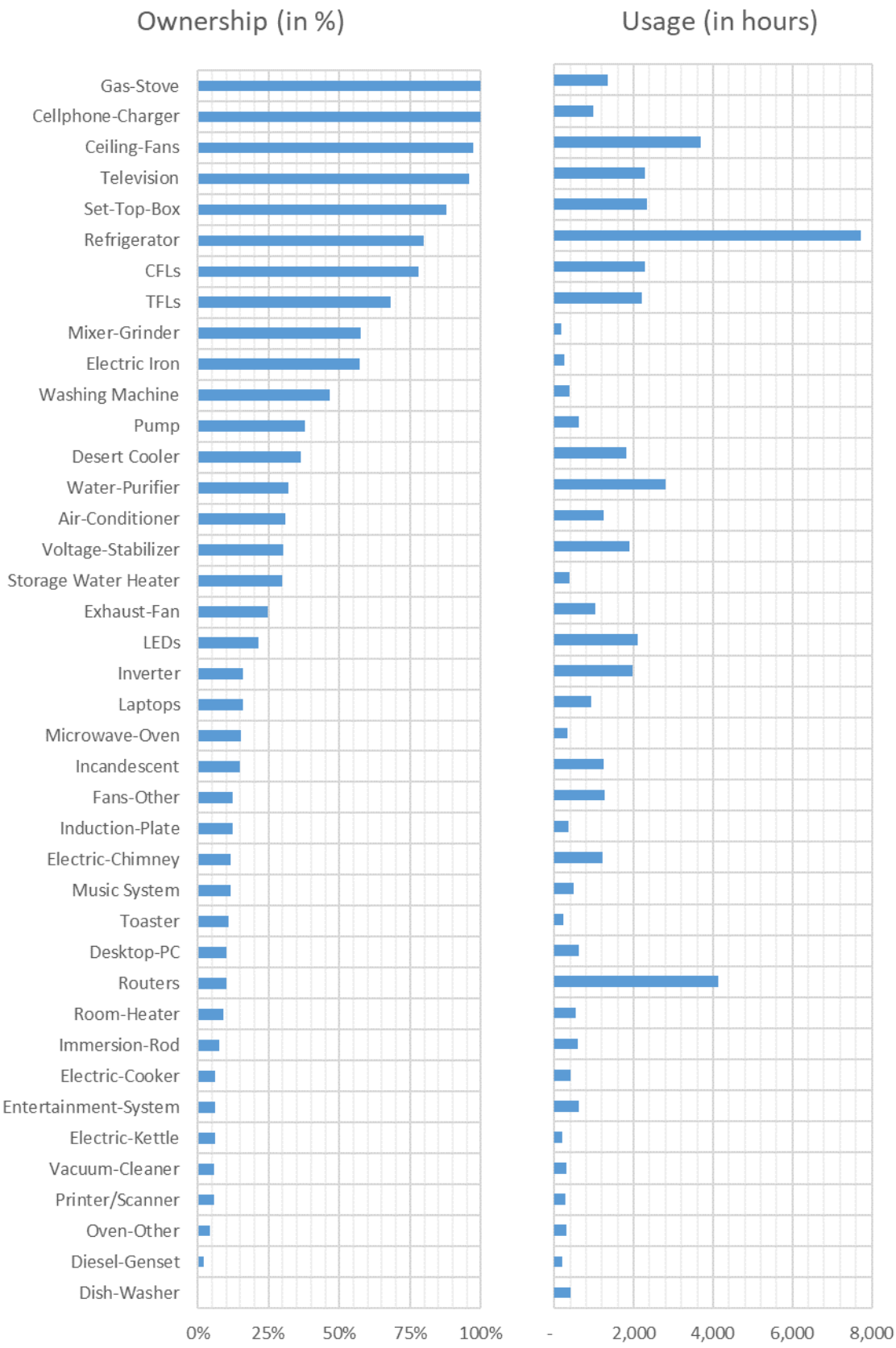

Figure 5: Ownership (percentage out of total surveyed households) and average annual usage hours of appliances

B. Energy Use

India is a tropical country, where summers are intense and dominate 4 out of its 5 climate types. While climate is a distinguishing factor, family composition and the socio-economic status are significant factors as well. The survey captured energy use information from households. This information has been categorized by climate, family type and income for analysis (see Table 2). From the table below, it can be inferred that energy consumption was higher in summers as compared to winters across family types, socio economic strata, and climatic zones except cold climate. In addition, energy consumption increases with increase in family size and socio economic classification.

Table 2: Variation in Energy Consumption with family size, socio economic strata and climatic zones

Category	Family Size	Socio Economic Strata	Climatic Zones
Energy Consumption	Energy consumption increases with increase in family size and was highest in summers.	Energy consumption increases with increase in socio economic classification i.e., higher the SEC, higher the consumption. Energy consumption was highest in summers.	Composite and warm and humid climatic zone consume highest energy in summers, except cold climate, where highest energy is consumed in winners.

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2. End use monitoring and data analysis

The shortlisting criteria for deployment of energy monitoring kits was based on ownership of major energy consuming appliances. The ownership pattern of key appliances in the households selected for monitoring is shown in figure 6 below:

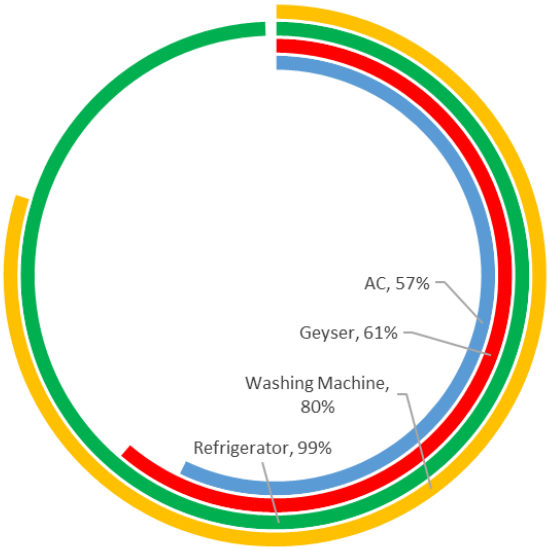

Figure 6: Ownership of key appliances in metered households

Similar to the survey trends, the monitored households also show that across households,

- Energy consumption was highest in summer months (March and June) owing to air conditioners, and winter months (January-February) are characterized by low energy use across monitored households.

- Though energy use is lower in the winter months, high peak demand is observed on account of water and room heaters. Room heaters are used primarily in cold and composite climate, while water heaters are used across climatic zones.

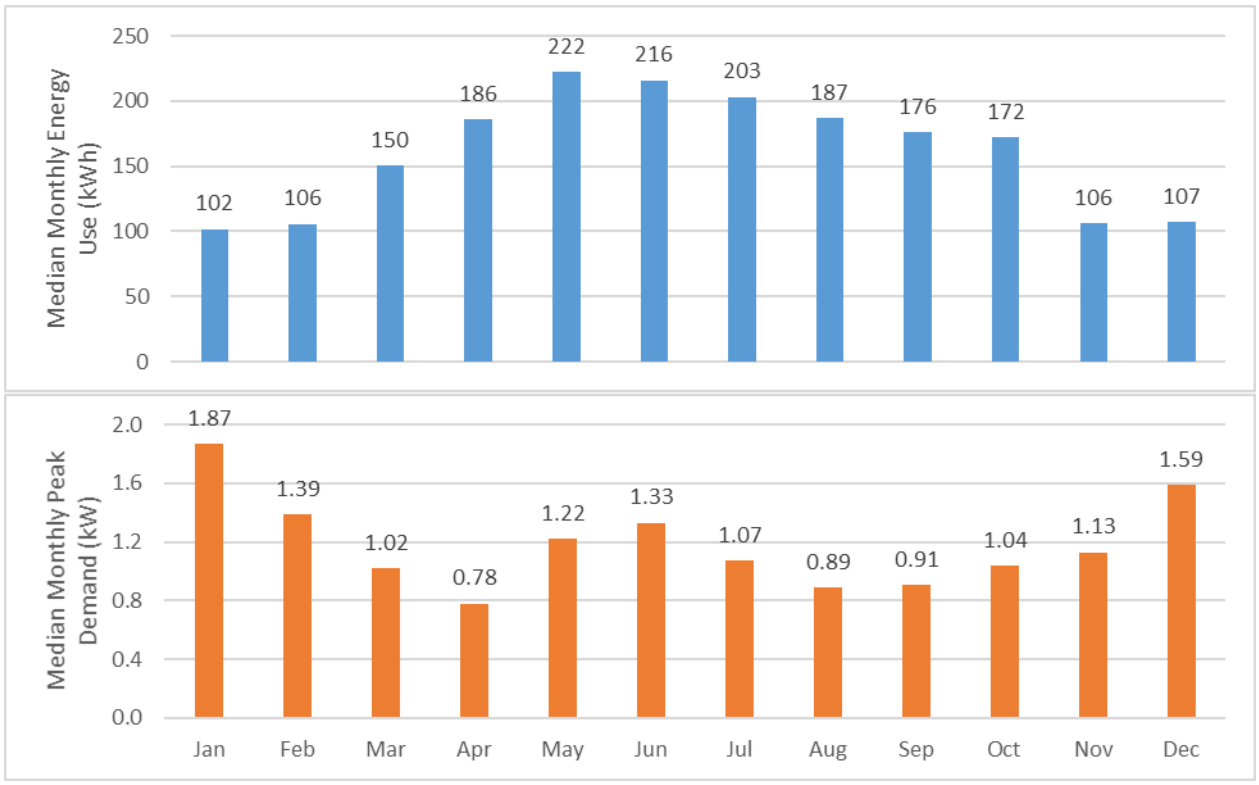

Figure 7: Median monthly energy demand in metered households

For detailed analysis, monthly energy use of an Air-Conditioned (AC) and Non-Air-Conditioned (Non-AC) households was disaggregated.

- Energy consumption of AC households was higher than non AC households throughout the year, not just in summers. Most households that own ACs belong to higher SEC groups and possess more appliances, which may explain higher energy consumption in AC households throughout the year.

- AC households consume at least 50% higher energy as compared to non AC household during summers as shown in the figure below:

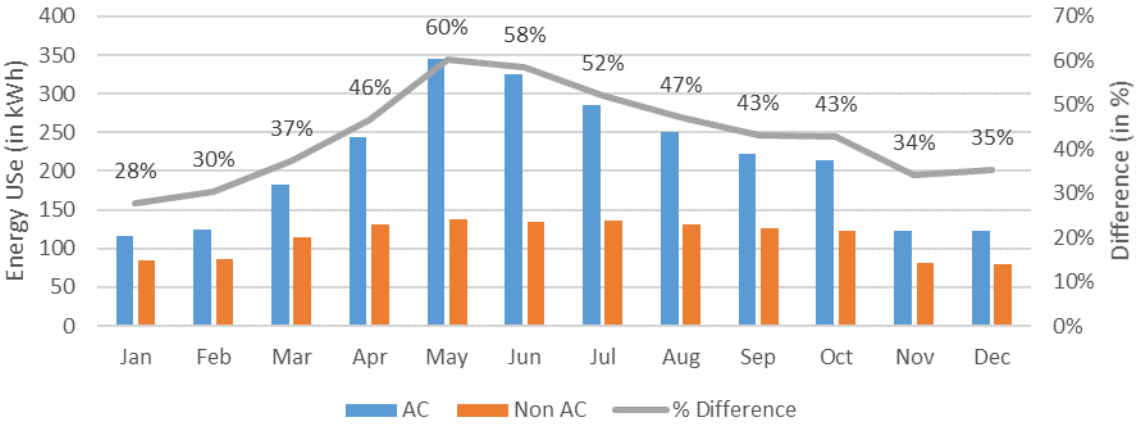

Figure 8: Monthly energy use comparison for AC and non AC households

- The magnitude of variation of peak demand (as shown in figure below) between AC vs non AC households is also highest in summers.

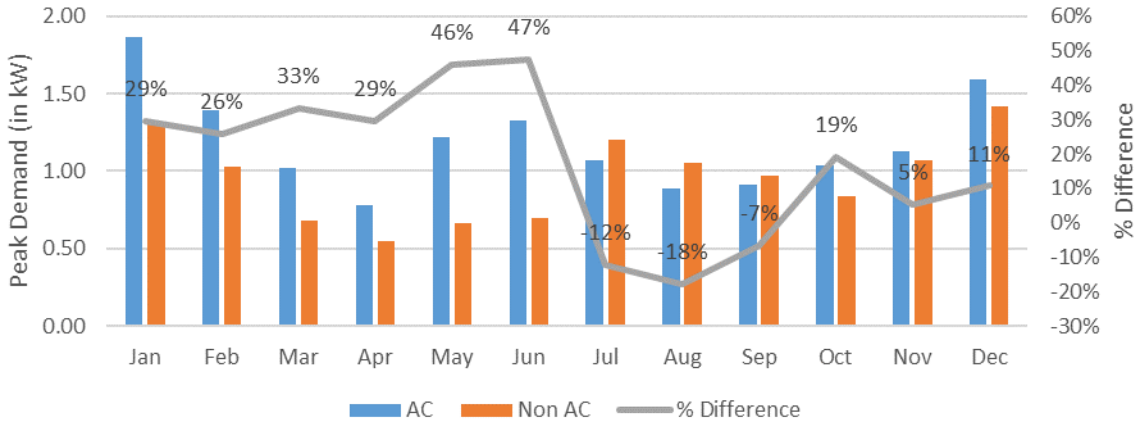

Figure 9: Peak demand comparison for AC and Non-AC households

It can therefore be concluded that AC is a significant contributor to overall energy use although the use varies with seasons.

The data was further analyzed to arrive at the energy use variation for AC and non AC households with family size, type of household, climatic zone as shown in the table below:

Table 3: Variation in energy use with seasons for AC and non AC households

Category	Family Type	Household Size	Climatic Zone
AC household	Joint family had highest energy consumption throughout the year, while nuclear with elders had high energy consumption in monsoon and winters.	Energy consumption increases significantly with increase in the size of household, the variation peaking in summers.	Composite zone consumes highest energy consumption, while temperate zone consumes lowest.
Non AC household	Energy consumption increased with increase in family size. Joint family had highest energy consumption throughout the year.	Energy consumption increases marginally with increase in household size.	Composite zone had highest energy consumption throughout the year particularly peaking in summers and monsoons.

Thus it can be concluded that the energy consumption increases with increase in size of the family and household. Composite climate zone had highest energy consumption.

Conclusion and way forward

The nationwide study combining survey and end use monitoring provides deeper understanding on appliance ownership pattern and residential electricity consumption in India's urban homes to developing customized policy interventions. The results reveal appliance ownership and energy use patterns to provide behavioral insights appliances across socio-economic, cultural and climatic factors. The findings of the survey were also validated by the end use monitoring for energy consumption.

Appliances such as cell-phone chargers, TV sets, set-top boxes, cooktops/stoves (fueled by liquid/gas fuel), refrigerators and ceiling fans have penetrated 80% or more market. Washing machines, electric cooking products, lighting products, air coolers and air conditioners are expected to continue growing and reach higher ownership levels.

Energy consumption is higher in summers as compared to winters across socio economic strata, dwelling type and socio climatic zones except cold climate. Space and water heating appliances are major contributors towards winter peak demand and summer peak is attributed to space cooling devices. Energy consumption increases with increase in family size and socio economic strata. Also, energy consumption of AC households is higher than non AC households throughout the year, not just in summers, which could be due to higher socio economic strata. Peak demand as well as energy use varies by seasons, climatic zone, socio economic strata and dwelling type. These can help in developing targeted demand response strategies.

Since the study was nationally representative, the energy consumption by appliances and its growth patterns can be extrapolated to forecast future energy demand. If conducted periodically, the study would enable better understanding of usage pattern and trends over the years thereby helping analyze the impact of energy efficiency policies more realistically. Overall, the data generated can potentially advise demand response programs, energy efficiency policies for appliances and buildings, and strategies for consumer behavior.

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