UNDERSTANDING ELECTRICITY CONSUMPTION AND APPLIANCE OWNERSHIP IN TWO CITIES SOUTH INDIA

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ABSTRACT

Residential electricity consumption in India has grown rapidly since 2000. With growing population and rapid urbanization, many studies have projected five to six times increase in consumption by 2030 under business-as-usual scenario. Electricity sector alone accounts for about 40% of India's total GHG emission, predominantly CO_2. Government has initiated various policy measures and schemes for promoting demand side management and efficient appliances. However, establishing ground level baseline and acquiring data-based evidence to validate these interventions is a challenge, particularly considering the very low penetration of smart meters. To complicate things, human behaviour aspects influencing decision on purchase of efficient appliances or generally determining conservation attitude is not easy to capture. VidyutRakshaka program was conceptualized to address some of these gaps and to provide field-based evidence.

Based on household electricity data from two cities, obtained through consumer-focused residential electricity conservation program VidyutRakshaka (VR), this paper will cover: (1) Presenting trends in consumption patterns within the city and across cities of Bangalore and Chennai and (2) Correlation of electrical appliance ownership with consumption disaggregated by size of the house. We believe that this analysis using ground-level data will benefit researchers and policy makers. It also provides inputs for strategizing interventions to meet our national goals on climate change and low carbon future.

Keywords—VidyutRakshaka, Home energy reports, Demand side management, Electrical appliance holding, household size based disaggregated data on electricity consumption

INTRODUCTION

VidyutRakshaka (VR) is a consumer-focused electricity conservation program, providing customised home electricity reports to participating households. The vision of the program is conserving electricity through awareness, nudges for long-term behaviour change, and information for better choice in electrical appliances.

The objectives of the program are:

1. Facilitate sustainable residential electricity consumption template for all categories of households through awareness and information

2. Demonstrate low carbon pathway to demand side management, in a resource efficient manner

3. Gain ground level, demographically disaggregated insights on residential electricity consumption

VR continues to be operational in Bangalore since 2015 and was piloted in Chennai in 2018. Participation is voluntary and free of cost. A generic awareness booklet is given on signing up for the program and then consumers receive customized home electricity reports at a certain frequency.

While home electricity reports constitute a critical component of the program, data obtained from consumers through the questionnaires provide valuable insights into residential consumption trends and electrical appliances. This paper is based on the study looking at the correlation of consumption with data on appliance ownership obtained from consumers in Bangalore and Chennai. The findings from the study would be useful in the context of increased emphasis on end user efficiency driven by electricity suppliers as recommended by the Intergovernmental Panel on Climate Change (IPCC) in their 5th Assessment report [Lucon, O et.al, 2014]

BACKGROUND

In cities, 70% of daily energy needs are electricity based and around 78 % of this comes from electricity generated from fossil fuel-based sources [Central Electrical Authority, 2014]. Residential (domestic) sector is the second largest consumer of electricity in India accounting for 24.2% [MOSPI, 2019] of total consumption. Our national Grid contributes 0.8 tCO_2\MWh to GHG emissions every year [Central electrical Authority, 2014]. In developing countries like India, residential buildings consume directly and indirectly 24.4 PWh every year [IEA, 2010]. These statistics give a sense of contribution of residential electricity consumption to GHG emissions.

Residential electricity consumption (REC)

Residential electricity consumption (REC) has grown by over 50 times from 1971 [Prayas (Energy) group, 2016]. Increasing urbanisation, effects of climate change resulting in extreme events and increasing economic prosperity, shifts focus of energy conservation on urban households using multiple high energy consuming appliances.

Role of electrical appliances in REC

To understand the effects of appliance ownership in REC in NCR region, a study published by Prayas Energy group in 2017 highlights the ubiquitous penetration of fans, TVs and fridges across households. With increasing income levels and rising ambient temperatures, penetration of ACs in Indian households is predicted to increase by two folds [Radhika Khosla, 2017]. In a study conducted in Pune, looking at data collected through metering of individual appliances, it was found that old refrigerators (more than 15 years old) consumed up to four times more electricity than 3 star labelled units [Khosla,R. 2017]. To understand adoption of LED lamps in households, Prayas Energy group's study in semi-urban Uttar Pradesh and Maharashtra reveals that in UP, 68% of households used only LEDs whereas in Maharashtra 54% used a combination of LED and CFL. The possible reason behind the difference being the previously run programs in Maharashtra to promote CFL [Prayas Energy group, 2019].

Another study using appliance stock method (quantity, power consumption and usage hours similarity), observed that appliance stock had 93% correlation with electricity consumption [Murthy, K. N.2001]. Letschert and McNeil of the Lawrence Berkeley National Laboratory (LBNL) calculated consumption by multiplying the appliance stock and usage per appliance while estimating potential savings in electricity by Indian households over the period from 2000 to 2030. The saving per appliance was estimated based on calculated difference between projected usage (based on present consumption) and energy efficient model. In a similar study with residential households, it was estimated that by shifting to energy efficient model, there would be an annual saving of 57 TWh which would not be possible in a business-as-usual situation [Prayas Energy group, 2016], proposing an urgent need for better penetration of energy efficient appliances in households.

Need for ground level granular data on REC in India

India does not have a formal Residential Energy Consumption Survey (RECS) unlike developed economies. Data on ownership of different appliances [Prayas Energy Group, 2016] is captured to some extent in census and NSSO's survey on consumer goods. The periodicity and the data coverage of those surveys are few and far between than needed to understand the emerging trends. Ground data on appliance ownership, their usage, and impact on consumption, relation to policies / schemes, are missing today. Without these, India's ambitious goals to climate change initiatives and SDGs may not gain ground as electricity generation's contribution to

GHG emissions is very high, even after accounting for its ambitious renewable energy targets.

This paper builds on valuable ground data directly collected from consumers in two cities (Bangalore, and Chennai) on REC. It takes a statistical approach and hence avoids biases. Such a study should help in obtaining insights about the role of electrical appliances in REC, particularly revealing opportunities for promoting energy efficient appliances.

DESIGN OF THE STUDY

The unique aspect of VR is its field level data driven approach motivating household consumers to voluntarily participate and share information on their electricity consumption. Statistically valid sampling methods were used to ensure adequate representation of households as explained in this section.

Choice of cities

VR program was launched as a pilot study in Bangalore in 2015 and has since grown organically to more than 4000 households in mid-2019. VR was piloted in Chennai in 2018. Table 1 lists some characteristic features that led to the choice of the cities and the samples therein.

Cities / Character	Climate*	Average Number of households**	Population density (Per sq. km)**
Bangalore	Temperate	12,72,413	12,000
Chennai	Warm - Humid	11,06,567	26,553

Table 1: Characteristics of the selected cities

**Based on BEE ECBC 2017*

BHK (Bedroom Hall Kitchen) as a common classifier

Getting floor area information from households was not reliable as observed in an earlier VR pilot in Bangalore. This necessitated the use of a more conversational classifier and BHK was one such common use terminology prevalent in India. Even though floor area to BHK mapping varies from city to city, BHK has proven to be a reliable though proxy indicator of relative floor space and affordability within a city for this study.

BHK can be interpreted as the dwelling room that the Indian Census uses to ascertain household sizes. Other studies have analysed and found dwelling and household size as likely predictors of electricity consumption. [Huebner, G et.al, 2016].

Electrical consumption indicators

The annual average consumption in units and per capita annual average consumption in units are the primary indicators. The program obtains the consumption data in units (kWh) from the electricity utilities and this is available as monthly data for Bangalore and bi-monthly data for Chennai. The annual averaging ensures that the analysis is not biased by factors like seasonality, locked houses, etc. The program also computes per capita data, using the occupancy of the house collected during the survey.

However, for the purpose of correlation study covered in this paper, only the annual average consumption is used. For this study done in July 2019, data of past 12 months was considered as the annual average.

Sample size and distribution:

For any study, if the population universe is in lakhs, then around 400 randomly chosen respondents present a good sample size for a 95% confidence level and a 5% margin of error[1].

VR participation in Chennai is 609 households and has crossed 4000 households in Bangalore. The recommended sample sizes of the respective categories were selected based on census 2011 figures of BHK wise households in the respective cities (Tables 2 and 3).

Dwelling rooms	No of Households in Bangalore district	% of total	VR coverage	VR % of total
No exclusive rooms	166393	7%		
1 BHK	789182	33%	1894	50%
2 BHK	753526	32%	1405	37%
3 BHK	437378	18%	473	12%
4 and 4+ BHK	230574	10%	38	1%

Table 2: BHK-wise households in Bangalore and VR coverage

Dwelling rooms	No of households in Chennai district	% of total	VR coverage	VR % of total

No exclusive rooms	26177	2%		
1 BHK	427430	39%	130	21%
2 BHK	339257	31%	256	42%
3 BHK	212778	19%	185	30%
4 and 4+ BHK	100925	9 %	38	6%

Table 3: BHK-wise households in Chennai and VR coverage

The participation from households was not controlled based on number of occupants of the households. However, the coverage has ensured a reasonable occupancy distribution in the sample (Figures 1 and 2, the numbers 1 to 10, denoting the actual occupancy in the houses).

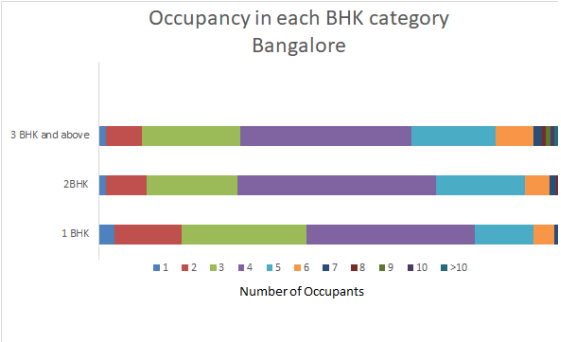

Fig 1: Occupancy among VR participating households in Bangalore

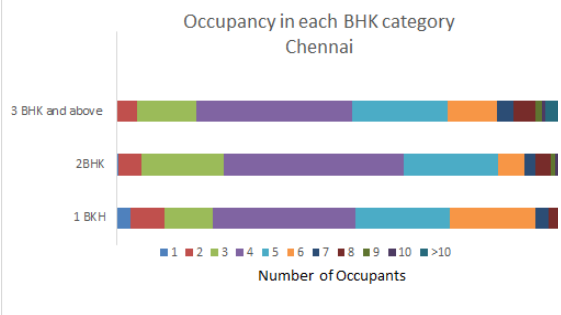

Fig 2: Occupancy among VR participating households in Chennai

EXECUTION OF THE STUDY

Registration for the program

Participation in VR requires registration, which can be done through a mobile app or through the stewards. Stewards are youth selected and trained in conducting home electricity surveys. Registration drives are conducted in various corporates, institutions, apartments through awareness sessions. Stewards undertake door-to-door registration in selected areas.

On registration, an awareness booklet on electricity conservation is given to the consumer. The same is available on mobile app also.

Survey questionnaire

Once registration is done, the participant is asked to take a survey.

After a few rounds of iterations, VR has settled on a questionnaire format divided broadly into three parts:

Part I: Consumer profile information and includes account no, sanctioned load as mentioned in the electricity bill, Location pin code, Mail ID for correspondence, BHK, Occupancy, type of residence and some socio-economic indicators.

Part II: Information on the various types of electrical appliances (lighting, heating, cooling, kitchen, entertainment), usage pattern, peak hour usage and penetration of solar appliances.

Part III: Consent from the consumer for obtaining consumption data from the supplier, promising data security and confidentiality.

Thus, the appliance data is directly collected from the participant.

Obtaining consumption data from utility:

As consumers have difficulty recalling past consumption and the program tracks the consumption of the participant, the electricity account IDs of the participants are used to obtain the consumption data directly from the supplying utility. This is done based on the consent given by the consumer in part III of the survey questionnaire described above. In the case of Bangalore, the data is obtained from Bangalore Electricity Company (BESCOM), and from Tamil Nadu Generation and Distribution Corporation (TANGEDCO) in Chennai.

Data confidentiality, privacy and security:

The data is obtained from BESCOM through an NDA protecting the personally identifiable information of consumers by both parties. TIDE follows prescribed standards for data privacy and data security (developed in line with national and international standards). The personal data collected is secured in an independent cloud platform following due security protocols. The data is not used by TIDE for any other programs or shared with any other partner. TIDE uses only anonymised aggregated data for all presentations and papers. Personal information like name and address are used only to send household electricity reports.

Data Analysis

The need for data cleaning is limited in VR due to the automated process of administering the questionnaire and recording answers in the mobile app. Still the data is standardized, validated, and scrubbed for duplicates. After merging the data directly collected from the consumer with consumption data obtained from the utility using the account ID, the data set is processed in categories of BHK within each city. The bottom and top 10 percentile households are not considered for aggregate analysis as they are treated as outliers. Such cases occur in practice due to many reasons like locked houses, billing errors, etc.

For understanding seasonal effect, monthly average temperature data for the respective cities was obtained from open sources. [world weather online, 2019]

Home report generation

For generating individual customized home electricity reports, each home is benchmarked based on the following models [Krishnan Sumathy, et al., 2017]:

a) **Understanding own consumption pattern historically**

b) **Understanding where the household consumption stands vis-a-vis neighbours**

c) **Understanding the break-up of consumption based on the categories like lighting, heating, cooling, etc**

Households report nudges them to set a goal for consumption with these benchmarking and provides customized recommendations to bring down consumption or transitioning to efficient appliances. Apart from the above, best practices already being followed, safety recommendations, tariff slab-based analysis are provided in the report to reinforce conservative behaviour.

For aggregated analysis

For each city, average annual consumption and per capita consumption is aggregated for each BHK category to arrive at the city level and BHK level benchmarks. One of the unique aspects of the VR program is the generation of such benchmarks in residential electricity consumption, emerging from field level data. Additionally, there is rich data on appliances and an attempt has been made to correlate the consumption with electrical asset ownership in different BHK categories in both cities.

Presently this analysis is used only to rank assets in order of their likely impact on consumption. It is possible to derive an analytical equation predicting the impact of assets on consumption, which is not in the scope of this paper.

RESULTS AND DISCUSSION:

After removal of Outliers, 3310 households in Bangalore and 572 households in Chennai qualify for the analysis on correlation of electrical appliance ownership to the consumption.

The range of consumption at the 10th and 90th percentile is tabulated in Table 4.

City	BHK Category	Annual electricity consumption in kWh	
		10th percentile	90th percentile
Bangalore	1 BHK	258	1828
	2 BHK	434	2660
	3 BHK and above	854	4531
Chennai	1 BHK	818	2998
	2 BHK	1228	5236
	3 BHK and above	1481	8650

Table 4: Distribution of consumption of VR consumers across the BHK categories and cities

This study uses data falling between the 10th and the 90th percentile value with respect to annual average consumption.

Figure 3 shows the BHK wise average annual and per capita consumption (kWh) of participating households of Bangalore and Chennai.

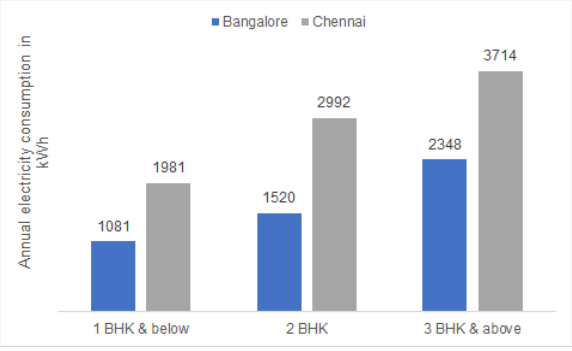

Fig 3: BHK wise average annual electricity consumption (in kWh)

This study will use the city wise BHK wise average annual consumption for correlating with electrical appliance data.

Trends in appliance ownership

In each of the cities, the appliance holding average was computed within the BHK categories. In Tables 6 and 7, those appliances with high holding average across different BHKs are listed with their average holding values.

Appliance	1 BHK	2 BHK	3 BHK and above
LED bulbs	1.41	2.65	4.82
Energy Efficient Tube lights	0.22	0.38	1.53
Storage type geyser	0.09	0.48	1.29
AC with star rating	0.0005	0.007	0.05
Refrigerator	0.62	0.92	0.96
Non-Cathode ray TV	0.49	0.92	1.78
Instant geyser	0.03	0.10	0.24
Incandescent bulbs	0.73	0.94	1.72
AC without star	0.00	0.006	0.07

Table 6: Selected electrical appliances and their holding average in different BHKs in Bangalore

Appliance	1 BHK	2 BHK	3 BHK and above
LED bulbs	1.38	2.1	4.3
Energy Efficient Tube lights	0.60	1.28	2.32
Storage type geyser	0.07	0.13	0.30
AC with star rating	0.26	0.80	1.67
Refrigerator	0.77	1.01	1.15
New model TV	0.72	0.92	1.47
Instant geyser	0.18	0.24	0.51
Incandescent bulb	1.81	1.89	2.27
AC without star	0.04	0.16	0.35

*Table 7: Selected electrical appliances and their holding average in different BHKs in Chenna*i

While LED bulbs are prevalent across the BHKs in both cities, the penetration of energy efficient tube lights is high in Chennai across the BHK categories compared to Bangalore. Whether this is due to policies or awareness needs investigation. The presence of incandescent bulbs along with LED bulbs indicates a mixed-use pattern, particularly in Chennai.

Absence of energy efficient fans in the list in both cities (due to a very low holding average) seen in contrast with the large LED penetration, shows the huge potential in this category. This finding corroborates a study done in 2017 which shows less than 1% penetration of energy efficient fans in households of Kerala [Jayaraman C, Sathaye.J, SasiK K, 2017]. The shift to energy efficient choices as in lighting sector has not happened with fans. This is an intent versus knowledge gap highlighted in Prayas Energy Group's study arguing that fans are rarely part of the energy efficient discussions, even though they are the most common electrical equipment [Singh D et al.2010].

We observe high penetration of star rated ACs in all BHK categories in Chennai compared to Bangalore. Bangalore shows relatively low holding of ACs. It also points to a possible opportunity to promote energy efficient fans in place of ACs in Bangalore, resulting in significant savings by replacing the old fans (>10 years).

The holding of storage type geysers is relatively low in Chennai, while there is significant holding of instant geysers.

NOTE: While Chennai data is pertaining to 2018 and later, some data in Bangalore is from 2015. Attempts are on to update these through a feedback study and through the mobile android application.

Correlation between electrical appliance holding and electricity consumption

Correlation coefficient analysis was done to find out the relative contribution of the electrical appliances to the annual average electricity consumption. For every participant, the holding value of each appliance is multiplied with the rated wattage and correlated with the annual consumption. The correlation index was then computed for participants in each BHK category for every appliance (with respect to consumption). Tables 8 and 9 show the electrical appliances ranked within each BHK category (**value of correlation index is mentioned in brackets**) in decreasing order of their correlation to consumption, for both the cities. Note that (i) sample sizes are different for Bangalore and Chennai and is not normalized as the correlation is done for every participant and (ii) consumption data is not normalised for seasonal variations in both cities.

Bangalore

Rank	1 BHK	2 BHK	3 BHK and above
1	Tube light (0.17)	Storage type geyser (0.10)	LED TV (0.23)
2	Refrigerator (0.17)	Incandescent bulb (0.07)	Tube light (0.21)
3	Storage type geysers (0.16)	AC with star rating (0.07)	Energy efficient tube light (0.14)
4	LED TV	LED bulbs	Fan (age less than

	(0.14)	(0.07)	10 years) (0.10)
5	LED bulb (0.135)	Refrigerator (0.04)	Fan (age more than 10 years) (0.10)

Table 8: Ranking of electrical appliances in decreasing order of correlation with electricity consumption across BHKs in Bangalore

Chennai

Rank	1 BHK	2 BHK	3 BHK and above
1	Tube light (0.24)	AC with star rating (0.30)	AC with star rating (0.47)
2	Refrigerator (0.15)	AC without star rating (0.29)	Tube light (0.27)
3	AC with star rating (0.13)	Energy efficient tube light (0.27)	Storage type geysers (0.25)
4	Fan (age more than 10 years) (0.12)	Refrigerator (0.24)	CFL bulbs (0.22)
5	Storage type geyser (0.10)	Storage type geyser (0.24)	Energy efficient tube lights (0.18)

Table 9: Ranking of electrical appliances in decreasing order of correlation with electricity consumption across BHKs in Chennai

Considering different climatic profiles affecting the usage of electrical appliances, a comparison of the correlation between the two cities is not justified.

Bangalore:

The presence of tube lights in the top two positions in 1 and 3 BHKs is of interest to note. This category of tube lights is only the fluorescent ones and not the energy efficient ones. The incandescent bulbs contribute to the overall consumption significantly in 2 BHK households indicating an opportunity for LED bulbs upgrade programs.

The absence of refrigerator in the top five for the 3 BHK possible indicates the dominance of other appliances in 3 BHK households.

Storage type geysers play a predominant role aligning with Bangalore's temperate weather needs. However, its absence in the top five in the 3 BHK category again indicates the dominance of other appliances.

We observe LED TVs as high contributors to total consumption as compared to even AC in 3 BHKs; this corroborates with the high holding value (>1). indicating multiple TVs in the same house.

Fans aged over 10 years contribute significantly to 3 BHK ranked in the Top 5 appliance. While 1 and 2 BHK households also have old fans, they are not significantly contributing to consumption. This indicates a potential consumer base for targeting for efficient fans, especially considering the low holding in all categories.

Chennai:

In Chennai, cooling appliances especially ACs with star rating have higher correlation with consumption in all categories which corroborates previous studies on the REC [Prayas energy group,2016].

As in Bangalore, the refrigerators are not in the top five in the 3 BHK category.

Tube lights (Non-LED) contribute to significant lighting load in all categories showing low penetration of energy efficient tube lights. The presence of CFL bulbs in 3 BHK shows the opportunity for replacement with LED bulbs

Water heating by use of storage water heaters are significant contributors in all categories. Policy initiatives to promote alternates like Solar water heaters or star rated geysers could help conservation.

CONCLUSION

As aspirations drive more consumption and uptake of electrical appliances, motivating consumers to transition to efficient appliances are becoming a necessity. Evidence based programs VR provide valuable insights that can help in this transition through right targeting and messaging.

The insights available through this study can be used for scaling uptake of affordable and efficient appliances through different business models (e.g. rolling out superefficient appliance programs). Such an effort is the need of the hour in India, considering our unique challenge to balance economic development with environmental conservation commitment.

While more data and detailed analysis will strengthen the interpretations, the correlation analysis highlights the need to have disaggregated data for policy making in dissemination of efficient appliances.

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