PLUGGING IN

A COLLECTION OF INSIGHTS ON ELECTRICITY USE IN INDIAN HOMES

DECEMBER, 2017

RESEARCH REPORT

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ABSTRACT

Electricity use in Indian homes – from lights, ceiling fans, televisions, refrigerators, among other appliances – has increased 50 times between today and 1971, even though India's per capita residential electricity consumption is less than a third of the world average. Residential electricity now outpaces growth in industrial, commercial and agriculture sectors. This striking statistic is on the increase, as India moves towards one of the largest urban transitions in history in the coming decades. What is the implication of this transition for household electricity use, as the urban population grows and income levels rise? What do we know about how electricity is currently used in homes across the country? And what drives our dramatically changing consumption patterns?These questions form the basis of a series on residential electricity consumption, jointly authored by the Centre for Policy Research, New Delhi and the Prayas (Energy Group), Pune. The collected insights that formed the series are complied in this document.

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Electricity Consumption in Indian Homes

Radhika Khosla, *Centre for Policy Research*
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Electricity use in Indian homes – from lights, ceiling fans, televisions, refrigerators, among other appliances – has increased 50 times between 1971 and today (seen in Figure 1), even though India's per capita residential electricity consumption is less than a third of the world average (World Energy Council, 2016). Residential electricity now outpaces growth in industrial, commercial and agriculture sectors (Central Statistics Office, 2017). This striking statistic is on the increase, as India moves towards one of the largest urban transitions (UN DESA, 2014) in history in the coming decades. What is the implication of this transition for household electricity use, as the urban population grows and income levels rise? What do we know about how electricity is currently used in homes across the country? And what drives our dramatically changing consumption patterns?

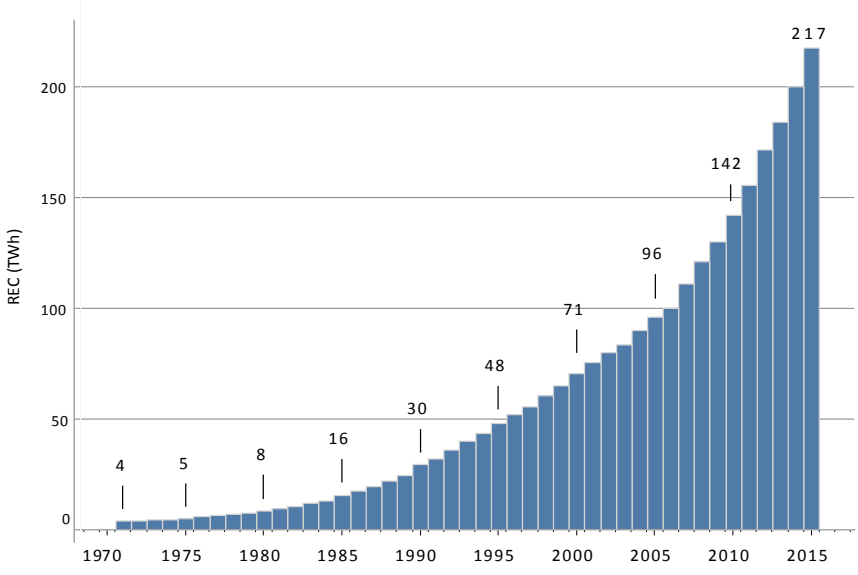
These questions form the basis of a new series on residential electricity consumption, jointly authored by the Centre for Policy Research, New Delhi and the Prayas (Energy Group), Pune. These findings draw from recently published work, and from new research that will be published in the next few months.

Specifically, the CPR findings are based on two new energy services surveys: 700 households in affordable housing units in Rajkot; and 5500 households representative of the National Capital Region or the broader Delhi area. The Prayas findings draw from two recent reports: a study (Chunekar et al., 2017) to analyse the impacts of India's large-scale LED bulb market transformation programme; and review (Chunekar et al., 2016) of trends in India's residential electricity consumption.

This series has two motivations

- First, is the sheer scale of residential growth and the challenge of meeting this demand in a sustainable manner. India's residences, which avail modern energy services such as cooling, clean cooking, lighting, and media access are predicted to account for 85% of the country's floor space by 2050 (GBPN, 2014). The population's development and lifestyle needs, coupled with the government's aim to provide uninterrupted electricity to all homes by 2019, is projected to increase electricity consumption five to six times between 2014 and 2030. A combination of rapid electrification, increasing incomes, and technological development will result in people buying more appliances and using more electricity to run them. Already, the residential sector uses about 25% of the country's total current electricity consumption (with a nine per cent growth in 2015-16) (Central Statistics Office, 2017) – at a time when less than a quarter of all households do not have an electricity connection (Ministry of Power, 2017) and those that do face frequent power cuts.

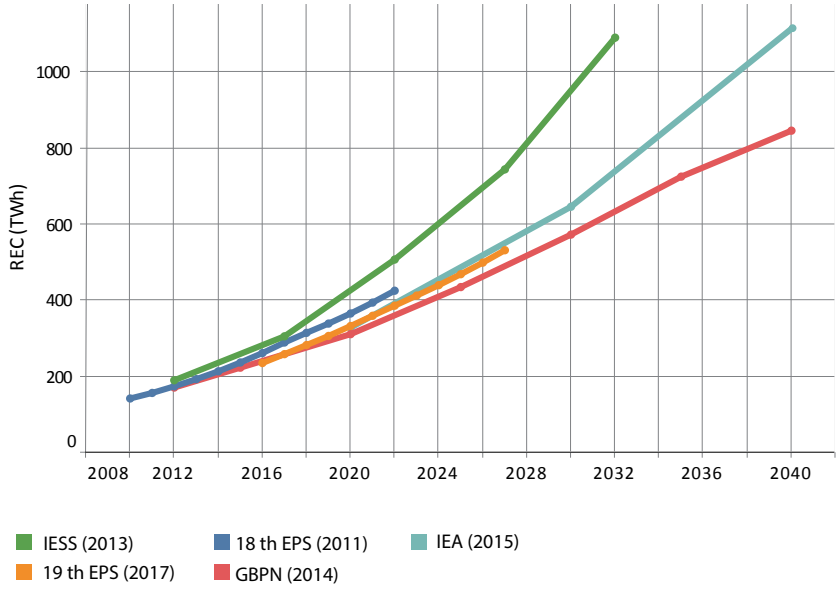
Figure 1: Trend in Residential Electricity Consumption in India (1971-2015). Decimals are approximated to their closest whole numbers.



Source: Ministry of Statistics and Programme Implementation (MOSPI) & Central Electricity Authority (CEA) data

- The second motivation is that in spite of the scale of current and future residential electricity use, an understanding of household consumption patterns and their drivers is limited. There is scarce publicly available data on the issue – evidenced by Figure 2, which shows how different studies predict dramatically different scenarios for the extent to which residential electricity use will grow. This large variation stems from differing methods, base-years and assumptions, even in business-as-usual cases. Variations also exist between government estimates, as seen by the difference in projections from the 18th and 19th Electric Power Survey (of India's Central Electricity Authority). This uncertainty in future demand estimates is a significant barrier to strategic energy and climate planning. Beyond quantitative data, we also lack an understanding of the social and political processes conditioning electricity consumption such as appliance purchasing decisions, success of efficiency policies, and electricity use and conservation behaviour. A rigorous understanding of residential consumption is essential for designing effective and credible energy efficiency programmes, optimising planning of power capacity addition, and to adequately adapt to changing business models and technologies.

Figure 2: Projections of residential electricity consumption from various studies (base case scenarios)



The scale of increased residential demand, the uncertainty in the extent to which it could increase, and the urban and demographic transitions underway make future electricity needs not only immense, but also potentially malleable. If unaddressed, this demand will put serious constraints on already stretched national resources, posing serious social, local environmental and climate change related burdens. But if considered strategically, the increased demand could be an opportunity – to lock-in an energy efficient and low-carbon development path. More so, demand-side interventions could substantially reduce the requirements of energy supply, bypass the structural inefficiencies and financial losses prevalent in electricity distribution, and shape path-dependent consumption trajectories.

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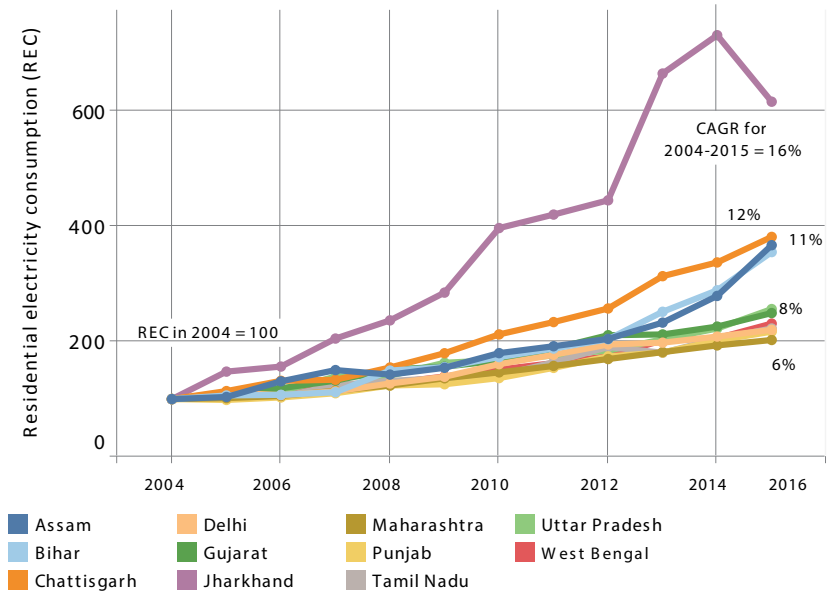
Trends in India's Residential Electricity Consumption

Aditya Chunekar and Sanjana Mulay, *Prayas (Energy Group)*

Electricity consumption in Indian homes has tripled since 2000. The percentage of households with access to electricity has increased from 55% in 2001 (Chandramouli, 2012) to more than 80% in 2017 (Ministry of Power, 2017a). In 2014, an electrified Indian household consumed about 90 units (kWh) (World Energy Council, 2016) of electricity per month on an average; enough to run four tube-lights, four ceiling fans, a television, a small refrigerator, and small kitchen appliances with typical usage hours and efficiency levels in India. This is three-fourths of the average monthly household consumption in China, a tenth of that in the USA, and a third of the world average (World Energy Council, 2016). In this post, we take a closer look at data on India's residential electricity and the disparities in access and consumption across states. We also reveal some inconsistencies between different sources, pointing to the need for better data.

All states show considerable increase in total residential electricity consumption in recent years according to data compiled by the Central Electricity Authority (CEA) from distribution companies (see Figure 1). Between 2004 and 2015, states like Assam, Bihar, Chhattisgarh, and Jharkhand with low initial household electrification showed a high growth rate of their residential electricity use (about 11%-16%). States with higher household electrification like Delhi, Punjab, Haryana, and Tamil Nadu grew at lower, but still substantial, rates (6%-8%), with high absolute numbers

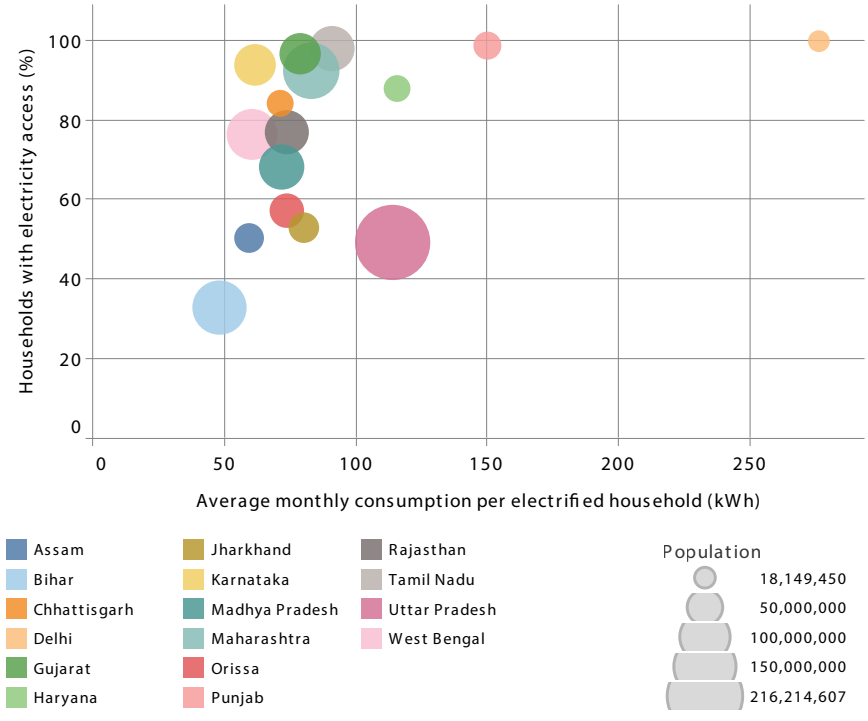
Figure 1: Residential Electricity Consumption growth in selected states (2004-2015)



Source: Annual General Reviews for individual years (CEA).

The CEA data along with the census data (Government of India, 2011) and the rural electrification data (Ministry of Power, 2017a) can be used to estimate average monthly electricity consumption of an electrified household in different states. We validate this against the tariff orders issued by state regulators and find interesting results (see Figure 2).

Figure 2: Household access and average monthly consumption per electrified household



Source: Authors' estimates from 2011 census and GARV dashboard

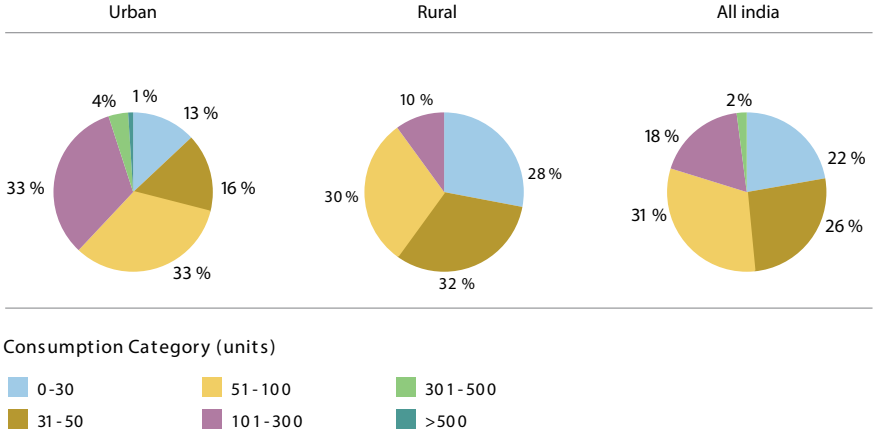
Three insights emerge:

- One, an electrified household in Delhi consumes about 250-270 units or kWh of electricity per month on average, approximately the same average amount consumed by an electrified household in Germany (World Energy Council, 2016). At the same time, such an electrified household in Delhi consumes significantly more than other Indian cities (Chandigarh: 208 units; Ahmedabad: 160 units; Puducherry: 150 units; and Mumbai: 110 units). This is in part due to high ownership of air-conditioners (12% of total households) and air-coolers (70%), and (Desai et al., 2008; Desai and Vanneman, 2015) tariff subsidies (PTI, 2016) in Delhi. Yet, other socio-economic reasons still need to be examined.
- Two, electrified households in larger states like Maharashtra, Gujarat, and Tamil Nadu, with higher rates of electrification, consume on an average a lower amount of about 80-90 units per month. Karnataka is on the lower end with about 60 units. On the other hand, households in Punjab (about 150 units) and Haryana (about 110 units) consume much more. . While there may be some discrepancies in the data due to incorrect reporting on use and number of consumers by distribution companies, the scale of these discrepancies is likely to be small given the limited number of un-metered and illegal connections in the residential sector.
- Three, states like Uttar Pradesh (UP), Jharkhand, and Chhattisgarh show high monthly household electricity consumption. It is unlikely that states with a high share of newly electrified households and low reliability of power supply (Prayas (Energy Group), 2017) consume as high as an average household in Chandigarh or Mumbai. The reported household consumption is high possibly due to metering issues. For instance, 40% of the total residential connections in UP are rural un-metered connections. As their actual consumption is not metered, the distribution companies estimate their consumption based on norms approved by the regulator (currently the norm is 144 kWh/kW/month, (UPERC, 2016) a high number). Distribution companies have not conducted any sample studies to justify this norm despite being asked by the regulators. High estimation of consumption from un-metered connections as well as measurement issues in metered connections can mask the actual consumption.

Finally, the electricity consumption within states also exhibit significant inequity at the household level. According to the National Sample Survey Office (NSSO)'s (MoSPI, 2014) surveys, about 20% of electrified households consume less than 30 units of electricity per month, while about 80% consume less than 100 units per month. In rural areas, 90% of the electrified households consume less than 100 units. This distribution varies with states. In most states, about 15-20% of all the households consume less than 30 units per

month. The states consuming the least electricity are Karnataka, West Bengal, Bihar, and Jharkhand. For more details on results see our recent report (Chunekar et al., 2016).

Figure 3: Households in India according to monthly consumption (in kWh or units)



Source: NSSO

Understanding the factors that lead to such variation in consumption patterns across states and households is important for managing future electricity demand (and to monitor the performance of schemes such as UDAY (Ministry of Power, 2017b) for the financial revival of distribution companies, and Saubhagya (Ministry of Power, 2017a) for providing electricity connections to all un-electrified homes). This requires accurate and comprehensive data on electricity consumption which, at present, is a serious area of concern (particularly the limited reporting by distribution companies).

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India's LED Lighting Story

Aditya Chunekar and Sanjana Mulay, *Prayas (Energy Group)*

Lighting is the most basic use of electricity in a home. Lighting's share in the total residential electricity consumption is estimated to be in the range of 18% to 27% (Chunekar et al., 2017). In 2013, about a billion and a half lighting devices (Elcoma India, 2016) were sold in India; half of them being incandescent bulbs followed by CFLs (31%), tube-lights (16%) and a negligible share of LED bulbs. In 2014, the government launched a programme to promote LED bulbs in Indian households and later named it UJALA (Unnat Jyoti by Affordable LEDs for All).

This is because LED bulbs consume less electricity, last longer, and does not contain mercury. The programme, arguably the world's largest, has sold more than 27 crore LED bulbs (Ministry of Power, 2017) with no subsidy from the government. How did the programme change India's lighting industry and consumer behaviour? What part of programme design worked and what can be improved? Answers to these questions can improve future programmes designed to improve energy efficiency in India. In this post, we discuss some key findings of our recent report Chunekar et al., 2017) where we surveyed manufacturers, retailers, households, and various stakeholders to understand the impacts of UJALA.

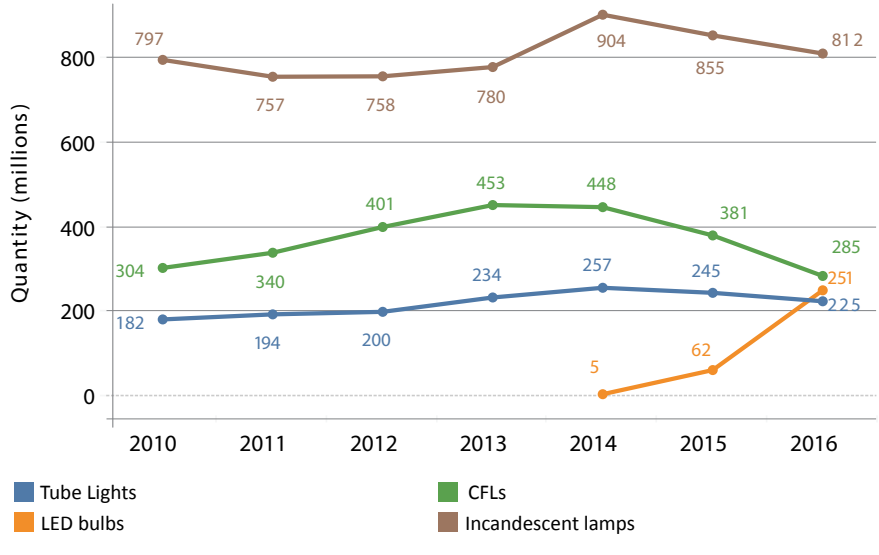
Innovative programme

Energy Efficiency Services Ltd. (EESL), a public sector company, is responsible for implementing the UJALA programme. The company bought LED bulbs in bulk from manufacturers through multiple rounds of competitive bidding. The large volumes and assured sales incentivised the manufacturers to drop the bid price from Rs. 310 per LED bulb in the first round to as low as Rs. 38 in later rounds. EESL sold these bulbs to consumers through contract vendors in co-ordination with the local electricity distribution companies (discoms), bypassing the retail supply chain and further bringing down the final distribution price. As a result, the current price of LED bulbs under UJALA is Rs. 70, about half of the price of the LED bulbs available in the shops. Yet, there is no subsidy from the government or the discoms. EESL also conducted innovative marketing campaigns to create public awareness.

LED bulb sales are up and prices down

The UJALA programme transformed the LED lighting industry in India. Demand for LED bulbs has gone up 50 times in the three years since 2014, while the retail market price (for bulbs sold beyond UJALA) has dropped to a third. The fall in prices can be attributed to the economies of scale achieved due to substantial demand creation by the UJALA programme, in tandem with the global trend of reduction in prices of the LED chips. India's LED bulb manufacturing capacity has also grown substantially, with about 176 registered manufacturing units in India.

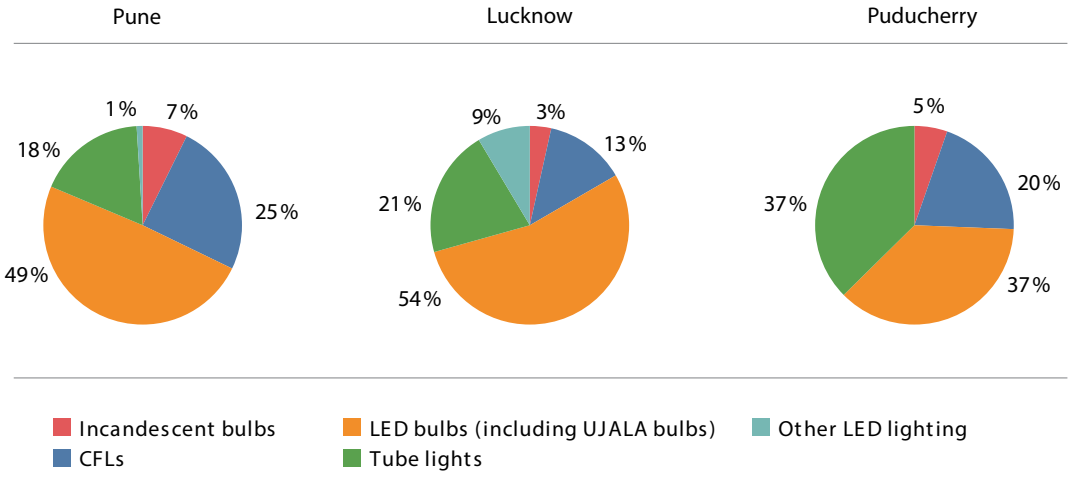
Figure 1: Sales trends of lighting devices in India



Source: ELCOMA

Our surveys show that LED bulbs are now a major source of lighting for the households that participated in the UJALA programme (Figure 2). Most of the households also said that they would buy a new LED bulb from the market when the installed LED bulb reached the end of its useful life.

Figure 2: Share of lighting sources in the surveyed households



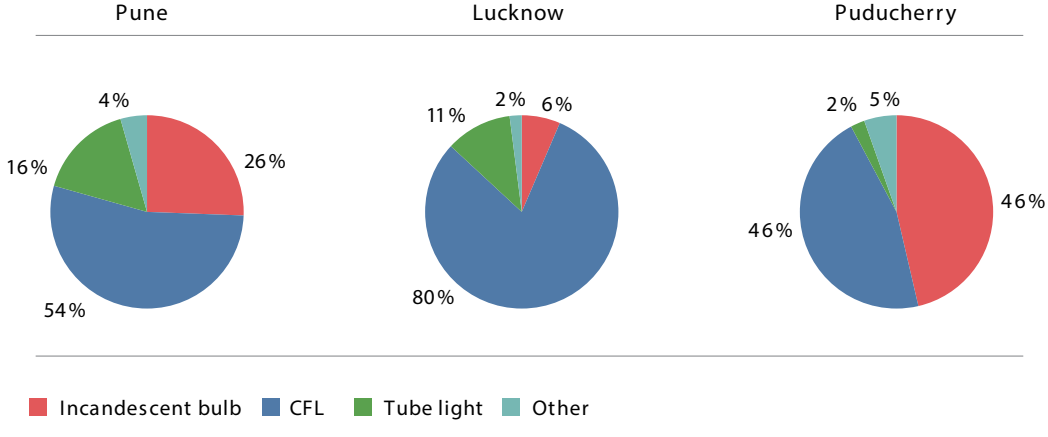
Source: Prayas Consumer survey (January – March 2017)

Incandescent bulbs are still around

The increased demand for LED bulbs seems to replace the demand for CFLs instead of incandescent bulbs. About 810 million incandescent bulbs were sold in 2016, a 5% drop over previous year's sale whereas the sales of CFLs have dropped by a third since their peak in 2013 (Figure 1). Our surveys corroborate this trend as we find that a considerably large proportion of the UJALA LED bulbs were used to replace CFLs, followed by incandescent bulbs and tube lights (Figure 3).

The more that people replace CFLs with LEDs, the lesser the saving that are actually realized. Our sample of households in Pune was

Figure 3: Lighting options replaced by LED bulbs bought under UJALA for surveyed households



Source: Prayas Consumer survey (January – March 2017)

distributed across different income classes. A typical LED bulb saved 2.5 times more in a low income household compared to a high income household. This makes a case for programme to focus more on low income households.

Table 1: Comparison between low, medium, and high income households surveyed, Pune

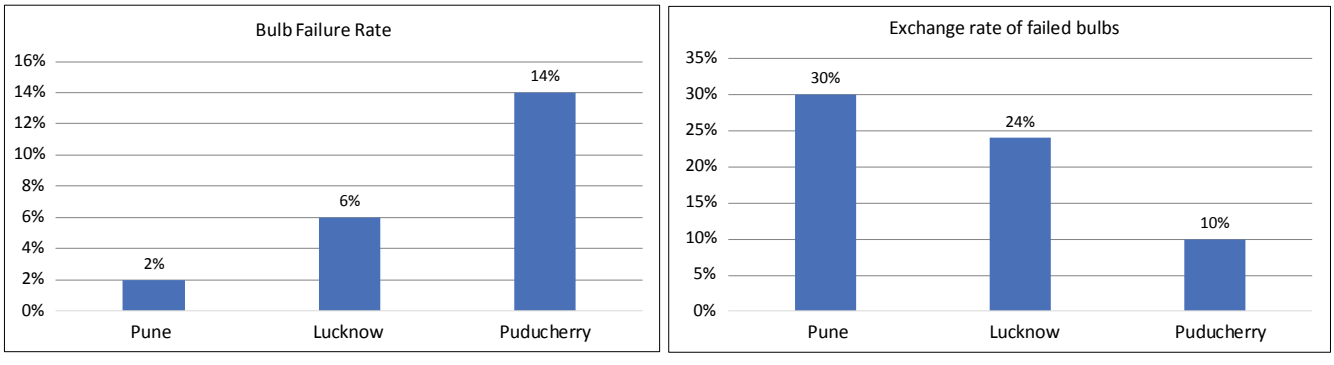
	% Incandescent bulbs replaced	Average usage (hours)	Annual savings (kWh)/LED bulb	No. of LED bulbs bought per HH
Low	45%	5.5	56	3
Medium	18%	3.6	27	5
High	18%	3.2	22	6

Source: Prayas Consumer survey (January – March 2017)

LED bulb quality and warranty is important

Our surveys found that 2% of LED bulbs failed in Pune after a year of launch of the programme, while 14% of the LED bulbs failed in Puducherry three years after the launch. The bulbs sold in Pune carried a warranty of 3 years while the bulbs sold in Puducherry carried a warranty of 8 years. However, very few households got their faulty bulbs replaced. Lower expectations from a government programme and higher tolerance levels for faults in low cost LED bulbs, ignorance about warranty, and hassles in the process were cited as reasons for not replacing the faulty bulbs under warranty.

Figure 4: Failure rate and exchange rate of UJALA bulbs (for surveyed consumers)



Source: Prayas Consumer survey (January – March 2017)

To conclude, UJALA has created a large and sustainable market for LED bulbs in India using the no-subsidy, bulk procurement model. Demand for LED bulbs has increased manifold and the retail market price (for the LED bulbs sold beyond UJALA) has dropped by a third. It has also created a significant awareness about LED bulbs, further contributing to increasing demand. Going ahead, EESL can ensure stricter monitoring and evaluation of the programme. It can also focus on low income households and small commercial establishments who are still buying incandescent bulbs. We focus on this aspect of LED use in low income households in the next post.

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Illuminating Affordable Homes

Radhika Khosla and Ankit Bhardwaj, *Centre for Policy Research*

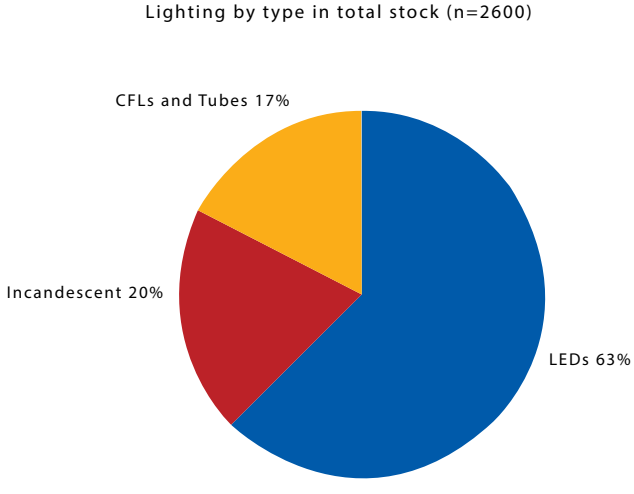
Electricity consumption debates, for the most part, focus on high-rise residential and commercial establishments, often ignoring low-income housing. The rationale for this omission is the low level of electricity use in affordable housing, with the assumption that little is at stake from its consideration in national energy and climate debates. This, however, may no longer be true.

As India urbanises, housing has been unable to keep pace. The housing shortage is reported ("Economic Times," 2017) to be near 19 million units, with low-income households accounting for the largest proportion. The government's 'Housing for All' (PIB, 2015) programme aims to fill this gap by providing affordable housing for 20 million households by 2022. This new construction will partly condition future energy use from the provision of basic services, with increased access to electricity and commercial appliance markets. In this post, we examine the most basic use of electricity within affordable homes – lighting.

Lighting forms a large share of electricity services availed by low-income homes and consequently the electricity bill. Technologically, LED bulbs provide the largest reduction in lighting electricity consumption, without reducing the amount of light provided, and with a lifespan that is up to 25 times (Energy Saver, n.d.) that of an ordinary bulb. However, LED bulbs cost more, which can deter the willingness of households to pay. As described in this series' previous post, the government's UJALA scheme has increased the use of LEDs by bringing down costs and increasing awareness. However, the programme's impacts on low income households, those with the potential for maximum benefits, are not yet clear.

Are lower income households purchasing technologically advanced LED bulbs? We conducted a survey in 2017, about a year after the launch of the UJALA scheme, in Rajkot, Gujarat to examine lighting services in low-income homes. This is part of an ongoing study on energy use in low income urban households under the CapaCITIES project. We find LED penetration in the sample surveyed is remarkably high at 63% of all bulbs (Figure 1).

Figure 1: LED penetration in the affordable housing sample (stock level

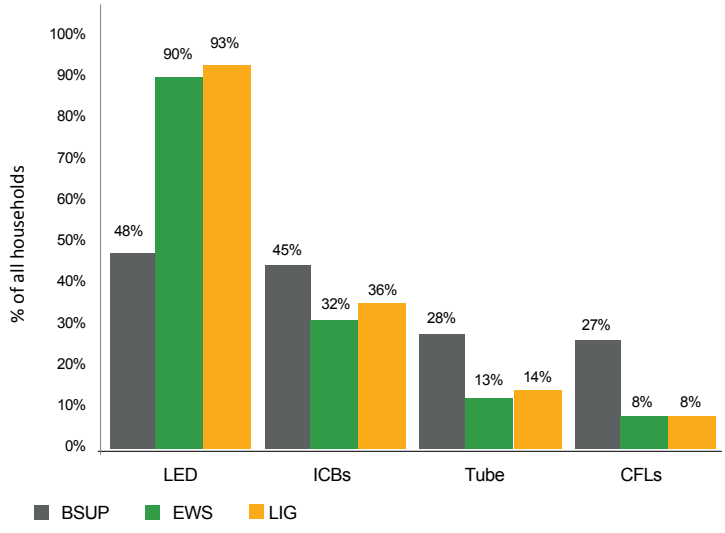


Source: Rajkot affordable housing energy survey (Khosla et al., in preparation)

Household assets and LED penetration

To understand this high rate of LED use, we categorise results according to the three types of government affordable housing: BSUP or Basic Services for the Urban Poor (built 2007 onwards); EWS or Economically Weaker Sections; and LIG or Low Income Groups housing (EWS and LIG are built under the Housing for All programme, 2015 onwards) (Figure 2). The categories broadly correlate to income – BSUP residents, on average, being the poorest in the sample, and LIG, the best off.

Figure 2: Household (LED, incandescent bulbs or ICBs, tube lights, compact florescent lights or CFLs) penetration rates

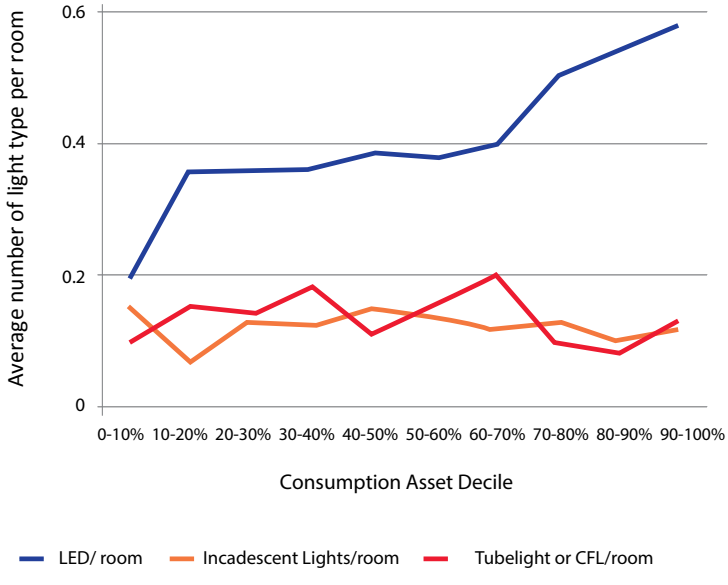


Source: Rajkot affordable housing energy survey (Khosla et al., in preparation)

Figure 2 shows that the widespread use of LEDs is especially true for EWS and LIG categories, with more than 90% having at least one LED. Tube lights, CFLs, and incandescent bulbs on the other hand have lower penetration rates in these homes. Further, homes are buying more than one LED. The mode number of LEDs in a EWS home is three, and in LIG homes is five. This is within the number provided under the UJALA scheme in Rajkot, which is up to 10 subsidised LEDs per home at Rs. 80 per 9W bulb.

We also find that LED ownership, standardised for home sizes, is correlated with household assets or their ability to consume (Figure 3). Richer homes buy more LEDs, though a degree of incandescent bulbs persist in the system. And while Figures 2 and 3 show a strikingly high rate of LED use, they also show that not all homes have made this transition. Specifically, BSUP homes – which are of the lowest-income of the three categories – have about half the LED penetration compared with EWS and LIG homes (Figure 2) and the mode number of LEDs owned in BSUP homes is zero.

Figure 3: Lighting ownership across the consumption asset index (standardized for number of rooms)

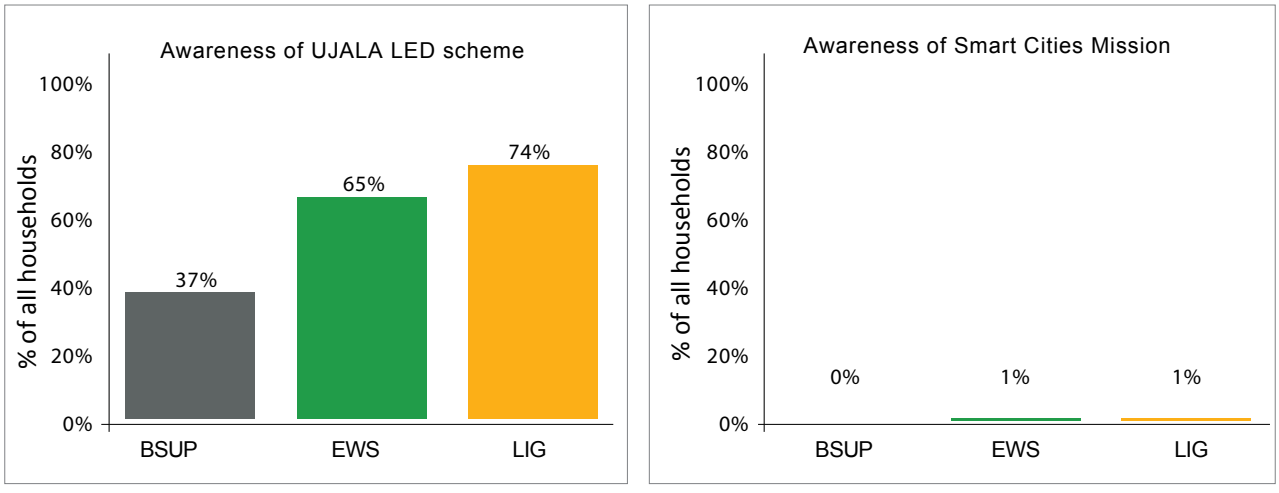


Source: Rajkot affordable housing energy survey (Khosla et al., in preparation)

Awareness of the LED scheme

Why do some households buy LEDs and others don't? Is the difference a function of households' awareness of the LED scheme (Figure 4)?

Figure 4: Awareness rates of the LED and Smart Cities schemes



Source: Rajkot affordable housing energy survey (Khosla et al., in preparation)

Awareness of the LED scheme maps on to the ownership of LED bulbs in housing types. EWS and LIG homes are much more aware about the scheme, and own many more LEDs, while the reverse is true for BSUP. To test if awareness about government schemes was generally high, or whether this was particular to UJALA, we also asked households of their awareness of the Smart City scheme which is well advertised in the city. Less than 1% of households reported awareness of this flagship city scheme – compared with high awareness of UJALA.

At the same time, it is not that all households know about the LED scheme – especially not the poorer BSUP homes. We find from discussions with residents that the most successful scheme awareness measure was the information that persons (predominantly men) got at the local utility bill payment centre. Bill payers could purchase LEDs at the payment centre itself, including with no upfront cost and monthly instalments, an option available by a third of the purchasers as per scheme representatives. Learning about a money saving scheme at the point of bill payment worked well to motivate participation. In addition, media campaigns for the scheme were important for those who spent time watching TV or listening to the radio, especially women. However, homes with different circumstances, such as in the lower income BSUP homes – where electricity connections and payment structures could be informal; the radio and TV were used less; and bills were paid by younger family members because of multiple jobs – did not benefit similarly. In the next round of LED deployment, unpacking these differences in scheme awareness will be important to influence path dependent lighting use patterns.

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The Efficiency of Appliances

Aditya Chunekar and Mrudula Kelkar, *Prayas (Energy Group)*

A small set of appliances such as fans, televisions, refrigerators, air-coolers, air conditioners, and water heaters contribute about 50-60% (Chunekar et al., 2016) of the total residential electricity consumption in India. Large scale adoption of energy efficient models of these appliances can thereby significantly reduce future electricity consumption in homes. In this post, we look at the government's Standards and Labeling (S&L) programme and three aspects of its effectiveness in achieving efficiency in the Indian appliances market.

The S&L programme is run by the Bureau of Energy Efficiency (BEE), under the Ministry of Power. Since 2006, the programme promotes efficient appliances through informative labels and by eliminating lower efficiency models through mandatory standards. BEE gives a 5-star rating to the most efficient models and a 1-star rating to the least efficient ones based on a pre-determined schedule, communicated through a label affixed on the appliance (Figure 1). Eight appliance categories, including air-conditioners and refrigerators are mandated to carry these labels, and no model can be sold unless it meets the 1-star rating, at minimum. The programme is voluntary for 13 appliance categories, including ceiling fans and washing machines, and manufacturers can sell these models without BEE labels and with an efficiency less than a 1-star rating.

Figure 1: BEE star label for air-conditioner

Mandate and tighten standards

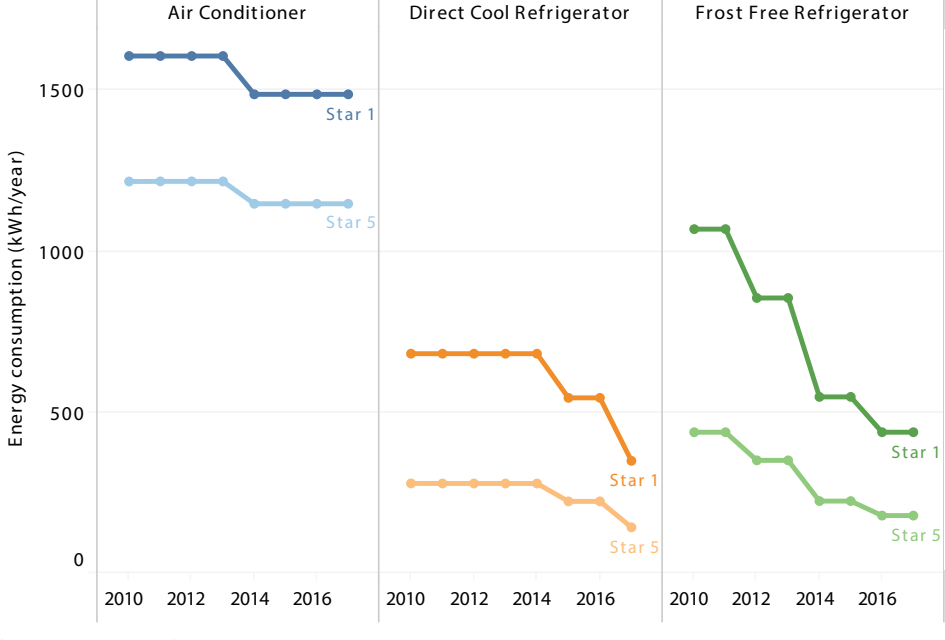
For any appliance, BEE starts with a voluntary S&L programme and usually makes it mandatory in two-three years. BEE's mandatory list has increased from two to eight and now covers most major appliances including, refrigerators and air-conditioners (Figure 2). Ceiling fans and air-coolers are notable exceptions. More than 95% (BEE, 2017) of the ceiling fans sold do not carry labels and consume more than twice the most efficient model available (Chunekar et al., 2011) in India. The programme has been voluntary for ceiling fans since 2010. Air-coolers guzzle much more electricity and are increasingly becoming popular but have not yet been included in the S&L programme. Making a programme mandatory for an appliance category ensures that inefficient models are not sold in the market.

Figure 2: List of appliances on the Standards and Labeling (S&L) Programme

Mandatory Appliances	Voluntary Appliances
Frost Free Refrigerators	Induction Motors
Tubular Fluorescent Lamps	Agricultural Pump Sets
Room Air Conditioners	Ceiling Fans
Distribution Transformers	Domestic LPG stoves
Room Air Conditioners (Cassette, Floor standing, Tower, Ceiling)	Washing Machine
Direct Cool Refrigerators	Computer
Electric Geysers	Ballast
Colour TV	Office Equipment
	Diesel Engine Driven Moonset Pumps for Agricultural Purposes
	Solid state inverters
	Diesel Generators
	Variable capacity air conditioners
	LED lamps

BEE also periodically tightens the standards and labels to keep up with and promote the most efficient commercially available technologies. So, today's 5-star model may become a 3-star model in the next phase and more efficient models can get the new 5-star tag. BEE (BEE, 2017) has periodically tightened ratings for frost-free refrigerators and the current 5-star ratings are comparable with international standards, but the 1-star rating still has a scope for improvement (Chunekar, 2014). The ratings for air-conditioners on the other hand can be tightened (Abhyankar et al., 2017b) further to align with the most efficient models available in India as well as abroad (Figure 3).

Figure 3: Tightening of star-labels for different appliances. (Approximate of typical appliances: 1.5 ton air-conditioner, 200 litre direct cool refrigerator and 300 litre frost-free refrigerator.)



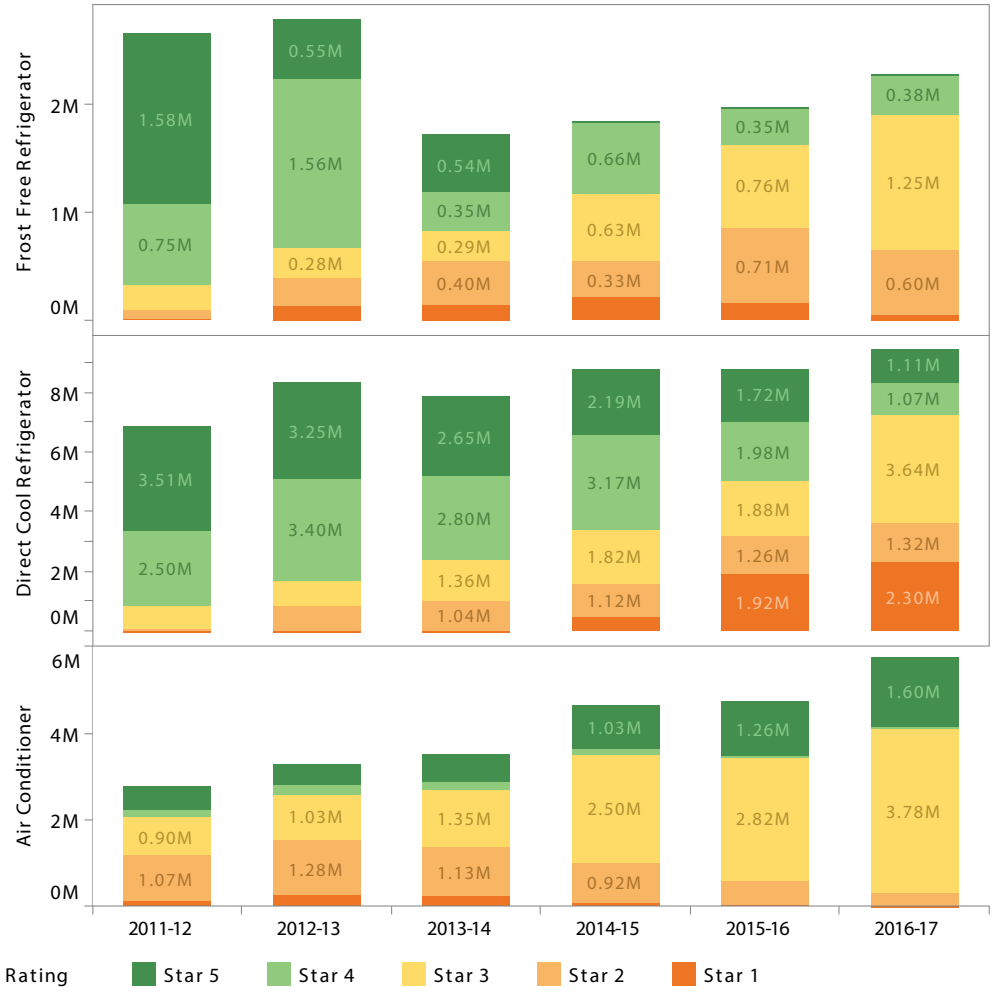
Source: BEE, with authors' assumptions for usage

Nudges and bulk procurement programmes

Mandating and tightening star-ratings is necessary but may not be sufficient for large scale adoption of energy efficient appliances. For example, appliance production data (BEE, 2017) shows a significant drop in the production of 5-star rated frost-free refrigerators after tightening in 2014 and 2016 (Figure 4). Also, the share of 3-star models is the highest in most of the appliance categories.

To promote 5-star rated appliances, complementary approaches like behavioural interventions and bulk procurement programmes can be useful. Consumer behaviour research (Simonson and Tversky, 1992) shows that consumers, faced with a menu of options, often simplify their decision making by choosing an option that resembles a 'middle' or 'compromise' option. Is this resulting in people buying more 3-star rated models? Can this be addressed by designing interventions that can nudge (Rathi and Chunekar, 2012) people towards buying more 5-star rated models? BEE's recent app (BEE, 2016) to estimate monetary savings from an efficient appliance helps consumers in understanding the labels. More such initiatives can be effective.

Figure 4: Appliance production across star-labels (in millions)



Source: BEE

Bulk procurement programmes (similar to UJALA for LED bulbs) (see post 3) can also help in market transformation to energy efficient appliances. These programmes can incentivise the production of the most efficient appliances (beyond 5-star) to pull up efficiency levels in the market. BEE can then further push market efficiency up by tightening standards. The programmes can smoothen the transition phase to higher standards and labels. However, one needs to be cautious about the rebound effect (Sorrell, 2007) where consumers buy more appliances because the programme has made buying and using them cheaper thus negating the expected savings.

Credibility of the S&L programme

A final point is regarding the credibility of the S&L programme. Transparency in the standards setting process and ensuring conformance with the standards is important to strengthen credibility. BEE has recently taken positive steps in this direction. It published (BEE, n.d.) proceedings of the technical committees that set the standards and labels, and data on appliances production across various categories is now available on the BEE website (BEE, 2017). Going ahead, BEE can also publish the check-testing results it is supposed to conduct on a random sample of appliances collected from the market. A periodic testing for conformance with the standards can significantly increase the consumer trust in the labels. If the models do not comply with the standards, BEE can publish the results in newspapers to warn consumers, as it has done once (Mitra, 2014) in the past.

To summarise, the Standards & Labeling Programme can effectively improve the efficiency of India's household appliances, as discussed in this post. However, this is a resource intensive activity. Given the limited resources, BEE can instead prioritise a smaller number of appliances with rigorous implementation, rather than adding more appliances to the programme.

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Appliances used in Affordable Housing

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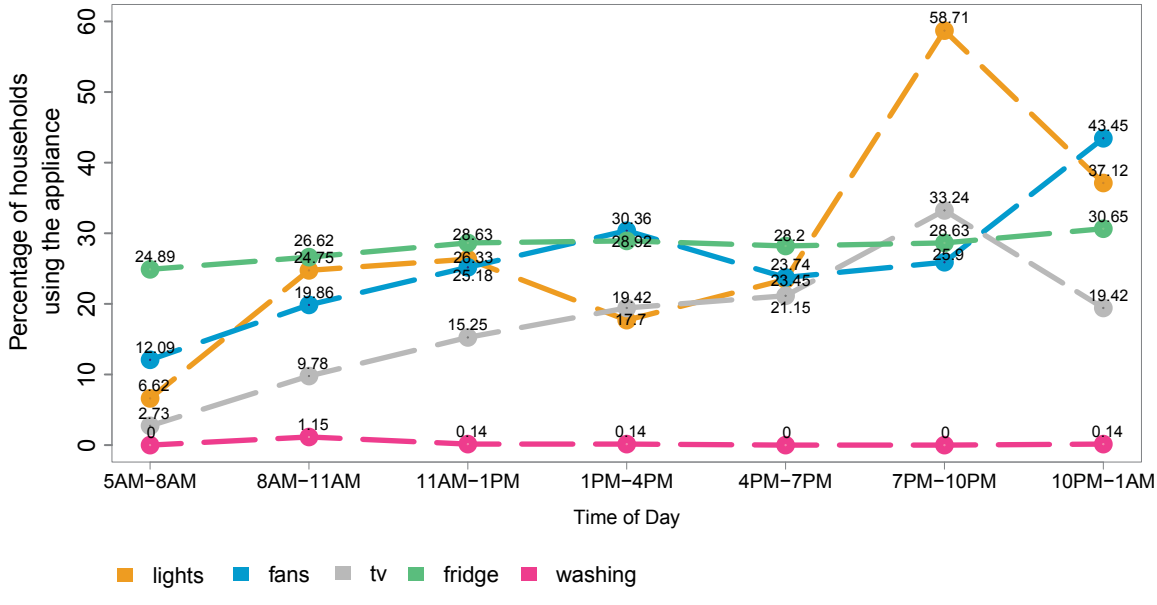
The large number of affordable homes to be built in the next few years has spurred the interest of cities, real estate developers, technology providers, amongst others. From an energy perspective, the unbuilt homes provide an important advantage. Because the bulk of low-income housing is yet to be constructed, the type of construction undertaken, the appliances they are designed for, and how they expend energy to cool and heat will shape the electricity consumption trajectories through the multi-decade lifetimes of these buildings. More so, new housing provides a physical setting for shaping preferences and practices around appliance purchase and electricity consumption that once set are not easily reversed. In this piece, we examine the energy services demanded within affordable housing, and identify which appliances households buy as their ability to consume increases.

We conducted a survey in 2017 in low-income houses in Rajkot, Gujarat to understand their electricity use patterns and the underlying drivers. This is part of our ongoing study on energy use in low-income urban households under the CapaCITIES project. Lighting, fans, televisions and fridges form majority of the appliance compositions in the affordable housing blocks.

Households use the services provided by these appliances most in the evening between 7-10 p.m., with usage of lighting and TV dominating. As shown in Figure 1, 59% of all households reported they used lighting in the previous evening and 33% of households watched television in that time slot. Fan usage peaked during the night, whereas a small number of fridges, on the other hand, were switched off during the night to save on the electricity bill.

These numbers indicate that not all households use lights in the evening, turn on fans while sleeping or always keep the fridge on. In discussions, some residents indicated that their work did not allow a '9 to 5' schedule where they spent the evening at home; others said they did not turn on lights as the street and hallway lights were enough to illuminate the homes.

Figure 1: Proportion of households availing energy services by time of day

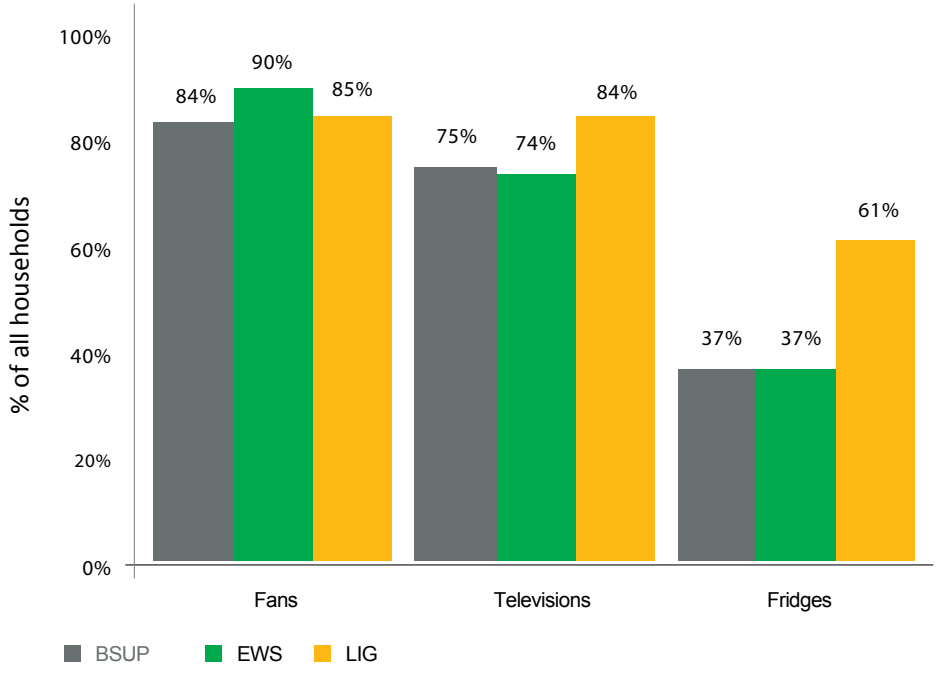


Source: Rajkot affordable housing energy survey (Khosla et al., in preparation)

To understand appliance use better, we categorised results according to the three types of government affordable housing: BSUP or Basic Services for the Urban Poor (built 2007 onwards); EWS or Economically Weaker Sections; and LIG or Low Income Groups housing (EWS and LIG are built under the Housing for All programme, 2015 onwards) (Figure 2). The categories broadly correlate to income – BSUP residents, on average, being the poorest in the sample, and LIG, the best off.

We find that fans are the most owned appliances across housing types, followed closely by televisions. Even in the lowest income BSUP homes, the rates of TV penetration are not dramatically different from the rates in higher income EWS and LIG homes. The difference in rates of appliance ownership between the three categories are most pronounced in fridges, where the LIG homes have the most fridges.

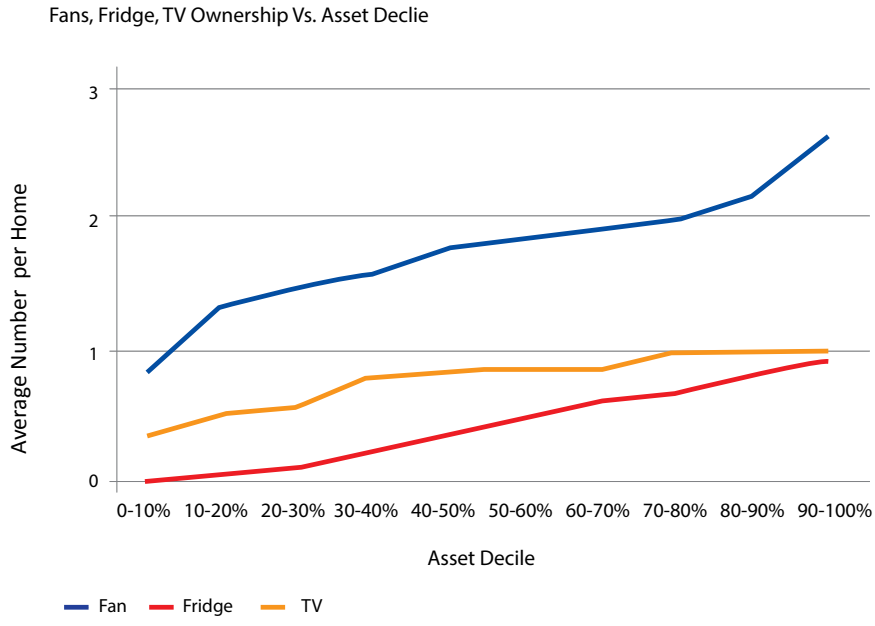
Figure 2: Appliance penetration rates in the affordable housing sample



Source: Rajkot affordable housing energy survey (Khosla et al., in preparation)

This trend is corroborated in Figure 3 which maps appliance ownership with a household's overall assets or ability to consume, as measured by an asset index. Most homes, even in the early deciles of the asset index, own a fan, and this number increases to two fans or even more as a household's assets increase. Fan ownership is followed by a TV, and the probability of owning a TV is quite high even though households may not own many other assets. TVs are more ubiquitous than coolers and fridges, in spite of the hot and dry climate and peak summer temperatures of the region. This result aligns with the literature that shows that over the past few decades, TV viewing has become the most important information and entertainment activities for the middle class and increasingly for lower-income families. Fridges, on the other hand, follow a more conventional pattern where their ownership rises gradually as households get wealthier (with an increased probability of ownership around the 9th and 10th decile of the asset index).

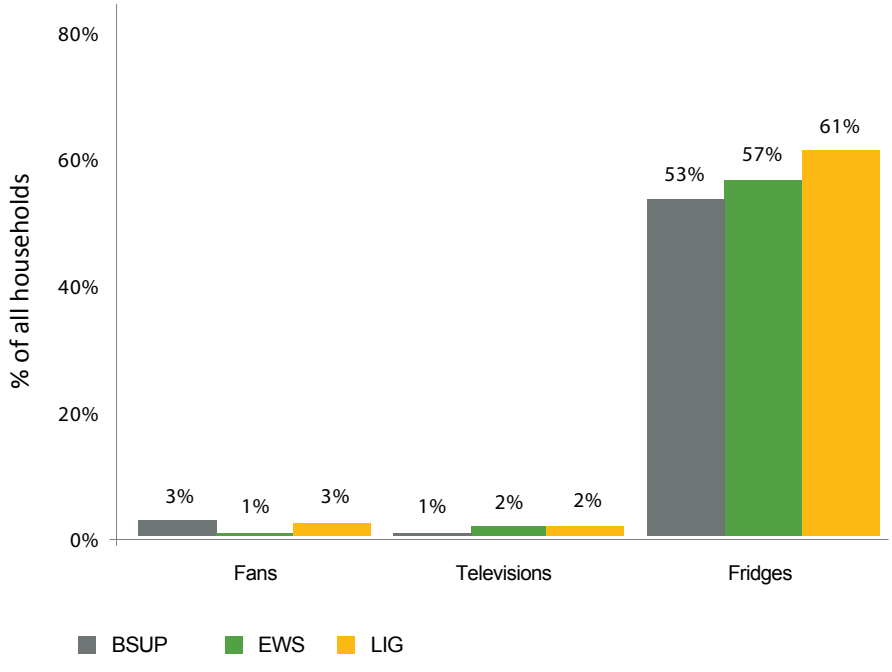
Figure 3: Appliance ownership across the consumption asset index for the affordable housing sample



Source: Rajkot affordable housing energy survey (Khosla et al., in preparation)__

It is clear that fans, televisions and fridges, form the bulk of appliances used within affordable housing units. These appliances, once bought, likely persist in households for a decade if not more, and can often then be passed on, second-hand, to other families. Further, because of the immense transition to affordable housing units that is ahead for India, the number of appliances, which will be bought for the first time is significant. As discussed in the previous piece of this series, appliances drive electricity consumption in homes and the adoption of energy efficient, or star rated, appliance models can significantly reduce this electricity use. We take a further look at the appliances used in the affordable housing sample to examine the number of appliances that are star-rated (Figure 4).

Figure 4: Percentage of star-rated appliances owned in the affordable housing sample



Source: Rajkot affordable housing energy survey (Khosla et al., in preparation)

Two striking insights emerge from Figure 4. First, while fans and TVs are by far the most ubiquitous appliances used within affordable housing, the number of rated appliances within these categories is minimal. Appliance shops in the vicinity of the affordable housing blocks corroborated that consumers had little awareness of energy savings from efficient fan and TVs, and that rated versions were only now entering the market. This presents a significant opportunity for scaling up the standards and ratings programme for fans and televisions, the energy savings from which are dramatic (Abhyankar et al., 2017a).

Second, the ratings programme for fridges is much more effective, as seen across the affordable housing types. Part of the reason for this is that the BEE (Bureau of Energy Efficiency) has mandatory and stringent standards for frost-free refrigerators (as opposed to a voluntary labeling for ceiling fans). In all cases, there is large scope for increasing the efficiency of appliances through a rigorous ratcheting up of standards and labels. Compared to the lack of consumer awareness of TV and fan ratings, shop attendants indicated that consumers were aware of fridge ratings, often asked for input on savings, and were wary of costs of running energy intensive fridges. This is also seen in the data by a proportion of households that turn off their fridges at night to save costs.

As more formalised housing and rising incomes set to increase the use of energy intensive appliances, their usage patterns suggest the enormous scope for this transition to be an energy efficient one. In the next post of this series, we continue to examine energy intensive appliances, with a view from the National Capital Region, which has the highest residential electricity consumption in the country.

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Electrifying the National Capital Region

Radhika Khosla, *Centre for Policy Research*

Managing India's urban transitions is a significant challenge, one that is further complicated by the need to address their energy implications. This burden is particularly relevant to the National Capital Region (NCR), with Delhi being among the highest residential electricity consuming areas in India. Yet, in spite of the scale of current and future residential electricity use, an understanding of Delhi and the NCR's household consumption patterns and their drivers is limited. In this post, we examine electricity demand in the NCR, which comprises of Delhi, much of Haryana, and parts of Uttar Pradesh and Rajasthan.

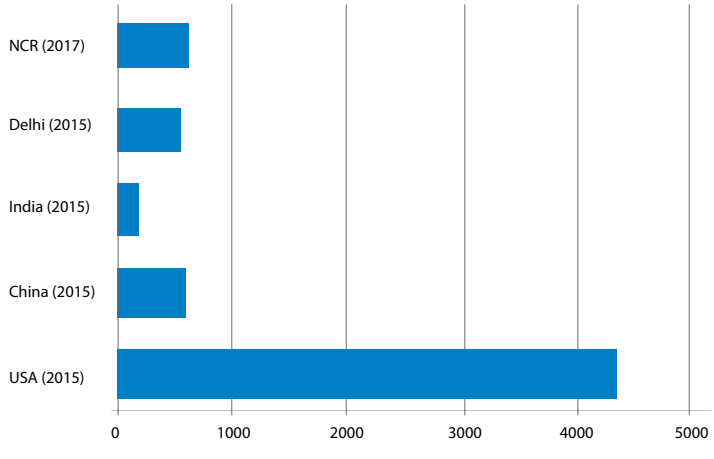
The NCR covers approximately 130 cities and towns, a land area of 22,500 square miles, and has an urban population of over 30 million that is growing at about 20% per decade. In order to capture effects that are representative of this large population, we use a detailed sampling method that covers about 5500 households. The sample was portioned with approximately 61% in Delhi, 23% in Uttar Pradesh, 13% in Haryana and 3% in Rajasthan. The survey, conducted in 2016-17, is in partnership with the Centre for the Advanced Study of India, University of Pennsylvania. We focus our findings around three questions:

- One, how much electricity does the NCR resident consume?
- Two, what are the electricity services that households in the NCR most consume?
- Three, how is the ownership of cooling appliances changing with increasing incomes and the ability of households to consume more?

How much electricity does the NCR resident consume?

To understand the NCR's electricity use on a per capita basis, we used the household electricity bill amount, local tariff rates, and the number of people within that household. We compared this number with recent per capita numbers from the literature for Delhi and India (Figure 1). We also compared the estimates with the USA and China to demonstrate the different contexts of developed and developing countries.

Figure 1: Comparisons of annual per capita residential electricity use



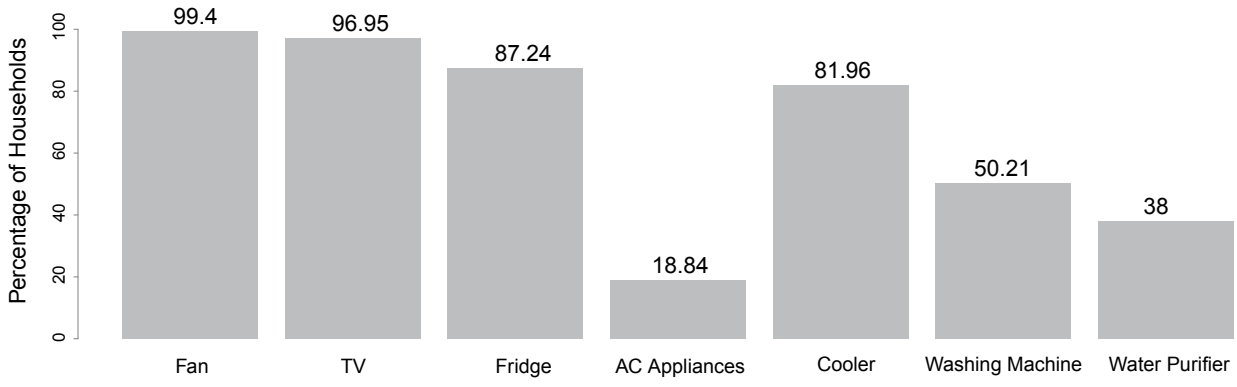
Source: EIA, 2017; US census bureau, 2017; NBSC, 2017; Niti Aayog, 2017; NCR survey, 2017.

In per capita terms, the US's per capita residential electricity use is about 25 times that of India's, and China's is about three times that of India. Within India, the residential electricity use per person, based on the survey, is broadly consistent with the statistics on Delhi from other sources, suggesting that Delhi is the driver of the NCR's energy use. The India average, on the other hand, is 3.5 times lower than the NCR number. In purely electricity terms, the NCR resident is the highest consuming in the country—a level that is continuing to rise. As incomes rise across other urban areas, it is likely that they will follow the NCR's current pattern of high consumption.

What drives the NCR's high energy use?

To understand the NCR's high energy use, we examine the energy services sought in the region by assessing the appliances owned by its households (Figure 2).

Figure 2: Appliances penetration rate in the NCR



Source: Electrifying the National Capital Region. Khosla and Sircar (in preparation).

Figure 2 shows that almost every NCR house has a fan, closely followed by a TV. TVs are more ubiquitous than coolers and fridges, in spite of the hot and dry climate and peak summer temperatures of the region. This result aligns with the literature that over the past few decades, TV viewing has become the most important leisure and entertainment activity for middle class families. Washing machines and water purifiers form the next set of appliances used. And while not represented graphically, the data shows that 63% of households in the NCR have a scooter while a smaller 17% have a car.

We contextualise and validate the results in Figure 2 by looking at similar appliance penetration numbers from other studies conducted for the Delhi (not NCR) region (Figure 3).

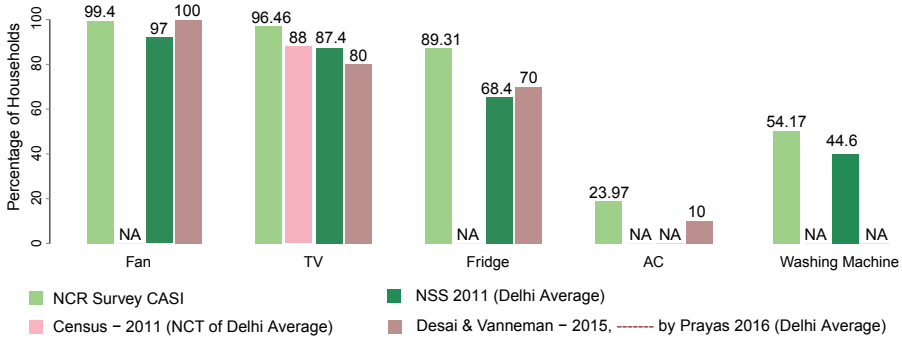
Figure 3 is based on three studies from the literature with data collected in 2011, and on the Delhi component (only) of the NCR survey which was undertaken in 2016-17. The Delhi component of the NCR survey consistently shows the largest penetration rates of the appliances (with a small exception for fans), with dramatic differences for fridges and ACs (air conditioners). It is likely that the NCR survey is capturing the rising appliance ownership within the last five years, compared to the earlier studies.

Changing nature of appliance use

As households transition towards higher levels of income, which appliances do they buy first? We apply this question to cooling appliances, which are among the most energy-intensive.

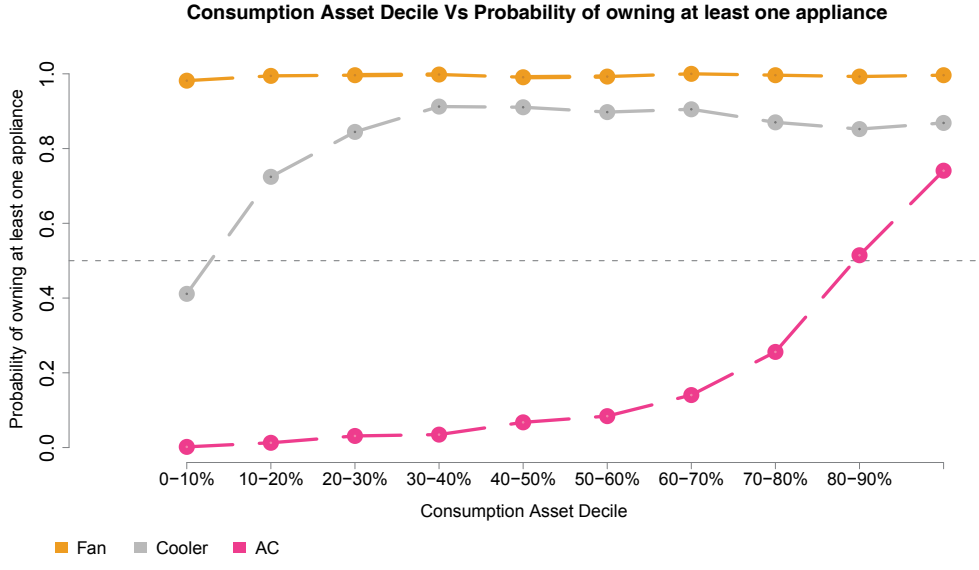
We examine the changing nature of cooling appliance ownership by developing an asset index, which maps appliance ownership with a household's overall assets or ability to consume. Figure 4 shows the ownership of at least one cooling device per household, ranging from a fan, cooler, and air conditioner, as per the asset index. As seen in Figure 4, almost every home in the NCR, irrespective of where it ranks on the asset index, owns a fan. The most prevalent cooling device, after a fan, is cooler, which households start acquiring as they enter the 4th decile. By contrast, only the top decile (at most) have an air conditioner.

Figure 3: Comparison of appliance ownerships results for Delhi from different studies



Source: Electrifying the National Capital Region. Khosla and Sircar (in preparation).

Figure 4: Cooling appliance ownership patterns as a function of the asset index



Source: Electrifying the National Capital Region. Khosla and Sircar (in preparation).

The implications of these cooling appliance ownership patterns could be the most significant in determining the trajectory of the NCR's, and by analogy other Indian cities', energy use. Literature and market studies predict that India is at the cusp of an exponential growth in the AC market (Davis and Gertler, 2015) and as income levels rise, the AC curve will likely mirror the current cooler curve. The impact on households of this AC penetration will be two-fold: access to cooler indoor environments as the probability of extreme temperatures rises, but also a marked increase in the household electricity bill. Furthermore, the systemic effects of increased electricity demand and greenhouse gas emissions from AC use are predicated to be dramatic (Shah et al., 2016).

The yet-to-be invested in cooling appliances, perhaps counterintuitively, offer a potential advantage. Since most energy-intensive purchasing decisions are yet to be made, there is occasion to still shape electricity-consuming preferences and practices. Once invested in, these consumption patterns are difficult to reverse. The current ability of households to pick energy efficient appliances (especially air conditioners), and shape infrastructure that increase thermal comfort without spiking the electricity bill, is a distinctive window to choose alternative pathways. The usefulness of this opportunity, however, will depend on the early decisions that policymakers, industry and households make. In the next, penultimate, post of this series, we explore broader usage patterns of appliances across India.

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Exploring the different uses of household appliances

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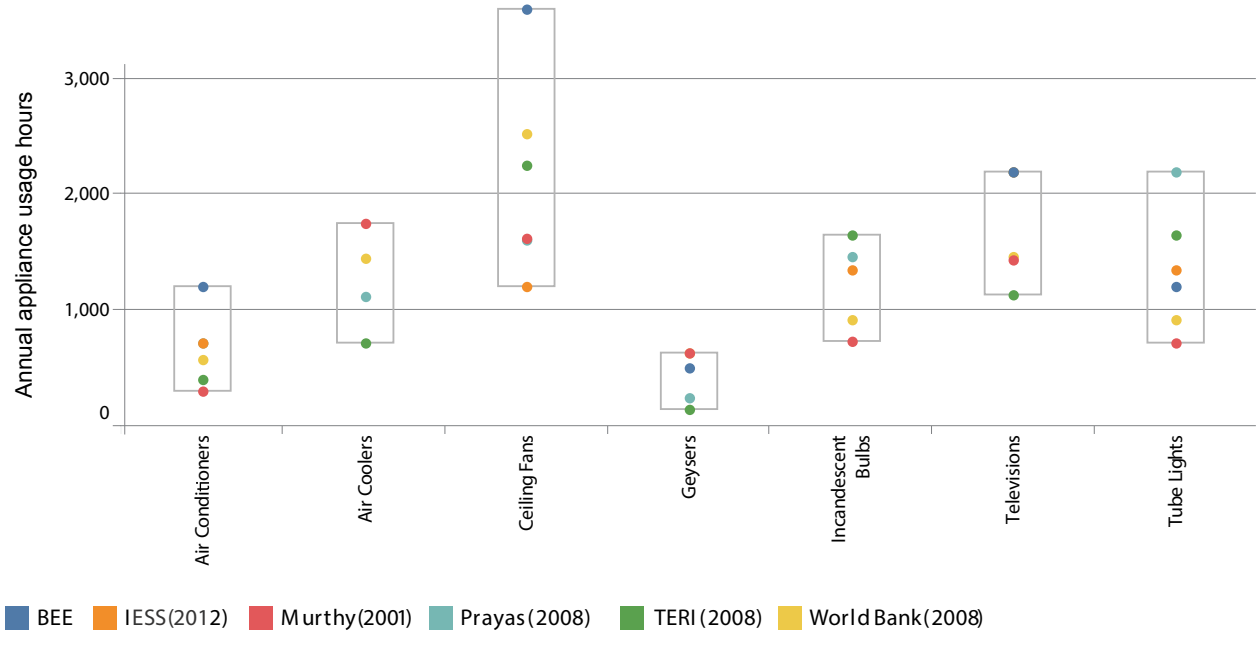
When and how do people use different household appliances in a day? This is an important question for electricity distribution companies that supply the electricity required to run these appliances. For instance, if the use of air-conditioners shoots up on a particularly hot summer afternoon, then the distribution company will have to buy additional electricity to meet the demand at that particular time. An equally important consideration for utilities and households is the electricity consumption of appliances in actual operating conditions, compared to the manufacturers' claims made under laboratory conditions. In this post, we look at broad appliance usage patterns observed in India and briefly discuss new work on measuring the actual use of electricity in households.

Households' use of appliances depends on a number of factors such as income, climate, and behavioural tendencies, among others. There is limited understanding of the household level use of different appliances in India and its variation across socio-economic conditions and geography. Studies that project India's residential electricity consumption assume nation-wide, uniform usage hours based on few local load research studies. There is a wide variation between these usage hours' assumptions as seen in Figure 1.

Figure 1: Compilation of usage hours of appliances from different studies



Source: Prayas (Energy Group), Residential Electricity Consumption in India: What do we know? December 2016 (Chunekar et al., 2016)

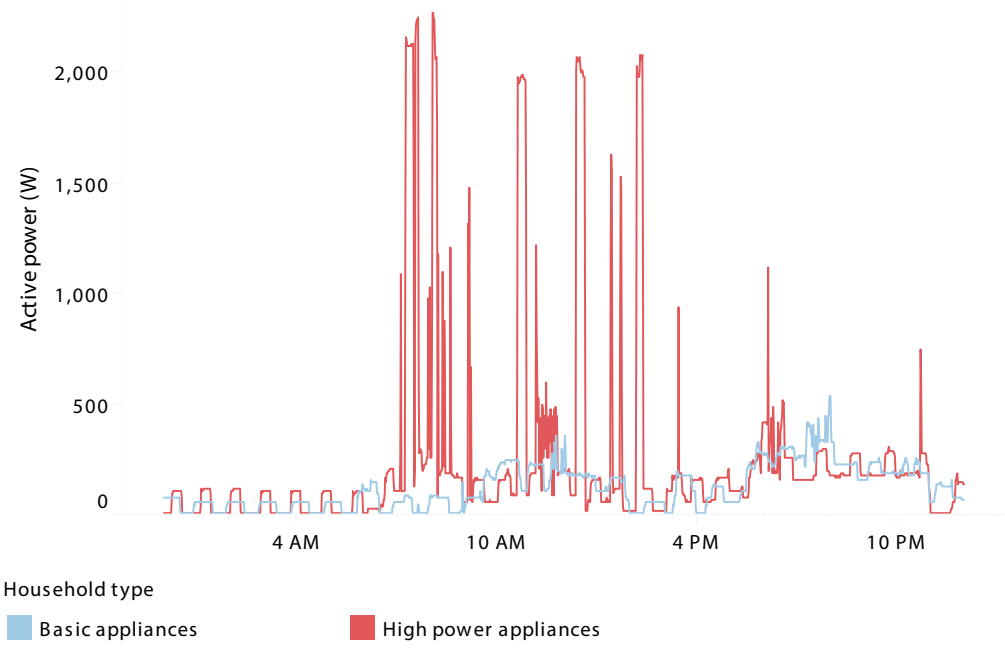
The load research studies estimate appliance usage patterns based on household surveys and load analysis of residential feeders. The Bureau of Energy Efficiency (BEE) under its capacity building programme (BEE, n.d.) commissioned about 30 such load research studies for public sector distribution companies all over India in 2015. However, these reports are not yet public, and a better understanding of appliance ownership and usage remains partial.

While surveys provide relatively low cost means to gather insights into various aspects like appliance ownership and purchase patterns, accuracy of information on actual electricity consumption can be limited. This is because of two key reasons: (a) respondents may have difficulty in recalling the actual use of appliances; and (b) the actual power consumption of appliances may be different from the rated power consumption claimed by the manufacturer. In order to address this gap, we have initiated a project to install metering devices in a sample of households to measure electricity consumption every minute and send the data to a central server. These devices will measure the aggregate household electricity consumption and consumption from selected key appliances. We have started with Pune and will eventually extend to other urban, semi-urban, and rural areas in India. Daily (anonymous) consumption patterns recorded by these meters will be periodically updated on a publically accessible website. The project builds on our existing electricity supply monitoring initiative (Prayas (Energy Group), 2017) which measures and publishes the quality of electricity supply in about 300 locations across the country.

We briefly describe insights based on initial data recorded from selected households in Pune below.

- People use different appliances at different times of the day. Load curves of households show the variation of electricity drawn by the household from the grid over the length of the day. Electricity distribution companies prefer a flatter load curve as it eases their supply operations. However, appliances like the air-conditioner, electric water-heater, and microwave oven can add significant peak demand. As the ownership of these appliances increase, (see post 7) it will be crucial for the distribution companies to understand the cumulative impact of their use on the load curve. Figure 2 shows the difference between the load curve of a household owning basic appliances and the load curve of a household owning high power appliances. Basic appliances include lighting, fans, and the refrigerator and high power appliances include an additional air-conditioner, electric-water heater and microwave oven.

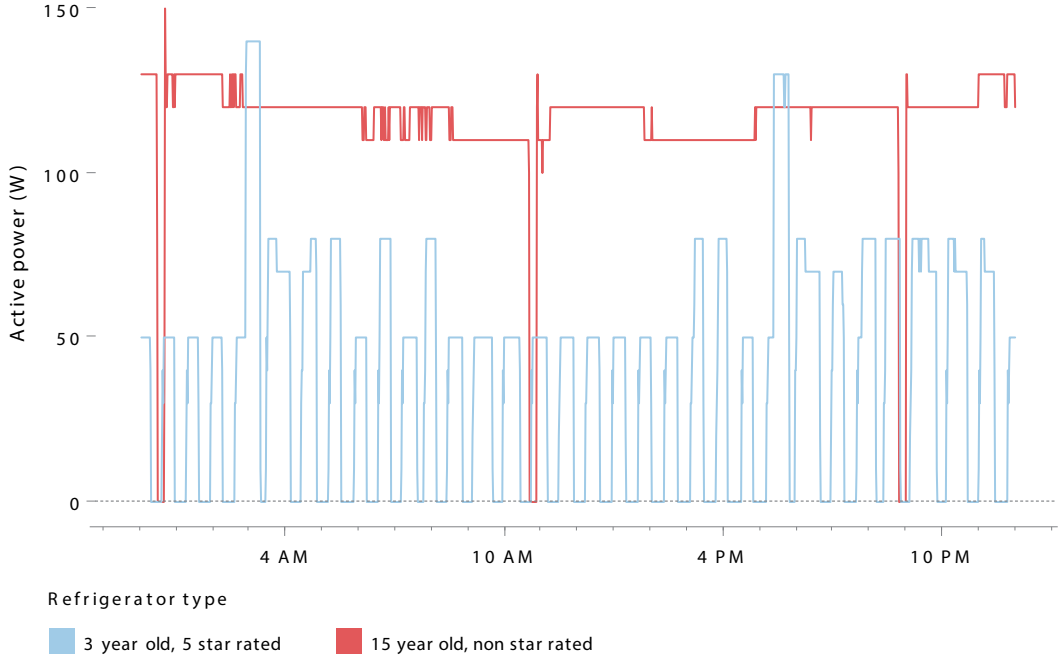
Figure 2: Comparison of load curves between households with basic appliances with high power appliances like air-conditioner, electric water-heater, and microwave oven, in addition to basic appliances.



Source: Data recorded by Prayas (Energy Group), Energy Group

- Refrigerators accounted for about 25% to 50% of the total electricity consumption of the selected households. This may change in the summer when ceiling fans, air-coolers and air-conditioners are used more. We found a significant variation in the actual electricity consumption of the refrigerators across homes. One 15-year old refrigerator consumed 4 times more electricity than a 3-year old 5-star refrigerator of same type and size. On an annual basis, this can mean the old refrigerator consumes about 1200 units (kWh) of electricity (contributing to the electricity bill with Rs. 6000-7000) compared to 300 units (about Rs. 1500-1800) by the new, efficient refrigerator. Load curves of both refrigerators (Figure 3) throw more light on this. The compressor, which consumes most of the electricity, is always on in the old refrigerator while it draws less power and periodically switches off in the new refrigerator, thus consuming less electricity. This may be because of the usage habits (frequent opening of the refrigerator

Figure 3: Load curves for refrigerators



Source: Data recorded by Prayas (Energy Group), Energy Group

door) or deteriorated performance of the working parts of the refrigerator.

Such insights can be useful across different stakeholder groups. They help distribution utilities understand the cumulative impact of high power appliances like air-conditioners and electric water-heaters on the load curve. Actual consumption data from a sample of appliances can also be used to design campaigns that highlight the magnitude of real impacts of energy efficiency on consumer electricity bills. The BEE, which is responsible for running the Standards and Labeling (S&L) programme, (see post 5) can use the data to modify the procedures and ratings to represent the actual consumption of appliances more accurately. Finally, manufacturers can use the data to understand the performance of their products under actual operating conditions.

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Role of human behaviour in driving electricity use

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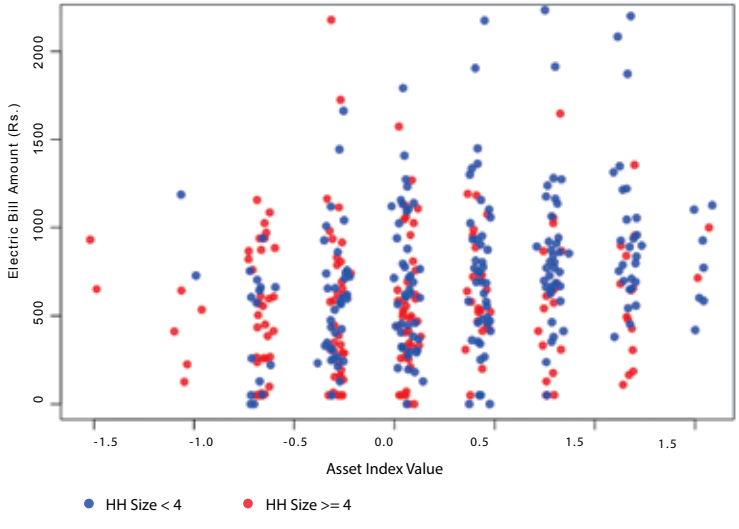
Energy-demand interventions are important for shaping consumption patterns as India's energy and technology infrastructure transitions. At the same time, implementation of demand-side solutions is not always straightforward because of the variety of influences on consumption decisions. In the final piece of this series, we initiate a discussion about the drivers of residential electricity consumption.

What conditions electricity use in homes? In particular, are there factors outside of the technological and physical aspects of the house structure and appliances that can have an impact on a household's electricity consumption? We examine this question in low-income households in Rajkot, Gujarat. The sample provides a suitable context in which to undertake this study, because it contains identical home units, each with the same floor area and layout. This architecture allows us to control for the physical effects of the building, the floor area and the surrounding climate across the sample. The work is part of our ongoing study on energy use in low-income urban households under the CapaCITIES project.

Conventional understanding suggests electricity consumption is a function of building, technological and climate characteristics. Alongside, appliance ownership within a household is a key driver of how much electricity is used. Homes which own only lights and fans will have a different consumption pattern to homes that also own a refrigerator and television—as will be reflected in a different (see post 8) electricity bill between the two. Thereby, in order to control for the effect of appliance ownership on electricity use, we develop an appliances-asset index that ranks each household according to the appliances they own. That is, households with the same rank on the index own the same appliance, in the same quantity. In affordable housing units, the index can also serve as a proxy for economic class, as wealthier households tend to have more and more expensive appliances. Having now controlled for the major building, technological and climate drivers of residential electricity use, we compare the metered electricity consumption (from the utility) of homes that have the same rank on the asset index, to test how similar or different their consumption will be (Figure 1).

Figure 1: Variation in electricity bills for households as per their score on the appliances-asset index



Source: Residential electricity use in affordable homes (Khosla et al. in preparation)

Figure 1 provides interesting initial results. It shows a dramatic difference in the electricity bills of homes, even when they own the same appliances (displayed by the same rank on the appliances-asset index between -1.5 and 1.5). Further, when categorised according to the number of people within a home to account for differences that may arise from differing number of household members (either less than or more than three per home in the Figure), the large variation in the bill remains.

What explains this difference in the electricity bill of homes that own the same appliances, have similar number of people, the same floor area, are in buildings with similar physical characteristics, and under the same weather conditions?
The literature on household energy use offers a number of different factors that influence electricity consumption. Many of these

are related to physical building characteristics, for instance, building age, materials, number of windows, etc. In addition, climate conditions are important drivers of how much electricity households consume to be thermally comfortable. And within the household, the area of the home, the number of people that inhabit it and the appliances owned are important determinants of how much electricity is consumed. Figure 1 is striking because in spite of controlling for all these aspects, the electricity bills of the homes are significantly different. This points to an important finding that human behaviour, or how people actually operate and use appliances, after they are purchased, is a key factor in driving electricity use. A better understanding of such human dimensions of energy consumption is particularly needed in the Indian context, where research on the role of behaviour and lifestyles in influencing household energy use is limited.

In addition to energy use behaviour, Figure 1's electricity bill variation could also be a function of the age and efficiency of the appliances, which can be different even for the same appliance type, along with differences in the orientation of the buildings of the different households. Uncovering these details and developing an interdisciplinary understanding of the techno-economics of electricity consumption, with the social and cultural roots of behaviour patterns, is needed to better predict the interactions between people, buildings and technologies. This will enable better management of household electricity use, especially as the urban population grows and income levels rise. More so, such insights are necessary for informed future consumption projections and policy choices, to step away from traditional economic models that assume humans make rational, utility-maximising, everyday decisions and that appliance usage hours (see post 8) are uniform across individuals, an assumption that many studies make. Ultimately, understanding how individuals, households, and more broadly, societies, use or convert electricity has much to bear on the effectiveness of demand-side measures (Creutzig et al., 2016).

At the conclusion of this residential electricity series, we hope its different themes have provided new insight into the challenges and opportunities of electricity use in Indian homes. These have included trends and disparities in access and consumption across states; the impact of the country's large LED lighting programme, including in affordable homes; the effectiveness of appliance standards and labels; the energy services demanded within affordable housing and more broadly, across the National Capital Region; metering appliance use patterns; and the role of energy use behaviour in influencing consumption. These findings drew from recently published work, and from new research that will be published shortly, all aimed at emphasising demand-side solutions for energy and climate change, within the context of development.

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