# Understanding peak periods of electricity use in Indian urban dwellings with and without air-conditioning

Rajat Gupta
Anu Antony
Low Carbon Building Research Group
School of Architecture
Oxford Brookes University
Oxford
United Kingdom
rgupta@brookes.ac.uk

Archana Walia
Neha Dhingra
CLASP India Program

Tanmay Tathagat
Piyush Varma
Environmental Design Solutions Pvt. Ltd
New Delhi
India

## Keywords
residential, electricity profile, monitoring, smart metering

## Abstract
To meet the recently-established net zero target by 2070 in India, national electricity grid needs to be rapidly decarbonised using renewables. This requires a deeper understanding of the timing and peak periods of residential electricity use which is expected to increase by five times by 2032. This paper uses statistical clustering techniques to develop representative daily electricity use profiles and determine peak periods of electricity use in the summer, monsoon and winter seasons, using time-series data. Smart meters recorded electricity use data at 30 seconds for 9–11 months (2018) across 89 urban dwellings in India representing different climatic zones. About 54 out of 89 dwellings owned at least one air-conditioning (AC) unit. An unsupervised clustering technique was used to group electricity use curves with similar patterns using a combination of hierarchical and k-means algorithm, to characterise the diurnal and seasonal variations. The maximum point difference was used to identify the daily peak usage period.

Three distinct clusters emerged. The first cluster with largely AC dwellings had a prolonged night time peak of the highest magnitude, while the second cluster had a mix of AC/non-AC dwellings and experienced a late evening peak. The third cluster with predominantly non-AC dwellings experienced a short morning peak of lowest magnitude. The duration and magnitude of peak periods in the two AC clusters were different, indicating use of multiple AC units. Seasonal variation in electricity use was prevalent at the sample (89 dwellings) and sub-sample (54 AC dwellings) level. Mean daily electricity use of AC dwellings (n:54) in the summer and monsoon seasons was found to be around 13kWh/day which was twice that of non-AC dwellings (n:35, 6.4kWh/day). For AC dwellings mean daily electricity use in the cooling season (summer and monsoon) was double that of the non-cooling season (winter), while such seasonal variation was subtle in non-AC dwellings. It is evident that daily electricity profiles of all three clusters indicate potential for reducing the magnitude and duration of peak electricity use in urban Indian dwellings.

## Introduction
India has pledged to attain net zero carbon emissions by 2070 at COP26(Vaughan 2021). However, with the current energy sector overshadowed by coal and nuclear power, the transition is anticipated to be challenging. This is confounded by the fact that residential building energy (electricity) consumption in India is projected to increase by five times by 2032 at an annual growth rate at 7.4 % (IESS 2021). Space cooling driven by air conditioning (AC) is expected to contribute 44% of the peak electricity load by 2050 rising from 10% in 2016, (IEA 2019).The Government of India has launched the India Cooling Action Plan (ICAP) in 2019 which aims to reduce cooling demand across all sectors by 20–25 % by 2037–38 advised by these projections (IEA 2020). Expanding or building new electricity coal or nuclear generation plants to meet this rising electricity demand is not sustainable, since this introduces significant social and environmental issues. While renewable energy (solar, wind) produces no carbon emissions, it is variable and intermittent. Such a system requires energy demand to be flexible and follow energy supply. This requires a deeper under-

standing of the timing of electricity use in dwellings especially in terms of peak electricity use over a day and across seasons. Nationwide campaign is required since residential electricity consumption in India tends to vary by geographical region, seasons, appliance ownership and use.

Despite this, there are limited number of studies in India on residential electricity use profiles and peak periods and how it varies over a day, across seasons and climatic zones, and by income group, appliance ownership and presence of air conditioning. A recent study in India by Agrawal et al. (2020) collected and analysed smart meter data from 93 dwellings in two Tier 2 cities in North India and found that dwellings with higher share of AC units experienced very high night-time peak demand, while the flat electricity use profile had the lowest share of AC units (Agrawal et al. 2020). Under the Smart Meter National Programme (SMNP), the aim is to roll out 250 million smart meters across India (Ministry of Power and Central Electricity Authority 2020) with 1.32 million smart meters currently installed (EESL 2020).

The high frequency electricity consumption data from smart meters can be used to generate daily electricity use profiles represented by peaks and troughs over 24 hours representing months, seasons or even a year. Statistical clustering of electricity profiles helps to group large amount of data into representative (typical) profiles (Marton et al. 2008) for understanding the pattern, timing and duration of the peak periods. It also helps to understand the likely drivers of residential electricity use. The most common form of clustering method in residential electricity studies was found to be k-means (Rhodes et al. 2014, Satre-Meloy et al. 2020, Viegas et al. 2016). However peak load and base load were determined in different ways across the studies (Yohanis et al. 2008). In one study base load was defined as the minimum level of electricity consumed continuously including the standby power of appliances, peak load was the maximum electrical load consumed at specific period (Cogan et al. 2005). Another study considered base load to represent first 30 % of load duration curve, followed by intermediate load which was 45 % after the base load, while peak load represented the last 25 % of the load duration curve (Muslim et al. 2017). A recent study identified the concentration of the peak period to be between the highest maxima in the morning and evening (Jeong et al. 2021).

Within this context, this paper uses statistical clustering technique to identify representative daily profiles and peak periods of residential electricity use across summer, monsoon and winter seasons, using high-frequency smart meter data. Smart meters recorded electricity use data at 30 seconds for 9–11 months (2018) across 89 urban dwellings located in different climatic zones in India. Given that 54 out of 89 dwellings had AC, cluster analysis was also done for the AC dwelling sample (n:54) to identify diversity in electricity use profiles of dwellings with one, two, three or more AC units.

## Methodology

The study adopted the cluster analysis method for categorising smart meter data into representative profiles of electricity use for different seasons. The profiles were used to determine the timing and magnitude of peak electricity use. Smart meter data were gathered from 89 dwellings representing the five climatic zones of India. Smart meters were provided by Zenatix and managed by Environmental Design Solutions. Data was collected every 30 seconds on electricity use (Wh), peak demand (W), Power factor, voltage (V) and frequency (Hz) from January 2018 to November 2018 translating to 9,53,280 data points per dwelling. These values were aggregated to one-min averages to preserve the granularity and shape of the electricity profile curve. The 89 dwelling sample was split into 54 AC dwellings and 35 non-AC dwellings. The dwellings in cold and temperate climatic zones had no AC units. The distribution of these 89 dwellings by climatic zone is shown in Table 1 below which also includes a map showing the geographical distribution of climatic zones. Since the composite, warm-humid and hot-dry climatic zones have a large geographical coverage, majority of study dwellings fell in these zones, while a smaller number of dwellings located in the cold and temperate zones in line with the national coverage.

To investigate seasonal variation, smart meter dataset was split into four time periods representing the *summer season* (March to June), *monsoon season* (July to October), *winter season* (November, February and January) and *overall* (9-11 months as proxy for the year). Although not all dwellings had data for the month of December, it was available for three months in winter (November, February and January). Three dwellings with AC had one month (November) of winter data, available while eight dwellings with AC had two months of winter data (November & February). Since the representative profile was of interest rather than the amount of electricity used in a season, this could be extracted from the available seasonal data. Given that 54 out of 89 dwellings had AC, deep dive was done to investigate the effect of number of AC units on electricity use profiles in summer and monsoon seasons.

Data cleaning was an arduous process where negative values for more than five minutes were ignored. All values were standardised and rescaled between 0-1 to eliminate the bias from higher kWh values. The time intervals of interest for data

**Table 1. Distribution of dwellings by climatic zones and a map of India showing climatic zones (EDS, 2019, NBC, 2005).**

| Climatic Zone | Number of dwellings | Proportion of dwellings | Number of cities | National distribution of dwellings |
|---|---|---|---|---|
| Hot-Dry | 10 | 11% | 1 | 17% |
| Temperate | 3 | 3% | 1 | 4% |
| Composite | 37 | 42% | 6 | 37% |
| Warm-Humid | 30 | 34% | 3 | 41% |
| Cold | 9 | 10% | 1 | 1% |
| **Total** | **89** | **100%** | **12** | **100%** |

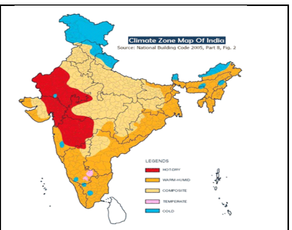

**Table 2. Descriptive statistics on mean daily electricity use for 89 dwellings.**

| Descriptive statistics | Mean daily electricity use in summer (kWh) | Mean daily electricity use in monsoon (kWh) | Mean daily electricity use in winter (kWh) |
|---|---|---|---|
| Mean | 10.7 | 9.8 | 5.8 |
| Median | 9.9 | 9.5 | 5.5 |
| Standard deviation | 4.6 | 3.4 | 2.9 |
| Max | 22.3 | 19.7 | 13.3 |

**Table 3. Mean daily electricity use for AC and non-AC dwellings across seasons.**

| Mean daily electricity use (kWh) | Overall | Summer | Monsoon | Winter |
|---|---|---|---|---|
| Non-AC dwellings (n:35) | 6 | 6.4 | 6 | 5.4 |
| AC dwellings (n:54) | 11 | 13.1 | 12.2 | 6.2 |

representation were typically 30 min or hourly. The electricity profiles were normalized (to be on a fractional 0 to 1 scale) using the maximum and minimum normalisation. Then each of these normalized overall and seasonal curves per dwelling were used as inputs for k-means clustering algorithm along with the squared Euclidean distance metric (Hair et al. 2014). The quality and cluster performance of the selected number of clusters was identified using the Davies-Bouldin index (DBI) where the best cluster group had the lowest coefficient. Across all datasets, lowest coefficient cluster number was selected for best representation of the profile shape. If DBI turned out to be inconclusive, silhouette index (SI) was used to assess cluster performance. The shapes of these normalised daily profiles were clustered based on one minute interval. The clustering analysis was also checked for stability by rotating or changing the order of the inputs. Once the clusters were extracted, absolute values were averaged and taken to view the profile patterns of use (Huebner et al. 2015). Since one-minute profiles contain a lot of noise they were represented as hourly profiles for ease of understanding. The peak electricity use for each cluster was then identified using the method adopted from Jeong et al to determine the maximum amount of electricity used during peak period , timing and the where the duration of the peak period was focussed (Jeong et al. 2021).

## Results

### DWELLING CHARACTERISTICS AND SEASONAL VARIATION IN MEAN DAILY ELECTRICITY USE

Statistical analysis of contextual data of 89 dwellings revealed that more than half the dwellings had floor area ranging from 50 $m^2$ to 150 $m^2$ which was the most common range of floor area found in literature (Rawal and Shukla 2014). About 68 % of the dwellings were inhabited by at least three residents and 35 dwellings had no AC units. Majority of the non-AC dwellings (34 %) were located in the warm-humid zone, while 61 % of dwellings located in the composite zone used at least one AC unit. While 40 % and 66 % of non-AC dwellings owned at least one geyser (for heating water) and one washing machine respectively, about 83 % of the AC dwellings owned at-least one geyser and one washing machine. Weak correlations (<0.5) were observed between mean daily electricity use (in summer and monsoon seasons) and number of AC units as well as floor area. Descriptive statistics for mean daily electricity use (kWh) for 89 dwellings reveal the significant seasonal variation across summer, monsoon and winter seasons as shown in Table 1 below. Mean daily and daily maximum electricity use were observed to be highest in the summer season followed by monsoon and winter seasons, likely to be due to the seasonal requirement for cooling. In fact, mean daily and daily maximum electricity use in the summer season were twice that of the winter season. The lower standard deviation (2.9kWh) in the winter season suggested that daily electricity use was clustered around the mean, while the higher standard deviation in summer (4.6kWh) and monsoon (3.4kWh) seasons indicated that electricity use was more spread out possibly due to the increased use of AC in these seasons.

The seasonal variation in mean daily electricity use was further analysed by presence or absence of AC. As shown in Table 2, mean daily electricity use of AC dwellings was found to be twice that of non-AC dwellings in the cooling seasons of summer and monsoon. This difference was much lower in the winter season between AC dwellings (6.2kWh/day) and non-AC dwellings (5.4kWh/day) indicating that AC dwellings operate in a similar way to non-AC dwellings in the winter season, affirming the mixed-mode operation of AC dwellings. Overall mean daily electricity use of AC dwellings was double that of non-AC dwellings indicating the influence of summer and monsoon seasons on overall energy use. Interestingly there was little seasonal variation in mean daily electricity use within non-AC dwellings across summer (6.4kWh), monsoon (6kWh) and winter seasons (5.4kWh). On the other hand, seasonal variation was more pronounced for AC dwellings wherein the wintertime mean daily electricity use (6.2kWh) was 52 % less that the summer mean daily (13.1kWh) and 49 % less than the monsoon mean daily (12.2kWh).

### DAILY ELECTRICITY USE PROFILES FOR THE OVERALL PERIOD AND ACROSS SEASONS

Cluster analysis of the electricity profiles of the 89 dwellings for the overall period (proxy for annual) revealed three clusters of dwellings with distinct peak periods. *Cluster 1* comprised 23 dwellings in warm-humid (n:6), hot-dry (n:3) and composite climatic zones (n:14) where 83 % of the dwellings had at least one AC unit. *Cluster 2* consisted of 39 dwellings located in

**Table 4. Mean daily electricity and peak electricity use for three clusters.**

| | Cluster-1 (n:23) | Cluster-2 (n:39) | Cluster-3 (n:27) |
|---|---|---|---|
| Mean daily electricity use in kWh | 12.5 | 7.9 | 9.2 |
| Peak period of electricity use | 9pm- 4am | 6am-9am | 6pm to 12am |
| Electricity used in the peak period | 5.6 | 2.4 | 3.2 |
| Proportion of daily electricity used in the peak period | 44.8% | 30.3% | 34.8% |

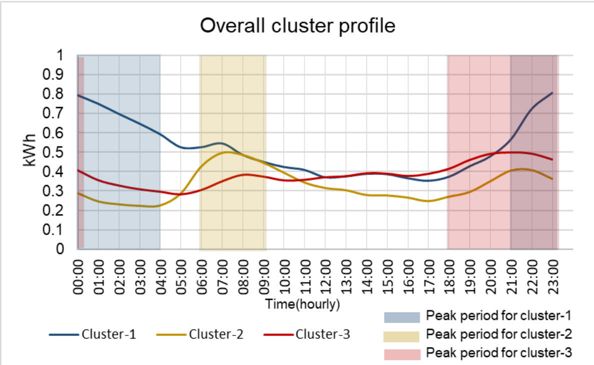


*Figure 1. Clusters of daily electricity profiles and peak electricity use for the overall period (n: 89 dwellings).*

warm-humid (n:12), cold (n:7), hot-dry (n:4), temperate (n:3) and composite (n:13) climatic zones where 49 % of dwellings had air conditioning. *Cluster 3* dwellings included 27 dwellings located in cold (n:2), hot-dry (n:3), composite (n:10) and warm-humid (n:12) climatic zones where 59 % of the dwellings had at least one AC unit.

The maximum point difference between diurnal and evening/night or late night peaks was used to identify the focus of the period of peak electricity usage. The mean daily electricity, amount of electricity used in the peak period along with its time duration are shown in Table . Mean daily electricity use and peak electricity use were highest in *Cluster 1* followed by Cluster 3 and then Cluster 2. Peak electricity use contributed to 44.8 % of the daily electricity use in Cluster 1, dropping to 30.3% and 34.8 % for clusters 2 and 3 respectively.

The electricity profiles and period of peak electricity use for the three clusters are shown in Figure 1. It was observed that peak period of electricity use for *Cluster 1* (predominantly AC dwellings) was not just the highest in magnitude but also the longest and occurred during night-time (9pm–4am, 7 hours). On the other hand, for *Cluster 2* (predominantly non-AC dwellings) the peak was shorter and occurred during the morning from 6am to 9am (3 hours), while *Cluster 3* (mostly AC dwellings) had a longer but a lower magnitude of peak starting in the evening at 6pm and continuing through the night to 12am (6 hours). Although mean daily electricity use of Cluster 1 was 1.6 times that of *Cluster 2*, peak electricity use was 2.3 times again indicating use of AC. The timing of peak periods suggest that *Cluster 1* dwellings used ACs during night-time for sleeping, as against likely use of geysers for hot water in the morning for *Cluster 2* dwellings. Although *Cluster 3* had a late evening peak period of around 6 hours (6pm to 12am), the amount of peak electricity used was 43 % less than *Cluster* 1, indicating a mix of cooling and possibly heating devices since some dwellings in *Cluster* 3 fell in the cold climate zone. Moreover 52 % of *Cluster 1* dwellings (with ACs) were located in the composite climate zone that tends to experience very hot summers and warm humid monsoon season, which could drive the use of AC during night time. Moreover 61 % of dwellings in *Cluster 1* had more than one AC unit, while in *Cluster 2*, 21 % of dwellings had more than one AC unit and in *Cluster 3,* 41 % of dwellings owned more than one AC unit. The increase in number of AC units led to an increase in the magnitude of peak electricity use during night time as evident in Figure 1.

In addition to the overall period, daily electricity profiles of the 89 dwelling sample were analysed for the summer, monsoon and winter seasons to identify any differences in the timing of peaks across seasons. As seen from Figure 2, in the *summer season*, three clusters emerged, interestingly with similar peak periods (night time, evening and morning) as those identified for the overall period in figure 1. Two summer clusters – *Summer cluster 1* (n: 25) with 80 % AC dwellings and *Summer cluster 2* (n:33) with 70 % AC dwellings observed late night (8pm–7am) and evening peaks (7pm–11pm) respectively, while *Summer cluster 3* (n: 31) with 64 % non-AC dwellings had a morning peak (6am-9am). This reaffirmed the use of AC during evening and night time by *Summer cluster 1* and *2* dwellings given that daily electricity use of *Summer cluster 1* was found to be twice that of *Summer cluster 3*. In the *monsoon season*, two distinct clusters were identified – *Monsoon cluster 1* (n:49) with 69 % AC dwellings experienced an extended evening-night time peak from 6pm-8am whereas *Monsoon Cluster 2* (n:40) with 50 % AC dwellings had a morning peak from 6am–9am. Again *Monsoon Cluster 1* with the evening-night time peak had a much higher daily electricity use and peak electricity use than *Monsoon Cluster 2*. Interestingly four distinct winter clusters emerged during the winter season with late night peaks mostly absent, apart from winter Cluster 3 which experienced night-time peak (possibly for room heating) of a lower magnitude than the summer or monsoon clusters. Winter clusters 1, 2 and 4 experienced early and late morning peaks possibly for the use of geysers for heating water and room heating.

When daily electricity profiles for non-AC dwellings (n:35) were analysed, two similar clusters emerged – Non-AC cluster 1 with mean daily electricity use of 3.8kWh and Non-AC cluster 2 with mean daily of electricity use at 4.9kWh. The proportion of daily electricity used in the peak period for the two clusters was less than 40 % and the peak period occurred in the morning during 6am to 10am. No significant seasonal variation in daily electricity profiles for non-AC dwellings was observed across the two clusters.

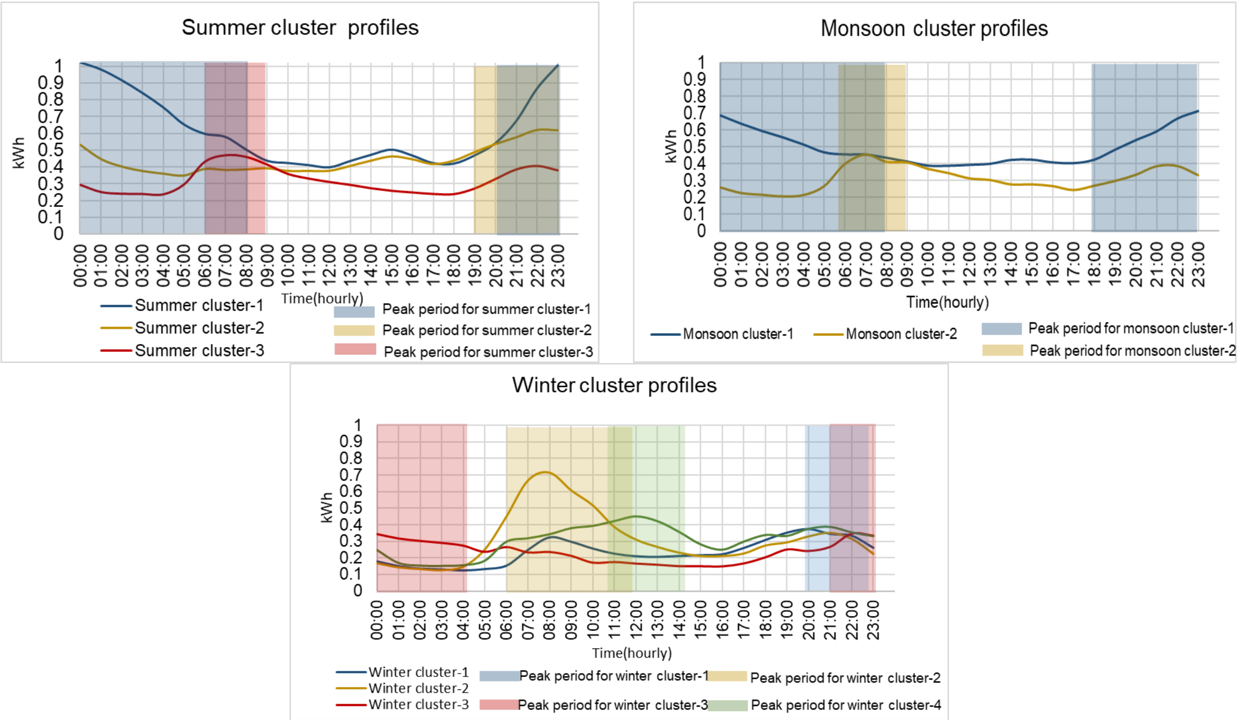


*Figure 2. Clusters of daily electricity profiles of AC and non-AC dwellings in the summer, monsoon and winter.*

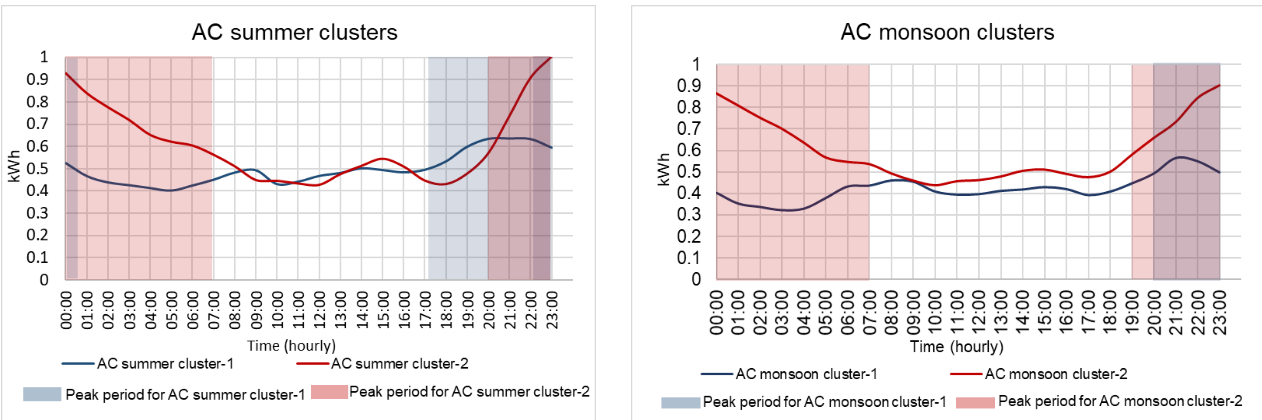


*Figure 3. Clusters of daily electricity use profiles of AC dwellings in the summer and monsoon seasons.*

#### SEASONAL VARIATION IN DAILY ELECTRICITY USE PROFILES OF AC DWELLINGS

In order to examine daily electricity use profiles of AC dwellings (n:54), cluster analysis was conducted for summer and monsoon seasons. Two distinct AC summer clusters emerged wherein 20 dwellings were grouped under *AC summer cluster 1* and remaining 34 dwellings were grouped under *AC Summer cluster 2*. Both clusters had 70 % of dwellings with one to two AC units with remaining 30 % of dwellings having three or more AC units, yet the daily profiles were dissimilar. *AC summer cluster 2* experienced a much longer peak period with higher magnitude during night time (four more hours) with peak usage double that of *AC summer cluster 1*. Likewise in the monsoon season, two clusters emerged with similar trend as the *AC summer clusters* although magnitude of the peaks in the *AC monsoon clusters* were slightly lower than the *AC summer clusters*.

## Discussion

The study characterised the 'annual' (overall) and seasonal electricity profiles of 89 AC and non-AC dwellings in India using a clustering approach to identify the timing and magnitude of peak period of electricity use. The three clusters that emerged for the 89 dwelling sample were distinctive with three peak periods occurring during *night time, late evening* and *morning* time. Since the cluster with predominantly AC dwellings experienced double the amount of peak electricity use as compared to a cluster with largely non-AC dwellings, it was clear that presence of air conditioning in dwellings determined the timing, magnitude and duration of peak electricity. The analysis also confirmed the anticipated prevalence of seasonal variation in the mean daily electricity use for the 89 dwelling sample. Seasonal variation was more pronounced for AC dwellings given that their mean daily electricity use in the cooling season (summer and monsoon) was double that of the non-cooling season (winter). Even the mean daily electricity profiles of AC dwellings showed a prolonged peak period of electricity use in the evening and night time in the summer and monsoon seasons. In addition to weather, use of multiple AC units was evident given that one of the AC clusters in summer and monsoon seasons had a much longer peak period of higher magnitude. On the other hand, non-AC dwelling clusters exhibited similar amount of electricity use across both cooling and non-cooling seasons. Even the two clusters that emerged for non-AC dwellings showed a similar trend in electricity profiles. While a large proportion of the morning peak could be met by the expected growth of rooftop solar in India to meet climate change targets, peak electricity use in late evening and night time peaks needs to be curtailed using demand side response strategies whether they are automated or manual. Pre-cooling can be used to curtail usage during peak hours, provided the building fabric can store coolth and release it during the peak period. This may requirement rapid improvement in the thermal performance of the building fabric of urban Indian dwellings using insulation since most existing dwellings have thermal mass due to RCC (reinforced cement concrete) based construction. Dwellings with smart meters can also be connected to time-of-use tariffs to encourage price signal based demand shifting.

These findings have important implications for residential energy policy in India. As residential air conditioning becomes widespread in India, the gap between mean daily electricity use in cooling and non-cooling seasons is likely to widen further, necessitating the need for additional electricity generation and expensive grid reinforcements. To avoid this, the demand for air conditioning should be minimised as much as possible through passive cooling measures at the building, neighbourhood and city scale. Currently the peak electricity demand period in India is considered to be in the morning from 7am to 8am and late evening from 6pm to 8pm. Given that clusters comprising AC dwellings experienced peak period of 6–7 hours occurring in the late evening and night time, it is likely that this may shift and expand the national peak period towards late night especially in the summer and monsoon seasons. Without demand management, additional electricity generation and storage will need to be planned to meet this expected seasonal surge in demand for peak electricity use, especially in AC dwellings.

## Conclusion

The study statistically analysed time-series data to develop representative daily electricity use profiles and determine peak periods of electricity use in 89 AC and non-AC dwellings in the summer, monsoon and winter seasons. About 54 out of 89 dwellings owned at least one AC unit. An unsupervised clustering technique was used to group electricity use curves with similar patterns using a combination of hierarchical and k-means algorithm, to characterise the diurnal and seasonal variations in daily electricity use profiles. The maximum point difference was used to identify the daily peak electricity usage period. Three distinct clusters emerged. The first cluster with largely AC dwellings had a prolonged night time peak of the highest magnitude, followed by the second cluster with predominantly non-AC dwellings had a short morning peak of lowest magnitude, and finally the third cluster which had a mix of AC/non-AC dwellings and experienced a late evening peak. Seasonal variation was prevalent at the sample (89 dwellings) and sub-sample (54 AC dwellings) level. For AC dwellings mean daily electricity use in the cooling season (summer and monsoon) was double that of the non-cooling season (winter). The duration and magnitude of peak periods in the two AC clusters were different, indicating the use of multiple AC units. On the other hand, seasonal variation in mean daily electricity use and electricity profiles was subtle in non-AC dwellings. Mean daily electricity use of AC dwellings (n:54) in the summer and monsoon seasons was found to be around 13kWh/day which was twice that of non-AC dwellings (n:35, 6.4kWh/day).

The representative electricity profiles developed in the study can be used by energy suppliers to develop time-of-use tariffs to stimulate residents to change the timing of their electricity demand in the peak period in response to price signals (demand response). Policymakers can use the findings to curtail the growth in electricity use in the cooling season in AC dwellings through passive measures at the building and neighbourhood scale. Industry can use the study findings to develop products and services that can enable residents to control the operation of AC units through smart controls.

In future, it is vital to significantly expand the study to a national scale to examine the diversity in daily electricity profiles of different socio-economic groups in India. In this regard, the ongoing national smart meter programme could be rapidly scaled up to move further and faster. Alongside smart meters, contextual data about the dwellings should be collected to help understand the underlying patterns of daily electricity profiles. Time-series data gathered by smart meters can also be used to develop services and products to enable residents manage the timing and duration of their daily electricity peaks, thereby introducing energy flexibility in India.

## Acknowledgements

We are thankful to the NEEM-CLASP study for providing the smart meter data for 89 dwellings. The analysis in this study has been conducted as part of the RESIDE project which has received funding from the Engineering and Physical Sciences Research Council (EPSRC), UK grant no: EP/R008434/1.

## References

Agrawal, S., et al. (2020). What smart meters can tell us insights on electricty supply and use in Mathura and Bareilly households. New Delhi, CEEW**:** 78.

Cogan, D., et al. (2005). National database of household appliances – understanding baseload and standby power use. New Zealand, HEEP project.

EESL (2020). Retrieved 25th November, 2020, from https://www.eeslindia.org/smnp.html.

EDS (2019). "Home - household energy monitoring dashboard 'national energy end-use monitoring." NEEM Dashboard. Retrieved 08 March 2022, from https://neem-dashboard.in/index.php

Hair, J. F., Jr., et al. (2014). Multivariate data analysis. Harlow, Pearson Education Limited.

Huebner, G. M., et al. (2015). "The shape of warmth: Temperature profiles in living rooms." Building Research & Information **43**(2): 185–196.

IEA (2019). "World energy outlook 2019." Retrieved 22/01/2021, from https://www.iea.org/reports/world-energy-outlook-2019/electricity#abstract

IEA (2020). "India cooling action plan (icap)." Retrieved 25/01/2021, from https://www.iea.org/policies/7455-india-cooling-action-plan-icap

IESS (2021). "All energy." from http://iess2047.gov.in

Jeong, H. C., et al. (2021). "Clustering of load profiles of residential customers using extreme points and demographic characteristics." Electronics **10**(3).

Marton, C. H., et al. (2008). "An order-specific clustering algorithm for the determination of representative demand curves." Computers & Chemical Engineering **32**(6): 1365–1372.

Muslim, H. N., et al. (2017). "Electrical load profile analysis and investigation of baghdad city for 2012–2014." International Journal of Current Engineering and Technology.

NBC (2005). National building code, Bureau of Indian Standards. 2: 1161.

Rawal, R. and Y. Shukla (2014). Residential buildings in india : Energy use projections and savings potentials**:** 1–50.

Rhodes, J. D., et al. (2014). "Clustering analysis of residential electricity demand profiles." Applied Energy **135**: 461–471.

Satre-Meloy, A., et al. (2020). "Cluster analysis and prediction of residential peak demand profiles using occupant activity data." Applied Energy **260**.

Vaughan, A. (2021). "Cop's big promises." New Scientist **252**(3360): 8.

Viegas, J. L., et al. (2016). "Classification of new electricity customers based on surveys and smart metering data." Energy **107**: 804–817.

Yohanis, Y. G., et al. (2008). "Real-life energy use in the uk: How occupancy and dwelling characteristics affect domestic electricity use." Energy and Buildings **40**(6): 1053–1059.