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Residential electricity use and perceived thermal comfort during the first wave of Covid-19 lockdown in India

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Abstract

The first wave of COVID-19 pandemic led to a nationwide lockdown in India from 25th March to 30th May 2020. This study examines the change in residential electricity consumption, use of air conditioning (AC) and well-being of residents during the lockdown period when normal activities became home-based and travelling was curtailed. An online household survey questionnaire was used to gather data about dwelling characteristics, occupancy, socio-demographics, AC and appliance usage, and resident well-being in terms of thermal comfort and neighbourhood support during the lockdown, from 360 households representing four climatic zones in India. A subset of 88 households provided three months of electricity consumption data (fuel bills) before and during the lockdown period.

Of the 360 households, 133 occupied high-rise apartments and 79 low-rise apartments while the remaining households inhabited row and detached houses. Overall 42% of households felt an improvement in support from their neighbourhood and community during lockdown; this improvement was perceived to be higher in apartment blocks possibly due to the close proximity of households. Occupancy hours of AC households increased by 75% during the lockdown along with an 28.9% increase in AC usage hours due to home-working. This is why mean monthly electricity consumption for AC households during the lockdown was found to be 292kWh, which was twice that of non-AC households (152kWh). The weather-corrected mean daily electricity consumption during lockdown (April 2020) for the 88-household sample was 10.5 kWh, as compared to 8 kWh before the lockdown (February 2020). As home-working and home-schooling continue through the pandemic, curtailing the rise of residential electricity use needs urgent attention from policy-makers.

Keywords: Electricity consumption, COVID-19, lockdown, survey, residential energy

1 Introduction

COVID-19 was declared as a global pandemic in March 2020 by the world health organisation (WHO, 2020). In the following months, the pandemic claimed hundreds of lives and infected millions around the world. While, social distancing and stringent lockdown measures were adapted by countries to reduce the impact of the virus, several countries are struggling to cope with the disastrous impact of the pandemic on the economic, health, travel, hospitality and educational sectors (Kanda and Kivimaa, 2020). To control the spread of the pandemic offices and schools were given orders to work from home around the world.

With more employees working from home, businesses saw an increase in remote-working technologies, increase in electricity savings and reduction in emissions and pollution from transport, has convinced employers to continue this trend after the pandemic (Abu-rayash and Dincer, 2020). One meta-study from the USA looked at the impact of working from home across 39 studies and found that 26 studies found a drastic reduction in electricity demand by avoiding commute and working from home, while eight studies found the impact to be neutral or negative (McWilliams and Zachmann, 2020). About 8% increase was observed in daily residential

electricity use in USA, while around 30% reduction was observed in commercial and educational institutions during the lockdown (Sönnichsen, 2020). Another study in the USA found that the decreased demand from industries have started to offset the increase in demand from residential households and have picked up the trend by June 2020 (Gillingham et al., 2020). In a UK study, it was reported that when working from home people living in houses were more comfortable that those living in apartments (Carmona et al., 2020).

As per the international electricity agency, India went into full lockdown on 25th March 2020 (IEA, 2020). The lockdown measures in India increased home-working, which led to a reduction in electricity demand from commercial and industrial establishments, but an increase in electricity demand from the residential sector. The recovery rate/increase of electricity demand when the lockdown measures were starting to lift was the highest for India, indicating a higher sensitivity to the lockdown. Despite the changes in electricity demand during the lockdown period, there is limited research on the effect of lockdown (time of stress) on residential energy use and thermal comfort in India.

To address this gap, this study uses a survey-based approach to examine the change in residential electricity consumption, use of air conditioning (AC), perceived thermal comfort and well-being of residents during the lockdown period when occupants spent more time indoors and schools, commute and other leisure activities were unavailable. The study also investigated the self-reported experience of occupants with their neighbourhood before and during lockdown, the changes to utilisation of spaces and appliances within the home and the variation in electricity use in households with and without air conditioning. The present study is conducted as part of five-year Indo-UK research project called RESIDE residential building energy demand reduction in India.

2 Methodology

A survey-based approach was used to gather field data. The survey was implemented online using Google Forms and included questions on dwelling attributes, appliance usage patterns, occupant perceptions and thermal comfort drawing from similar survey based studies (Theodoridou et al., 2011, Brounen et al., 2012, Zhang et al., 2018, Vakalis et al., 2019, Filippini and Pachauri, 2004, Indraganti and Rao, 2010, Desai and Vanneman, 2011, NSSO, 2012, Jain et al., 2014, Singh et al., 2018). The study considered *before-COVID* period as February 2020 and *during-COVID* as April 2020 since some lockdown measures were eased from the beginning of May 2020. Since the survey was gathered during the summer, weather correction was done for cooling degree days (CDD).

2.1 Survey design

The questionnaire survey was designed to gather details about the dwelling attributes, socio-demographic variables, well-being & perception of community during lockdown, appliances and its usage hours, electricity consumption and occupancy comfort profile which are shown in Table 1. Boegle et al found that a major part of the consumption comes from: fans, lighting (incandescent bulbs and tube lights), refrigerators, ACs, air coolers, electric water heater, televisions (active mode) and stand-by power (incl. Set-Top-Boxes, DVD Players, TVs, and Computers). Together, these nine end-uses or appliances were used as proxy to interpret electricity consumption. As the survey was collected during the summer, the focus was on space cooling such as air conditioning and desert cooler. In total, eight appliances details were gathered for this analysis. The online survey was distributed to households across India through networks of researchers and institutions in India.

Table 1. Variables used in the questionnaire survey

Variables	**Categories**	**Type of data**
Physical characteristics		
1. **Dwelling Type**	Standalone house; Row houses; Apartment block(<4 storey); Apartment block(>4 storey); House(with one common wall adjacent); Other	Categorical
2. **Dwelling location**	City	Categorical
Socio-demographics		
3. **Gender** of respondent	Male; Female	Categorical
4. **Occupation** of respondent	Service; Business; Student; Homemaker; Retired	Categorical
5. **Age** of respondent	Number	Numeric
6. **Total number of occupants**	Number	Numeric

Well-being & Community		
7. **Sense of community before lockdown**	Some; Strong and No sense of community	Ordinal
8. **Neighbourhood support during lockdown**	Very poor, Poor, OK, Well, Very well	Ordinal
9. **Change in support from neighbours, local groups and services**	Worsened a lot, Worsened a bit, No change, Improved a little, Improved a lot	Ordinal
10. **Stress & reasons for stress**	Job; Short-term and long-term impacts of the virus; loneliness and others	Categorical
11. **Activity throughout the day**	Passive/active work	Categorical
Occupancy patterns		
12. **Most occupied room during weekdays and weekends before lockdown**	Bedroom; Living room; Kitchen; Dining room; Other; Study	Categorical
13. **Most occupied room during weekdays and weekends during lockdown**	Bedroom; Living room; Kitchen; Dining room; Other; Study	Categorical
14. **Time spent at home before and during lockdown**	Less than one hour per day; 1-3 hours per day;4-6 hours per day;7-9 hours per day;10-12 hours per day; More than 12 hours per day	Categorical
Appliances & Usage		
15. **Usage of 9 appliances (refrigerator, ceiling fans, TV, Washing machine with and without dryer, desert cooler, laptop/desktop computer, LEDs and AC) per day before and during lockdown**	Less than one hour per day; 1-3 hours per day;4-6 hours per day;7-9 hours per day;10-12 hours per day; More than 12 hours per day	Categorical
16. **No. of AC's**	Number	Numeric
17. **Location of AC**	Bedroom; Living room; Kitchen; Dining room; Other; Study	Categorical
Thermal comfort		
18. **Thermal sensation**	Cold; Cool; Slightly cool; Neutral; Slightly warm; warm; Hot	Ordinal
19. **Thermal perception**	Much too cool; Too cool; Comfortably cool; Comfortable; Comfortably warm; Too warm; Much too warm	Ordinal
20. **Thermal acceptability**	Clearly acceptable; Just acceptable; Neutral; Just unacceptable; Clearly unacceptable	Ordinal
Electricity consumption for 3 months		
21. **Electricity consumption in Feb, Mar and April 2020**	INR	Numeric
22. **Electricity cost in Feb, Mar and April 2020**	kWh	Numeric

2.2 Sample size

Random sampling was conducted across India through distribution of the survey to occupants of different cities through professional networks, resident housing associations, local educational establishments etc. The survey was conducted from May-June 2020 to coincide with the cooling season. Good quality survey data was gathered for 360 households covering four climatic zones in India. The respondents were requested to provide electricity consumption data. About 93 households provided electricity data , however one cold zone data and four extreme outliers were removed for an unbiased analysis, narrowing down to 88 households with data on electricity use across three months (February, March and April) covering the before and after lockdown period.

Since the data collected was during the summer period which was defined as March to June in order to achieve uniformity across various climatic zones of India. The ECBC classifies Indian regions into five different climatic zones based on their outdoor temperature and relative humidity of each city (Pawar et al., 2015, BEE, 2017). All 360 households have been classified according to the five climatic zones defined by the ECBC. Across the sample of 360 households, 275 households had at least one AC while 85 were non-AC households. In the 88 household sample with electricity data, 71 households had at least one AC while 17 were non-AC households.

The month of February 2020 was regarded as the period of "before lockdown" while April was regarded as the "during lockdown" period. To account for any weather related effect, residential electricity use was weather corrected using cooling degree days. A paired t-test was conducted to examine the impact of the lockdown on electricity consumption. Spearman's correlation was used to explore the relationship between thermal comfort perception and behaviour of occupants during lockdown.

3 Results

Across the sample of 366 households (representing 1,504 occupants), 133 households (36%) inhabited apartment blocks greater than 4 storey , 79 households (21%) occupied apartment blocks less than 4 storey and 69 households (19%) resided in standalone houses with the remaining in row houses. It was noted here that 52% of the respondents were female and 48% male. While 44% of the respondents worked in the service sector, 22% had their own business. The respondent ages ranged from 18 years to 72 years, with 67% of the occupants falling under 18-30 age range while 21% of the occupants were in the 31-50 age group. The median number of occupants per household was found to be four.

3.1 Neighbourhood and community

The occupants in apartment blocks felt a stronger sense of community before the lockdown as compared to occupants of standalone houses. Only 12 % felt there were no sense of community. Overall, across all households, the sense of community increased during lockdown. This increase was highest amongst those living in high-rise apartments above 4 storeys (17%), followed by high-rise apartments below 4 storeys (14%). The lowest sense of community was felt among occupants in row houses (<1%). This could likely be due to the closer proximity apartments and shared communal spaces. About 71% of respondents felt they were well supported by their neighbourhood environment and this perception increased during the lockdown, while 42% of respondents felt an improvement in support from neighbours, local groups and services during the lockdown. About 68% (91 out of 133) respondents living in apartments (>4 storeys) and 75% (60 out of 79) of respondents in apartments (<4 storeys) felt an improvement in support from the neighbourhood and local services as compared to 61% respondents (42 out of 69) inhabiting standalone houses. Unsurprisingly 46% of the respondents confirmed they were stressed out majorly due to the long-lasting effects of Corona virus.

3.2 Space utilisation:

There were interesting trends observed in the space utilisation of homes with and without air conditioning (AC) given that number of hours spent working from home increased a from 1-3 hours to 4-6 hours a day. While 57% of respondents occupied a different room during lockdown such as the drawing, dining and kitchen areas, there was much limited adaptation in AC households with only 8% of respondents shifting their occupancy to a different room during lockdown. In such households, occupancy of bedrooms increased by 9% possibly because most of the bedrooms had AC units. This implies that households without AC offered more opportunity for adaptation since they were not restricted by the presence of AC in certain rooms.

3.3 Use of appliances

Understandably respondents from composite and hot-dry climates use AC the most during the summer period. This is why there was an increase of 40%, 27% and 18% in AC usage per day during the lockdown period amongst households in the composite, hot-dry and warm-humid climatic zones. AC usage can be used as proxy for electricity consumption as seen in a study conducted in Japan (Hara et al., 2015). The rise in residential electricity use can be explained to an extent by (self-reported) hours of appliance usage. Overall higher appliance usage was noted during the lockdown period. While refrigerator and washing machines had similar usage hours before and during lockdown, usage of ceiling fans, TV, computer, desert coolers and LEDs increased significantly.

Before the lockdown, usage of refrigerator, ceiling fans, AC and LEDs contributed the highest hours of usage. However the lockdown saw an increase in usage of other applinaces – such as computers, ACs, celing fans and desert coolers translating to an overall increase of 60% in desert coolers, 52% increase in laptop/desktop computer and 42% increase in TV across all households. Across AC and non-AC households, higher number of appliances were used in non-AC households than AC households during lockdown with an increase of 30%. In non-AC

households, about 110% increase in desert coolers was observed, while washing machines and computer usage increased for non-AC households. The appliance usage hours varied by climatic zones with households in the composite zone experiencing higher usage of appliances indicating significant electricity use during the lockdown period. It was also observed that warm-humid and cold zone households used more ceiling fans, TV and refrigerator during the lockdown.

3.4 Thermal Comfort

The online survey was conducted from 20th May to 19th June representing the summer season. Responses to thermal comfort were completed mostly during 6pm-11pm. Nearly 34% of occupants were doing passive work while 30% were involved in some form of active work while other activities were scattered and less than 15%. The thermal sensation votes were measured using the seven-point scale by ASHRAE while the thermal preference votes were measured by Nicol's five-point reference scale.

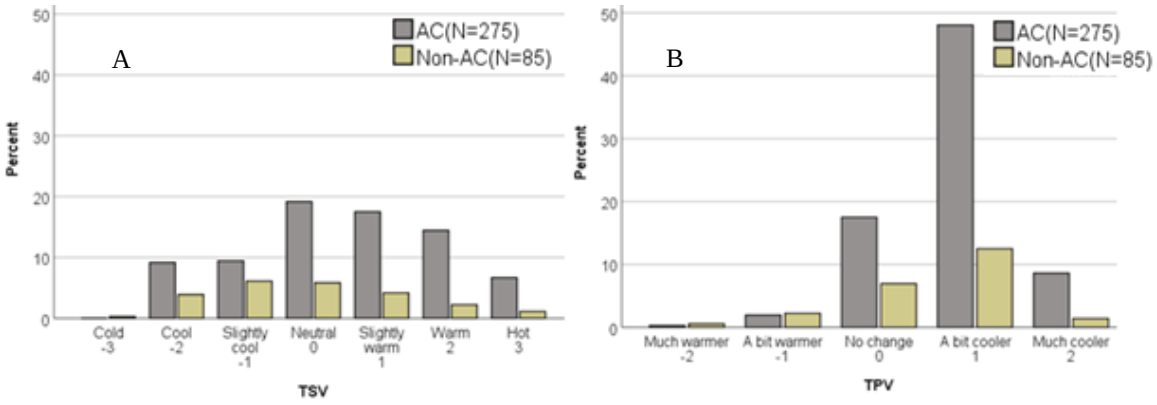

Figure 1. (A) Temperature sensation vote (TSV) (B) Temperature preference vote (TPV) across AC and non-AC households

The distribution of thermal sensation votes (TSV) and thermal preference votes (TPV) across AC and non-AC households is shown in Figure 1. As evident 69 (19%) of 275 responses in AC households perceived the indoor temperature to be neutral while 63 (17%) occupants perceived the indoor temperature to be slightly warmer. Across non-AC households, 22 (6%) of the 85 responses preferred the indoor temperature to be a bit cooler, while other responses were scattered. As with the TPV, there were 173 responses (48.1%) of 275 responses that preferred 'a bit cooler' in their thermal preference among AC households while 45 responses (12.5%) among 85 responses preferred 'a bit cooler' amongst non-AC households.

In AC households, the mean TSV scale was found to be positive or slightly skewed towards the warmer side with a mean of 0.5 (N=275 and SD=1.45), while across the non-AC households, the mean TSV was found to be slightly skewed towards the cooler side with a mean of -0.12 (N=85 and SD=1.41). The mean TPV (of the 5-point scale) was found to be 0.82 (N=275 and SD =0.66) for AC households while for non-AC households the mean TPV was 0.5 (N=85 and SD=0.83). These measurements show that perceived thermal sensation and thermal preference vote across AC and non-AC households was not exceedingly different, indicating that AC households may not be using AC when thermal comfort survey was conducted. While occupants in AC households perceived indoor temperature to be warmer and preferred cooler temperature, while occupants in non-AC households perceived indoor temperature to be cool but still preferred a cooler temperature. This indicates a higher tolerance to warm temperatures amongst non-AC dwelling occupants.

The distribution of air sensation votes (ASV) and air preference votes (APV) across AC and non-AC households is shown in Figure 2. The ASV reveals that 134 (37.2%) of 275 responses in AC households perceived the indoor air movement to be 'neither high nor low' while across non-AC households 36 (10%) occupants perceived the indoor air movement to be 'neither high nor low'. As with the APV, there were an equal number of 118 responses (32.78%) of 275 responses that preferred 'a bit more' and 'no change' in their indoor air movement among AC

households, while 41 responses (11.39%) among 85 responses preferred 'no change' in their indoor air movement among non-AC households.

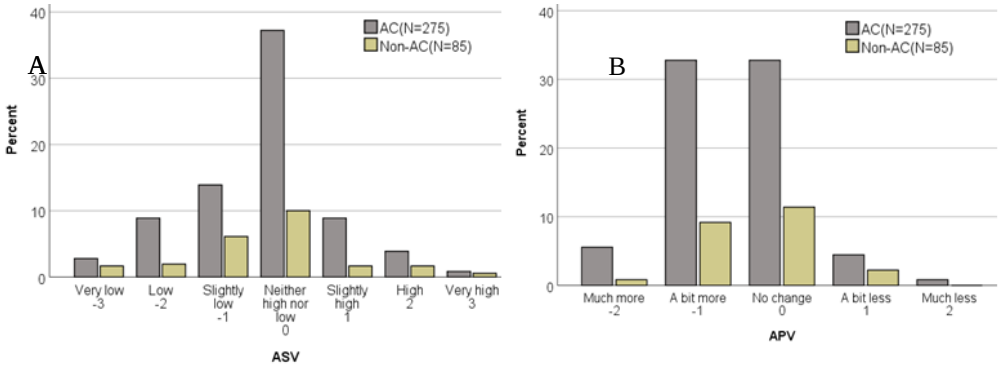

Figure 2. (A) Air sensation vote (TSV) and (B) Air preference vote (TPV) across AC and non-AC households

Among AC households, the mean ASV scale was negative or slightly skewed toward low air movement with a mean of -0.27 (N=275 and SD=1.15), while across the non-AC households, the mean ASV was also found to be slightly skewed towards a lower air movement with a mean of –0.35 (N=85 and SD=1.29). The mean APV (of the 5-point scale) was found to be -0.49 (N=275 and SD =0.76) for AC households while for non-AC households the mean APV was -0.36 (N=85 and SD=0.7). It is clear that occupants in both AC and non-AC households perceived indoor air movement to be lower and preferred a bit more air movement. Only 27.5% of the respondents in 275 AC households and 12.5% of the non-AC households perceived indoor humidity to be 'just right', the mean HSV scale was found to be negative with a mean of -0.65 in AC households and -0.52 in non-AC households. Less than a third of respondents found the indoor temperature, indoor humidity and air movement to be acceptable. These results imply the likely use of AC by occupants to meet comfort needs, which could drive electricity consumption during the lockdown period.

3.5 Residential Electricity Use

The unadjusted daily mean electricity use for the sample of 88 dwellings was found to be 7.6 kWh, 8.6 kWh and 10.1 kWh in the months of February, March and April 2020 respectively. For AC households, the mean monthly electricity consumption across the three months was found to be 292kWh with a mean monthly electricity bill was 2575 INR or US$28. These figures were reduced to half for non-AC households with a the mean monthly electricity consumption of 152kWh at 990 INR or US$11. The electricity consumption data for February, March and April 2020 was also weather corrected to observe any non-weather-related rise in electricity use across the 88 households. The standard base temperature of 18°C across all locations (for HDD and CDD) was used was used to calculate the normalised weather consumption as follows:

Weather corrected kWh=kWh/degree day * Total average degree days(over a 5 year period) (Bizee, 2020)

The weather-corrected mean daily consumption before (February) and during (April) lockdown were found to be 8 kWh and 10.5 kWh respectively. For a base temperature of 23°C in April and 18°C in February, the daily mean consumption was 8 kWh before the lockdown and it was 10.9 kWh during the lockdown. The electricity consumption before lockdown (February) and during lockdown (April) were compared against each other using the Wilcoxon signed rank test (a non-parametric test was used as the electricity consumption data was not normally distributed even after transformation). An overall increase of 35% rise in electricity rise was noted due to the effect of the lockdown. A non-parametric paired sample-test was done to further emphasise that there was a significant difference in consumption from the effect of lockdown. Across February and April, a standardised test statistic of 6.5 was observed along with 78 positive differences and 10 negative differences indicating that the lockdown had a significant ($p<0.001$) effect on the electricity consumption. The weather corrected data shown in Figure 3 shows increase in electricity consumption during April (during lockdown) across AC and non-AC households.

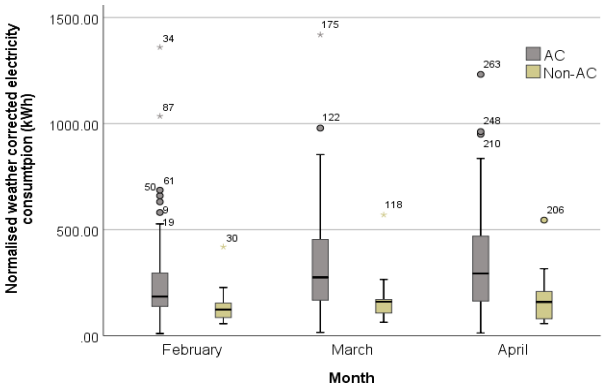

Figure 3. Boxplot of weather corrected consumption across February, March and April for AC and non-AC households.

The electricity consumption data was compared with the survey data results which showed that 69% of the respondents in AC households and 21% of non-AC perceived their electricity consumption had increased during the lockdown. A rise in electricity use as reported by AC and non-AC households although the magnitude of the rise was lower in non-AC households (9%) as compared to AC households (44%).

4 Discussion

The study has confirmed a rise in electricity use in Indian dwellings during the lock down period albeit the rise was smaller in magnitude in non-AC households as compared to AC households. This was more evident in the hot-dry regions for AC households while non-AC electricity consumption saw an increase for warm-humid regions. While a non-parametric paired sample-test was done to emphasise the significant difference in consumption from the effect of lockdown, an overall increase of 31% increase in electricity use was noted due to the effect of the lockdown. This rise can be explained by the fact that only a small proportion of households (AC/non-AC) perceived their indoor environmental conditions (temperature relative humidity, air movement) to be acceptable, confounded by the change in occupancy patterns especially home-working during the lockdown period in India. Although the number of hours during the week had increased, non-AC households occupied more common rooms during the lockdown, while AC household occupants spent more time in (bed)rooms where AC's were located.

Before lockdown, usage of refrigerator, ceiling fans, AC and LEDs, contributed to the highest hours of usage. However the lockdown period saw an increase in usage of laptop/desktop computers, ACs, ceiling fans and desert coolers. While higher number of appliances were used in non-AC households than in AC households during lockdown, electricity usage was driven by the use of ACs. The increase in electricity use in non-AC households occurred in the warm-humid zone due to the increased usage of ceiling fans, TV and refrigerator during the lockdown. On the other hand in the AC households especially in the hot-dry climatic zone, the rise in electricity use was due to the increased use of AC use in the lockdown period. Besides electricity use, there was consensus that *sense of community* had increased during the lockdown especially in apartment blocks, possibly due to the close proximity of households and access to communal areas.

This study has also provided deeper insights into using an online survey based approach to gather bottom-up data about residential electricity use during periods of stress when normal activities of office-based work and schooling were moved to the home environment. Such a change could lead to unexpected surges in residential electricity with new periods of peak load, which could lead to power cuts if the demand is not managed properly. The findings of this study across a diverse range of climatic regions in India can be used to build resilience in residential buildings.

5 Conclusion

In this study, a questionnaire survey was conducted among 360 households scattered across India to investigate the impact of lockdown on residential electricity use when there was a complete shutdown of schools, offices, commute and other leisure activities during the pandemic. The survey data gathered demographic attributes, appliances usage, occupancy, occupant thermal comfort, residential electricity use (across February, March and April 2020) and socio-demographic attributes before and during lockdown while examining weather corrected residential electricity of 88 households. Appliance usage including AC usage, wellbeing of occupants were investigated before and during the lockdown period. Perception of thermal comfort during the lockdown period was also measured.

Overall 42% of households felt an improvement in support from their neighbourhood and community during lockdown; this improvement was perceived to be higher in apartment blocks possibly due to the close proximity of households. Occupancy hours of AC households increased by 75% during the lockdown along with an 28.9% increase in AC usage hours due to home-working. The rise in electricity use in Indian dwellings during the lock down period was confirmed albeit the rise was smaller in magnitude in non-AC households as compared to AC households. Mean monthly electricity consumption for AC households during the lockdown was found to be 292kWh, which was twice that of non-AC households (152kWh). The weather-corrected mean daily electricity consumption during lockdown (April 2020) for the 88-household sample was 10.5 kWh, as compared to 8 kWh before the lockdown (February 2020). Findings of this study can help to improve the resilience of Indian dwellings during stressful conditions and future events. Also as home-working and home-schooling continue through the pandemic, curtailing the rise of residential electricity use needs urgent attention from policy-makers.

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