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 a 29% increase in AC usage hours due to home-working. This is possibly why mean monthly electricity consumption for AC households during the lockdown was found to be 292kWh almost twice that of non-AC households (152kWh). Following weather-correction, mean daily electricity consumption for the 88-household sample was found to have increased from 8 kWh/ day before lockdown to 10.5 kWh during lockdown. 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 were 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 reported utility firms found the home energy use was increased by 30% (BBC News, 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 was limited research on the effect of lockdown (time of stress) on residential energy use and thermal comfort in India. While the early impact of COVID-19 on overall electricity consumption was quantified, extensive research in understanding residential energy was lacking, especially in India. Such data from residential electricity profiles can locate, identify and solve any intermittent issues as well as provide more accurate forecasts, useful for utilities and policymakers to account for such events. Additionally, survey report from global work-from home reveals the future of workplace may extend to a blended approach even after the pandemic with 77% of respondents fully productive working from home, which was why this understanding residential energy use was even more vital (Kamouri and Lister, 2020).

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 curtailed. 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 was conducted as part of a five-year Indo-UK research project called RESIDE on 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). In this study the *before-COVID* period was chosen 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) at 18˚C for India (Bhatnagar et al., 2018).

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) (Boegle Alexander, 2007). 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 preference**	Much cooler; A bit cooler; No change; A bit warmer; Much warmer	Ordinal
20. **Thermal acceptability**	Clearly acceptable; Just acceptable; Neutral; Just unacceptable; Clearly unacceptable	Ordinal
21. **Non-thermal sensation**	*Air movement*- Very low, Low, Slightly low, Neither high nor low, Slightly high, High , Very high *Humidity*- Very humid, Humid, Slightly humid, Just right, Slightly dry, Dry, Very dry	Ordinal
22. **Non-thermal preference**	*Air movement*- Much more, A bit more, No change, A bit less, Much less	Ordinal
23. **Non-thermal acceptability**	*Air movement*- Yes; No *Humidity*- Yes; No	Ordinal
Electricity consumption for 3 months		
24. **Electricity consumption in Feb, Mar and April 2020**	INR	Numeric

25. **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 residents of different cities through professional networks, resident housing associations and local educational establishments. The survey was conducted from May-June 2020 to coincide with the summer period/ cooling season which runs from March to June in India. Responses were received from 360 respondents (52% female, 48% male) representing 360 households, covering four climatic zones as defined by the Indian Energy Conservation Building Code (ECBC) (Pawar et al., 2015, BEE, 2017). The respondents were requested to provide electricity consumption data. About 93 households provided electricity data, however one response from the cold climatic zone and four extreme outliers were removed for unbiased analysis, narrowing down to 88 households with data on electricity use across three months (February, March and April) covering the *before* and *during* lockdown periods. Of the 360 households, 275 households had at least one AC while 85 households did not have any AC units (non-AC). Within 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 "before lockdown" period while April was regarded as "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.

The smaller sample size was justified by comparing results of this study with similar studies (NPP, 2021, Agrawal and Pathak, 2020, Madurai Elavarasan et al., 2020). One of the studies by Thapa et al., gathered data on thermal comfort of occupants during lockdown from 406 responses covering different climatic zones of India (Thapa et al., 2020). The sample size used in this study may not be statistically representative of the entire Indian population but does provide insights into the patterns of electricity use during a lockdown period.

3 Results

Across the sample of 360 households (representing 1,504 occupants), 133 households (36%) inhabited apartment blocks greater than four storey, 79 households (21%) occupied apartment blocks less than four storey and 69 households (19%) resided in standalone houses with the remaining in row houses. 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 respondents falling in the 18-30 age range, while 21% of the respondents 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. Overall, across all households, feeling 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 feeling of community was felt to be lowest 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 76% (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:

Interesting trends were observed in the space utilisation of homes with and without ACs, given that number of hours spent working from home increased from 1-3 hours to 4-6 hours a day. While 57% of respondents occupied a different room during lockdown such as the drawing room, dining room and kitchen areas in non-AC households, there was 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 ACs 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 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 lockdown, usage of refrigerator, ceiling fans, AC and LEDs were responsible for the highest hours of usage. However the lockdown period 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 the 360 household sample. In non-AC households, increase of 110% in desert coolers was observed. The appliance usage hours varied by climatic zones with households in the composite zone experiencing higher usage hours of appliances, while households in warm-humid and cold climatic zones increased their use of ceiling fans, TVs and refrigerators during the lockdown.

3.4 Thermal Comfort

The online survey with questions on thermal sensation vote (TSV) and thermal preference vote (TPV) was conducted from 20th May to 19th June 2020, 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. The TSVs were measured using the seven-point scale by ASHRAE while TPVs were measured by Nicol's five point reference scale.

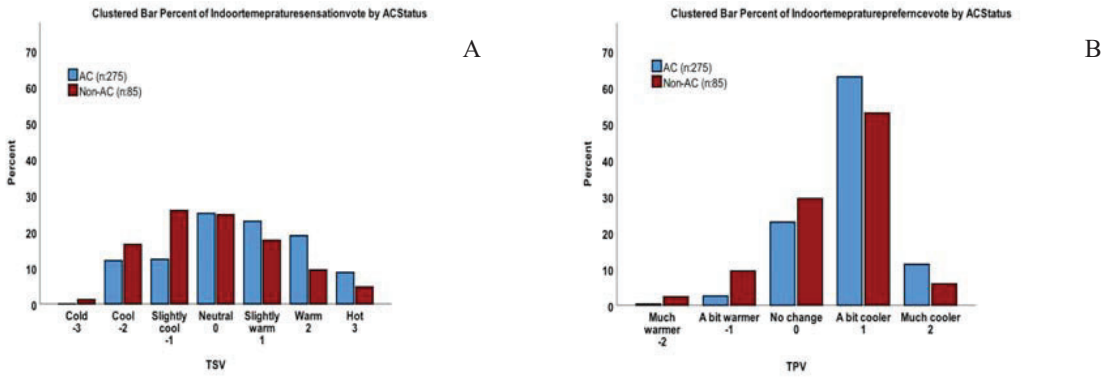

Figure 1. (A) Temperature sensation vote (B) Temperature preference vote (TPV) across AC /non-AC households

The distribution of TSV and TPV across AC and non-AC households is shown in Figure 1. As evident 69 (25%) out of 275 responses from AC households perceived their indoor temperature to be neutral while 63 (23%) occupants perceived the indoor temperature to be slightly warmer. Across non-AC households, 22 (23%) out of 85 responses preferred the indoor temperature to be a bit cooler. With regard to TPV, 173 out of 275 responses (63%) from AC households preferred it to be 'a bit cooler', while 45 out of 85 non-AC household responses (53%) preferred to be 'a bit cooler'.

In AC households, the mean TSV scale was found to be skewed towards the warm side with a mean of 0.5 (N=275 and SD=1.45), while in non-AC households, mean TSV was found to be skewed towards the cool side with a mean of -0.12 (N=85 and SD=1.41). The mean TPV (on the five-point scale) was found to be 0.82 (N=275 and SD =0.66) for AC households, and 0.5 (N=85 and SD=0.83) for non-AC households indicating the preference of the households to be 'bit cooler'. The results of TSV and TPV for AC households indicate that respondents may not be in a room with AC or the AC was not on when they responded to the thermal comfort survey. Interestingly despite different TSVs, both AC and non-AC households preferred to be a bit cooler probably due to summer season in which the survey was conducted.

The distribution of air sensation votes (ASV) and air preference votes (APV) across AC and non-AC households is shown in Figure 2. As shown, the majority of respondents in AC and non-AC households perceived the indoor

air movement to be low to 'neither high nor low'. Despite this 43% responses in AC households preferred 'no change' in indoor air movement, while 48% non-AC households preferred 'no change'.

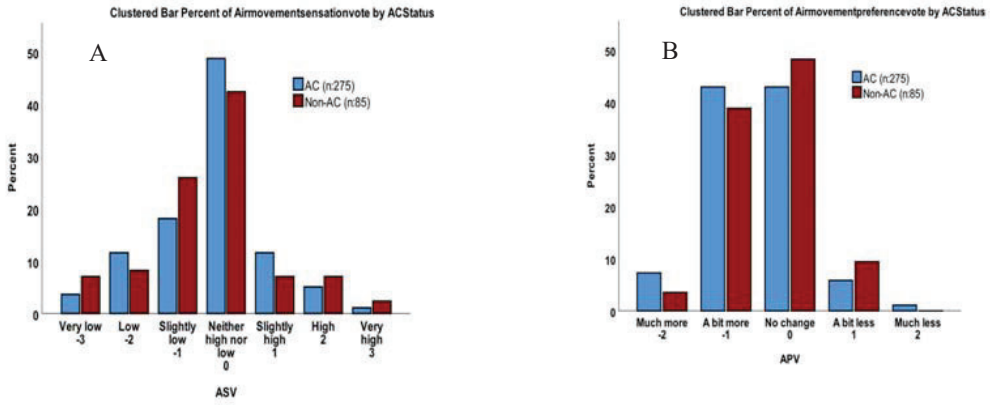

Figure 2. (A) Air sensation vote (TSV) and (B) Air preference vote (TPV) across AC and non-AC households

Among AC households, mean ASV was negative and skewed toward low air movement with a mean of -0.27 (N=275 and SD=1.15), while across non-AC households, mean ASV was slightly skewed towards low air movement with a mean of -0.35 (N=85 and SD=1.29). The mean APV was found to be -0.49 (N=275 and SD =0.76) for AC households and -0.36 for non-AC households (N=85 and SD=0.7). It is clear that majority of respondents in both AC and non-AC households perceived indoor air movement to be low and preferred a bit more air movement likely to be for create a cooling effect given the summer season.

In terms of humidity, only 36% of respondents in AC households and 53% of non-AC households perceived indoor humidity to be 'just right'. Given that almost a third of respondents found the indoor temperature, indoor humidity and air movement to be acceptable, it may trigger the use of cooling devices including ACs.

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 of INR 2,575 (US$28). These figures were reduced by half in non-AC households with mean monthly electricity consumption of 152kWh and electricity cost of INR 990 (US$11). The electricity consumption data for February, March and April 2020 was also weather corrected to account for the effect of weather on electricity use. 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, indicating an overall increase of 28% in electricity use during the lockdown. For a base temperature of 23°C in April and 18°C in February, the daily mean consumption was 8 kWh before the lockdown increasing to 10.9 kWh during lockdown. The electricity consumption before lockdown (February) and during lockdown (April) were compared using the Wilcoxon signed rank test which is a non-parametric test since electricity consumption data was not normally distributed even after transformation. 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 on the following page revealed a rise in electricity consumption during April (lockdown) in AC and non-AC households. These results are similar to the study by Elavarasan et.al. where-in the national residential energy demand for India was found to increase from 24% to 36% during the first wave of the lockdown (Madurai Elavarasan et al., 2020, NPP, 2021). A similar 15% rise in electricity consumption was observed across 1000 households in 2020 (during lockdown) and 2019 (no lockdown) (Qarnain et al., 2020).

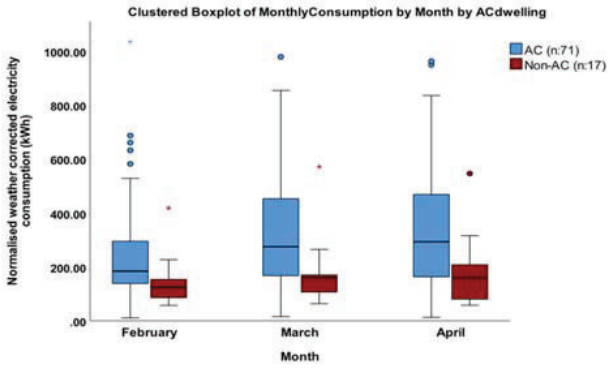

Figure 3. Boxplot of weather corrected consumption across February, March and April for AC and non-AC households.

The rise in 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, although the magnitude of the rise was lower in non-AC households (9%) as compared to AC households (44%). This rise in electricity use is expected due to home-schooling and home-working.

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. Statistical tests showed an overall increase of 28% in residential electricity use 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. The non-AC households occupied more possibly able to adapt to the warm weather by occupying different rooms during the lockdown, while AC household occupants spent more time in (bed) rooms where AC's were located.

Before the 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 AC households especially in the hot-dry climatic zone, 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.

Majory of respondents from households with and without ACs perceived thermal sensation on the warm wide and preferred to be a bit cooler. The survey study by Thapa et al. (2020) also showed that respondents felt temperatures to be warm and preferred to be cooler especially in the hot humid climate (Thapa et al., 2020). This study finds that electricity use increased during the lockdown period aligning with other studies that showed an increase in residential electricity as compared to the pre-COVID period (Qarnain et al., 2020, Madurai Elavarasan et al., 2020). This study did not focus on the *after* lockdown period. As lockdown started to ease from May 2020 in India, a study by Delhi-based utility that accounts for 0.24 million residential consumers reported that 5.4% of consumers used less electricity in May 2020 than the previous year of May 2019 (Pathak et al., 2020). Another study by Agarwal and Pathak (2020) found that post-lockdown, AC households experienced a significant drop in AC usage due to maintenance issues, COVID advisory measures to delay use of AC and reduced income.

This study has also provided insights into using an online survey based approach to gather bottom-up data about residential electricity use and household characteristics, during periods of stress, when normal activities of office-based work and schooling were moved to the home environment. The obvious limitation of the study approach is that it inadvertently excludes households that may not have access to internet or mobile phones. In such a case, telephone based survey could be conducted.

5 Conclusion

In this study, an online questionnaire survey was conducted amongst 360 households located 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. Weather corrected residential electricity use of 88 households was examined before and during the lockdown. The online survey gathered contextual data on socio-demographics, appliance usage, AC usage, occupancy, thermal comfort and monthly residential electricity use in the months of February, March and April 2020. As part of the online survey, data on thermal sensation and thermal preference votes were also collected.

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 a 29% increase in AC usage hours due to home-working. This change in lifestyle led to a rise in monthly electricity use in dwellings during the lock down period, although the rise was smaller in magnitude in non-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 for the 88-household sample was found to be 10.5 kWh during lockdown (April 2020), as compared to 8 kWh before lockdown (February 2020).

In future such an unforeseen rise in electricity use could lead to a surge in residential electricity with new periods of peak load, which could lead to power cuts if the demand is not managed properly. Moreover, 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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