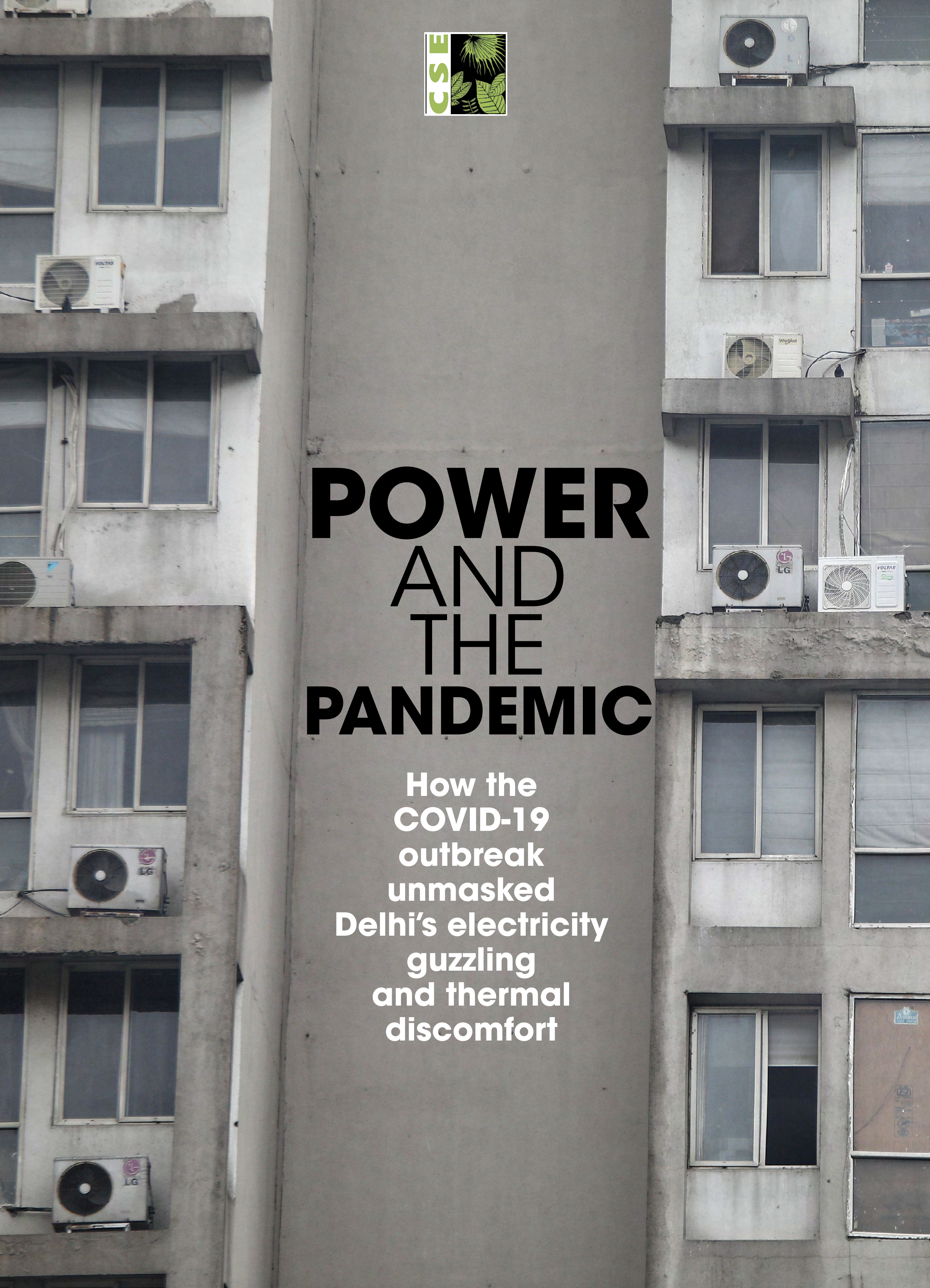

POWER AND THE PANDEMIC

How the COVID-19 outbreak unmasked Delhi's electricity guzzling and thermal discomfort

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Citation: Avikal Somvanshi and Anumita Roychowdhury 2020, *Power and the pandemic: How the COVID-19 outbreak unmasked Delhi's electricity guzzling and thermal discomfort*, Centre for Science and Environment, New Delhi

Published by
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AN OVERVIEW

The severe lockdown and slow reopening of the economy during the COVID-19 pandemic has presented a unique opportunity to understand the trends in electricity consumption in our cities. While diverse uses of electricity — residential, commercial, retail, industry, agriculture among others — add up to contribute to the overall electricity demand in normal times, the lockdown phases have uniquely isolated the influence of residential demand. With economic activities coming to a near halt, only the households remained active users.

But this is not a simple and an obvious story of substantial drop in power consumption during hard lockdown. There is in fact, a more complex message around the pattern of residential demand. Despite the lower economic activities compared to previous summers, residential demand remained obstinate and bullish due to higher heat stress and resultant thermal discomfort during this summer lockdown. Not many have noticed this story though; public attention was drawn more towards the visible blue sky during the pandemic.

The lockdown occurred during summer when heat waves lash Delhi. This has further helped to reaffirm the pronounced effect of heat stress on thermal discomfort and its impact on active cooling demand in residential sector. Understanding this connection is critical, as climate change will increase frequency and intensity of heat waves in the future. If built environment is not designed for thermal comfort, heat stress will increase cooling demand and use of energy intensive mechanical cooling systems undoing the carbon savings from other energy efficiency measures.

After all, cities as end users of resources drive energy consumption. The World Energy Outlook of the International Energy Agency has estimated that cities guzzle nearly 70 per cent of the global electricity consumption.[1] Cities are like 'thermal units' that require taming to reduce pollution and warming impacts. The lockdown has helped to understand some of the aspects of guzzling.

Centre for Science and Environment (CSE) has, therefore, carried out a rapid analysis of real time electricity demand during the lockdown and unlocking phases in Delhi. Delhi as a big energy guzzler makes an important case study. CSE's earlier analysis (Power Pangs 2018 and Midsummer Nightmare 2019) had found that Delhi's peak electricity demand was consistently higher than Mumbai, Kolkata and Chennai taken together. Delhi's appetite for electricity almost tripled since 2000. Domestic and commercial consumers together accounted for almost 75-80 per cent of annual electricity consumption in Delhi during the period 2010 to 2017. On an average, an electrified household in Delhi consumed about 260 kWh of electricity monthly in 2016–17, that were up from 155 kWh in 2000, which is almost three times the national figure of 90 kWh. This is similar to the electricity consumption of an average German household, according to World Bank data (2014).[2]

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1. *Anon 2019. World Energy Outlook 2019, International Energy Agency, Paris. Avaiable at https://www.iea.org/reports/world-energy-outlook-2019, as accessed on 1 August 2020*
2. *Electric power consumption (kWh per capita). Available at https://data.worldbank.org/, as accessed on 1 August 2020*

Data and methodology

Electricity data: The study is solely based on analysis of highly granular real time data available in public domain via official agencies. Real time electricity consumption data of 5-minute granularity has been sourced from the State Load Dispatch Center, Delhi, which ensures integrated operation of Delhi's power system. This data is publicly available.

Electricity data used in this study is not segregated by end-use; therefore, the study quantifies the aggregated impact of weather on the city's power demand. There are bound to be variations in the behaviour of each sector (domestic, commercial, industry and others) in relation to weather condition, and further study is needed to quantify them.

Weather data: The weather data has been sourced from the CPCB's CAAQMS network. The data is of 15 minute granularity. Delhi has 38 CAAQMS stations. But quality of weather data is not consistent all across, as weather monitoring is not the primary objective. After careful assessment of quality of available weather data from these stations, 10 stations that have most consistent data starting from January 2018 were selected and considered. These stations include Dwarka Sector 8, Mandir Marg, Najafgarh, Narela, Nehru Nagar, Okhla Phase 2, RK Puram, Rohini, Vivek Vihar, and Wazirpur. These stations are geographically well distributed across in Delhi and cover rural, urban, residential, commercial, and industrial areas within Delhi. Mean of the observations form these stations has been considered representative of weather condition in Delhi.

Daily mean temperature arrived from this dataset was found to have 0.93 correlation coefficient with the data available from IMD weather station at IGI airport. But IMD data could not be used as only temperature data of 24 hourly granularities is available in public domain, which is insufficient for this analysis.

Heat index has been used instead of absolute air temperature as a measure of external thermal conditions. Heat index is a measure of how hot it really feels when relative humidity is factored in with the actual air temperature. Heat index has been computed using formula given the United State's National Oceanic and Atmospheric Administration (NOAA) in their National Weather Service Technical Attachment (SR 90-23).

Time frame of the study: 1 January 2018 to 31 July 2020

To carry out this assessment of the impact of lockdown on the pattern of electricity demand in the city, CSE analysed real time electricity consumption data of 5-minute granularity from the State Load Dispatch Center, Delhi, the apex body responsible for integrated operation of Delhi's power system. It also included weather data of 15 minute granularity from the continuous ambient air quality monitoring (CAAQM) stations that are reported by the Central Pollution Control Board (CPCB) (*see Box: Data and methodology*).

The correlation with the weather data has helped to understand residential sector's sensitivity to weather conditions and behavioural response. The analysis has considered the following time slots: Pre-lockdown - 1 January to 21 March, Lockdown 1.0 - 22 March to 14 April; Lockdown 2.0 - 15 April to 3 May; Lockdown 3.0 - 4 May to 17 May; Lockdown 4.0 - 18 May to 31 May; Unlock 1.0 - 1-30 June; and Unlock 2.0 - 1-31 July. Wherever applicable, comparisons with pervious years have been indicated.

KEY FINDINGS

- **Overall demand for electricity dropped during complete lockdown, but bounced back quickly:** The overall electricity demand during the severe lockdown dropped substantially compared to the corresponding time in the previous years and the pre-pandemic times — but it also bounced back substantially with partial reopening and higher heat stress during the un-lockdown phases.

On the eve of the Janata Curfew (March 22), the average electricity demand dropped by 23 per cent (563 MW) compared to the previous day — March 21 — or by 18 per cent (426 MW) if compared with the previous Sunday (March 15), a holiday. During the lockdown phases the lowest demand (1,748 MW) was recorded on March 29, just before the onset of high summer. It rose to over 4,000 MW by the end of May, the high summer: thus, the demand more than doubled within the lockdown period and with a small reopening of the economy in the later part. During the unlock phases, the average daily demand increased further. It was only 10 per cent lower than the corresponding period in 2019.

One would have expected that the overall peak electricity demand during this season would remain much lower than the peak demand of the pervious summers. But it is interesting to note that the daily average demand hovered around 4,000 MW during most of unlock phases with limited reopening. The season's highest average (5,287 MW) and peak (6,305 MW) were recorded on July 3. During the last couple of years the seasonal highs have also been recorded pretty much around the same dates. But it is notable that the peak level recorded during this summer was just about 10 per cent lower than 2019's high of 7,372 MW.

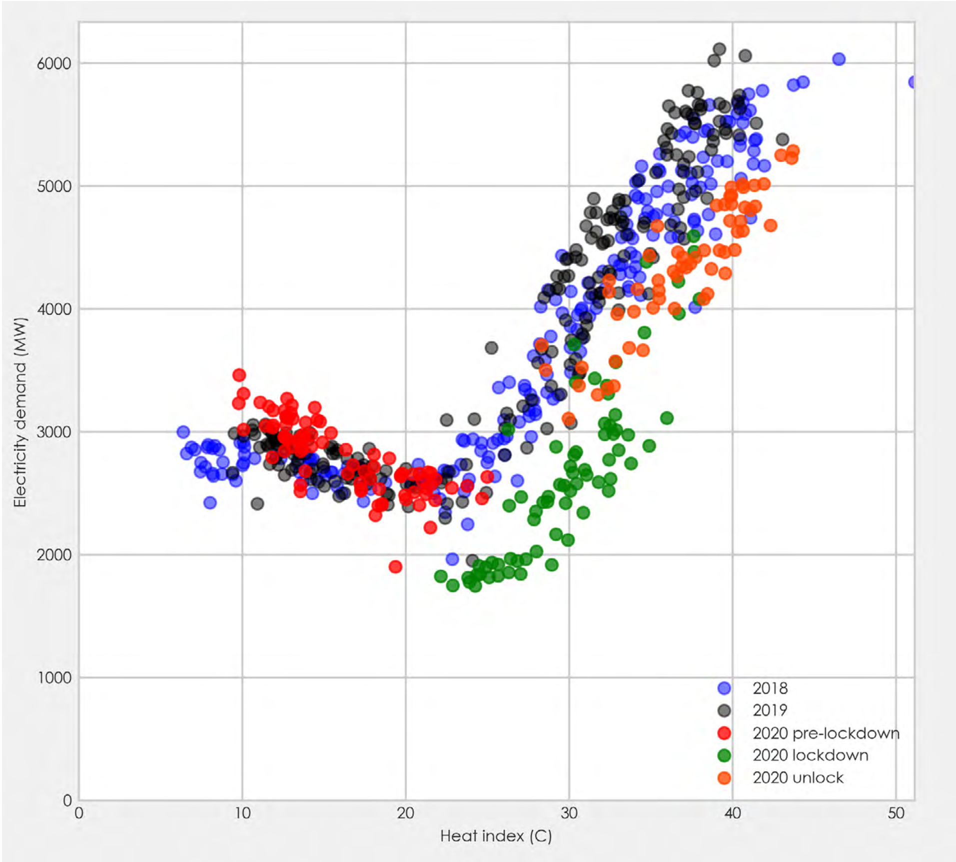
It is also notable that the overall reduction was not that dramatic even though there was mass exodus of migrant workers and their families from the city that started during lockdown 2.0 and continued through lockdown 3.0 and lockdown 4.0. It has been reported that about seven-eight lakh migrants had left the city — this implies less active households in Delhi in that timeframe. Despite this, the city's overall demand for electricity increased substantially. Migrants are small users of electricity. This also validates the class disparity in electricity consumption in the city and reinforces whose summer demand and needs of cooling is responsible for the city's voracious appetite for electricity.

- **Despite the lower economic activities, heat stress made electricity demand bullish:** This year, lockdown reduced the total overall demand but the trend with heat index remained the same as previously seen. Explosive rise in electricity demand was delayed by a few degrees and started when daily mean heat index crossed 27-28°C. Every degree rise resulted in 187 MW increase in electricity demand during lockdown — this was 6 per cent higher than 2019 (*see Graph 1*).

  When the heat wave lashed towards the end of May lockdown (May 24-27), economic activities were restored slowly but the level of activity was still way below the normal levels of corresponding period in 2019 and 2018. But even with lower level of economic activities, both daily average and peak demand in the city were higher than the levels recorded on the same dates in 2019 and 3 per cent lower on same days in 2018. This shows that the change in heat stress and lack of thermal comfort can influence electricity demand substantially even if economic activities remain sub-optimal.

- **Night-time energy peak bears out the disproportionate impact of residential cooling demand:** During lockdown and economic slow-down, night-time (midnight to 4 AM) electricity demand remained more obstinate

Graph 1: Lockdown's impact on Delhi's electricity consumption



Source: CSE analysis

and high. During lockdown, every degree change in daily mean heat index (influenced by weather paramerters including temperature, humidity etc) led to over 225 MW change in the average night-time demand. It was about 6 per cent lower than 2019 — but it was about 20 per cent higher per degree increase computed for the whole day (midnight to midnight) during the lockdown.

When the heat wave lashed in May, night-time peaks were consistently higher than afternoon peaks. Lockdown 4.0 was marked by a short heat wave that started on 24 May with ambient temperature hitting 47°C on May 26. It ended with rains on May 28. By this time, afternoon peak had developed mostly due to opening of some commercial activities and also due to increased heating of building envelopes. During the heat wave episodes night peaks were significantly higher than afternoon peaks. This reflects the high demand for active cooling. Even at the moderately lower range of heat index, the night-time demand increased faster than the whole day demand. This shows that threshold tolerance level of thermal comfort for sleeping is lower than that needed for daytime activity.

- **Peak energy demand during afternoon flattens, shifts to night-time during lockdown:** There was no visible afternoon peak during the first two phases of lockdown. During the previous year, the night peak and afternoon peak have been comparable with one edging out the other with smallest of margins. During the hard lockdown phase, afternoon peak was registered only once — thus the number of days with high afternoon peak is down from 29 days in 2019 summer to just one day during this summer. Afternoon peak started to develop by the end of lockdown phases, but even then night-time peak dominated 51 out of 60 days during the unlocking phases.

It is likely that the commercial and retail establishments were closed and did not contribute towards peaking during the day. But 'work from home' has also not impacted the daytime residential electricity consumption to that extent. Air conditioning for work at home should ideally have overtaken or at least be equal to the night peak. But data indicates that people likely to have not turned on their AC during the daytime as much as they did during night. They seemed to have relied more on adaptive thermal comfort approaches during the day preferring higher level of comfort during night and resorted to more selective use of air conditioners.

While this trend needs deeper investigation, it is notable that active cooling is expensive and household budgets cannot sustain infinite use of air conditioners as is possible in offices. It is also likely that the controversy around the role of air conditioner in making the virus thrive in ducts and on cooled surface restrained usage to some extent leading to more selective usage. These factors may have contributed to influence the day-time demand pattern. But this needs more investigation and is beyond the scope of this analysis.

- **Cooler rainy days prove the importance of designing well-ventilated buildings to reduce active cooling or air conditioning hours:** During the pandemic period there were days that experienced intense showers. A thunderstorm on June 29 knocked down the ambient temperature by 11°C (HI 17°C) between 4-7 PM. This led to an almost instant drop in city's electricity load from 6,234 MW to 3,844 MW. This amounts to 38 per cent drop in just three hours. This indicates that people could experience improvement in thermal comfort due to lowering of heat stress and also leverage the openings and windows to access cooler air outdoor to improve comfort conditions and reduce the need for active cooling.

- **Impact of lighting requirement on electricity demand:** The lockdown phase also created a unique opportunity to understand the impact of lighting requirement on electricity demand. This opportunity came on April 5, 2020, when all households across the city switched off domestic lights at 9 PM to express solidarity with nation's fight against the pandemic. Delhi's power demand fell to 1,257 MW at 9:10 PM from 1,960 MW at 8:50 PM. The demand returned to normal cycle by 9:45 PM. There was a drop of 703 MW in 20 minutes. This is the best measurement of active artificial lighting load of the city till date. This roughly translates into 10 per cent of the city's night-time peak load. In fact, if evening peak is considered lighting can make up about 20 per cent of that peak. In fact, lighting demand dominates peak during fall and spring seasons when space-cooling or space-heating requirements are minimal or non-existent.

THE WAY FORWARD

This exercise has been deeply insightful to understand the pattern of electricity demand in Delhi when influence of diverse set of economic activities are controlled and removed. This to a great extent has helped to isolate the pronounced influence of residential demand and response to heat stress. The overall level of electricity demand and the peaks had reduced during the hard lockdown compared to the normal times of the previous years. But with partial unlocking and even with lower level of economic activities, heat waves and related thermal discomfort spiked the peaks again — taking it quite close to the peaks of previous summers.

There is a message for the post pandemic 'new normal'. The learning from the lockdown phases challenges the current approaches that predominantly focus on only energy efficiency in energy management in buildings. It is still not comprehensive enough to go much beyond the narrow technological solutions for energy efficiency to aggressively seek architectural design interventions and heat management strategies in urban habitat to reduce the overall thermal load on buildings and the city. This is urgently needed to allow and enable greater bio controls of day lighting and ventilation to adjust according to season and weather and reduce/minimise the number of air conditioned hours in a year. India needs operational framework for thermal comfort requirements with sufficiency measures.

In Delhi and the rest of India, the building stock is still dominated by the mixed mode buildings that allow use of mechanical cooling as well as passive cooling. There is higher level of thermal tolerance at a city/community level and people are responsive to external weather conditions. Delhi data is showing how people and these hybrid buildings are taking immediate advantage of even short-term improvement in weather conditions resulting in massive energy saving. This will have to be leveraged for the 'new normal' to make thermal comfort central to all interventions and not energy efficient technologies in isolation to build more climate resilient structures. This has a great scope of promoting adaptive thermal comfort as well as thermally comfortable building through passive design to reduce air-conditioned hours. This needs to be promoted in both residential and commercial buildings. The electricity demand pattern during summer lockdown has indicated voracious appetite for electricity in the residential sector that is largely driven by cooling demand.

Official and commercial usage under normal conditions are high but their relative share in the overall electricity demand is lower than the residential demand in Delhi. But the daily demand from air-conditioned buildings in the commercial and industrial sectors is somewhat static in nature and comparatively less responsive to outdoor-temperature and heat conditions. They largely keep their active cooling systems running for the fixed duration of the office hours. There are bigger opportunities in residential sector.

India's Cooling Action Plan (ICAP) has already provided for 'thermal comfort for all'. But this requires a quick operational framework that will enable architectural design solutions, appropriate material, thermal load management, strategic and selective use of active cooling approaches and demand management measures to reduce the overall air-conditioned hours. This needs to be backed by city-wide heat mitigation plans. Establishing this interconnectedness is important to reduce the overall thermal load in a climate constrained world.

IMPACT OF THE PANDEMIC ON DELHI'S ELECTRICITY DEMAND

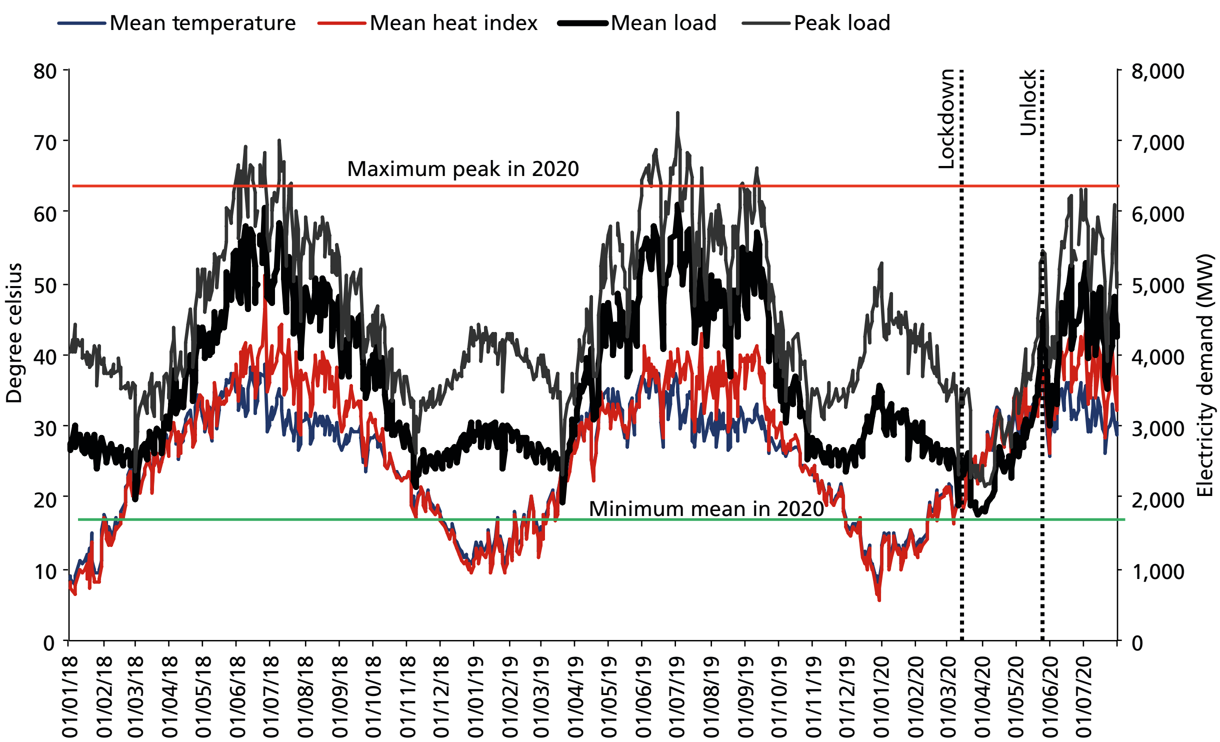
Pandemic-related confinement measures and closure of commercial and industrial activities locked up people inside their homes. As a result, electricity demand dropped to its lowest level recorded in recent years, with dramatic reduction in demand from services and industry only partially offset by higher residential use.

Demand for electricity has steadily recovered after lockdown restrictions were gradually softened. Average daily demand in month of July has recovered substantially recording a level that is only 10 per cent lower than the level registered in July of 2019 even when reopening of economic activities and services are still suboptimal. It must be noted that the data has not been corrected for weather and July this year is on an average 1°C hotter on heat index compared to July of 2019 (*see Graph 2*).

IMMEDIATE IMPACT ON THE DAY OF THE JANATA CURFEW

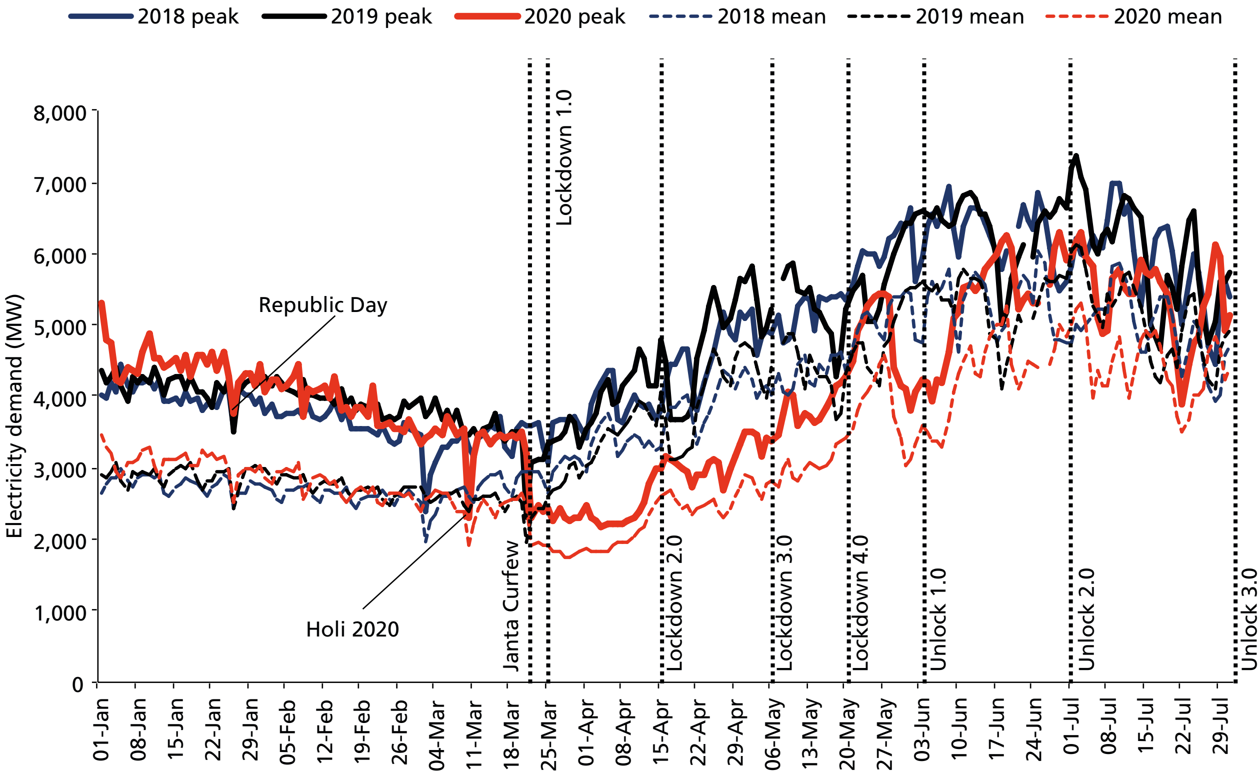
The first set of measures to control spread of pandemic were announced on March 18, but the nationwide complete lockdown started on March 25. In between, on March 22, the government had rehearsed the lockdown and

Graph 2: Daily trends in electricity demand and heat index in Delhi



Source: CSE analysis

Graph 3: Daily electricity demand in Delhi through various phases of the lockdown



Source: CSE analysis

announced Janata Curfew (people's curfew) day, when people voluntarily observed a 14-hour curfew (from 7 AM to 9 PM). Janata Curfew was successful in Delhi. Delhi went into official lockdown right after Janata Curfew on March 23 and shut down all public transportation and sealed state borders. This was followed by the more severe national lockdown from March 25 onwards.

The city's electricity demand had crashed on March 22 itself when Delhiites enthusiastically participated in the Janata Curfew (*see Graph 3*). The average electricity demand for the day dropped by 23 per cent (563 MW) compared to March 21 or 18 per cent (426 MW) if compared to the previous Sunday (March 15). Daily peak demand showed a bigger dip. The peak demand of the day was lower by 29 per cent (939 MW) compared to March 21 or 33 per cent (1,127 MW) if compared to the previous Sunday (March 15). The city had not yet hit the high summers.

The drop may appear dramatic but it is actually similar (in fact marginally lower) to the drop in demand that was noted on the national holiday on the occasion of Holi when people and commercial establishments in any case observe shutdown during daytime similar to Janata Curfew day. Interestingly, the Janata Curfew (1,898 MW) recorded near identical daily average demand as the Holi holiday (1,902 MW) that was celebrated on March 10, 2020. In fact, in the last three years, the daily average demand on the occasion of Holi holidays dropped by 21-27 per cent and daily peak demand dropped by 31-35 per cent, both higher percentages compared to Janata Curfew.

But unlike Holi day, the electricity demand levels did not bounce back next day of Janata Curfew. Electricity demand marginally increased (less than 40 MW) on following couple of days before being knocked down again by enforcement of stricter national lockdown.

TRENDS THROUGH THE LOCKDOWN PHASES

Imposition to national lockdown on March 25 did not produce any immediate dramatic impact on city's electricity demand and daily average was in fact 23 MW higher than the Janata Curfew level on March 25. Daily demand started to fall marginally as the enforcement improved over next few days with the lowest demand (1,748 MW) recorded on March 29, which was a Sunday. The demand started to rise steadily after that and it surpassed Janata Curfew level on April 6. Daily average demand stood at 2,522 MW on April 14, the last day of lockdown 1.0. Peak demand behaved a little differently as its lowest level (2,157 MW) was reached only on April 4, but it rapidly climbed to 3,009 MW on April 14.

Negligible relaxations were granted during lockdown 2.0 but the daily average and peak demand continued to climb and reached 2,890 MW and 3,521 MW on May 1 respectively. The lockdown restrictions were relaxed for lockdown 3.0, but whole of Delhi was categorised as red zone; therefore, none of those relaxations were extended to Delhi. Albeit the daily average demand continued to rise and stood at 3,139 MW on May 17 (last day of lockdown 3.0). Peak demand hit 4,077 MW on May 9 but on May 17 it had cooled a tad down to 3,995 MW. But summer heat was also setting in during these phases.

The city's demand climbed by almost 1,400 MW (80 per cent increase) in less than two months even when lockdown had flattened the curve of all human activities and reduced it to a homogenised minimum. During the same time, the peak demand increased by almost 90 per cent.

In fact, the massive exodus of migrant workers and their families from the city that started during lockdown 2.0 and continued through lockdown 3.0 and lockdown 4.0 had reduced the number of active households in Delhi over this timeframe. But it did not seem to have had much impact on the city's overall demand for electricity. This just validates the class disparity in electricity consumption in the city and reinforces whose summer body is responsible for city's voracious appetite for electricity.

On an average, the electricity demand during the first three phases of lockdown was 31-41 per cent lower than demand recorded for same time frame in 2018 and 2019 (*see Table 1*). But the situation changed with lockdown 4.0 that kicked in from May 18. People were allowed to come out of their homes. It reduced the mandatory stay at home from 24 hours to 12 hours (7 PM to 7 AM) a day; private mobility was allowed, offices reopened with 33 per cent staff and many commercial activities resumed.

All these additional activities have considerable electricity footprint. But logically they should not spike demand to within 17-23 per cent of 2018 and 2019 levels.

But that's what happened and it can be argued that it was the impact of the heat stress that scorched most of the days of lockdown 4.0. In fact, at the height of the heat wave (May 24-27) both daily average and peak demand of the city was found to be higher than the levels recorded on same dates in 2019 and 3 per cent lower on same days in 2018. It may be noted that the corresponding

Table 1: Change in average demand through the lockdown phases

	Average daily mean electricity demand			Change from 2018 and 2019
	2018	2019	2020	
Pre-lockdown	2,692 (16)	2,751 (15)	2,803 (16)	–4 - –2 per cent
Lockdown 1.0	3,268 (28)	3,297 (28)	1,946 (26)	40-41 per cent
Lockdown 2.0	3,941 (31)	4,045 (30)	2,562 (30)	35-37 per cent
Lockdown 3.0	4,249 (32)	4,422 (31)	2,924 (32)	31-34 per cent
Lockdown 4.0	4,978 (35)	4,570 (33)	3,812 (34)	17-23 per cent
Unlock 1.0	5,301 (39)	5,327 (37)	4,254 (37)	20 per cent
Unlock 2.0	4,944 (38)	5,060 (36)	4,439 (37)	10-12 per cent

Note: Value in parentheses is average daily mean heat index in degree celsius for that time frame.
Source: CSE analysis

days in 2019 and 2018 were not heat wave days. But electricity demand surged during the heat wave days in May 2020 even when economic activities were far less than the corresponding days in 2019 and 2018. This shows that change in heat stress and lack of thermal comfort can influence electricity demand substantially even if economic activities are sub-optimal.

UNLOCK AND RECOVERY IN ELECTRICITY DEMAND

This first phase of reopening or 'unlocking' started on June 1. It was termed as Unlock 1.0. It limited the lockdown restrictions to containment zones, while all kinds of activities were permitted in other zones in a phased manner. Offices were permitted to function at full strength subject to practicing social distancing. Shopping malls, religious places, hotels and restaurants reopened from June 8. Night curfews were further reduced and were in effect from 9 PM to 5 AM. Unlock 2.0 kicked in on July 1 and it further reduced restrictions outside containment zones and further limited the night curfew to 10 PM-5 AM. Nevertheless, restrictions on international air travel, operation of metros and recreational activities (swimming pools, gymnasiums, theatres, entertainment parks, bars, auditoriums and assembly halls) remained during both phases of unlock.

As expected, the daily average demand climbed and crossed 5,000 MW mark on June 18. Daily average demand hovered around 4,000s in most of the unlock phases. Season's highest average (5,287 MW) and peak (6,305 MW) were registered on July 3. In the last couple of years, seasonal highs have been recorded pretty much around similar dates but it was 10 per cent lower than 2019's high of 7,372 MW.

HEAT STRESS AND ELECTRICITY DEMAND

The link between heat stress and increased demand for cooling and therefore higher electricity consumption is well understood. This is starkly showing up in the electricity consumption pattern in the city and more sharply during the lockdown period. When overall economic activity is low in the city and most of the commercial and retail centres are closed, it is the residential demand for cooling that spiked demand over the regular and rather constant use of electricity for lighting and other usage. It is the cooling load that is highly variable and influences the peak demand more strongly.

This is an important evidence to inform regulations that are setting the terms for energy efficiency and thermal comfort in buildings. This matter also assumes significance in the context of the growing climatic stress and rapid change in extreme weather events including heat stress. The adaptive strategies in urban areas need to account for these variables while designing buildings.

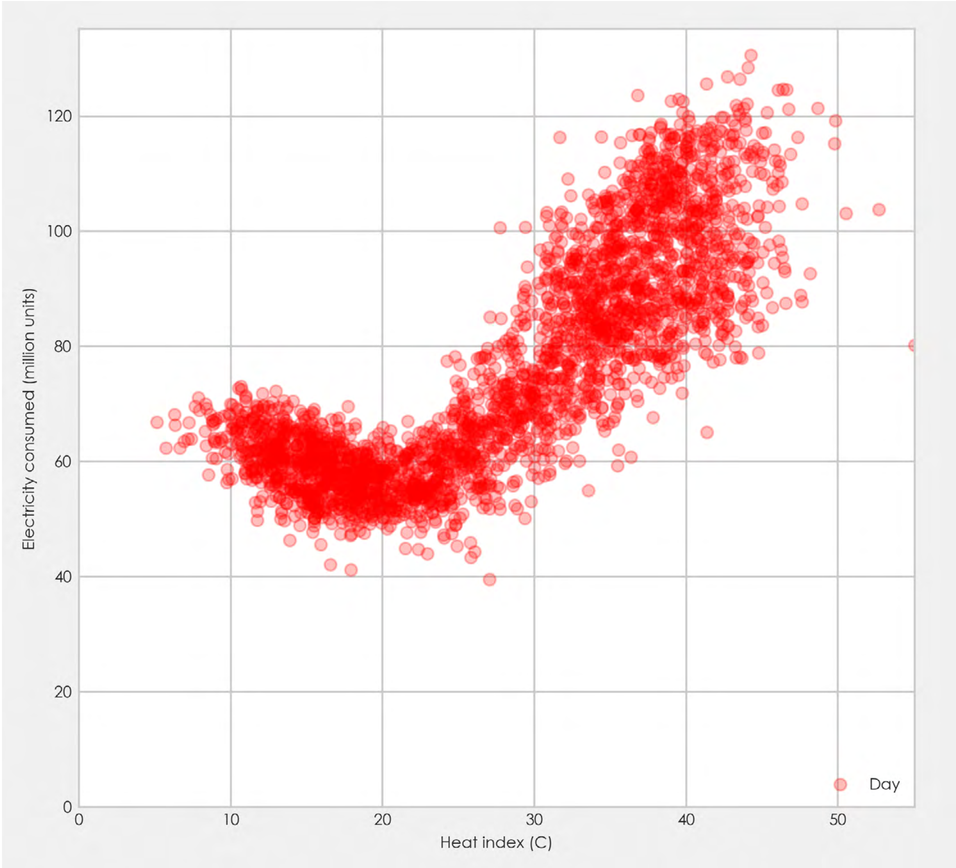
HEAT STRESS AND DELHI'S ELECTRICITY DEMAND

As the lockdown phases coincided with the summer heat it gave us an opportunity to understand the impact of changing outdoor ambient temperature on the electricity demand in the city. On May 24, 2020 Delhi clocked 5,264 MW peak electricity demand. This was the peak demand and it was 4 per cent higher than the corresponding May 24 in 2019. Both May 24 in 2020 and in 2019 were weekdays and the peak build up around the same time in night — around 11:30 PM. But the difference in the level of economic activities and also temperature levels on both these days was dramatically different. In May 24, 2020, was part of the lockdown 4.0 restrictions when almost all commercial and industrial units were shut in the city and night curfew prevailed from 7 PM to 7 AM. Also, this year, the average heat index for May 24 was almost 8ºC higher than the corresponding day the previous year. This shows even with lower economic activity but with higher heat index the electricity demand skewed well beyond the level of demand previous year. This certainly bears out stronger impact of residential demand for cooling that overwhelms demand from other sources.

Correlation between Delhi's electricity demand and heat conditions

Delhi's electricity demand is highly seasonal and CSE's 2019 report "Midsummer Nightmare" had established that outdoor heat condition was one of the primary driving factors for daily and seasonal variation in electricity consumption in the city. Data showed that electricity consumption in the city during summer starts to rise explosively after the daily maximum heat index crosses 31-32°C mark or daily mean heat index crosses 24-25°C (*see Graph 4*). The trend curve between electricity consumption and the outdoor environment conditions was found to be an asymmetric U-shape, where the minimum consumption corresponds to neutral climatic period when heating and cooling are insignificant and the energy demand is almost inelastic to the temperature, while the maximum consumption corresponds to the periods of the lower and higher ambient temperatures or heat index depending on the season.

Graph 4: Delhi's electricity consumption as a proxy to its response to thermal discomfort



Source: CSE, Midsummer Nightmare, 2019

That analysis had used archival daily consumption data from 2010 to 2018 and had found it to have high correlation (0.81 Pearson correlation coefficient) with the heat index and the least squared regression had an adjusted R-squared of 0.65.

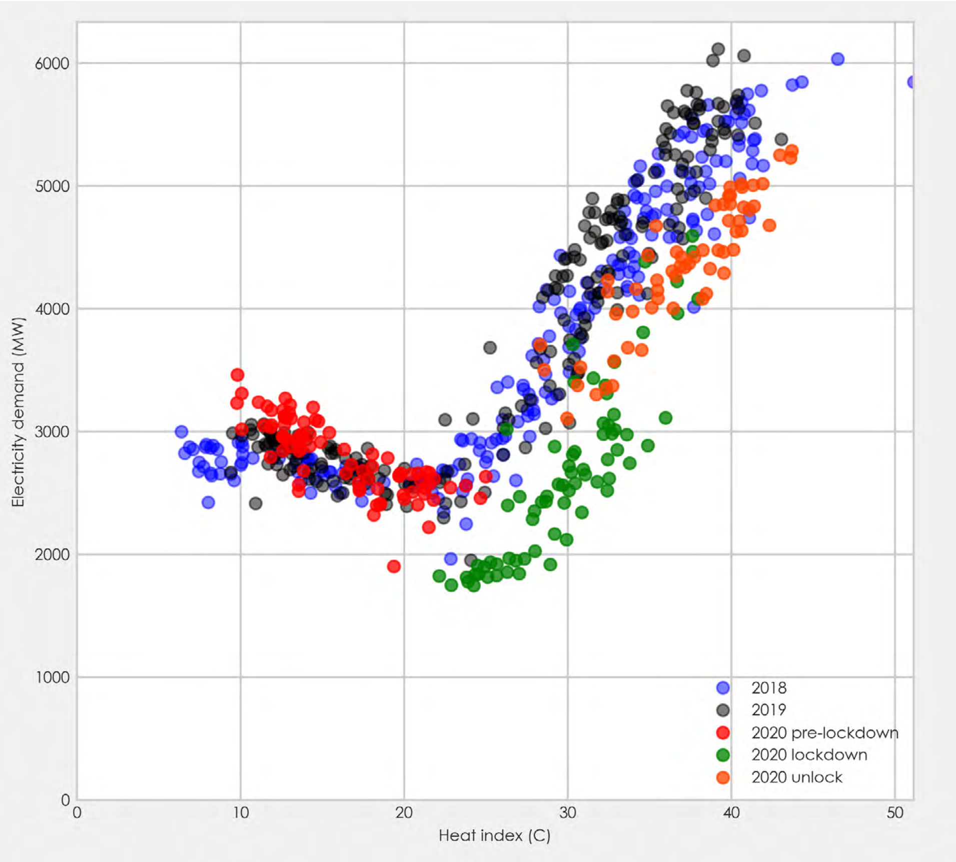
The 'Midsummer Nightmare' study was limited to analysis of daily consumption data as more granular data was not available. Also, one of the critical assumptions that study made was that the demography and scale of economic activities in the city had changed minimally within a year.

This correlation holds even for lockdown: Lockdown and availability of real time demand data of five-minute granularity has made possible to further confirm impact of heat on city's electricity and especially understand thermal comfort threshold and people's behavioral response at homes.

The current analysis done with real-time data has reconfirmed this asymmetric U-shape relation (*see Graph 5*), with even higher (0.88) Pearson correlation coefficient for year 2018 and 2019, and the linear regression having an adjusted R-squared of 0.77.

The smooth relation between electricity load and heat index as observed since 2010 has been interrupted by lockdown this year as it dramatically changed the base assumption that demographic and scale of economic activities in the city

Graph 5: Lockdown's impact on Delhi's electricity consumption



Source: CSE analysis

remain unchanged within a year. But this has allowed us to observe how this relation plays out at homes as lockdown has filtered out most other electricity consumers from city's data.

Since lockdown data is almost exclusively that of residential nature, its analysis particularly captures electricity consumption behavior of people at their home. As expected, the data points representing time frame of lockdown has dropped out of the annual curve but it is merely an offset and it retains trend seen in preceding years. Further, it shows that the threshold after which electricity demand rises explosively lags for homes compared to the city. During lockdown electricity demand rises explosively started to rise only after the daily maximum heat index crosses 34-35°C mark or daily mean heat index crosses 27-28°C. Good 2-3°C higher tolerance for thermal discomfort.

Given the fact that lockdown period has not overlapped with the winter season, it has allowed for linear regression models to be used to further this analysis. Simple least squared models are made for the March 22-July 31 timeframe for 2018, 2019 and 2020. All three were found to of high significance and accuracy (*see Table 2*). The model for lockdown period has an adjusted R-squared of 0.86 and according to it every degree rise in the heat index led to 187.2 MW increases in daily mean load of the city during lockdown. This per degree rise coefficient during lockdown is considerably higher than the coefficient calculated for 2018 and 2019, which indicates that homes are more sensitive to

Table 2: Electricity demand regression result summary

Regression equation	Electricity demand = coeff*HI + intercept			
	2018	2019	2020	combined
Pearson correlation coefficient	0.92	0.92	0.93	0.83
Adjusted R-squared	0.85	0.84	0.86	0.68
HI coefficient	148.12	177.42	187.20	172.65
Intercept	-582.43	-1352.13	-2774.26	-1637.29
Standard error	5.48	6.81	6.50	5.98

Note: HI stands for Heat Index. Regression valid only for HI values higher than 20°C. Data for 22 March to 31 July for each year.

Source: CSE analysis

heat conditions than commercial and industrial, even though they have higher tolerance to heat.

Isolated impact of residential demand

Lockdown trends in electricity demand have helped to isolate the impact of residential demand. Mandatory stay-home curfew that initially was applicable for 24 hours of the day was progressively reduced with each new phase of lockdown. During unlock 2.0 the curfew was limited to 10 PM to 5 AM. Night-time electricity demand has exclusively coming from the residential sector (baring some load from street lights and essential services like hospitals) till July 31 — the end of unlock 2.0.

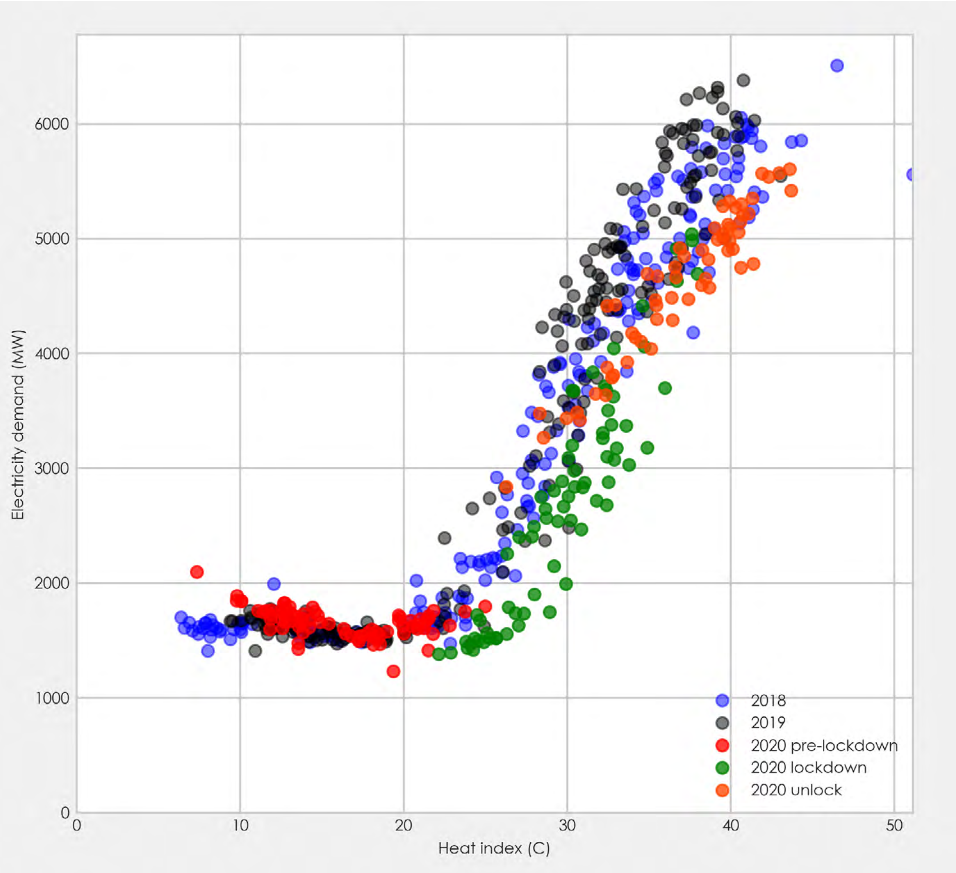
Five-minute granularity of the real-time data for night-time electricity demand has been used. Based on the curfew rules, data from 10 PM-5 AM should be exclusively residential for entire duration of all phases of lockdown and unlock, but to be extra cautious this analysis was done using average demand from midnight to 4 AM. Mean heat index of the previous day was used for this analysis instead of the day of demand.

The nighttime analysis has resulted in a mirrored L shape relation with very high (0.93) Pearson correlation coefficient for combined dataset for 2018 and 2019, and the linear regression having an adjusted R-squared of 0.86. The trend exhibited by nighttime data is significantly different than the trend observed in whole day data (*see Graph 6*). Basically, the additional demand noticed for winter days in the whole day data is missing in the nighttime data. Meanwhile, the summer profiles are almost identical.

Further, unlike the whole day, the night-time data points representing time frame of lockdown have not dropped out of the annual curve and perfectly fit with trend observed in the preceding years. It also shows that the threshold after which electricity demand raises explosively lags is lower than the one noted for whole day and has remained unaffected by the lockdown. The night-time threshold is the daily maximum heat index crosses 29-30°C or daily mean heat index crosses 22-23°C — good 2-3°C lower than whole day threshold.

Similar to the whole day analysis, linear regression analysis was carried out for each year separately using the night-time data. All three were found to of high significance and accuracy (*see Table 3*). Unlike whole day, results showed more consistancy across the years. Every degree change in daily mean HI leads to over 225 MW change in average power consumed between midnight and 4 AM during lockdown. This is considerably higher than 187 MW per

Graph 6: Delhi's night-time electricity demand



Source: CSE analysis

Table 3: Night-time electricity demand regression result summary

Regression equation	Electricity demand = coeff*HI + intercept			
	2018	**2019**	**2020**	**combined**
Pearson correlation coefficient	0.91	0.92	0.95	0.88
Adjusted R-squared	0.83	0.85	0.90	0.78
HI coefficient	190.55	240.06	225.64	218.17
Intercept	-2047.69	-3416.59	-3874.75	-3106.04
Standard error	7.44	9.04	6.46	5.89

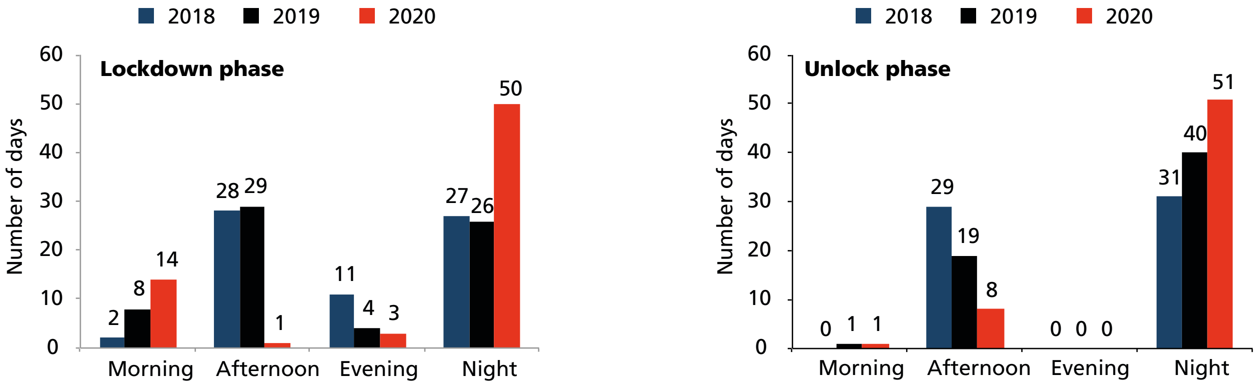
Note: HI stands for Heat Index. Regression valid only for HI values higher than 20°C. Data for 22 March to 31 July for each year.

Source: CSE analysis

degree computed for whole day. This implies people are not only resorting to mechanical cooling at lower outdoor heat index but are also consuming 20 per cent more electricity per degree change in heat index.

It is also quite evident that electricity consumption only starts to rise after the daily mean HI cross 22-23°C threshold. Implying people's home are unable to natually maintain thermal comfort conditions indoor post ambient daily mean heat index crosses 23°C, which roughly corresponds to daily maximum heat index crossing 30°C.

Graph 7: Distribution of daily electricity demand peaks during lockdown and unlock phases



Source: CSE analysis

Peak demand shifts entirely to night-time during lockdown

We have established so far that Delhi's demand for electricity is intrinsically linked with outdoor heat index. We have also established that Delhi homes are more sensitive to higher heat indices during nighttime. But to establish how powerful is the impact of Delhi's desire to sleep in cool comfort, we have analysed city's peak demand trend. Night-time peak is driven by the powerful impact of residential use of air conditioners (ACs).

The lockdown peak demand has almost completely shifted to night. In fact during lockdown (till May 31) afternoon, peak demand was registered only once and that too because the rains had cooled down the evening and made night more sleepable (*see Graph 7*). The trend was similar during unlock period as well with peak demand building up at night on 51 out of 60 days.

Afternoon peak flattens

A notable change during the lockdown phases is the near disappearance of the afternoon peak demand while nighttime peaking continued. In previous years night peak and afternoon peak were distinct and comparable with one edging out the other with smallest of margins during summer. But during the lockdown afternoon peak is almost nonexistent. The practice of work from home did not influence this trend. The same residential air conditioners that spiked the nighttime peaks did not influence the afternoon usage to that extent.

The only logical explanation could be that people were not turning on their ACs during the day (with hottest temperature outdoors) to the same extent as they were during night. This has several implications. Demand for cooling comfort is higher during sleep time. More adaptive comfort approaches are adopted during daytime at home. This is also driven by the economics. Household budgets cannot sustain the indefinite use of ACs — especially multiple ACs, at home. Therefore, frugality is more pronounced in home environment than in office environment where establishment costs are borne by the employer.

There is another possibility that is unique to the pandemic though this is conjectural. During the initial stages of lockdown the usage of air conditioners became controversial for aggravating the contagion through ducts in centrally air conditioned structures like offices and also because of the prospect of viruses thriving in cool surfaces of air conditioned homes. Anecdotal evidences suggest that initially people were hesitant and making conscious choices of reducing AC usage and were more selective about the timing of the usage. This might have shifted most of the usage to nighttime. Also several guidance were issued to suggest that while using ACs some ventilation must be allowed to curb the virus and to prevent recirculation of stale air. These factors may have also contributed to this trend towards lower afternoon usage. But this needs more investigation.

Otherwise, earlier analysis of hourly and daily electricity demand has shown that the demand curve during the day always has its lowest point around pre-dawn hours and demand rises and falls during the course of the day generally registering two peaks — afternoon and nighttime. Timing and magnitude of these peaks has a seasonal trend. This has been documented in the report 'Midsummer Nightmare'. Roughly, days in a year can be divided into two subsets: days with morning-evening peaks and days with afternoon-night peaks. Morning-evening peak days are characteristic of winter season with morning (8 AM-12 PM) peak being of higher magnitude; evening peak (5-8 PM) is generally driven by switching on of artificial lighting, and they usually overtake morning peak during spring and fall seasons. This peak combo is understood to be driven by non-space cooling related appliance usage.

Afternoon-night peak days are characteristic of summer and are driven by usage of space cooling related appliance. Peak times largely depend on intensity of commercial activities, i.e. afternoon peaks are higher on weekdays and night peaks are higher on weekends. The shift between the two peak combos happens during spring and fall seasons. Data from previous years have shown that during the transitioning of the morning and evening peaks, get subsumed by a mega afternoon peak at the start of the season with no night peak. Later in summer, as the weather gets hotter night peaks start to dominate. This trend has changed drastically this year. The transition between the peak combos happened around second week of April (relatively late due to late onset of summer), but it was a direct jump from morning to night peak. By second half of April, the city had only one peak coming around midnight (*see Graph 8*). Afternoon peak becomes distinguishable only in month of May.

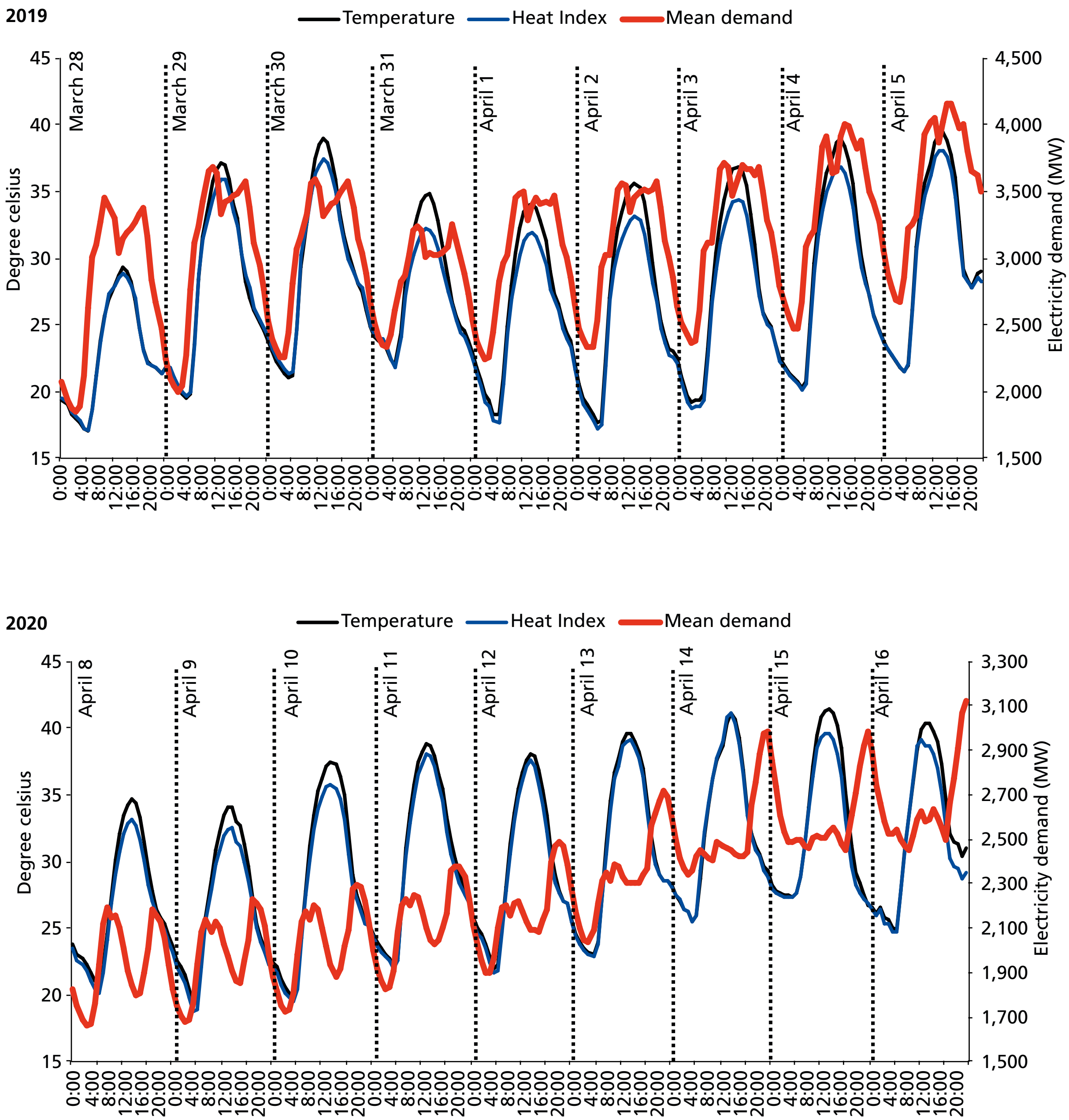
Night-time electricity demand: Building architecture and sleepless nights

Yet another important observation is regarding the impact of nighttime demand. This is starkly evident during heat waves when nighttime peaks are consistently higher than afternoon peaks. Lockdown 4.0 was marked by a short heat wave that started on May 24 with ambient temperature hitting 47°C on May 26. It ended with rains on May 28. By this time afternoon peak had developed mostly due to opening of some commercial activities and also due to increased heating of building envelopes. During this heat wave night peaks were significantly higher than afternoon peaks (*see Graph 9*).

It may be noted that the building-envelop, which shields indoor from outdoor heat, does not completely block the heat ingress but delays it. Material assembly of the walls and roofs keep absorbing the heat from the sun and stores it until it can no long store it and starts transferring it to cooler indoors. The exact time-lag in this heat transfer is dependent upon multiple factors but two most important one are the amount of heat outdoors and capacity of the material to block (insulation) and store (thermal mass) the heat.

What seems to have happened during the first two phase of lockdown when summer had just set in and ambient heat was on the rise the buildings could absorb the heat during the day and transferred indoors only after sunset.

Graph 8: Peak transitions in 2019 and 2020

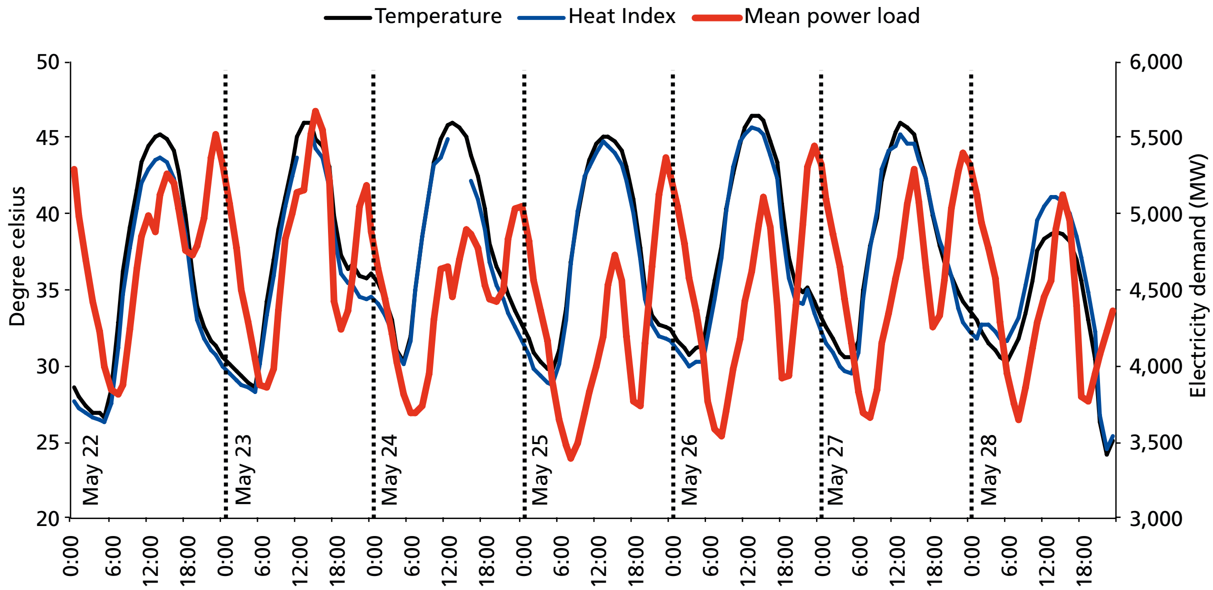


Source: CSE analysis

Therefore, indoors were comparably cooler during the daytime and people could comfortably work from home with limited use of air conditioning. Most probably first line of mechanical defense (ceiling fans) sufficed to meet the cooling needs.

During night the building-envelop starts to transmit the absorbed heat into the rooms and adds to thermal discomfort. Human body also has different thermal comfort requirements for sleeping and generally requires lower temperature conditions. Traditionally, this problem was overcome by sleeping in open air (terrace or courtyard) or by watering of floor/slab to cool down the building. This was a daily evening routine.

Graph 9: Impact of heat wave on electricity demand



Source: CSE analysis

These traditional fixes are not feasible in contemporary buildings and given the lifestyle changes. Dependence on energy intensive air conditioning is increasing. Therefore it is important to achieve thermal comfort. The overnight usage of AC also cools down building envelope making it ready to absorb heat next day and delay the need for active air conditioning during the early part of the day.

What happens when rains cool down the summer heat?

During summer months, intermittent rains and squalls bring some respite from summer heat. That also has immediate impact on electricity demand as cooling demand is reduced. On July 5, 2020, heavy rains brought major relief to the city with daily average heat index dropping by almost 8°C compared to July 4. This resulted in the city's average daily demand dropping by about 1,000 MW. This was a higher drop than compared to the daily average drop of 564 MW on the day of Janata Curfew compared to its preceding day.

Even if we compute the difference between the highest daily average recorded in the week preceding lockdown and the lowest average recorded during the lockdown, it only works out to be 887 MW and it took nine days to get there. This is not a rare event. Nine instances of demand changing by over 600 MW have been recorded since last year (*see Table 4*). This makes amply clear, between economic activities and weather, which has more control over the city's appetite for electricity.

This has also shown how quickly people switch off ACs if temperature is bearable and they can bio-control air flow by maximising ventilation. Most buildings in Delhi are hybrid in nature that allow people to open a window if outdoor conditions are cooler and switch off ACs.

This phenomenon is visible in Delhi's load curve. For instance, on June 29, a thunderstorm hit the city around 4 PM and knocked down the ambient temperature by 11°C (HI 17°C) by 7 PM. This led to an almost instant drop in

Table 4: Dates when the daily mean demand changed by over 600 MW

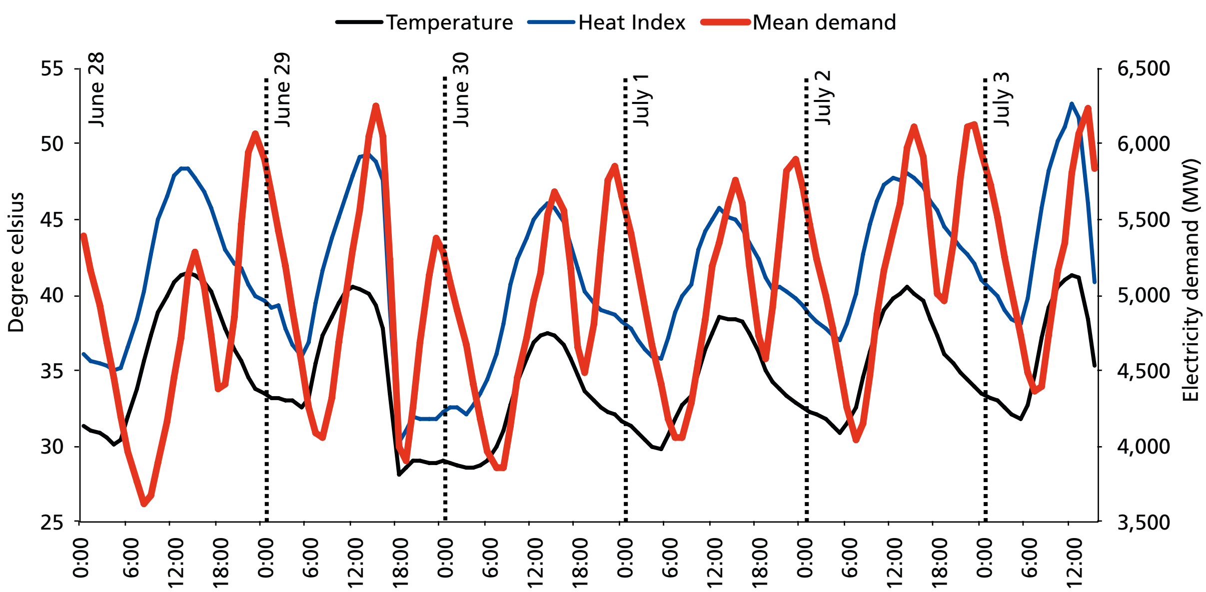
Date	Change in mean demand (MW)	Change in mean heat index (°C)	Remark
22/03/2020	-563	0.2	Janata curfew
22/09/2019	-617	-5.2	
19/08/2019	625	5.6	
15/08/2019	-632	1.3	Independence day
25/07/2019	-646	-8.0	
29/05/2020	-671	-4.4	
18/06/2019	-693	-2.8	
01/09/2019	-710	-4.5	
20/06/2020	-818	-8.1	
05/07/2020	-1052	-7.7	

Note: Negative value indicates a decrease in comparison to previous day

Source: CSE analysis

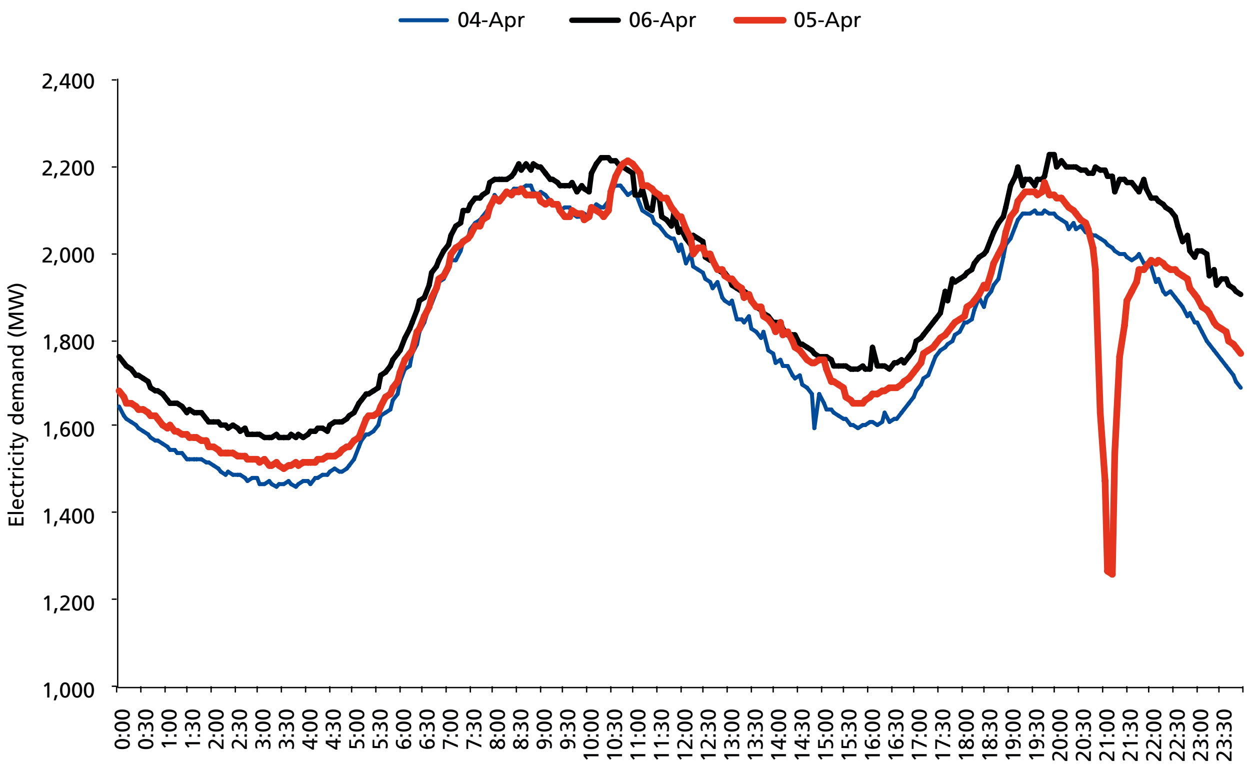
city's load from 6,234 MW to 3,844 MW — that amounts to a 38 per cent drop in three hours (*see Graph 10*). The instant drop can be attributed to people instinctively shutting down ACs to enjoy the cool breeze outdoor. The cooling down of the building envelopes due to the rain can be seen in significantly lower night peak (683 MW) compared to previous night. And impact of such weather event can be seen on city's load for next two days. Multiple such trends are evident every year; more extreme was recorded on June 9, 2018, when a dust-storm brought down ambient temperature from 34ºC to 23ºC (HI 42ºC to 25ºC) between 4:45-5:45 PM, and the peak demand for electricity fell from 5,870 MW to 3,257 MW (a 45 per cent drop in an hour).

Graph 10: Impact of thunderstorm on electricity demand load



Source: CSE analysis

Graph 11: Impact of lighting on instantaneous electricity demand



Source: CSE analysis

Lighting load and electricity demand

It was also possible to see the impact of lighting on electricity demand during this period. On April 5, 2020, all households across the city switched off domestic lights at 9pm in solidarity with nation's fight against the pandemic. At that time, Delhi's power demand fell down to 1,257 MW at 9:10 PM from 1,960 MW at 8:50 PM (*see Graph 11*). The demand went back to its normal cycle by 9:45 PM. This 703 MW drop in 20 minutes is best measurement of active artificial lighting load of the city till date. This roughly translates to 10 per cent of city's nighttime peak load. If we consider limited days when evening peak is the highest, this implies lighting makes up just about 20 per cent of that peak. This dominates evening peaks and are exclusively observed during spring and fall seasons when space-cooling or space-heating are not in use.

THE NEXT STEPS

This analysis of the electricity demand during summer lockdown has established the voracious appetite for electricity in the residential sector largely to meet cooling demand. Even when offices and retails were shut residential cooling demand had an overwhelming impact. The overall level of electricity demand and the peaks had reduced during the hard lockdown compared to the normal times of the previous years. But with partial unlocking and even with lower level of economic activities, heat waves and related thermal discomfort spiked the peaks again — taking it quite close to the peaks of previous summers.

There is a message for the post pandemic 'new normal'. The learning from the lockdown phases challenges the current approaches that predominantly focus on only energy efficiency in energy management in buildings. It is still not holistic enough to go much beyond the narrow technological solutions for energy efficiency to aggressively seek architectural design interventions and heat management strategies in urban habitat to reduce the overall thermal load on buildings. This is urgently needed to allow and enable greater bio controls of day lighting and ventilation to adjust according to season and weather and reduce/minimise the number of air conditioned hours in a year. India needs operational framework for thermal comfort requirements with sufficiency measures.

There is an opportunity. Our cities are still dominated by mixed mode buildings that allow the occupants to flexibly use active cooling and bio controls. There is higher level of thermal tolerance at a city/community level and people are responsive to external weather conditions. Majority are still not trapped in fully air-conditioned buildings without options for bio control of day-lighting and ventilation. This is the opportunity to promote adaptive thermal comfort and design thermally comfortable buildings with strategic combination of energy efficient technologies.

India's Cooling Action Plan (ICAP) has already recognised the need for 'thermal comfort for all' and to make thermal comfort standard central to building energy management. This now requires an operational framework.

This analysis has also made it clear that the building based approach also needs city-wide heat mitigation plans. Establishing this interconnectedness is important to reduce the overall thermal load in a climate constrained world. Every piece of this jigsaw will have to be in its perfect place to create an environmentally sustainable and socially equitable solution.

OPERATIONALISE THERMAL COMFORT FOR ALL

ICAP has underlined the need for behavioural and psychological change towards adaptive thermal comfort practices. There is an immediate need to establish adaptive thermal comfort benchmarks for various climatic zones in India, for both domestic and occupational application. The latest version of National Building Code has introduced an adaptive comfort model but it is limited to office application and agnostic to different climatic zones in India.

It is important to understand that application of adaptive thermal comfort is not limited to the function of building design and operation. It is also about human ability to respond to thermal variations in the immediate surrounding and adapt to them, in the process re-configuring what feels thermally comfortable. This is important to understand. At this moment the ICAP approach is to use the adaptive model to train thermostat setting of an AC. It is more important to govern the condition that will require switching off the ACs.

The building codes — ECBC and NBC — need to link design and energy efficiency guidelines with adaptive thermal comfort delivery explicitly using practices specific to the Indian climates. Adopt a Bush Shirt Rule to allow people freedom to dress for comfort at work and for formal engagements.

OPTIMISE ARCHITECTURAL DESIGN TO REDUCE HEAT LOAD

Institutionalise a holistic and integrated approach for thermally comfortable and energy-efficient building designs to minimise cooling needs using passive design elements and then using the most efficient system for active cooling. Modify building by-laws and related regulations to mainstream the requirements of adaptive thermal comfort standards. This needs to make use of passive design interventions in a way that limits and minimises dependency on active space cooling in a year. Building by-laws and other concerned regulations including ECBC and ECBC-R need to integrate thermal comfort. This requires widespread adoption and stringent enforcement. Energy disclosure policy will further discipline such requirements.

INSTITUTE AN INCLUSIVE APPROACH TOWARDS THERMAL COMFORT

Already, policies and programmes related to affordable housing sector (both formal and informal self-construction as well as rental housing) have started to get financial support as in the case of Pradhan Mantri Awas Yojana. It is important to link government funding and support with performance indicators related to thermal comfort requirements to promote passive cooling design for economically weaker section. This can include viability gap funding for incorporating additional features like cool roofs, appropriate insulation, sun-shades, wind-towers, appropriate walling assembly etc.

Meanwhile, mandate provision of sun-shade for all windows and make a design provision for installing desert coolers in all new housing. Builders have resorted to providing provision only for ACs in new buildings making it difficult for people to use any other means for cooling.

RETROFIT AND RETRO-COMMISSION EXISTING BUILDINGS TO IMPROVE THEIR THERMAL COMFORT PERFORMANCE

This is needed to reduce cooling requirements and energy consumption. Develop detailed guidelines to include provision of shading, ventilation, insulation etc. For example, this should include addition of sun-shades to any exposed glass in the facade, cool roofs and capping of thermostat of building heating, ventilation and air conditioning among others. It is important to set mandatory minimum indoor temperature settings for summer and maximum indoor temperature for winter to reduce thermal requirement, and energy consumption while maintaining a healthy working as well as living environment.

TAKE STEPS TO REDUCE URBAN HEAT ISLAND EFFECT AND HEAT STRESS

Develop and implement heat action plans in cities to control heat island effect from concrete and built environment. Also adopt urban heat-reject management plan to minimise impact of waste heat being ejected into the environment by air conditioning systems operating in a city. Develop guidelines on location and installation of compressor units of ACs in line with the guidelines for smoke exhaust for on-site power generator systems.

Ahmedabad was the first city to prepare and implement a heat action plan, which is designed more for emergency response in the event of a heat wave. There is a need to include short- and long-term plans to reduce the effect of urban heat islands in cities as part of these heat action plans. Municipal bodies need to develop and adopt urban heat action and mitigation plans that present actions to increase preparedness, information-sharing, and response coordination to reduce the health impact of extreme heat on vulnerable populations. Clean air plans being drafted in many cities can serve as model for these plans.

INITIATE AWARENESS BUILDING CAMPAIGNS

Run aggressive market awareness campaigns to sensitize both the construction community as well as the end-users towards the multiple benefits of energy-efficient buildings — reduced operational costs, health and comfort, environmental and societal benefits.

This report unlocks a not-so-obvious, unnoticed story of electricity consumption in Delhi during the pandemic-induced lockdown, and offers a complex message around the pattern of residential demand. Despite the lower economic activities compared to previous summers, residential demand remained obstinate and bullish due to higher heat stress and resultant thermal discomfort during this summer's lockdown.

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