# Electricity consumption in commercial buildings during Covid-19

RESEARCH

GERALD P. DUGGAN
PABLO BAULEO
MICHAEL AUTHIER
PATRICIA A. ALOISE-YOUNG
JONATHAN CARE
DANIEL ZIMMERLE

*Author affiliations can be found in the back matter of this article

## ABSTRACT

The Covid-19 pandemic had wide-ranging effects on how people lived, worked and learned. Consequently, electricity use was altered from pre-pandemic patterns. The deviation from expected electricity usage patterns in commercial properties due to the Covid-19 pandemic was analyzed in a medium-sized American city. The focus on a single community (1) allows usage to be linked specifically to the timing of public health and executive orders; and (2) provides a fine-grained, detailed understanding of usage in different property classifications (*e.g.* restaurants, hotels, schools, outpatient medical facilities, offices, and religious organizations). Electricity consumption data from 2019, adjusted for average daily temperature, were used to calculate expected use in 2020. Electricity usage was found to be lower than expected for most commercial property classes, but the timing and magnitude of these effects varied. For example, within the hospitality industry, hotels evidenced a larger and more sustained decrease in usage (–17%) as compared with restaurants (–11%). In addition, usage patterns for outpatient medical facilities can be linked to specific executive orders. Together, a heterogenous rate of electricity use is found to vary according to specific types of commercial properties.

### PRACTICE RELEVANCE

In much of the research regarding electricity usage, utility customers are placed into the broad categories of residential, commercial and industrial. These groups are viewed as homogeneous. This study examined different property classes within the commercial group during the Covid-19 pandemic. Although electricity usage was lower than expected for most commercial property classes, the timing and magnitude of these effects varied. For example, within the hospitality industry, hotels evidenced a larger and more sustained decrease in usage than did restaurants. In addition, usage patterns for outpatient medical facilities were linked to specific executive orders. Together, these data sources allowed for a detailed examination of Covid-19's effect on electricity use for specific types of commercial properties and it revealed that their response to the pandemic varied widely. Thus, it is an oversimplification to view commercial properties as a single, homogeneous group.

**CORRESPONDING AUTHOR:**
**Gerald P. Duggan**
Energy Institute, Colorado State University, Fort Collins, CO, US
dugganj@colostate.edu

**KEYWORDS:**
big data; building stock; commercial buildings; Covid-19; electricity consumption; energy data; energy demand; lockdown; smart meter; US

**TO CITE THIS ARTICLE:**
Duggan, G. P., Bauleo, P., Authier, M., Aloise-Young, P. A., Care, J., & Zimmerle, D. (2023). Electricity consumption in commercial buildings during Covid-19. *Buildings and Cities*, 4(1), pp. 851–866. DOI: https://doi.org/10.5334/bc.361

# 1. INTRODUCTION

In 2020, many municipal, state, and national governments imposed quarantine shutdown protocols in response to Covid-19. This pandemic response resulted in what has been called 'the biggest psychological experiment in history' (Denworth 2020). It changed how people worked, learned, shopped—virtually every area of life—and it affected how they used energy. The effect of Covid-19 policies on electricity usage across different sectors sheds light on the malleability of electricity usage and provides insights into the potential impact of policy instruments on energy conservation more generally.

## 1.1 ENERGY USE DURING THE COVID-19 PANDEMIC

The effect of the pandemic on energy use has been documented in a variety of large-scale studies. Specifically, studies conducted in Europe, South America, Australia, Asia, and North America have shown overall reductions in energy use during Covid-related lockdowns (*e.g.* Abu-Rayash & Dincer 2020; Agdas & Barooah 2020; Farrow 2020; Jiang *et al.* 2021; Mehlig *et al.* 2021; Rokicki *et al.* 2022; Tingting Xu *et al.* 2021). In addition, many of these same studies have described increases in residential energy use over the same time period (*e.g.* Farrow 2020; Kang *et al.* 2021; Krarti & Aldubyan 2021). Thus, the overall decrease in energy use is attributable to reduced demand by the industrial and commercial sectors (*e.g.* Burleyson *et al.* 2021; Farrow 2020; Krarti & Aldubyan 2021; Rokicki *et al.* 2022). The majority of these studies have focused on energy use in countries (*e.g.* UK, Australia), large cities (*e.g.* Ontario, Santiago, Tokyo), or utility service areas with 1 million or more customers (San Diego Gas and Electric, Midcontinent Independent System Operator) and have used the broadscale utility classifications of residential, commercial, and industrial. Together, these large-scale studies provide an excellent overview of the impacts of the shutdown. However, Burleyson *et al.* (2021) have argued that increased granularity, specifically in terms of spatio-temporal scale and level of aggregation, is needed in order to fully understand the effects of Covid-19 on energy-use patterns.

A few studies have analyzed data with greater temporal granularity, showing how Covid-19 affected times of peak usage, particularly for the residential sector (*e.g.* Anderson & James 2021; Debnath *et al.* 2022; Kirli *et al.* 2021, Ku *et al.* 2022). For example, Kawka & Cetin (2021) took a deeper dive into the impacts of the pandemic on residential electricity patterns using high-resolution, disaggregated data for 225 housing units from 2018 to 2020. They analyzed shifts in electricity use related to heating, ventilation and air-conditioning (HVAC) loads, non-HVAC loads, and whole-home loads, and found increased electricity use during periods that occupants would usually be away from home. In addition, a few studies have examined data with greater spatial granularity, demonstrating how the timing and restrictiveness of government orders coincided with changes in electricity usage (Rouleau & Gosselin 2021; Santiago *et al.* 2021; Snow *et al.* 2020). However, very few studies on electricity usage during the pandemic have included a greater level of granularity with regard to customer class.

Gui *et al.* (2021) provided a detailed analysis of electricity usage in higher education buildings, but these patterns were not compared with other sectors. In contrast, Kang *et al.* (2021) used weather-adjusted monthly utility data in South Korea across a variety of customer types. They examined year-over-year change in energy use during January–May 2020 and found that educational and research facilities showed the greatest decreases in consumption (16–32%), followed by (from largest to smallest): religious, hotels, sales, office, and medical. Similarly, Sánchez-López *et al.* (2022) analyzed monthly resolution electricity data (January–September 2020) in Chile across a number of 'economic sectors' (a mixture of industrial and commercial classifications). They found that in June 2020, when the quarantine was fully implemented, the hotel and restaurant category showed a 75% decrease relative to 2019. They also observed decreases in energy use for education (schools and universities, which were closed for the duration of the study) that were similar in magnitude to Kang *et al.* (2021) (ranging from 11% to 36%). However, in contrast to other studies that showed reductions in the industrial sector, Sánchez-López *et al.* (2022) found that the mining and quarrying sector actually increased its energy use in 2020. The authors explain that these industries were considered a critical service in Chile, which highlights the importance of specific Covid-19 policy decisions for electricity usage patterns during the pandemic.

The present study adds to the literature by demonstrating the effects of the pandemic on electricity usage by analyzing daily smart meter data from a medium-sized US city from 2019 to 2020. By focusing on a single community, it is possible (1) to link usage to specifically timed public health and executive orders, and (2) to provide a detailed picture of usage across different property classifications. As such, a nuanced view is presented of the electricity consumption responses of varying business types resulting from the government-mandated changes in operation.

### 1.2 CONTEXT FOR THE PRESENT STUDY

The US has more than 300 small and mid-sized cities, and more people live in these cities than in the country's own largest cities (Statistica n.d.; World Population Review n.d.). Fort Collins, Colorado, a community of approximately 175,000 residents spread over an area of 50 square miles (130 $km^2$), is home to Colorado State University (CSU), which has a student body of 35,000. The Fort Collins healthcare system provides services to northern Colorado, southern Wyoming, and western Nebraska. In addition, Fort Collins is known for its thriving micro-brew industry and a plethora of restaurants. In 2016, it generated US$274.6 million in revenue from tourism (Ferrier 2017). Overall, Fort Collins has an economic mix typical of many mid-sized US cities.

Fort Collins has a municipal electricity provider (Fort Collins Utilities) that serves about 50 square miles (130 $km^2$) of territory and 77,000 customers. In 2016, Fort Collins Utilities established a research collaboration with CSU to share load interval data and other datasets for the purpose of detailed analyses and the creation of research techniques to analyze these large-scale sources of information. During the pandemic, Fort Collins Utilities performed a detailed analysis of the shutdown's impact on electric power consumption in the city. This analysis provided a mechanism for tracking actual electric consumption versus expected consumption and was used to monitor the financial impacts of the shutdown. An analysis tool is deployed to integrate electricity use with detailed property classifications and the timing of public health orders to demonstrate the impact of Covid on electricity consumption across different sectors. This study adds to the literature on the impacts of Covid-19 on electricity use by providing a more fine-grained analysis than previously available.

Most of the buildings in Fort Collins use natural gas for heating. The study authors have no access to natural gas consumption data, so they were not included.

## 2. METHODS

### 2.1 SAMPLE CHARACTERISTICS

In 2015, Fort Collins transitioned all of its electricity customers to advanced metering infrastructure. These smart meters collect detailed 15-min interval data for approximately 77,000 electrical accounts. Billing records allow customers (and thus loads) to be accurately categorized into high level groups such as residential, commercial, and industrial. Further, each account is associated with publicly available building data maintained by the Larimer County Assessor. These building data are based on permitting information, not on owner information, and are rolled up into the property classification. Thus, property classifications are independent of ownership information. In contrast to traditional utility classifications, which are based on their peak demand, the property classifications maintained by the county are based on the type of activity occurring at that premise and are far more specific. Thus, integrating meter data with property classifications enabled differentiation between the usage patterns of property types such as offices and restaurants.

#### 2.1.1 Account selection for analysis: utility classifications

Fort Collins Utilities provides electric service, metered at 15-min intervals, for approximately 77,000 accounts, with approximately 69,000 of these accounts representing residential customers. Locations that changed function (*e.g.* a location that was a hair salon in 2019, then became a fast-food restaurant in January 2020) and newly constructed buildings were excluded from the analysis. In addition, any location where there was a change of rate class or property type (see both below) was removed from the analysis, ensuring the analysis maintained a constant number of accounts and account types. After excluding these premises, a total of 76,912 premises were left for use in the analysis.

These remaining premises fell into five distinct rate codes: residential, GS, GS-25, GS-50, and GS-750. GS-25, GS-50, and GS-750 refer to accounts where the annual average of each month's peak-power demand is below 25, between 25 and 50, between 51 and 750, or more than 750 kW, respectively. Roughly speaking, the GS class consists of small commercial stores (such as 'Mom and Pop' stores), GS-25 is comprised of medium commercial groups (large retail stores, typically of a national chain franchise), GS-50 is large commercial (grocery stores, big-box store, office buildings, *etc.*) and GS-750 consists of industrial customers. The GS-750 class was not included in the final analysis of this paper because the group was relatively small, containing only 15 accounts. Also, these accounts tend to be process centric and their energy consumption is driven more by the production activities in their facilities than by a thermal model, the modelling technique used in this study. This resulted in a final sample containing a total of 68,038 accounts in the residential class, 7549 in the GS class, 648 in the GS-25 class, and 677 in the GS-50 class.

#### 2.1.2 Account selection for analysis: property assessor classifications

The Larimer County Property Assessor classifies properties according to the buildings on each parcel of land. There are 321 different options of varying detail and redundancy in the county classification system. This list was meticulously reviewed and condensed into 28 classifications. The mapping between these classifications underwent extensive manual verification and intervention before being automated. The 28 classifications align with ENERGYSTAR Portfolio Manager building types, with the intent that it allows for regional building comparisons using Commercial Buildings Energy Consumption Survey (CBECS) data (EIA 2012). Thus, this classification was used in the present study to refine the 'commercial' classification used by the utility and enable a more fine-grained analysis of the effect of public health orders.

At the time of writing, when parcels contain multiple buildings, property data can only be connected to utility data at the parcel level, not the individual building level. This means that the county's improvement data had to be aggregated to the parcel level. To address this, each parcel was assigned the classification for the largest building on the parcel. In some cases, this resulted in parcels that had mixed-use premises, both residential and commercial, on the same property. An example of this are buildings that have retail shops on the first level and apartments on the floors above. These properties are classified as 'mixed'. Unfortunately, this method was not effective for strip malls. These properties are identified by the county as strip malls, but typically contain units with a mix of retail, offices, food service, *etc*. Consequently, strip malls were excluded from the analysis.

Very few premises in Fort Collins contain multiple customers behind a single meter. All these are condominiums and are classified as residential customers in the 'residential multi family' category.

Finally, three groups (transportation, parking, and residential home owners' association—HOA) were excluded from the analysis because, similar to the GS-750 properties, their consumption activities are process driven, mostly independent from thermal-based consumption.

After all these considerations, the following groups were included in the analysis: education (Poudre School District—PSD), food sales (groceries), food service (restaurants), healthcare—outpatient, lodging, mixed (a combination of residential and commercial units), office, public assembly (movie theaters, music venues, lodges, *etc.*), religious, retail mall, and services (hair or nail salon, *etc.*). The number of premises within each of these classifications is shown in Table 1.

For clarity, in the education group only the PSD K-12 buildings are included in the analysis. Other educational establishments (charter schools, community colleges, CSU) are excluded. The inclusion of only PSD K-12 buildings ensures that all the selected facilities would follow the same lock-down schedule. Additionally, the results of the K-12 group are more widely applicable to other communities, as not all communities are home to large universities.

DOI: 10.5334/bc.361

| PREMISE CLASSIFICATION | PREMISE COUNT | ACTUAL CONSUMPTION, 2019 (MWh) | ACTUAL CONSUMPTION, 2020 (MWh) | % CHANGE, 2019 TO 2020 |
|---|---|---|---|---|
| Business in converted home | 145 | 7.9 | 7.6 | –4.1% |
| Education | 142 | 46.8 | 40.3 | –13.7% |
| Education (PSD K-12 only) | 70 | 42.5 | 34.7 | –18.4% |
| Food sales | 96 | 30.6 | 28.5 | –6.8% |
| Food service | 267 | 63.2 | 56.2 | –11.1% |
| Healthcare | 35 | 6.1 | 9.3 | 51.9% |
| Healthcare inpatient | 20 | 46.3 | 45.9 | –0.8% |
| Healthcare outpatient | 258 | 26.0 | 25.4 | –2.6% |
| Lodging | 117 | 38.0 | 31.4 | –17.3% |
| Mixed | 235 | 14.4 | 12.4 | –14.5% |
| Office | 903 | 372.3 | 346.6 | –6.9% |
| Outbuilding | 199 | 3.0 | 3.2 | 7.1% |
| Parking | 25 | 2.0 | 1.0 | –52.7% |
| Public assembly | 150 | 35.6 | 28.7 | –19.2% |
| Public service | 22 | 4.7 | 4.2 | –11.6% |
| Religious | 111 | 16.0 | 14.0 | –12.9% |
| Residential HOA | 5 | 0.1 | 0.1 | –3.45% |
| Residential manufactured | 1601 | 29.0 | 29.9 | 3.1% |
| Residential multi family | 6599 | 166.7 | 165.7 | –0.6% |
| Residential single family | 42807 | 938.7 | 983.1 | 4.7% |
| Retail | 375 | 78.6 | 73.0 | –7.1% |
| Retail mall | 353 | 42.2 | 35.7 | –15.4% |
| Services | 183 | 20.5 | 19.6 | –4.3% |
| Storage | 113 | 8.2 | 8.0 | –2.1% |
| Transportation | 6 | 0.9 | 0.8 | –8.8% |
| Utility | 7 | 24.4 | 22.7 | –6.9% |
| Healthcare vet | 33 | 5.3 | 5.3 | 0.2% |

**Table 1:** Number of parcels associated with each grouping from the ENERGYSTAR Portfolio Manager

*Note:* HOA = Home Owners' Association; PSD = Poudre School District.

## 2.2 PROCEDURE FOR MODELING EXPECTED ELECTRICITY USAGE

### 2.2.1 International Performance Measurement and Verification Protocol (IPMVP)

Many techniques exist to determine the energy impact of system updates or improvements at the building level. This paper extends one such technique, IPMVP Option C (Tanguay n.d.), to examine the effects of the pandemic. Energy management professionals are familiar with IPMVP Option C, which is typically used when a specific building has multiple systems updated or improved in an energy-efficiency retrofit (*e.g.* light-emitting diode (LED) lighting installation, window replacements, and/or building automation system optimization) and an evaluation of the energy savings from the retrofit(s) is needed. In such a case, the overall energy consumption of the facility is measured via utility meters, typically over a period of 12 months before (baseline period) and 12 months after (reporting period) the intervention. Weather variations over the baseline and reporting periods are controlled via a linear regression on heating degree-days (HDD) and cooling degree-days (CDD).

In the current study, a modified version of the IPMVP methodology was used to examine the effect of the Covid-19 shutdown on electricity usage across the whole City of Fort Collins. This is a valid generalization of the IPMVP methodology because the pandemic created multiple modifications to a 'facility' by changing occupancy patterns of commercial facilities (capacity limits in stores, different operating hours) and residential consumption patterns (working and studying from home, frequency and timing of clothes washing loads, dishwasher loads, television watching hours/week, number of meals cooked at home, *etc.*). When considering model selection, it is important to note that IPMVP has four options from which to choose. Option C is recommended to be used when (1) the impact is expected to exceed the baseline period by over 10% and (2) the only available data are 12 monthly utility bills. However, Option C is an appropriate choice, even when the expected deviation is less than 10%, when more granular data are available. In the present study, 15-min interval smart meter data from 1 January 2019 to 31 December 2020 were aggregated into 24-h windows.[1] Thus, smart meters provided the actual consumption before and during the pandemic while the expected consumption (*i.e.* consumption in the absence of a pandemic) was estimated by a modification of the IPMVP Option C method as described below.

### 2.2.2 Weather normalization procedure

Fort Collins is located in a region with a semi-arid climate with four distinct seasons and low annual precipitation. Summers range from mild to hot (average temperature in July is 73.1°F/23°C) with low humidity. Winters range from mild to moderately cold (average temperature in December is 31.2°F/–0.4°C). Annual snowfall is about 50 inches (1.27 m) and average precipitation is 15.9 inches (400 mm). The city receives plenty of solar radiation with 300 days of sunshine per year. Given these clearly demarcated weather patterns, meteorological conditions play a significant role in electricity consumption. Temperature is a primary indicator of electricity usage, while solar radiation, humidity, and previous-day average temperature are second-order corrections to temperature when modeling electricity consumption. The present research uses temperature as the sole weather parameter and ignored any hysteresis properties of weather on electricity consumption. Fort Collins has a fairly small area (50 square miles/130 $km^2$), so a single temperature source was used for all regressions.

In Fort Collins, heating is most commonly provided by gas-burning, forced-air systems. In contrast, cooling is provided by electric air-conditioning units. Thus, the relation between temperature and electricity consumption differs for cold and warm temperatures. The electricity consumption of a group of accounts can be parameterized by two temperature splines (above and below the equilibrium point for heating and cooling, 55°F/13°C) and by using the day-type classification (weekday, weekend) as a secondary parameter. As shown in Figure 1, a linear fit is applied to temperatures ≤ 55°F/13°C (left) and a parabolic fit is applied to temperatures > 55°F/13°C (right).

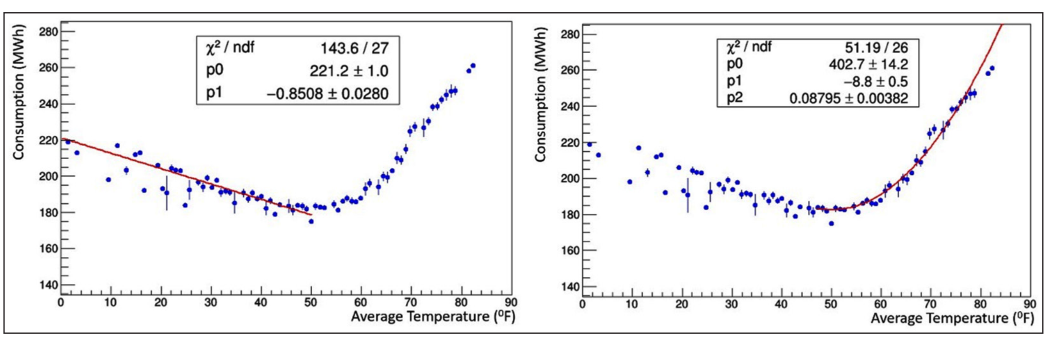


**Figure 1:** Regression of energy daily consumption versus average daily temperature (for weekdays in this case) for a given subset of accounts.

Average daily temperatures for each day in 2020 were plugged into these regression equations to create daily expected consumption, *i.e.* what the electricity consumption *would have been* in the absence of a pandemic, by using the average temperature for each day (in the measurement year, 2020). By comparing the actual consumption from the metering data with the expected consumption, it is possible to estimate the impact of the Covid-19 pandemic as the ratio of the two values (*i.e.* as a percentage increase or decrease).

The analysis for the education group required an additional parameter for its model, which was an indicator variable for 'in-session' or 'in-recess'. This binary variable accounted for summer vacations, spring break, *etc*. Therefore, electricity usage was modelled for day type (weekend–weekday) for both in-session or in-recess periods, based on the modified IPMVP model, and the relevant set of parameters was applied to each day during 2020. For purposes of comparison, the remote teaching period in 2020 was considered 'in-session', as classes were being held even though the buildings were unoccupied.

### 2.3 TIMELINE OF COVID-RELATED EVENTS IN FORT COLLINS

Table 2 shows a timeline of important Covid-related events in Fort Collins (collected from Husch Blackwell n.d.; State of Colorado n.d.). As this timeline shows, numerous actions were taken by the Colorado governor and the Colorado Department of Health and Environment (CDPHE) in March 2020 that affected every sector. However, over the remainder of the year there was a decoupling of these orders which allowed an examination to be made of the effects of these orders on specific sectors.

**Table 2:** Timeline of relevant Covid-related events in Fort Collins, CO

| DATE, 2020 | EVENT | AFFECTED GROUP(S) |
|---|---|---|
| 9 March | First Covid-19 case in Fort Collins | |
| 11 March | Governor Jared Polis declared a state of emergency | |
| 15 March | Colorado State University (CSU) suspended in-person learning and closed the university to all but critical personnel. In August, CSU partially opened for hybrid learning, with most classes still online, and it was fully online from 21 November 2020 to the end of the year | Residential |
| 18 March | Governor Polis suspended in-person instruction for all K-12. Poudre School District (PSD) returned to hybrid learning (50% capacity) from 5 October to 23 November, and was fully online for the remainder of the year | PSD, residential |
| 19 March | The Colorado Department of Health and Environment (CDPHE) issued a public health order that limited all mass gatherings to no more than 10 people (it started being relaxed on 1 June) | All except medical |
| 19 March | Governor Polis suspended all elective and non-essential surgeries and medical procedures (through to 26 April) | Medical outpatient |
| 25 March | Governor Polis issued a stay-at-home order. On 26 April it was replaced with the less restrictive safer-at-home order (through to 1 June). From June to December, restrictions (*e.g.* capacity limits) varied according to the number of cases and hospitalizations, but there were no further stay-at-home orders | All except medical |

## 3. RESULTS

The Covid-19 pandemic arrived in northern Colorado in early March 2020. This means that the *expected* consumption can be calculated for the first two months of 2020 (before the full impact of Covid-19) and compared with the actual consumption for these two months to validate our model.

### 3.1 UTILITY CLASSIFICATION RESULTS

The modified IPMVP Option C model for customer class was performed via GUI in ROOT (CERN n.d.), carefully fitting the data and uncertainties to obtain the lowest possible chi-square. Figure 2 shows a graph of *absolute expected* versus *absolute actual* electricity use. Since industrial (GS-750) accounts were excluded from the study, they are not included in Figure 2. Despite daily variations due to weather, it is possible to observe that the model follows the actual electricity consumption for all classes quite well until mid-March 2020, when the overall electricity use became noticeably lower than predicted. This pattern lasts until June, and another drop can be observed in the autumn. This reduction is driven by the commercial sector that started to have a significant drop in consumption in March. Although this pattern varied in magnitude across the year, it was largely sustained through the end of 2020. In contrast, the residential sector performed largely as expected, seeing only a limited increase in consumption during the summer.

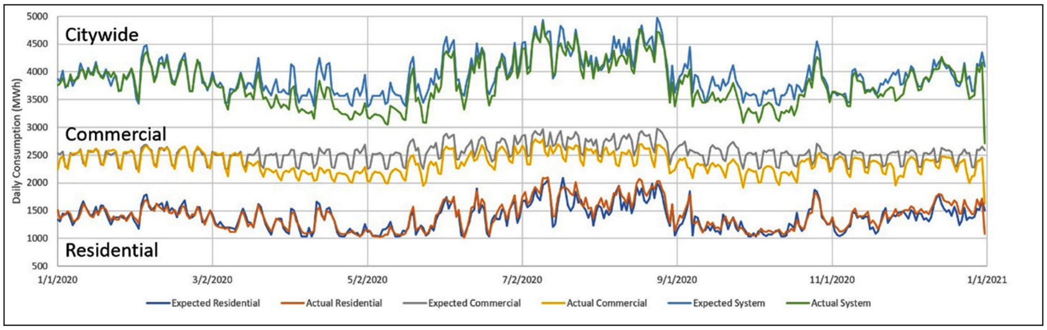


**Figure 2:** Breakdown of expected versus actual daily electricity consumption broken down by commercial and residential sectors.

Figure 3 shows a breakdowns by utility rate code. All groups were normalized to their expected value so as to show more clearly the drop in consumption starting in mid-March 2020. The plot is smoothed out by creating a five-day rolling average of the ratios. Clearly the residential group has much larger fluctuations than the commercial, but does not show a significant decrease or increase in consumption.

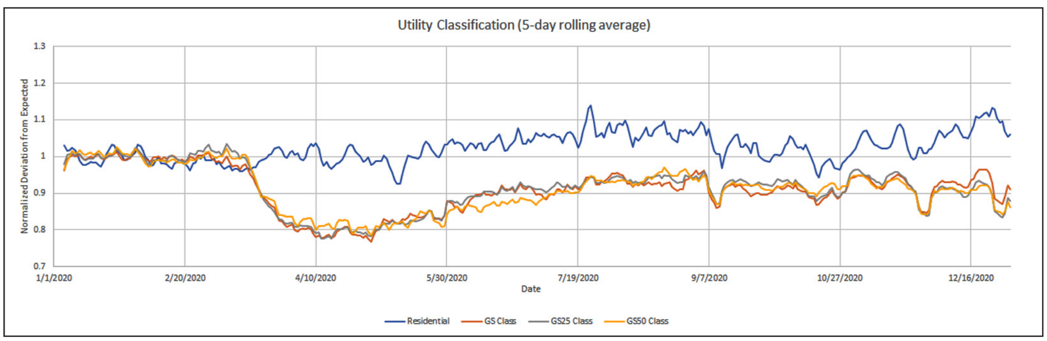


**Figure 3:** Daily consumption deviation from expected.

Table 3 presents a monthly summary with customers segmented by utility rate code. Shaded values are statistically significant, while bold values indicate a decrease of the actual value relative to the expected value. Consistent with findings from other researchers, commercial customers of all sizes showed statistically significant declines in their electricity usage in 2020 compared with the expected value. Moreover, the decreases are most pronounced in April–June when government-imposed restrictions were strongest. Residential patterns show less variability, with the summer demonstrating single-digit increases relative to expected values. It should noted that the presence of CSU in Fort Collins limits the generalizability of the results in the residential classification. Specifically, in March 2020, not only were CSU classes moved online but also the university essentially told students not to return after spring break. There was a concern that if tens of thousands of students returned to Fort Collins after traveling, that this would fuel the spread the Covid-19 in the community. Thus, many residences were empty, especially from March to August 2020. This likely accounts for the fact that observed increases in residential use were smaller than those reported by other studies.

| CLASS | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Residential | 0% | −1% | −1% | 0% | 0% | **4%** | **6%** | **6%** | **3%** | −1% | **3%** | **7%** |
| GS | −1% | 0% | **−9%** | **−21%** | **−16%** | **−11%** | **−8%** | **−7%** | **−9%** | **−10%** | **−9%** | **−8%** |
| GS-25 | 0% | 0% | **−8%** | **−21%** | **−17%** | **−10%** | **−8%** | **−6%** | **−8%** | **−9%** | **−8%** | **−11%** |
| GS-50 | 0% | −1% | **−7%** | **−19%** | **−17%** | **−13%** | **−9%** | **−6%** | **−8%** | **−8%** | **−9%** | **−11%** |
| System | 0% | 0% | **−3%** | **−7%** | **−7%** | **−3%** | −2% | −1% | −2% | **−3%** | **−3%** | −1% |

**Table 3:** Monthly deviation from expected consumption, 2020.

*Note:* Shaded entries are statistically significant deviations; bold entries are a reduction relative to the expected value.

The results for the commercial sector largely mirror those found by other researchers around the world. It is noteworthy that the rate classes, which represent different sized commercial entities, showed remarkably similar patterns of use. However, as demonstrated below, these results obscure the heterogeneity that exists within the commercial sector. The following section examines these entities, not according to their size, but rather by their function.

### 3.2 DETAILED PROPERTY CLASSIFICATION RESULTS

To develop a deeper understanding of the impact of the pandemic on electricity results, commercial customers were further subdivided into the property classification schema described above. Table 4 presents a monthly summary with customers broken down by property classification. Shaded values are statistically significant, while bold indicates a decrease of the actual value relative to the expected value. These data show that for virtually every class of commercial entity there were significant decreases from the expected consumption from March to December 2020. The only exceptions to this were in services (*e.g.* hair and nail salons) and outpatient medical facilities.

**Table 4:** Monthly deviation on electricity consumption broken down by different commercial sectors, 2020.

*Note:* Shaded values are statistically significant deviations; bold entries shows the reduction relative to the expected value.

| PROPERTY CLASS | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K-12 schools | 1.0% | –1.0% | **–20.0%** | **–51.0%** | **–51.0%** | **–39.0%** | **–18.0%** | **13.0%** | **–29.0%** | **–18.0%** | **–12.0%** | **–9.0%** |
| Food sales | 0.6% | 0.4% | **–3.8%** | **–8.6%** | **–9.8%** | **–10.2%** | **–8.4%** | **–8.3%** | **–10.0%** | **–10.0%** | **–9.7%** | **–9.4%** |
| Food service | –1.3% | 0.6% | **–10.6%** | **–28.4%** | **–24.1%** | **–13.0%** | **–9.5%** | **–8.2%** | **–9.4%** | **–8.5%** | **–11.5%** | **–19.0%** |
| Healthcare outpatient | 3.1% | 3.8% | –3.8% | **–13.9%** | **–4.6%** | –2.9% | –2.7% | –2.3% | –3.6% | –3.3% | –1.9% | 0.1% |
| Lodging | –1.6% | 0.4% | **–14.6%** | **–33.7%** | **–35.5%** | **–25.8%** | **–17.1%** | **–12.9%** | **–17.2%** | **–13.4%** | **–14.8%** | **–13.5%** |
| Mixed | –2.0% | 0.6% | **–9.5%** | **–30.4%** | **–30.4%** | **–16.1%** | **–13.3%** | **–12.9%** | **–16.7%** | **–16.6%** | **–15.6%** | **–13.5%** |
| Office | 0.1% | –0.3% | **–3.5%** | **–8.0%** | **–8.3%** | **–9.5%** | **–11.6%** | **–9.8%** | **–8.3%** | **–7.7%** | **–7.4%** | **–8.2%** |
| Public assembly | 0.1% | 0.3% | **–16.4%** | **–37.2%** | **–35.7%** | **–26.4%** | **–22.4%** | **–20.5%** | **–18.2%** | **–18.5%** | **–17.2%** | **–19.7%** |
| Religious | 4.7% | 5.9% | –5.8% | **–19.0%** | **–23.3%** | **–20.3%** | **–19.1%** | **–16.8%** | **–18.3%** | **–13.2%** | **–12.9%** | **–13.9%** |
| Retail mall | 1.6% | –0.2% | **–11.5%** | **–30.9%** | **–27.1%** | **–23.1%** | **–20.2%** | **–18.7%** | **–16.9%** | **–15.2%** | **–10.8%** | **–12.5%** |
| Services | 6.7% | 7.3% | –1.7% | **–21.5%** | **–12.8%** | –5.3% | –5.1% | –2.0% | –4.6% | –5.0% | –6.5% | –4.1% |

Although almost every group showed significant decreases throughout the year, there was temporal variability consistent with the timing of executive and public health orders. For instance, outpatient medical facilities showed a significant decline in usage following Governor Jared Polis's executive order D 2020 009 which banned elective and non-essential medical procedures, but quickly rebounded after the order was rescinded (Figure 4).

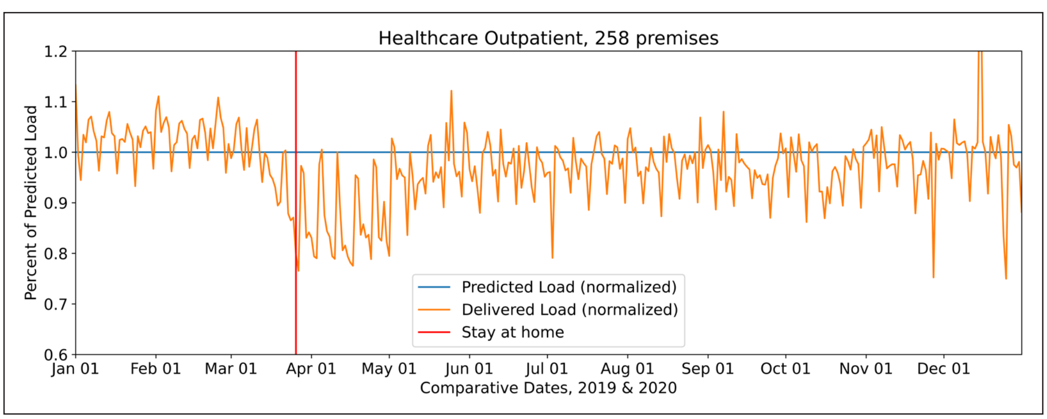


**Figure 4:** Daily consumption deviation from expected for the healthcare outpatient.

Similar temporal patterns can be traced in the data for schools. Figure 5 shows actual 2020 usage as a percentage of expected use for the local public school system. K-12 buildings showed substantial reductions in use during the time that instruction was fully online (April, May, September). Smaller decreases were evident when children returned to school in October and November. These smaller reductions are likely due to reduced use of PSD buildings outside of regular school hours

DOI: 10.5334/bc.361

because extracurricular activities were curtailed and the school district did not rent out buildings for community events due to increased cleaning protocols. The increase in usage observed in August was likely the result of a concentrated effort by district facilities professionals to increase ventilation and filtration in the buildings before the resumption of in-person learning. This deviation was confirmed with the PSD energy manager (personal communication) who explained that the schools were run as if occupied after being equipped with new MERV-13 filters.

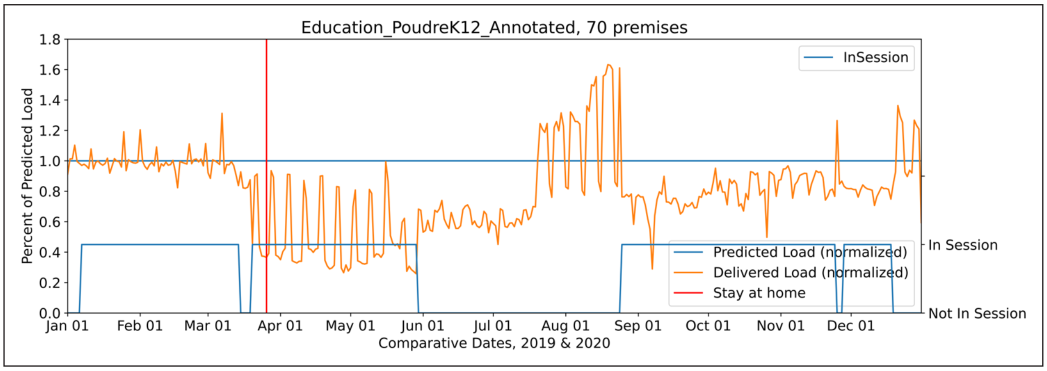


**Figure 5:** Daily consumption deviation from expected for the Poudre School District (K-12 schools) property classification.

In addition to temporal patterns, the detailed analysis revealed variations in the pandemic's impact within the commercial sector. The hospitality industry (food service and lodging) showed substantial decreases in electricity usage in April and May (Figures 6 and 7). They maintained smaller decreases throughout the rest of the year. Notably, these reductions are larger for the lodging industry (including hotels and motels but not Airbnb- or Vrbo-type of units) than for restaurants. This could be due to usage scaling more with occupancy for hotels (*e.g.* HVAC set points) or, alternatively, it might be due to the availability of a take-out option for restaurants (which would entail the kitchen being in use even when the dining area was not). To distinguish these potential explanations, the 2020 sales tax revenue data for Fort Collins were examined. These data support the take-out explanation: restaurants saw a 16.4% decrease compared with 47.2% for lodging (Financial Services, City of Fort Collins 2021). Even with a take-out option, however, the restaurant industry showed a noticeable dip in late November and December 2020, which coincides with an increase in Covid-19 cases and hospitalizations in the county.

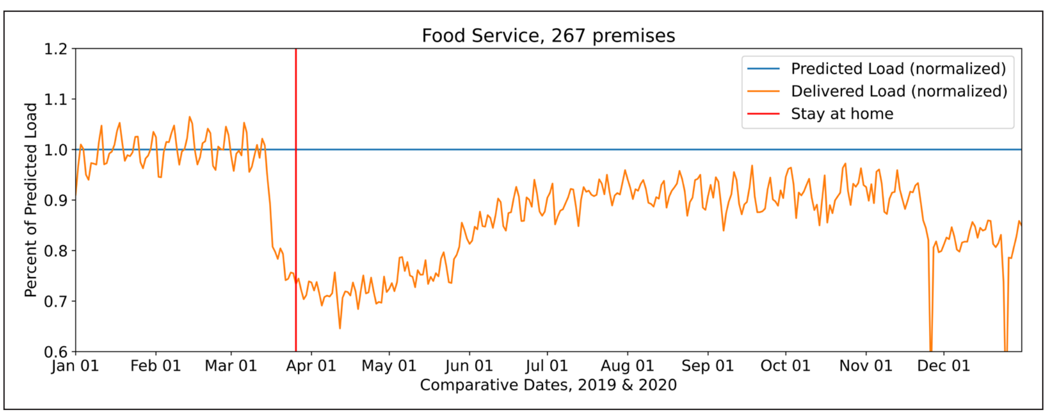


**Figure 6:** Daily consumption deviation from expected for the food service property classification.

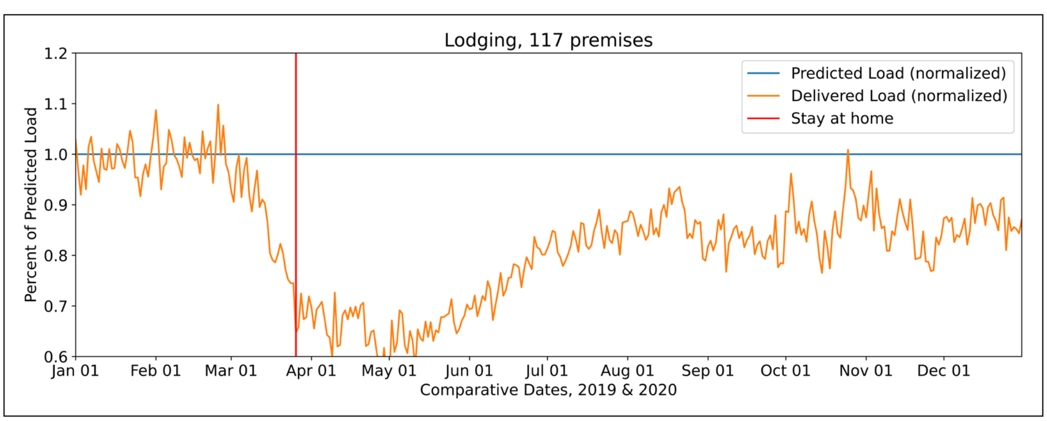


**Figure 7:** Daily consumption deviation from expected for the lodging property classification.

In contrast to the hospitality, healthcare, and educational sectors, which showed substantial temporal variability across 2020, other groups were less variable. The public assembly and religious categories (Figures 8 and 9, respectively) maintained double-digit reductions for the entire year. Initially, gatherings of 10 or more were prohibited. Even after these prohibitions were lifted, there were substantial limits placed on these activities by the CDPHE, and many houses of worship chose to remain closed to protect their congregants.

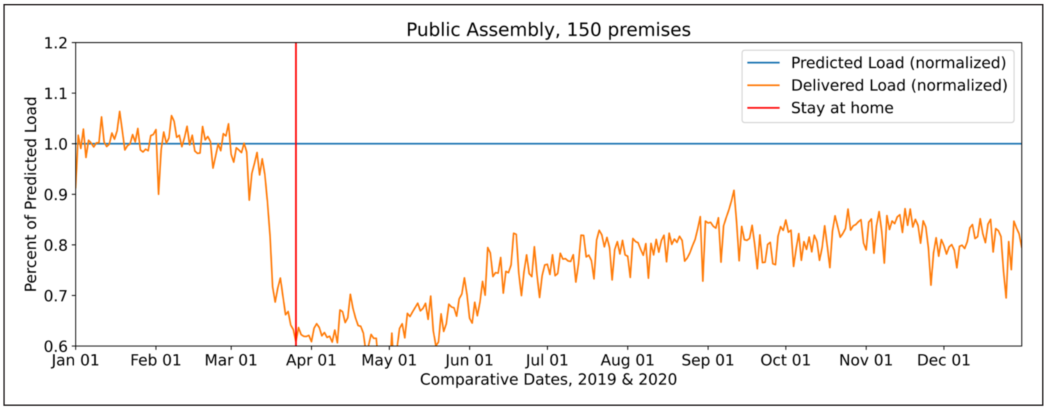


**Figure 8:** Daily consumption deviation from expected for the public assembly property classification.

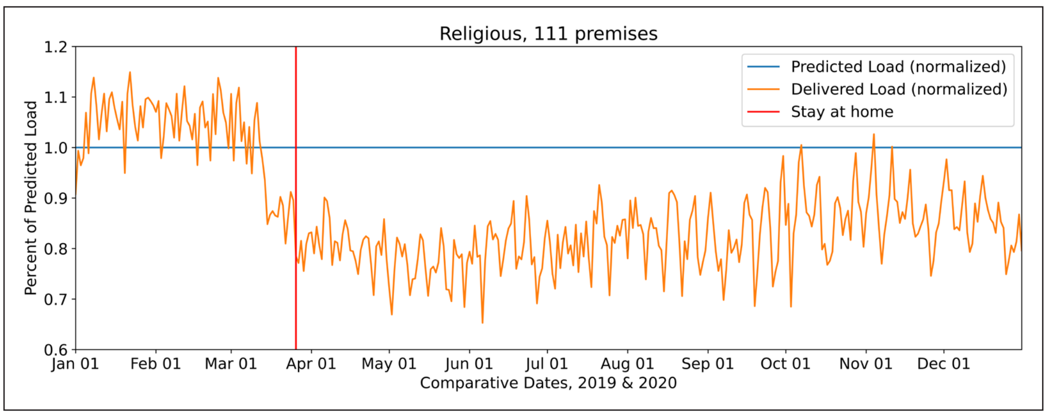


**Figure 9:** Daily consumption deviation from expected for the religious property classification.

The office group also showed a gradual drop (suggesting that businesses were starting to function remotely even before the stay-at-home order) and it became fairly stable and predictable immediately after the stay-at-home order. It is the only group that became steady and predictable starting on that day (Figure 10), indicating that the majority of remote workers were not back in the office during the period under study.

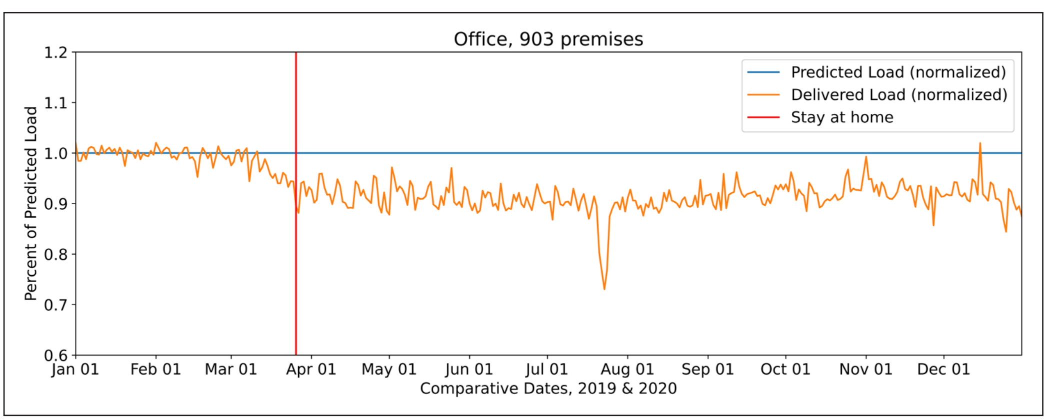


**Figure 10:** Daily consumption deviation from expected for the office property classification.

Finally, the food sales category showed single digit, but significant, decreases for the whole year. This result is surprising because these businesses were classed as critical and their operations were not substantially curtailed by the government. However, some grocery stores limited their hours of operation due to staffing shortages and to give overworked staff time to clean and restock (Powell 2020).

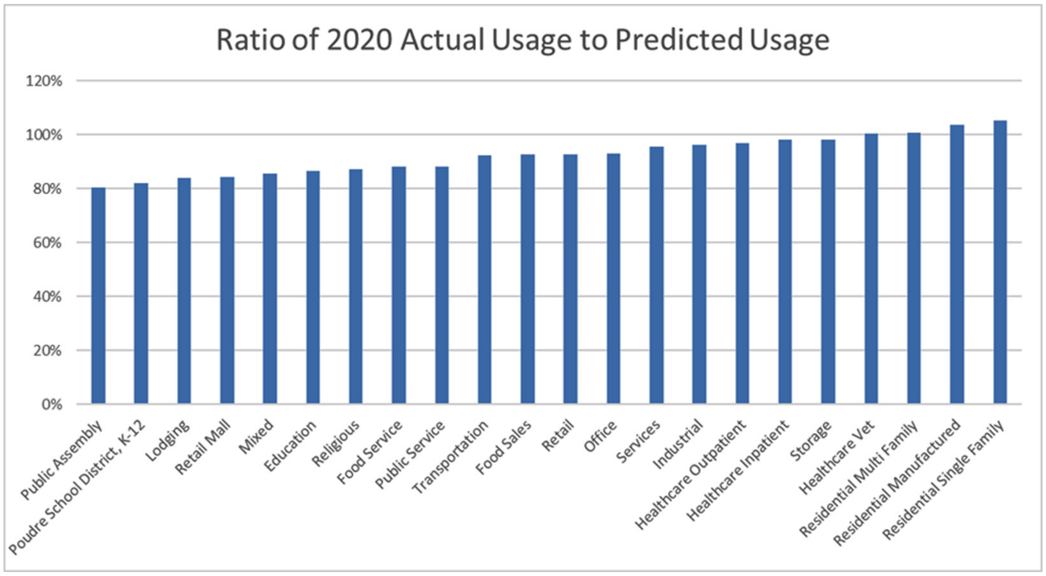


**Figure 11:** Ratio of actual to predicted electricity use in 2021 grouped by property classification.

To summarize, the commercial sector showed significant decreases in electricity consumption compared with what was expected based on 2019 consumption, and that the residential sector showed a small increase. However, groups within the commercial sector demonstrated different magnitudes of change (Figure 11) and also varying temporal patterns which often aligned with executive and health orders that impacted them directly.

## 4. DISCUSSION

### 4.1 FINDINGS AND IMPLICATIONS

The present study focused on the impact of Covid-19 on electricity usage in the commercial sector in a small city. This has provided a more detailed and nuanced description of the effect of executive and health orders on hospitality, education, healthcare, and other commercial property classes. This work contributes to, and extends, the literature on the energy impacts of the Covid-19 pandemic. To the authors' knowledge, this is the first study of this scope to analyze the impact of the pandemic at such a granular level while grouping meters by both customer and business type.

Using the traditional utility classifications commonly adopted in energy research, we found that from March to June, and again in late autumn, overall electricity consumption patterns were disrupted. The decreases in the commercial sectors were significant and sustained. Unlike other studies, only a small consumption increase was observed in the residential sector (in summer). Thus, the overall effect was a total reduction in electricity consumption of 2.5%. This created a revenue shortfall and significant financial cash-flow issues for the utility. As a benchmark, about 6.7% of the annual utility expenses are allocated to staff salaries, therefore a 2.5% reduction in electricity consumption represents a significant impact on the utility's financial operations and overall viability of the business.

Although researchers and utility professionals refer to the 'commercial sector' generically, the truth is that there is substantial variability within this group of utility customers. By combining smart meter data with information from the county property assessor, this revealed heterogeneity within the commercial class that was undetectable when focusing purely on rate classifications. For instance, restaurants and hotels are often considered together under the umbrella of 'hospitality,' but these businesses showed very different patterns of electricity usage across the pandemic.

These patterns also shed light on how people responded to the pandemic and generate more research questions. For instance, once restrictions were lifted, electricity consumption for the services sector (predominantly hair and nail salons) rebounded, but religious institutions showed sustained decreases in usage. Is this because of choices by the institutions themselves of whether to return to business as usual or are they reflective of people's choices and priorities about the activities they are willing to curtail? In fact, examination of the plots shows that for every group, usage began to decline before Governor Polis issued a stay-at-home order. Thus, the effects on energy usage observed in this and other studies are not purely due to the enactment of formal policies, but also due to people's perceptions regarding their safety.

Perceptions of safety apply to customers and also business owners. The public assembly group (theaters, movie theaters, concert venues) and the office group never fully recovered in 2020, even after restrictions were lifted. Many entertainment venues canceled shows or limited capacity, and many remote workers stayed home throughout 2020, even without explicit policies requiring them to do so.

Some of the variability across groups is likely due to the individual business' ability to adapt to changing policies and perceptions. For instance, healthcare facilities are accustomed to rigorous safety and cleaning protocols and could therefore resume operations quickly once restrictions were lifted. In contrast, PSD was slower to respond, resulting in a decision to delay in-person classes until October 2020. Thus, there are implications for organizational researchers to explore in this regard.

Although the current study was conducted during the pandemic, the results generalize beyond it. The variability in the responses of the different business classes underscores the functional significance of energy usage. Utilities tend to view the commercial class as homogenous. In contrast, this study shows that businesses will vary in their response to incentives just as they did to Covid policies. Take, for example, load shifting (*e.g.* the willingness to curtail use during peak cooling in the late afternoon). The results demonstrate that restaurants were able to remain financially viable while reducing their energy usage by focusing on take-out. Thus, restaurants could be encouraged to reduce their peak consumption by eliminating their table service between lunch and dinner.

The results also add to the growing literature on telecommuting that has emerged from analyses of energy use during the pandemic (*e.g.* Shi *et al.* 2023). Hook *et al.* (2020) suggested that:

> teleworking may lead to more energy being used at home […] without any compensating reductions in the energy used at work (*e.g.* offices may continue to be heated and lit as much as before).
>
> (p. 5)

The present results clearly demonstrate the inaccuracy of this prediction. Teleworking can reduce the energy consumption in offices, even in a situation such as the pandemic where businesses did not have time to move to smaller offices with lower energy demands.

## 4.2 LIMITATIONS

A major limitation of the present study was that it focused exclusively on electricity usage. Space heating accounts for 32% of energy use in commercial buildings, and in Fort Collins the majority of buildings are heated with natural gas forced-air systems. It is unclear whether natural gas usage would follow a similar pattern to our observed results for electricity.

The weather-corrected model reproduced the actual electricity consumption during January–February 2020 quite well. In all cases the actual consumption was only 1–2% systematically higher than the modeled consumption across all classes. That difference is consistent with previous year-over-year increases and thus could be considered an econometric energy impact attributable to the strong economic growth experienced through 2019 carrying over into the first few months of 2020. These observed increases in early 2020 suggest that the reported decreases (as compared with expected use) are likely to be underestimates of the actual effect of the pandemic.

Although a very rich dataset was analyzed, neither the electricity usage data nor the property classifications were created for the purposes of research. For example, fewer than 150 commercial properties have rooftop photovoltaic systems installed, and all their generation is consumed onsite. For these properties, the utility records only the net-metered consumption, not the total actual electricity usage. While this does impact the electricity consumption data, the effect is very small. Large commercial photovoltaic systems are metered separately and were excluded from the study. There are few, if any, electric vehicle chargers installed at commercial properties during the study period. There were some on city properties, but those tend to be separately metered. Many more chargers have been installed and will be a bigger consideration going forward.

In addition, some anomalous load behavior was observed but not rigorously examined:

- Two significant dips in consumption occur in the food service segment. The dates for these decreases correspond to Thanksgiving and Christmas and could possibly be attributed to a decrease in holiday customers during the Covid shutdown.
- Consumption in the office segment had a significant dip at the end of July 2020 compared with July 2019. The data showing this dip are valid, but the actual cause of the decrease was not investigated.

There are limitations to the generalizability of these findings. First, as mentioned previously, Fort Collins is home to a large university. It is likely that the exodus of the majority of the students in March 2020 impacted the residential usage patterns. Second, the specific results (*e.g.* a drop, partial rebound, and another drop for the food service industry) should not be viewed as reflective of the patterns likely to be observed in other communities. However, the mechanisms for this pattern (stay-at-home order → drop; Covid-19 cases decline and restrictions lifted → rebound; Covid-19 cases increase → drop) are likely to generalize to other locations and different-sized communities. These are the key take-aways from this research. Although these results may not be directly transferable to other locations, due to a unique industry mix, they do provide insight about the variability of impacts across industries and the effect of Covid-19 policies on those industries.

## 5. CONCLUSIONS

What energy usage during the Covid-19 pandemic demonstrates is the effect of behavior on energy use. People's behavior changed, and energy consumption changed with it. It is difficult to overestimate the impact the Covid-19 pandemic had on people's lives. A model was implemented to predict electricity usage based on past data and outdoor temperatures. Its goal was to quantify the impact of the Covid-19 pandemic on electricity usage in a medium-sized city.

Two years of 15-min interval smart meter data were combined with property classification data to create a rich dataset, with a substantive sample size. A wide variety of impacts were examined. The ability to drill down to the level of business type uncovered unique consumption patterns.

This study contributes to the literature on the Covid-19 pandemic by presenting the results of a year-long study of the pandemic's impact on electricity usage patterns of approximately 77,000 premises. The large dataset provides a unique level of granularity and depth that may not be easily replicated in other studies.

## NOTE

1 Data for 26 October 2020 were excluded from the analysis because air quality in Fort Collins was significantly, adversely affected by the Cameron Peak and East Troublesome Fires—the two largest wildfires in Colorado history. These fires, which occurred almost simultaneously, resulted in residents being instructed to stay indoors with their windows closed when possible.

## AUTHOR AFFILIATIONS

**Gerald P. Duggan** orcid.org/0000-0002-4508-7811
Energy Institute, Colorado State University, Fort Collins, CO, US

**Pablo Bauleo** orcid.org/0009-0006-3560-6880
Fort Collins Utilities, Fort Collins, CO, US

**Michael Authier** orcid.org/0000-0003-2549-6244
Fort Collins Utilities, Fort Collins, CO, US

**Patricia A. Aloise-Young** orcid.org/0000-0001-6375-1352
Department of Psychology, Colorado State University, Fort Collins, CO, US

**Jonathan Care** orcid.org/0000-0002-3643-0825
Fort Collins Utilities, Fort Collins, CO, US

**Daniel Zimmerle** orcid.org/0000-0003-2832-048X
Energy Institute, Colorado State University, Fort Collins, CO, US

## COMPETING INTERESTS

The authors have no competing interests to declare.

## DATA AVAILABILITY

The data used in this research project have not been made available, as Fort Collins Utilities complies with the 'Red Flags Rule' from the US Federal Trade Commission which mitigates identity theft. Under this rule, energy consumption cannot be disclosed.

## REFERENCES

**Abu-Rayash, A.,** & **Dincer I.** (2020). Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic. *Energy Research and Social Science*, 68. DOI: https://doi.org/10.1016/j.erss.2020.101682

**Agdas, D.,** & **Barooah, P.** (2020). Impact of the COVID-19 pandemic on the U.S. electricity demand and supply: An early view from data. *IEEE Access*, 8, 151523–151534. DOI: https://doi.org/10.1109/ACCESS.2020.3016912

**Anderson, B.,** & **James, P.** (2021). Covid-19 lockdown: Impacts on GB electricity demand and $CO_2$ emissions. *Buildings & Cities*, 2(1), 134–149. DOI: https://doi.org/10.5334/bc.77

**Burleyson, C. D., Rahman, A., Rice, J. S., Smith, A. D.,** & **Voisin, N.** (2021). Multiscale effects masked the impact of the COVID-19 pandemic on electricity demand in the United States. *Applied Energy*, 304. DOI: https://doi.org/10.1016/j.apenergy.2021.117711

**CERN.** (n.d.). ROOT: Analyzing petabytes of data, scientifically. *ROOT*. https://root.cern/

**Debnath, R., Bardhan, R., Misra, A., Hong, T., Rozite, V.,** & **Ramage, M. H.** (2022). Lockdown impacts on residential electricity demand in India: A data-driven and non-intrusive load monitoring study using Gaussian mixture models. *Energy Policy*, 164. DOI: https://doi.org/10.1016/j.enpol.2022.112886

**Denworth, L.** (2020). The biggest psychological experiment in history is running now: What can the pandemic teach us about how people respond to adversity? *Scientific American*, 8 June. https://www.scientificamerican.com/interactive/the-biggest-psychological-experiment-in-history-is-running-now/

**EIA.** (2012). Commercial Buildings Energy Consumption Survey (CBECS). Energy Information Administration (EIA). https://www.eia.gov/consumption/commercial/

**Farrow, H.** (2020). *Commercial down v residential up: COVID-19's electricity impact*. Energy Networks Australia. https://www.energynetworks.com.au/news/energy-insider/2020-energy-insider/commercial-down-v-residential-up-covid-19s-electricity-impact/

**Ferrier, P.** (2017). Tourism study hints at why people visit Fort Collins. *Coloradoan*, 17 September. https://www.coloradoan.com/story/money/business/2017/09/27/tourism-study-hints-why-people-visit-fort-collins/705070001/

**Financial Services, City of Fort Collins.** (2021). *Sales and use tax collection report—December 2020* (11 January).

**Gui, X., Gou, Z., Zhang, F.,** & **Yu, R.** (2021). The impact of COVID-19 on higher education building energy use and implications for future education building energy studies. *Energy & Buildings*, 251. DOI: https://doi.org/10.1016/j.enbuild.2021.111346

**Hook, A., Court, V., Sovacool, B. K.,** & **Sorrell, S.** (2020). A systematic review of the energy and climate impacts of teleworking. Environmental Research Letters, 15, 093003. DOI: https://doi.org/10.1088/1748-9326/ab8a84

**Husch Blackwell.** (n.d.). *Colorado: State-by-state COVID-19 guidance*. https://www.huschblackwell.com/colorado-state-by-state-covid-19-guidance

**Jiang, P., Fan, Y. V.,** & **Klemeš, J.** (2021). Impacts of COVID-19 on energy demand and consumption: Challenges, lessons and emerging opportunities. *Applied Energy*, 285. DOI: https://doi.org/10.1016/j.apenergy.2021.116441

**Kang, H., An, J., Kim, H., Ji, C., Hong, T.,** & **Lee, S.** (2021). Changes in energy consumption according to building use type under COVID-19 pandemic in South Korea. *Renewable & Sustainable Energy Reviews*, 148. DOI: https://doi.org/10.1016/j.rser.2021.111294

**Kawka, E.,** & **Cetin, K.** (2021). Impacts of COVID-19 on residential building energy use and performance. *Building & Environment*, 205. DOI: https://doi.org/10.1016/j.buildenv.2021.108200

**Kirli, D., Parzen, M.,** & **Kiprakis, A.** (2021). Impact of the COVID-19 lockdown on the electricity system of Great Britain: A study on energy demand, generation, pricing and grid stability. *Energies*, 14(3), 635. DOI: https://doi.org/10.3390/en14030635

**Krarti, M.,** & **Aldubyan, M.** (2021). Review analysis of COVID-19 impact on electricity demand for residential buildings. *Renewable & Sustainable Energy Reviews*, 143. DOI: https://doi.org/10.1016/j.rser.2021.110888

**Ku, A. L., Qiu, Y. L., Lou, J., Nock, D.,** & **Xing, B.** (2022). Changes in hourly electricity consumption under COVID mandates: A glance to future hourly residential power consumption pattern with remote work in Arizona. *Applied Energy*, 310. DOI: https://doi.org/10.1016/j.apenergy.2022.118539

**Mehlig, D., ApSimon, H.,** & **Staffell, I.** (2021). The impact of the UK's COVID-19 lockdowns on energy demand and emissions. *Environmental Research Letters*, 16. DOI: https://doi.org/10.1088/1748-9326/abf876

**Powell, R.** (2020). Coronavirus shopping surge causes King Soopers stores to change hours of operation. *Coloradoan*, 14 March. https://coloradoan.com/story/news/2020/03/14/coronavirus-surge-prompts-king-soopers-grocery-stores-change-hours/5052028002/

**Rokicki, T., Jadczak, R., Kucharski, A., Bórawski, P., Bełdycka-Bórawska, A., Szeberényi, A.,** & **Perkowska, A.** (2022). Changes in energy consumption and energy intensity in EU countries as a result of the COVID-19 pandemic by sector and area economy. *Energies*, 15(17). DOI: https://doi.org/10.3390/en15176243

**Rouleau, J.,** & **Gosselin, L.** (2021). Impacts of the COVID-19 lockdown on energy consumption in a Canadian social housing building. *Applied Energy*, 287. DOI: https://doi.org/10.1016/j.apenergy.2021.116565

**Sánchez-López, M., Moreno, R., Alvarado, D., Suazo-Martínez, C., Negrete-Pincetic, M., Olivares, D., Sepúlveda, C., Otárola, H.,** & **Basso, L. J.** (2022). The diverse impacts of COVID-19 on electricity demand: The case of Chile. *International Journal of Electrical Power & Energy Systems*, 138. DOI: https://doi.org/10.1016/j.ijepes.2021.107883

**Santiago, I., Moreno-Munoz, A., Quintero-Jiménez, P., Garcia-Torres, F.,** & **Gonzalez-Redondo, M. J.** (2021). Electricity demand during pandemic times: The case of the COVID-19 in Spain. *Energy Policy*, 148. DOI: https://doi.org/10.1016/j.enpol.2020.111964

**Shi, Y., Sorrell, S.,** & **Foxon, T.** (2023). The impact of teleworking on domestic energy use and carbon emissions: An assessment for England. *Energy & Buildings*, 287. DOI: https://doi.org/10.1016/j.enbuild.2023.112996

**Snow, S., Bean, R., Glencross, M.,** & **Horrocks, N.** (2020). Drivers behind residential electricity demand fluctuations due to COVID-19 restrictions. *Energies*, 13(21), 5738. DOI: https://doi.org/10.3390/en13215738

**State of Colorado.** (n.d.). *2020 Executive orders*. https://www.colorado.gov/governor/2020-executive-orders

**Statistica.** (n.d.). *Number of cities, towns and villages (incorporated places) in the United States in 2019, by population size*. https://www.statista.com/statistics/241695/number-of-us-cities-towns-villages-by-population-size/

**Tanguay, D.** (n.d.). *International performance measurement and verification protocol (IPMVP)*. Efficiency Validation Organization (EVO). https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

**Tingting Xu, A., Weijun Gao, B., Yanxue Li, C.,** & **Fanyue Qian, D.** (2021). Impact of the COVID-19 pandemic on the reduction of electricity demand and the integration of renewable energy into the power grid. *Journal of Renewable and Sustainable Energy*, 13(2), 1–12. DOI: https://doi.org/10.1063/5.0045825

**World Population Review.** (n.d.). *The 300 largest cities in the United States by population 2023*. https://worldpopulationreview.com/us-cities

**TO CITE THIS ARTICLE:**
Duggan, G. P., Bauleo, P., Authier, M., Aloise-Young, P. A., Care, J., & Zimmerle, D. (2023). Electricity consumption in commercial buildings during Covid-19. *Buildings and Cities*, 4(1), pp. 851–866. DOI: https://doi.org/10.5334/bc.361

**Submitted:** 21 June 2023
**Accepted:** 15 September 2023
**Published:** 10 October 2023