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# Impacts of the COVID-19 lockdown on energy consumption in a Canadian social housing building

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## HIGHLIGHTS

- Energy use in a residential building was compared before and during COVID lockdown.
- At the beginning of the lockdown, electricity use in the middle of the day increased by 46%.
- At the beginning of the lockdown, hot water use in the middle of the day increased by 103%.
- COVID-19 effects were only observed when lockdown measures were stricter.
- No major change in space heating use was observed during the lockdown.

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## ABSTRACT

The COVID-19 pandemic hit societies in full force in 2020 and compelled people all around the world to change their lifestyle. The time spent at home significantly surged during the pandemic and this change in occupancy can have a direct impact on building energy consumption. COVID-19 lockdowns also accelerated the transition towards telework, a trend that many expect to last. Changes in energy consumption under lockdown is thus a valuable asset to forecast how energy could be consumed in buildings in the future. Here, we aim to quantify the impacts of the COVID-19 lockdown on the energy consumption (electricity, hot water and space heating) in residential buildings by answering these two questions: (i) Did the lockdown lead to changes in total energy consumption?, and (ii) Did the lockdown lead to changes in consumption patterns (i.e. time of the day at which energy is consumed)? To do so, we compared the energy consumption measured in a 40-dwelling social housing building located in Quebec City (Canada) during four months of lockdown to those of the months that preceded the lockdown. It is found that consumption patterns for electricity and hot water changed for the first two months of the lockdown, when the most intensive lockdown measures were applied. Overall consumption slightly increased for these two energy expenditures, but the more important change was that consumption occurred throughout the day instead of being concentrated in the evening as observed before the lockdown. Results shed light on the impact of lockdown on energy bills for consumers and on how energy utilities might be solicited during this kind of episode.

## 1. Introduction

On March 11th, 2020, the World Health Organization declared Coronavirus disease-19 (COVID-19) a global pandemic [1]. In order to slow down the spread of the virus, governments all around the world established lockdown measures that are in most cases still in effect nearly a year later [2], at least to some extent.. Lockdowns have had numerous consequences on the economy, employment, and day-to-day life of citizens. According to Google's COVID-19 Community Mobility Reports, occupation of retail & recreation centers in Canada decreased by 63% during the first month of the pandemic whereas occupation of residential buildings increased by 21% [3]. This led occupants to modify their habits and behaviors in residential buildings, as they must adjust to being more often at home. Changes in occupancy schedules directly lead to changes in energy consumption of buildings [4–6], so the changes in habits induced by COVID-19 lockdowns could affect building energy consumption patterns, although to our knowledge, this is largely undocumented at this point.

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Since the COVID-19 pandemic is a new phenomenon, research in literature related to its impact on the field of energy is quite scarce. The impact of governmental restrictions related to the COVID-19 on electrical load, generation and transmission was investigated in 16 European countries [7]. In the period of active restrictions, most of Europe was characterized by a remarkable load drop. Generation from coals, gas and nuclear sources was reduced in favour of renewables. A similar pattern was observed in Malaysia, where it was reported that the COVID-19 induced a reduction of air pollutants, allowing more sunlight to reach photovoltaic panels, which increased the generation of solar energy [8]. As for residential buildings, a study projects that the share of residential buildings on total building electricity demand in Nigeria went from 43% under business-as-usual conditions up to 49% in a total lockdown scenario [9]. In a household survey conducted in New York, respondents reported on aggregate that their electricity usage starts later in the morning under the COVID-19 lockdown than before and that is stays relatively constant for the rest of the day [10]. About half of the respondents reported a higher volume of electricity usage than before the pandemic, while only a few reported lower usages. This survey is backed by monitored data from 400 New York City apartments which displayed a 23% increase during the middle of the day for weekdays and a 10% increase for weekend days [11]. Energy firms in the UK reported similar findings, with a 30% of home electricity use during the middle of the day and reductions of 21% in the morning and of 7% in the evening [12]. Using simulations, Zhang et al. tested different lockdown scenarios to assess the changes in annual energy demand for a mix of residential buildings [13]. The space heating demand went from 27.4 kWh/m$^2$ with the base case scenario to 19.9 kWh/m$^2$ under a scenario where the buildings are occupied for all hours of the year, due to the increase in internal heat gains.

Outside the field of energy, changes to occupant behavior in residential buildings have also been documented. For waste management, Ikiz et al. show that the pandemic has disrupted practices that were moving buildings towards higher levels of waste diversion [14]. In the city of Joinville in Brazil, there has been an increase of 11% of urban water consumption in residential buildings along with important decreases (53%, 42% and 30%) in commercial, industrial and institutional buildings [15]. Another study compared the physical activity rate of 143 individuals before and during the COVID-19 lockdown [16]. Total physical activity reduced from 7,809.7 to 4.135.7 MET-min/week during the pandemic, demonstrating a significant reduction in physical activity of individuals as they are constrained at home. In a building in London, it was reported that despite more hours of occupancy, occupants relied less on natural ventilation during lockdown and that the average duration of opened windows state was noticeably shorter [17]. In all these studies, it is undeniable that COVID-19 lockdowns affected the behavior of people in buildings.

Beyond the COVID-19 related lockdowns themselves, the pandemic has greatly accelerated the continuing trend toward teleworking [18–20]. Studying occupant behavior in residential buildings under the COVID-19 lockdown thus gives us a preview of how people could behave in the future as they are expected to stay more often at home. There have been studies on the influence of telework on energy consumption [21]. Studies in the past reversed the energy-saving potential of programmable thermostats to predict a 5–15% increase in heating or cooling energy on teleworked days [22,23]. However, the value of programmable thermostats has been questioned since then as occupants tend not to use them optimally (if at all) [24]. The impact of telework on space heating and cooling demand is thus still not fully known. As for electricity, bottom-up simulations suggest that electricity use of dwellings could increase by 10–20% when occupants telework, depending on the number of people staying at home [25]. However, the most recent literature review on telework and home energy use reports that no paper was found that used detailed power metering to measure electricity use during teleworked days [21], so we have no confirmation concerning these figures. In short, the impact of telework on home energy use still appears uncertain.

This review reveals that there is a lack of data concerning energy consumption behavior in residential buildings when people spend more time at home, whether this increase of occupancy is due to the COVID-19 pandemic or to telework. Most of the scientific knowledge on this topic is based on rough estimates or numerical simulations, with no detailed measured data. Since people are expected to stay at home more often in the future [26], it is important to know how a shift in occupancy will drive energy consumption in residential buildings. Most of the reports on the impact of COVID-19 lockdown on energy use in buildings focused on one aspect of energy use. For instance, some strictly look at consumption of electricity. Although the information is valuable, it would be preferable to have a full assessment of energy use, since there are various energy sectors in buildings (space heating, electricity, cooling…). Most studies on the impact of COVID-19 focus on electricity use, probably because it is the most available data. The "stochastic" aspect of occupant behavior must also be considered when evaluating the impact of the COVID-19 lockdown. In general, there is a lot of temporal and spatial variability in the energy consumption patterns in residential buildings since occupant behavior changes day after day. Differences of consumption observed under the lockdown might not be due the lockdown itself, but to the 'natural' variation. Statistical tests are needed for a thorough assessment of energy consumption patterns under the lockdown.

In this paper, we aim to address these shortcomings by doing a full assessment of energy use in a residential building during the lockdown. This case study building is a 40-dwelling social housing building located in Quebec City, Canada. It has been heavily monitored since occupation started in 2015 [27]. This paper compares three main energy expenditures in dwellings (i.e., space heating, domestic hot water and electricity) before and during the lockdown. This comparison is based on statistical tests to separate the impact of the COVID-19 lockdown from the natural variability of energy consumption patterns in buildings. We specifically aim to answer two questions: (i) Did the COVID-19 lockdown lead to changes in total energy consumption? and (ii) Did the COVID-19 lockdown lead to changes in consumption patterns (i.e., time of the day at which energy is consumed)? Although the COVID-19 phenomenon is recent, we have not seen any such comparison in the literature so far, in particular for these three energy expenditures and using statistical tests. The following section describes in more details the case study and our methodology to estimate the pre and post COVID-19 differences of energy consumption. Then, Section 3 presents the results for electricity, domestic hot water and space heating. The timeline of the lockdown and its impact on energy use is also presented, followed by a short discussion.

## 2. Materials and methods

### 2.1. Case study building

The monitored building is a 40-apartment social housing building located in Quebec City, Quebec, Canada. The building has an annual heating demand of approximately 35 kWh/m$^2$. A district heating hot water loop provides heat to the building, which is then redistributed to the apartments by radiators. The district heating system also supplies energy for the domestic hot water system. There is no AC in the building, so thermal comfort in summer relies entirely on natural ventilation.

The building has been heavily monitored since its operation phase started in October 2015. For all 40 dwellings, space heating consumption and use of domestic hot water are recorded by sensors that probe water temperatures (at an accuracy of ±0.4%), flow (±0.3%) and energy (±0.7%) in pipes at the entrance and exit of each apartment. More documentation on the sensors that measure space heating and hot water use can be found in [28]. Additional data is measured from eight of the 40 dwellings: electricity consumption (as measured by Hydro-Québec, the supplier of electricity in Quebec), air temperature (±0.2 °C) and humidity (±3%). These measurements are performed every 10 min. Furthermore, window states (open/closed) and exhaust fans states (on/off) are recorded every minute for these eight dwellings. Centralized building data, such as its total heat and electricity consumption, is also collected at a 10-minute frequency. Hourly weather data is obtained from a nearby weather station (around 1.5 km).

### 2.2. Evaluating the impact of COVID-19 lockdown

The government of Quebec declared a health emergency related to the COVID-19 pandemic on March 13th, 2020. Unfortunately, a computer problem prevented data acquisition starting a few days before that date and due to the COVID-19 restrictions, the computer was only reactivated on March 25th, 2020. A day before, all non-essential services in the province were shut down for sanitary reasons. We have thus defined March 25th, 2020 as the beginning of the “COVID-19 period” for this study, meaning that we have compared energy use before and after that date. Schools, recreational and shopping centers, bars and restaurants and all non-essential businesses were already closed before March 25th. We have chosen to use data that goes up to July 25th, so the studied period has a duration of four full months. This period of time covers the reopening of the economy in the province of Quebec, which is summarized in Table 1.

For the sake of comparison, a control period is needed to assess whether the COVID-19 lockdown led to changes in energy consumption. This control period was chosen to be the year that goes from March 2019 to February 2020. Including the spring 2019 season allows us to have a dataset with comparable weather conditions to the ones observed during the lockdown, which can influence certain adaptive behaviors such as the use of space heating and windows. We also wanted the control period to end when the pandemic started, so that we could see if there was any immediate change in energy consumption, so the full year had to be used for the control period. Other control periods were used (such as using all 4 years of data that preceded the lockdown or only using the spring seasons of previous years) and yielded results similar to those obtained from the 1-year control period. For the sake of conciseness, only results from the 1-year control period are reported in this paper. According to operating agents of the building, household changes were minimal during the control year, so this variable was not taken into account in the comparison.

In this paper, we want to answer two questions: 1. Did the COVID-19 lockdown lead to changes in total energy consumption?, and 2. Did the COVID-19 lockdown lead to changes in consumption patterns (i.e. times of the day at which energy is consumed)? These questions are applied to the three main energy expenditures, i.e. i) Electricity, ii) Domestic hot water, and iii) Space heating, both at the scale of a multifamily residential building and of individual units. A logical hypothesis would be that by increasing the time spent in the building, the lockdown led to an increase in energy consumption, but reduced peak demands. These peaks usually happen early in the morning and during the evening, i.e. before people go to work and after they come back home. By restricting people at home during midday, occupants have more choice as to when they will undertake activities that consume energy.

**Table 1**
Summary of the different phases of the economy reopening in Quebec, Canada.

| Phase | Resuming activities | Date |
|---|---|---|
| Preliminary | Garage, Mining sector, Landscaping, Housing construction | April 15th |
| Stage 1 | Retail business with outdoor access | May 4th |
| Stage 2 | Primary schools, Construction sites, Manufacturing field (50 employees or 50% of employees) | May 11th |
| Stage 3 | Individual outdoor sports and activities | May 20th |
| Stage 4 | Manufacturing field (100%) | May 29th |
| Stage 5 | Shopping centres, Personal care services, Professional Health care | June 1st |
| Stage 6 | Summer camp, Restaurants, Outdoor team sports facilities | June 15th |
| Stage 7 | Places of worship, Cultural venues, Bars, Professional sports | June 25th |

To answer these questions, indicators are needed for a data-based comparison of energy-related behavior before and during the lockdown. The indicator chosen to answer the first question is the daily energy consumption:

$$I_1 = \sum_{i=1}^{24} E_i \tag{1}$$

where $E_i$ is the amount of energy consumed during hour i. The indicator that measures whether there were changes in the time of the day at which energy is consumed is based on the root mean squared error (RMSE):

$$RMSE = \sqrt{\sum_{i=1}^{24} \frac{\left(E_i - E_{i,control}\right)^2}{24}} \tag{2}$$

The average daily profile of energy consumption was computed from the control period data. Then, the energy profile of each day of the lockdown is compared to this average profile using Eq. (2). This comparison is made on an hourly basis. A large RMSE value means that the profile of the analyzed day greatly diverges from the average profile. However, this great divergence does not necessarily mean that consumption happened at different times during that day. It can be simply caused by the energy consumption levels being different, which is already measured by the first indicator. To take out this variable, we normalized all daily profiles by dividing them by the total energy consumption of that day:

$$I_2 = 100\% \times \sqrt{\sum_{i=1}^{24} \frac{\left(\frac{E_i}{\sum_{i=1}^{24} E_i} - \frac{E_{i,control}}{\sum_{i=1}^{24} E_{i,control}}\right)^2}{24}} \tag{3}$$

In short, we calculated the proportion of daily energy use for every hour. There is a high level of variability related to occupant behavior, which in turn yields a high variability of the energy consumption patterns. This means that for a single household, there can be significant day-to-day variations in energy consumption. These variations can also be seen between different months of a year. Therefore, there is a possibility that differences observed between the control and lockdown periods are due to the “natural” variance of consumption patterns and not caused by the COVID-19 lockdown itself. We thus need a statistical test for a proper assessment of the changes induced by the lockdown. This test compares the goodness of fit between the behavior observed before and during the lockdown. We chose the Z-test as our statistical test:

$$Z_{month} = \frac{\overline{x}_{control} - \overline{x}_{month}}{\sqrt{\frac{\sigma_{control}^2}{n_{control}} - \frac{\sigma_{month}^2}{n_{month}}}} \tag{4}$$

where $\overline{x}$ is the mean value, $\sigma$ the standard deviation of the value and n the number of days contained in the group (here $n_{control}$ is 365 days with the 1-year control period). For each day contained in the control and lockdown periods, we calculated the two indicators $I_1$ and $I_2$. Then, we separated all days in monthly-based groups, which enabled us to compute the average $\overline{x}$ and standard deviation $\sigma$ values of these two indicators for each month. By comparing these values to the ones related to the complete control period ($\overline{x}_{control}$ and $\sigma_{control}$), we calculated the Z-score associated to each month with Eq. (4). We then translated these Z-scores into p-values. These p-values indicate the probability of obtaining Z-scores at least as extreme as those observed under the assumption that the month and control distributions are the same. We used the *normcdf* function in Matlab to directly convert Z-scores into p-values. Z-scores and p-values were calculated for all months in both the control and lockdown periods.

Use of electrical appliances and domestic hot water consumption are mostly non-adaptative behaviors, i.e. the influence of environmental conditions on these behaviors is minimal [29–31], with the notable exception of the change in the use of artificial lighting according to the seasons. For these energy expenditures, we can directly apply the two chosen indicators to answer our questions. On the other hand, space heating is strongly impacted by outdoor conditions. Comparing directly space heating consumption during the lockdown with that during the control period would thus be misleading. Each day of the control and lockdown periods were thus adjusted when calculating the first indicator by dividing the heat consumption of every hour by the total heating degree-hours of the day:

$$I_{1,heating} = \frac{\sum_{i=1}^{24} E_i}{HDH_{day}} \tag{5}$$

where $HDH_{day}$ is the heating degree-hours of the day as calculated with a base temperature of 18 °C. As for the second indicator, since hourly data is already normalized with the total day consumption, the normalization with the heating degree-hours was not needed.

## 3. Results and discussion

### 3.1. Electricity consumption

The case study building consumed a total of 417.5 kWh per day during the control period, which corresponds to a daily average of 10.4 kWh per dwelling. In the total lockdown period, the average daily electricity use was 10.6 kWh per dwelling – electricity consumption increased by less than 2% during the lockdown. Considering that the “randomness” of occupant behavior in buildings can generate month-to-month variations, this increase appears non-significant. However, differences can be seen when breaking down the lockdown period by months. The electricity consumption reached an average daily value of 12.2 kWh per dwelling in the first month of the lockdown (+17.5% increase in electricity consumption compared to the control period), 10.5 kWh in the second month (+1.0%), 9.8 kWh in the third month (−5.8%) and 10.5 kWh in the fourth month (+1.0%). For the sake of clarity, we will refer to the first month as ‘April 2020’ for the rest of the paper even if the real first month goes from March 25th to April 25th. The same will be done for the three other months of the lockdown, which will be referred as the calendar month that best fit their covered period. In the 12 months contained in the control period, there was 11.4 kWh per dwelling used per day in the month with the maximal electricity consumption level (October 2019) and 9.8 kWh in the month with the lowest consumption rate (April 2019). The daily demand of 12.2 kWh per dwelling reached during April 2020 thus represents a level of consumption that was not seen during the control period. It appears that the lockdown led to a direct increase in electricity consumption during that month, which was the month with the most stringent lockdown measures (see Table 1).

Fig. 1 plots the average daily electricity consumption profile of the building for the control period and each of the four months of the lockdown. The differences between the months of lockdown are apparent in this figure. In April 2020, electricity use is more uniformly distributed at a relatively high rate of consumption from 8AM to 9PM, which contrasts with the typical consumption profile during the control period where electricity consumption slightly raises throughout the day until a peak of consumption is reached in the evening. Note that in spite of the more evenly spread profile, the peak demand observed during the first month of the lockdown was as high as those seen during the control period. The reduction of consumption in the evening is even more apparent in May and June, where people consumed more electricity during the day compared to the control period, but drastically reduced

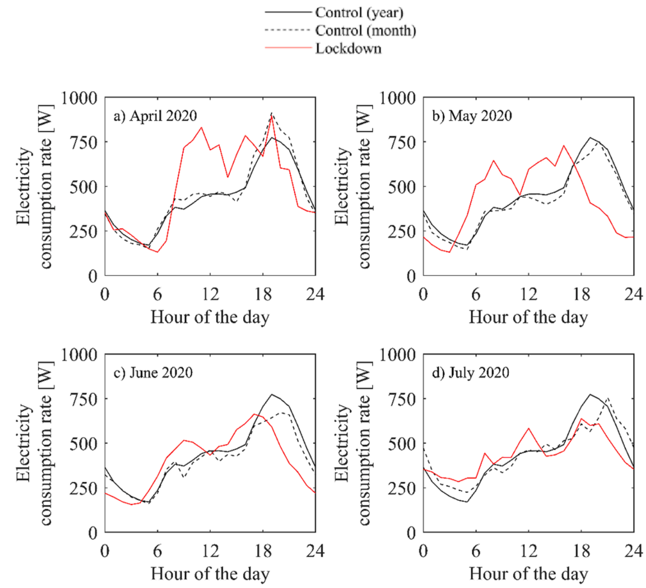


**Fig. 1.** Building average daily electricity consumption profiles observed during the control year and the fourth months of lockdown. Each month of the lockdown is also compared with its corresponding month in the control period (e.g.: April 2020 with April 2019). Consumption is normalized by the number of dwellings.

their consumption in the evening. In July, the pattern of consumption returns to the expected behavior from the control period as the two curves become very close. The last months of the lockdown are in the summer, which could explain in part why electricity use is lower in the evening compared to the control period (the control period includes winter months during which more artificial lighting is needed).

Tables 2 and 3 respectively display the average values of indicators $I_1$ and $I_2$ for the eight dwellings whose electrical consumption was monitored. From these tables, we can see that households react differently to the lockdown. For instance, the 7th dwelling saw an important increase of electricity consumption in April 2020, but on the other hand there was actually a decrease in the 6th dwelling for the same month. The RMSE value in the 1st dwelling was 3.28% for the control year and 4.98% for April 2020, meaning that times of the day when occupants consumed electricity changed during the lockdown. In the 4th dwelling, RMSE went down from 3.43% to 1.98% in April 2020. This signifies that the daily profiles observed that month were actually close to the average control profile. These differences between households, which could be explained by socioeconomical factors (age of occupants, employment status…), show that the changes in energy consumption observed during the lockdown vary across dwellings. Table 3 shows that the average RMSE value measured for the whole building was 1.98% during April 2020 (34.7% bigger than the average RMSE value of the control year), 1.69% for May (+15.0%), 1.39% in June (−5.4%) and 1.42% in July (−3.4%). Occupants at the building scale used electricity at different times of the day during the first two months of the lockdown, confirming what was shown in Fig. 1.

To measure the goodness of the fit between the control period and every month considered in this study, the p-value related to the two indicators are shown in Fig. 2. The bottom section in the graphs represents the values calculated for the 12 months of the control period whereas the top section exhibits the values related to each month of the lockdown. On the left-hand side, we have the values for the eight monitored dwellings and the single bar on the right-hand side is for the whole building. The p-value expresses how good the behavior observed during a single month matches with the one observed across the complete control period, so yellow boxes in the grids convey that there is a large discrepancy in consumption behavior between the month

**Table 2**
Average daily consumption of electricity for the building and eight monitored dwellings during the control and lockdown periods. Values are expressed in kWh/unit.

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Building |
|---|---|---|---|---|---|---|---|---|---|
| *Control months* | | | | | | | | | |
| March 2019 | 10.1 | 11.5 | 8.0 | 11.4 | 17.9 | 6.6 | 9.4 | 8.9 | 10.5 |
| April 2019 | 8.9 | 9.4 | 8.4 | 10.3 | 16.4 | 6.6 | 9.3 | 8.7 | 9.8 |
| May 2019 | 10.3 | 12.4 | 9.4 | 12.0 | 12.5 | 6.5 | 7.6 | 8.8 | 9.9 |
| June 2019 | 10.6 | 13.0 | 8.8 | 12.2 | 13.3 | 7.1 | 11.6 | 9.1 | 10.7 |
| July 2019 | 11.9 | 12.1 | 9.9 | 11.0 | 16.1 | 7.0 | 10.8 | 10.2 | 11.1 |
| August 2019 | 11.5 | 14.0 | 9.1 | 14.1 | 14.9 | 7.3 | 11.0 | 8.2 | 11.3 |
| September 2019 | 11.6 | 11.7 | 9.0 | 13.6 | 13.0 | 7.5 | 10.8 | 7.6 | 10.6 |
| October 2019 | 14.2 | 11.9 | 9.8 | 14.9 | 13.3 | 7.3 | 11.3 | 8.2 | 11.4 |
| November 2019 | 12.8 | 12.4 | 9.4 | 14.0 | 11.5 | 8.0 | 11.1 | 8.2 | 10.9 |
| December 2019 | 12.3 | 9.4 | 8.5 | 11.2 | 13.2 | 7.6 | 10.9 | 7.2 | 10.0 |
| January 2020 | 15.3 | 8.8 | 4.9 | 11.5 | 12.7 | 7.5 | 10.8 | 8.2 | 10.0 |
| February 2020 | 8.9 | 8.4 | 3.6 | 12.2 | 17.9 | 10.1 | 11.9 | 9.4 | 10.3 |
| Average | 11.5 | 11.3 | 8.2 | 12.4 | 14.4 | 7.4 | 10.5 | 8.6 | 10.5 |
| *Lockdown months* | | | | | | | | | |
| April 2020 | 10.3 | 12.3 | 12.8 | 14.7 | 10.9 | 6.2 | 14.2 | 16.6 | 12.3 |
| May 2020 | 10.8 | 9.1 | 9.5 | 11.4 | 11.8 | 6.6 | 11.0 | 11.2 | 10.5 |
| June 2020 | 10.3 | 9.7 | 8.4 | 11.2 | 13.1 | 6.5 | 9.7 | 9.2 | 9.8 |
| July 2020 | 9.8 | 7.7 | 3.6 | 19.5 | 22.0 | 7.0 | 5.5 | 10.2 | 10.5 |
| Average | 10.3 | 9.7 | 8.6 | 14.2 | 14.4 | 6.5 | 10.1 | 11.8 | 10.6 |

**Table 3**
Average daily RMSE values related to electricity use for the building and eight monitored buildings during the control and lockdown periods. Values are expressed in %.

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Building |
|---|---|---|---|---|---|---|---|---|---|
| *Control months* | | | | | | | | | |
| March 2019 | 3.52 | 3.51 | 3.69 | 3.77 | 2.98 | 2.64 | 3.82 | 3.13 | 1.44 |
| April 2019 | 3.78 | 3.83 | 3.62 | 4.20 | 3.12 | 2.58 | 3.65 | 3.05 | 1.43 |
| May 2019 | 3.36 | 3.70 | 3.74 | 3.43 | 3.16 | 2.40 | 3.54 | 2.98 | 1.42 |
| June 2019 | 3.44 | 3.90 | 3.65 | 3.50 | 3.22 | 2.73 | 3.45 | 3.49 | 1.49 |
| July 2019 | 3.62 | 3.38 | 3.45 | 3.04 | 3.23 | 2.43 | 3.60 | 3.23 | 1.48 |
| August 2019 | 3.70 | 3.86 | 3.67 | 3.37 | 3.19 | 2.68 | 3.68 | 3.39 | 1.54 |
| September 2019 | 3.48 | 4.14 | 3.62 | 2.99 | 3.27 | 2.64 | 3.79 | 3.32 | 1.50 |
| October 2019 | 3.07 | 3.81 | 4.09 | 3.19 | 3.28 | 2.84 | 3.65 | 2.75 | 1.48 |
| November 2019 | 3.26 | 3.62 | 3.93 | 3.00 | 3.58 | 2.73 | 3.69 | 3.17 | 1.48 |
| December 2019 | 2.97 | 3.63 | 4.19 | 3.60 | 3.57 | 3.16 | 3.31 | 3.62 | 1.48 |
| January 2020 | 2.52 | 3.80 | 4.01 | 3.54 | 3.32 | 2.91 | 3.50 | 3.56 | 1.45 |
| February 2020 | 2.69 | 3.34 | 3.28 | 3.48 | 3.15 | 2.70 | 3.30 | 2.98 | 1.47 |
| Average | 3.28 | 3.71 | 3.74 | 3.43 | 3.26 | 2.70 | 3.58 | 3.22 | 1.47 |
| *Lockdown months* | | | | | | | | | |
| April 2020 | 4.98 | 2.26 | 3.35 | 1.91 | 2.89 | 2.32 | 4.21 | 3.41 | 1.98 |
| May 2020 | 3.03 | 3.59 | 4.72 | 3.64 | 3.88 | 3.13 | 3.82 | 3.25 | 1.69 |
| June 2020 | 3.32 | 3.97 | 4.62 | 3.75 | 3.93 | 2.92 | 4.77 | 3.43 | 1.39 |
| July 2020 | 2.66 | 3.74 | 3.67 | 3.32 | 3.21 | 2.68 | 3.50 | 2.98 | 1.42 |
| Average | 3.50 | 3.39 | 4.09 | 3.15 | 3.48 | 2.76 | 4.07 | 3.27 | 1.62 |

represented by these pixels and the control period.

For the total day consumption, there are multiple months with yellow pixels during the control period, so the fact that the level of consumption is different between months is not necessarily due to the COVID-19 lockdown. However, the concentration of yellow pixels is higher during the lockdown period. Using a cut-off significance level of p-value = 0.05, there were a total of 34 cases during the control period where the difference in consumption level between the control period and these specific months was statistically significant. Considering that the control period contains a total of 96 values (12 months during the control year times 8 monitored dwellings), this means that 35.4% of the months in the control period were statistically different in terms of the electricity consumption rate. During the lockdown, 59.4% of the months (19 out of 32) were statistically different. In April 2020, 6 out of the 8 dwellings had changes in behavior in terms of daily consumption.

The differences between the control and the lockdown periods is even more distinct when looking at the RMSE values, which again express if there were changes in time of the day when electricity was consumed. Yellow cases are rarer during the control period for the RMSE value than there were for the total day consumption. The particularly blue bar at the right side of the graph means that at the building scale there was zero month during the control period that had a significant difference with the whole control period. At the dwelling scale, 12 control months out of 96 (12.5%) were different. During the lockdown, there was 11 statistically different months out of 32 for a ratio of 34.4%, which is a large increase when compared to the control period. The statistically different months are particularly concentrated during the first two months of the lockdown when application of lockdown measures was at its most intensive stage. In fact, in July 2020, the behavior appears to return to the norm of the control period with a high concentration of blue cases.

We saw that in the control year 35.4% of the months at the dwelling scale statistically differ from the average of the whole control period when looking at the total electricity consumption. If we assume this ratio to be the true rate of 'different' months in a typical year, we can compute the probability of observing at least as many 'different' months as we recorded during the lockdown. For instance, in April 2020, 6 out of the 8 dwellings were behaving differently in terms of total electricity consumption. There is a 2.51% probability of this occurring if the proportion of 'different' months is indeed 35.4%. Results for all months and

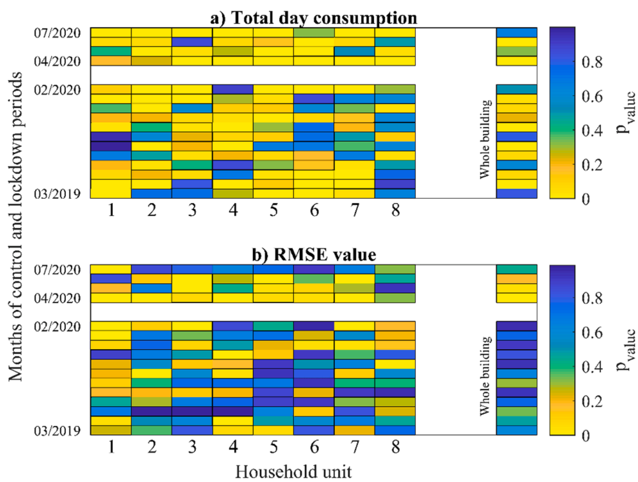


**Fig. 2.** Statistical test scores that measure how the monthly a) total day consumption, and b) RMSE values for electricity consumption differ from the values for the whole control period.

indicators are displayed in Table 4. The number of dwellings with different behavior in terms of RMSE value (when occupants consumed electricity) is particularly rare for the first month of the lockdown with the probability of having 5 'different' dwellings out of 8 being 0.09% according to data from the control period. The probability that the lockdown had an impact on times when occupants used electricity during that month is thus practically equal to one.

### 3.2. Domestic hot water consumption

The baseline DHW consumption of the case study building measured during the control period is 152.6 L per dwelling every day. During the lockdown, this figure was 178.0 L in April 2020 (17.2% increase), 150.9 L in May (−1.1%), 145.0 L in June (−5.0%) and 115.5 L in July (−24.3%). These variations of DHW consumption appear high, but they are not unprecedented. In the 12 months of the control year, the consumption rate fluctuated between 114.2 and 180.2 L per dwelling per day. There is a great month-by-month variability in DHW consumption even at the scale of the building, as seen in Table 5. Like their electricity counterparts, Tables 5 and 6 give the average total daily consumption and RMSE values calculated for all control and lockdown months. Although data from 40 dwellings are available, we decided for the sake of simplicity to only report in these two tables the measurements from the same 8 dwellings shown in Tables 1 and 2. These dwellings are ranked in the same order as in the previous tables. The monthly variability in total DHW consumption observed during the control year at both the dwelling and building scales means that it would take extremely large differences between the control and the lockdown months for the impact of the lockdown on total DHW consumption to be deemed statistically significant. An interesting aspect when comparing Table 2 and Table 5 is that when looking at individual dwellings, some observations made from the former table are also present in the latter. For instance, it was shown in Table 2 that the 6th dwelling was different from the other dwellings in that electricity use was lower during the lockdown than during the control year. This is also true for hot water use, where the rate of consumption went from 88.0 L/day to 69.9 L/day during the lockdown.

**Table 4**
Probability of observing at least as many dwellings with different behaviors of electricity consumption for the four months of the lockdown according to the control dataset.

| Months | Total daily consumption [%] | RMSE value [%] |
|---|---|---|
| April 2020 | 2.51 | 0.09 |
| May 2020 | 11.11 | 26.58 |
| June 2020 | 96.75 | 6.47 |
| July 2020 | 2.50 | 64.72 |

As to when occupant consumed hot water during the lockdown, the comparison with the control period is made in Fig. 3. During the control year, hot water consumption is typically minimal during the night, then a first peak is reached in the morning followed by a slowdown in the afternoon until a larger peak is observed during the evening. In the first two months of the lockdown, consumption of hot water is much larger during the day than in the evening – an observation that was also seen for electricity. It appears that occupants took advantage of their increased time at home to do hot water intensive activities during the day. This effect seems to have lasted for two months as consumption in June and July 2020 went back to the typical profile with the maximal peak of consumption reached in the evening. In fact, the peak of consumption went from happening at 3PM in May to 6PM in June and 7PM in July. 7PM was the time when the peak of consumption happened during the control year.

The average RMSE value for April 2020 related to the whole case study building is 3.23% (see Table 6), which is substantially higher than the RMSE values calculated for all 12 control months. The RMSE value was also higher in May 2020 than in the control months with a value of 2.60% and then went back to standard values in June and July.

Fig. 4 showcases the p-values associated to each month for DHW daily consumption and RMSE value for all 40 dwellings. As seen for electricity, there are multiple yellow pixels (i.e., months that have large discrepancies with the whole control period in terms of consumption patterns) in the control period for both indicators. Out of the 480 months contained in the control period at the dwelling scale (12 months times 40 dwellings), 197 (41%) were statistically different from the average computed from the whole control period. In the lockdown, this ratio actually went down to 37.5% (60 months out of 160). Even in April 2020, only 14 out of 40 dwellings (35.0%) displayed significant differences in behavior. It appears that the lockdown did not impact the total consumption of DHW at the scale of the dwelling. These results suggest that even if people spend more time at home, they do not necessarily use more hot water. However, the times when they use that water does change as previously shown in Fig. 3. 139 months out of the 480 months of the control period (28.9%) were different in terms of RMSE value. This ratio went up to 50.0% (80 out of 160) during the lockdown. In April 2020, 60% of the dwellings (24 out of 40) exhibit differences when looking at the RMSE value.

As was done for electricity, we computed the probability of observing the number of dwellings with a different behavior during the lockdown based on what control data suggests. These probabilities are displayed in Table 7. Once again, the results heavily suggest that the lockdown directly affected when people used hot water in April 2020 (probability of 0.02% of seeing 24 'different' dwellings out of 40) and that the lockdown did not lead to a change in total DHW consumption.

### 3.3. Space heating consumption

Fig. 5 reports the proportion of the average daily space heating at each hour of the day, for the four lockdown months and for the control year. During the control year, the space heating consumption is mostly constant throughout the day. There is a slight decrease of consumption during midday, potentially due to solar radiation partially heating the building. There is a smaller decrease in the evening which corresponds to periods when more heat is internally generated via electrical appliances. Because the space heating consumption of the building appears to be marginally affected by its occupation schedules, it would be expected for the lockdown to have a minimal impact on the consumption of space heating. This seems to be the case according to the four dashed curves in Fig. 5. No major departure from the control period is found when comparing these curves with the profile for the control period. Note that since outdoor conditions are different for all the plotted curves, we have

**Table 5**
Average daily consumption of domestic hot water for the building and eight monitored buildings during the control and lockdown periods. Values are expressed in L/unit.

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Building |
|---|---|---|---|---|---|---|---|---|---|
| *Control months* | | | | | | | | | |
| March 2019 | 89.7 | 229.0 | 217.1 | 38.9 | 148.1 | 94.2 | 480.3 | 117.4 | 121.1 |
| April 2019 | 135.0 | 210.7 | 242.0 | 100.7 | 160.7 | 70.0 | 536.3 | 123.3 | 130.2 |
| May 2019 | 234.5 | 342.9 | 262.9 | 96.5 | 173.2 | 76.1 | 443.5 | 123.2 | 146.9 |
| June 2019 | 275.0 | 324.7 | 268.3 | 108.3 | 159.7 | 86.0 | 639.0 | 134.7 | 165.5 |
| July 2019 | 304.2 | 270.6 | 306.5 | 95.8 | 211.3 | 91.6 | 506.1 | 183.5 | 169.5 |
| August 2019 | 338.7 | 328.7 | 282.3 | 154.2 | 200.0 | 100.3 | 602.3 | 159.0 | 179.6 |
| September 2019 | 278.6 | 277.9 | 272.9 | 98.9 | 148.6 | 85.4 | 523.6 | 132.1 | 155.3 |
| October 2019 | 320.6 | 306.5 | 292.3 | 130.3 | 167.7 | 85.2 | 556.5 | 185.8 | 174.7 |
| November 2019 | 328.3 | 350.0 | 285.7 | 147.3 | 165.7 | 109.7 | 606.7 | 188.0 | 180.1 |
| December 2019 | 289.4 | 193.9 | 299.4 | 130.0 | 205.5 | 83.5 | 568.1 | 162.9 | 156.3 |
| January 2020 | 250.0 | 185.0 | 166.3 | 135.0 | 192.0 | 90.3 | 440.0 | 134.0 | 138.3 |
| February 2020 | 90.0 | 130.6 | 56.5 | 129.0 | 150.3 | 83.9 | 408.4 | 96.8 | 114.2 |
| Average | 244.5 | 262.5 | 246.8 | 117.5 | 173.6 | 88.0 | 525.9 | 145.1 | 152.6 |
| *Lockdown months* | | | | | | | | | |
| April 2020 | 245.9 | 312.5 | 382.4 | 211.5 | 182.9 | 74.6 | 633.1 | 283.8 | 178.9 |
| May 2020 | 192.6 | 167.8 | 289.7 | 122.7 | 192.7 | 82.3 | 601.3 | 147.1 | 150.9 |
| June 2020 | 212.2 | 233.0 | 260.4 | 112.9 | 170.0 | 79.9 | 524.3 | 148.4 | 145.0 |
| July 2020 | 156.8 | 206.0 | 51.0 | 64.2 | 175.0 | 42.7 | 62.7 | 124.9 | 115.5 |
| Average | 201.9 | 229.8 | 245.8 | 127.8 | 180.2 | 69.9 | 455.4 | 176.1 | 146.7 |

**Table 6**
Average daily RMSE values related to domestic hot water use for the building and eight monitored buildings during the control and lockdown periods. Values are expressed in %.

| Months | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Building |
|---|---|---|---|---|---|---|---|---|---|
| *Control months* | | | | | | | | | |
| March 2019 | 11.76 | 8.90 | 9.83 | 10.91 | 9.70 | 9.97 | 7.00 | 9.28 | 1.95 |
| April 2019 | 11.46 | 8.85 | 10.11 | 11.52 | 9.62 | 10.81 | 7.20 | 9.14 | 2.16 |
| May 2019 | 9.12 | 7.79 | 9.48 | 11.56 | 9.82 | 10.58 | 7.65 | 8.25 | 1.94 |
| June 2019 | 8.56 | 7.45 | 9.96 | 11.67 | 10.61 | 10.21 | 7.23 | 9.17 | 2.19 |
| July 2019 | 8.59 | 8.65 | 9.74 | 11.54 | 10.28 | 9.53 | 8.89 | 8.83 | 2.34 |
| August 2019 | 8.00 | 8.69 | 9.69 | 11.23 | 10.53 | 9.63 | 7.58 | 8.97 | 2.19 |
| September 2019 | 8.46 | 8.18 | 8.99 | 12.20 | 10.96 | 9.28 | 7.59 | 8.62 | 2.59 |
| October 2019 | 8.18 | 7.68 | 8.93 | 10.99 | 1.07 | 8.74 | 7.35 | 8.23 | 2.06 |
| November 2019 | 8.72 | 8.09 | 8.89 | 11.20 | 11.18 | 9.94 | 7.35 | 7.97 | 2.05 |
| December 2019 | 8.76 | 10.06 | 8.59 | 11.45 | 9.67 | 10.78 | 7.05 | 8.67 | 2.02 |
| January 2020 | 8.21 | 12.13 | 10.65 | 10.29 | 10.30 | 10.51 | 7.46 | 8.84 | 2.19 |
| February 2020 | 10.18 | 11.02 | 13.79 | 9.98 | 10.24 | 10.51 | 7.55 | 8.95 | 2.04 |
| Average | 9.17 | 8.96 | 9.89 | 11.21 | 10.25 | 10.04 | 7.49 | 8.74 | 2.14 |
| *Lockdown months* | | | | | | | | | |
| April 2020 | 10.65 | 7.55 | 10.74 | 12.31 | 12.02 | 10.47 | 8.42 | 10.18 | 3.23 |
| May 2020 | 10.24 | 10.41 | 10.60 | 12.63 | 11.04 | 10.65 | 7.77 | 10.68 | 2.60 |
| June 2020 | 8.23 | 12.02 | 9.94 | 10.93 | 10.33 | 11.20 | 7.42 | 9.46 | 2.13 |
| July 2020 | 7.11 | 11.23 | 14.25 | 17.33 | 10.89 | 12.07 | 13.63 | 9.48 | 2.23 |
| Average | 9.06 | 10.30 | 11.38 | 13.30 | 11.07 | 11.10 | 9.31 | 9.98 | 2.55 |

decided to show the proportion of the daily heating demand in Fig. 5 instead of directly plotting the average heat consumption profiles.

The p-values related to our two indicators for space heating are displayed in Fig. 6. The grids are bluer when compared with their electricity and DHW counterparts, which signifies that there is less month-to-month variability for space heating consumption. During the control period, 1.7% of the months (8 out of 480) were different in terms of their daily space heating consumption and 8.8% (42 out of 480) in terms of the RMSE value. These ratios for the lockdown period respectively are 1.2% (2 out of 160) and 11.9% (19 out of 160). In other words, no major change is observed between the control and lockdown periods.

Occupants can affect the space heating demand by their control of the thermostat. We compared the measured indoor temperatures before and during the lockdown and found no major difference. The average indoor temperature was measured at 23.57 °C before the lockdown, with a standard deviation of 0.42 °C. During the lockdown, these figures were respectively 23.48 and 0.39 °C. In other words, the thermostat control did not appear to have changed during the lockdown. For this comparison, we excluded moments when the outdoor temperature was greater than 12 °C as we were looking for data when the heating system was operating. It should be noted that there is no programmable thermostat in the building.

The control of windows is another way for occupants to influence the heating demand of their dwelling, so we also compared the window opening behavior of the control and lockdown periods. For this part of the analysis, we restricted the control period to the months of April 2019 to July 2019, which correspond to the months of the year of the lockdown. In this way, the control period does not contain winter months when windows are more often closed. A window during this control period was opened on average 403.2 min per day. During the lockdown period, windows were opened 422.4 min per day, which represents an increase of 4.8%. In terms of the number of changes of the window state (opening/closing windows), the change between the two years is more drastic. A window was opened 6.4 times per day during the control period versus 8.7 times per day during the lockdown period (+35.4%). Consequently, once a window is opened, it remained opened on average for 63.0 min in the control period and 48.7 min during the lockdown. It appears that people staying at home led to a raise in window openings,

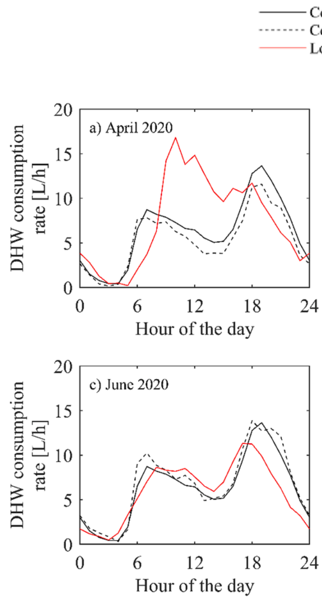


**Fig. 3.** Building average daily domestic hot water consumption profiles observed during the control year and the four months of lockdown. Each month of the lockdown is also compared with its corresponding month in the control period (e.g.: April 2020 with April 2019). Consumption is normalized by the number of dwellings.

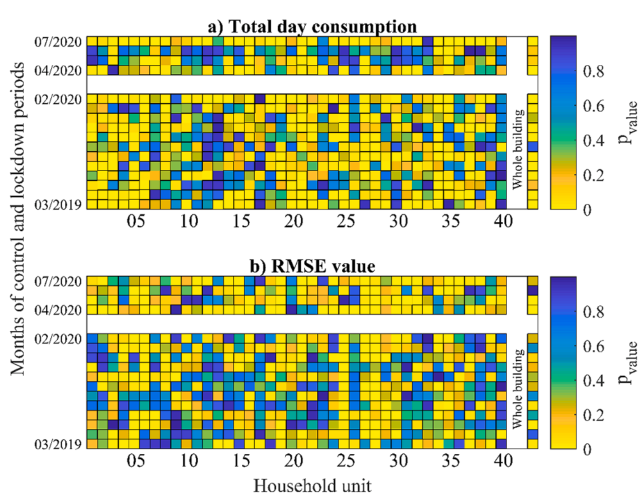


**Fig. 4.** Statistical test scores that measure how the monthly a) total day consumption, and b) RMSE values for DHW consumption differ from the values for the whole control period.

**Table 7**
Probability of observing at least as many dwellings with different behaviors of hot water consumption for the four months of the lockdown according to the control dataset.

| Months | Total daily consumption [%] | RMSE value [%] |
|---|---|---|
| April 2020 | 82.55 | 0.02 |
| May 2020 | 97.30 | 24.40 |
| June 2020 | 100.00 | 24.40 |
| July 2020 | 32.51 | 19.55 |

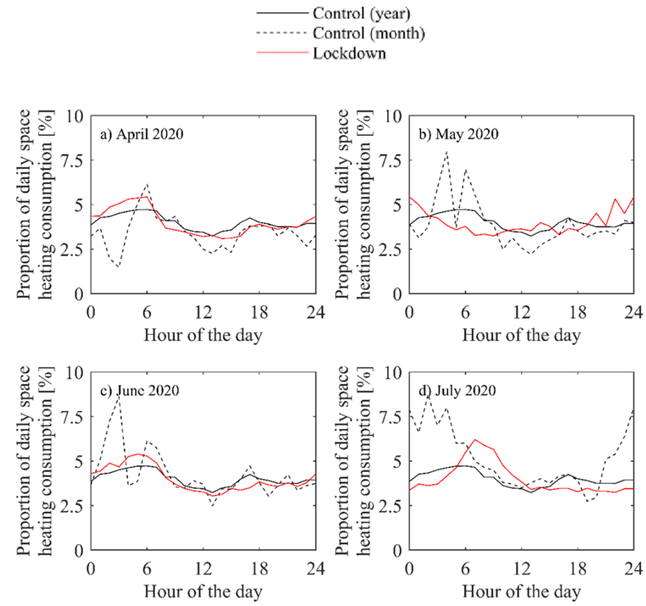


**Fig. 5.** Proportion of daily space heating consumption in the building for the average day observed during the control year and the fourth months of lockdown. Each month of the lockdown is also compared with its corresponding month in the control period (e.g.: April 2020 with April 2019).

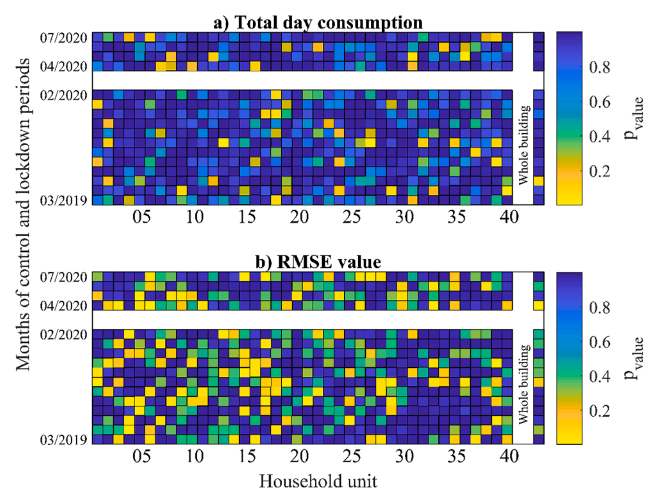


**Fig. 6.** Statistical test scores that measure how the monthly a) total day consumption, and b) RMSE values for space heating consumption differ from the values for the whole control period.

but that windows stayed opened for a shorter period.

### *3.4. Time evolution of the impact of lockdown*

The previous subsections showed that they are differences between the four months of lockdown, which could be related to changes in the governmental directives related to the lockdown. The effects of the lockdown on energy consumption were usually only seen during the first two months of the lockdown period, which goes from March 25th to May 25th, 2020. After May 25th, electricity and hot water appear to go back to the normal pattern of the control period. To study the longitudinal effects of the lockdown, we calculated the 7-day rolling averages of our two indicators at the building scale for both electricity and DHW use for the whole duration of the lockdown period. These averages are provided in Fig. 7. In Fig. 7, the upper dashed line represents the maximal value of the 7-day rolling averages measured during the control year. In all

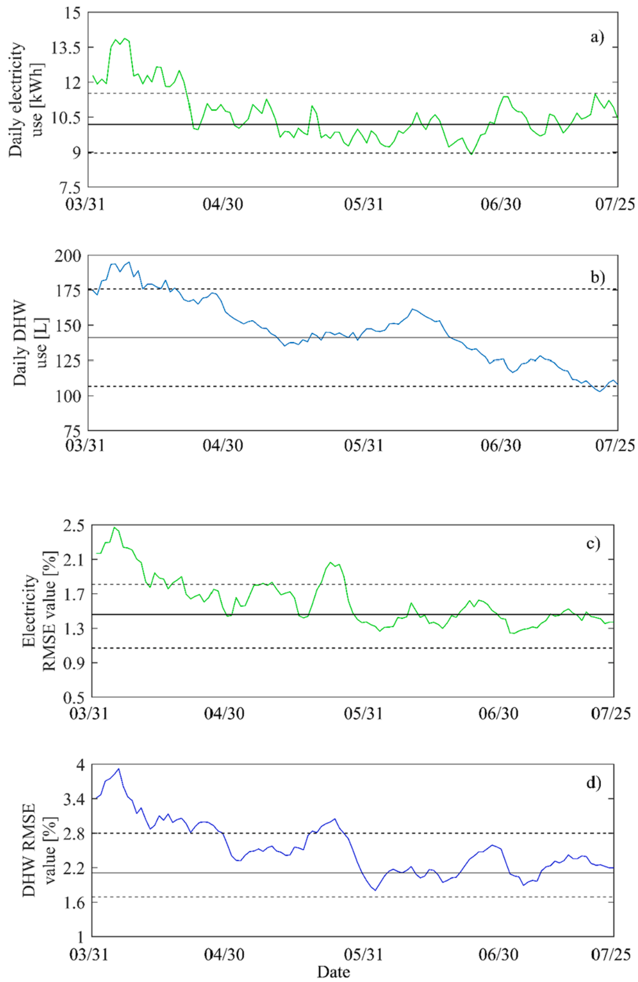


**Fig. 7.** Timeline evolution of the a) daily electricity use, b) daily DHW use, c) RMSE value for electricity, and d) RMSE value for DHW at the building scale during the lockdown. Dashed and full black lines convey the maximal, mean, and minimal value measured during the control year.

graphs, the indicators measured at the beginning of the lockdown period are above this maximal values lines, so the 7-day rolling averages at that time all reached levels unseen during the control period. In terms of total energy use, the 7-day averages remain above the maximal value from the control period until mid-April for both electricity and hot water. With the RMSE values, the impacts of the lockdown seem to last longer, until mid-May.

Again, the economy reopening in Quebec is summarized in Table 1. By mid-May, the date when the lockdown appears to stop having an impact on energy consumption in the case study building, primary schools, retail businesses, construction sites, the manufacturing sector and individual outdoor sports facilities were all re-opened. Economic activities still closed at that date include high schools and universities, shopping centres, bars and restaurants.

### 3.5. Discussion

The results showed that when the lockdown was at its most intensive stage, there was a significant shift of electricity and hot water consumption during the middle of the day. If we define the 'middle of the day' as going from 9AM to 5PM, the use of electricity during the middle in the day went up by 46% in April. This figure is even more staggering for hot water, as consumption of hot water increased by 103%. In our literature review, we mention reports that the electricity consumption during the middle of the day increased by approximately 20% in New York City and 30% in the UK. The increase of electricity consumption in the case study building of this study is larger than what has been observed so far in other buildings. Socioeconomical factors could explain this difference. For instance, we mentioned that there are many young families in the case study building, so their home lifestyle might be more affected by the closure of daycare centers and primary schools than most buildings. Other reasons explaining why the shift is larger in the case study building are differences in general lifestyle between different countries and the differences in terms of lockdown measures. We have found no other study to compare the 103% increase of hot water use during the middle of the day, so it is difficult to benchmark that results. Nonetheless, our study suggests that the shift of hot water consumption is considerably larger than the shift for electricity use.

The previous paragraph suggests that the general patterns observed during the COVID-19 lockdowns are also seen elsewhere, but at different scales. We expect these observed patterns to be present in similar buildings located in countries with general lifestyle close to the one of Canada. However, there might be differences in other countries. Given the current gap in literature, there is clearly a need to disseminate more energy data analysis related to the COVID situation, from different regions of the world and different contexts. We believe that this study is a first step towards expending the knowledge on the impact of lockdown on energy consumption patterns in residential buildings and will help to develop a thorough comparison between regions of the world.

It is uncertain to what extent the abovementioned shift in electricity and hot water use could be a sign of what is coming in future buildings. On one hand, the COVID-19 pandemic might go on for multiple years, and other pandemics (or, more probably, regionalized epidemics) are possible. Teleworking is also expected by many to become more popular, so the lifestyle seen during the lockdown might continue even without any lockdown measures. On the other hand, the shift lasted for approximately two months in the case study building, when lockdown measures were intense. The shift disappeared when the lockdown measures were loosened. At the time of writing this paper, many countries are facing a second wave of COVID-19 and partly "re-lockdowning" – we need to continue monitoring the impacts of such lockdowns on energy consumption in residential buildings to see if observations made in the first wave are repeated.

If a shift in energy consumption does occur in the future, it will have a direct impact on the operation and planning of energy utilities and governments, in addition to affect people's energy bills. The daily peaks of energy consumption can occur at a different time of the day, so demand-side management would be strongly affected by such a shift. The design and operation of residential buildings themselves might need to be adapted to this change so that their energy performance and indoor air quality are optimized to the new reality. For instance, if the lockdown occurred in summer, overheating issues would surely arise if people stayed at home all day and use electrical appliances, which drives up the internal heat gains. It might force buildings such as the one studied in this paper to install AC units instead of relying on natural ventilation to drive away the heat in summer. This would significantly change the energy breakdown of the building. Energy consumption in general would increase, with occupants using more electricity and hot water. Current low carbon roadmaps of the building sector [32–34] would need to consider such a change.

## 4. Conclusion

In this paper we have compared the energy consumption patterns observed in a Canadian social housing building during the COVID-19 lockdown with the ones that were measured before the lockdown. The 'lockdown' dataset constituted the first four months of the lockdown and is compared to our 'control' dataset which contains data for the full year preceding the lockdown. This comparison was made for electricity, domestic hot water, and space heating and applied to both the whole building and individual dwellings. Since energy consumption of a building has a natural variance on the temporal scale due to occupant behavior, our comparison is based on the Z statistical test.

At the building scale, there was a significant increase of electricity and hot water consumption during the first month of the lockdown, which was not seen during the control year. However, this increase only lasted for the first month of the lockdown and is not observed for the rest of the lockdown. An important proportion of daily electricity and hot water consumption was also displaced from the evening to midday.. Note that even though overall consumption increased, peak values during the lockdown were approximately the same as those observed under normal conditions – they just occurred at different times of the day. This time displacement of energy consumption lasted for the first two months of the lockdown. We did not observed changes in space heating consumption. At the dwelling scale, there is a great 'natural' dwelling-to-dwelling and month-to-month variance in energy use both during the lockdown and the control period. Some dwellings had significant changes during the quarantine while others saw no change at all.

## CRediT authorship contribution statement

**Jean Rouleau:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. **Louis Gosselin:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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