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The Impact of COVID-19 on the Energy Consumption of the Residential Buildings

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Abstract— Since the start of the COVID-19 pandemic, Governments were shutting down cities and setting them under strict lockdowns. These unpredictable lockdowns caused a major shift in the energy consumption demand structure. This paper will shine the light on the electricity, gas, and water consumptions of residential buildings from different locations in the United States, and determine if the consumptions at these residential buildings have or have not seen a clear increase or decrease. Next, the paper will compare percent changes in electricity, gas, and water consumptions with other residential buildings at three different climate zones and find out if the climate zone really has an effect on the intensity of the percent change of the electricity, gas, and water consumptions of a building during COVID-19. The consumption data that are used in this paper were acquired from the monthly bills of a number of students studying at the University of Dayton in the state of Ohio in the United States. These 24 months of data were divided into a Pre COVID-19 and during COVID-19 Year. Then, these were compared using percent change to determine how much more or less energy is used. An average residential building for each climate zone was selected and was compared in a similar fashion. From the analysis we did on the collected data, we observed that the climate zone indeed has an effect on the intensity of energy consumption during COVID-19, even if it is insignificant.

Keywords— COVID-19, Climate zone, Building energy consumption, Residential Buildings, Percent change

I. INTRODUCTION

There is no denying that COVID-19 has a significant impact on all of our lives. Many well-known industries have been viciously affected by this pandemic. A lot of companies and firms have permanently shut down. Countless businesses and shops have vanished; all in a short period of time. In addition, the energy industry is facing a big challenge which is the energy fluctuations during the COVID-19 [1]. It is believed that residential energy consumption has grown since the beginning of the pandemic. In addition, residential buildings from harsh climate zones could see a higher ramp in energy consumptions.

II. BACKGROUND

COVID-19 has an impact on many major sectors in the world and it created many challenges. These challenges vary from one sector to another and from one country to another. A lot of effort is needed to overcome these challenges.

A. ENERGY CONSUMPTION DEMAND CHALLENGES

Many energy companies are facing hard times to keep up with the changes that occurred in the past year. The energy use of the consumers has changed since the beginning of the virus due to the lockdowns, travel ban, and many other strict restrictions [2]. The change of energy demand during the pendemic is certainly a hard and crucial challenge in the energy industry [3]. Due to the lockdown, most of the electricity demand was focused on the residential sector while the industrial and commercial sectors had a decline in the demand for energy consumptions. According to the International Energy Agency, global energy demand could decline by 6% compared to 2019 [4]. The variation of energy consumption use is a serious problem in different countries. In 2020, Italy's electricity consumption decreased by 37% compared to the same period in 2019 [4]. In China, the decrease in energy consumption was an average of 1.5% which was identified in January 2020[5]. During the first trimester of 2020, Brazil's energy consumption dropped down in commercial and industrial sectors by 2.2% and 0.4% respectively[4].

B. ENERGY SECURITY CHALLENGES

Many starting small businesses and shops were failing to fight for their survival through the COVID-19 pandemic. People working on labor were losing their jobs because their work environment cannot be substituted with an online alternative during the lockdown. The rates of unemployment were intensifying. In fact, governments from different places in the world were put in a hot spot. Just in the United States, the government received more than twenty million unemployment support applications [5]. These numbers are alarming. Being Unemployed during lockdowns is challenging. Many will be on the radar of energy insecurity, specifically people who are from the low-income class and who are struggling with paying their energy bills even before the pandemic. Now, being with no monthly income during lockdowns, spending more time at home is projected to increase energy consumption. Not being able to handle more expensive utility bills will lead this group of people to use unconventional dangerous methods such as trash burning to keep their bodies at a comfortable level during lockdowns [6]. This suggests that low-income houses might use less energy during lockdowns due to the income constraint. Unlike the previous group of people, a study suggests, more energy is used by high-income households during the pandemic [7].

C. IMPACT ON RESIDENTIAL ELECTRICITY CONSUMPTION DEMAND

The electricity consumption demand has changed a lot since the start of the pandemic, especially after the governments declaring the lockdown restrictions. The residential sector has the most significant increase in electricity consumption demand during the lockdown period. For example, in Canada, the electricity consumption in the middle of the day has increased by 46% during the beginning of the lockdown [8]. In Australia, the residential electricity demand has increased by 14% when compared to one week before and after the lockdown. In Ireland, the increase in electricity demand was 11-20%, but the comparison was two weeks before and after the lockdown. The United States had a significant electricity demand in the residential sector with an increase of 32% when compared between 3 weeks after the stay home lockdown and the same periods of 2017-2019. This shows that the pandemic has indeed a significant impact on the electricity consumption in the residential sector which helped many energy companies to understand these changes in electricity demand patterns and try to overcome these challenges [9].

D. CLIMATE ZONE AND GEOGRAPHY

ASHRAE has implemented a standard that defines each climate zone based on its geographic location. These climate zones were defined mostly to have consistent regulation when constructing a building. It would be less complex for the builders to have a climate zone that can consist of many buildings that have the same regulations and requirements [10]. From figure 1, it shows that parts of zones 1,2, and 3 in A are hot-humid parts; zones 3 and 4 in A are mixed humid; zones 2 and 3 in B are hot dry; zone 4 in B is mixed dry; zones 5 and 6 are cold; zone 7 is very cold; zone 3 and 4 in C are marine, and zone 8 is subarctic [11].

III. METHODOLOGY

The methodology process started by calculating each building's percent change for the energy consumption before COVID-19 and after. Next, we divided each building into its appropriate climate zone. Then, all buildings that had enough data were compared to each other by the percent change. The next step was to choose a single building that had the average of all buildings that are within the same climate zone. Finally, the chosen house of each climate zone is going to be compared with each other.

A. CALCULATION

In each house, the percent change was calculated for electricity, gas, and water consumption between before and during COVID-19. The calculation includes the percent change of all months. This step was done to easily compare the houses and detect how much the energy consumption has changed compared to before. This equation is used to calculate the percent change (Equation 1).

$$Percent\ Change = \frac{During\ COVID19\ Consumption - Pre\ COVID\ Consumption}{Pre\ COVID\ Consumption} x\ 100 \quad (1)$$

B. USED DATA

Data for residential buildings used were collected from students' utility bills and were given to us by Dr. Alshatshati at the University of Dayton. The data includes 2 years' worth of information about monthly electricity, gas, and water consumptions from March 2019 to February 2021. A total of 38 was collected; however, 13 of them were excluded and will not be used in this paper since they did not provide all the monthly consumption values for the two years.

C. CLIMATE ZONE DISTRIBUTION

All chosen buildings were distributed into a suitable climate zone based on the ASHRAE standard. Each climate zone consists of many counties and cities. Climate zone 4A includes 6 chosen buildings, and these buildings are from different cities like Cincinnati, OH; Rome, GA; and Woodbine, MD. On the other hand, climate zone 5A consists of 18 buildings which were from Dayton, OH; Swanton, OH; Xenia, OH; Hamilton, OH; Mason, OH; Troy, OH; Avon, OH; Kettering, OH; Orchard Park, NY; Wauconda, IL; Cranberry Township, PA; and Springfield, IL. Finally, climate zone 3A includes just a single building located in Plano, TX.

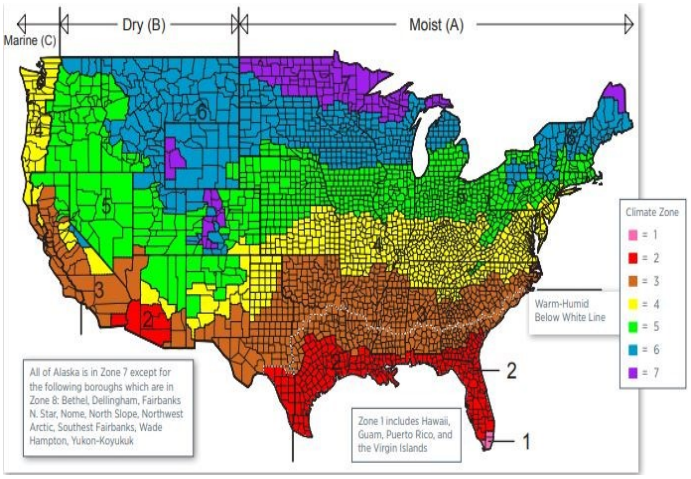

Figure 1 [11]

IV. RESULTS

In this section, the results of each climate zone are going to be discussed. For each climate zone, the percent change of electricity, gas, and water consumption of all buildings are going to be analyzed. Next, we will evaluate the percent change of the average buildings that were chosen in each of the three climate zones.

A. Climate Zone 5A (18 buildings)

The total electricity, gas, and water percent change for Zone 5A buildings are plotted in figure 2.

- Electricity consumption percent change:

When comparing year 1 (March 2019 till February 2020) with year 2 (March 2020 till February 2021) 8 out of 18 buildings from Zone 5A showed a less than 20% increase in electricity consumption. Four buildings had an increase between 20% to 40% in energy consumption, and Building #5 showed the most percent increase which is close to 52%. 3 buildings' electricity consumption were decreased during COVID-19. 2 of which had a very low percent decrease of about 2% and Building #6 had a 34% decrease in electricity consumption.

- Gas consumption percent change:

For the difference in gas consumption between the 2 years, most of the buildings experienced a percent increase in gas consumption ranging from 4% to 47%; whereas, only 4 buildings had a small reduction in the consumption not exceeding 5.25%.

- Water consumption percent change:

Next, when observing the water percent change from Figure 2, 14 buildings showed an increase in the usage of water, and 3 of them had more than a 30% increase. Further, 4 buildings had a decrease in the water usage ranging from 6% to 57%.

B. Climate Zone 4A (6 buildings)

The total electricity, gas, and water percent change for Zone 4A buildings are plotted in figure 3.

- Electricity consumption percent change:

3 buildings in this zone witnessed an increase in their electricity use when compared with the year before COVID-19. The electricity consumption of one of these buildings had doubled. In addition, 1 building did not see any increase or decrease in the total energy used when comparing the consumption of the 2 years. Also, 2 out of the 6 buildings showed a decrease in the electricity demand with one showing 25% less usage than the previous year.

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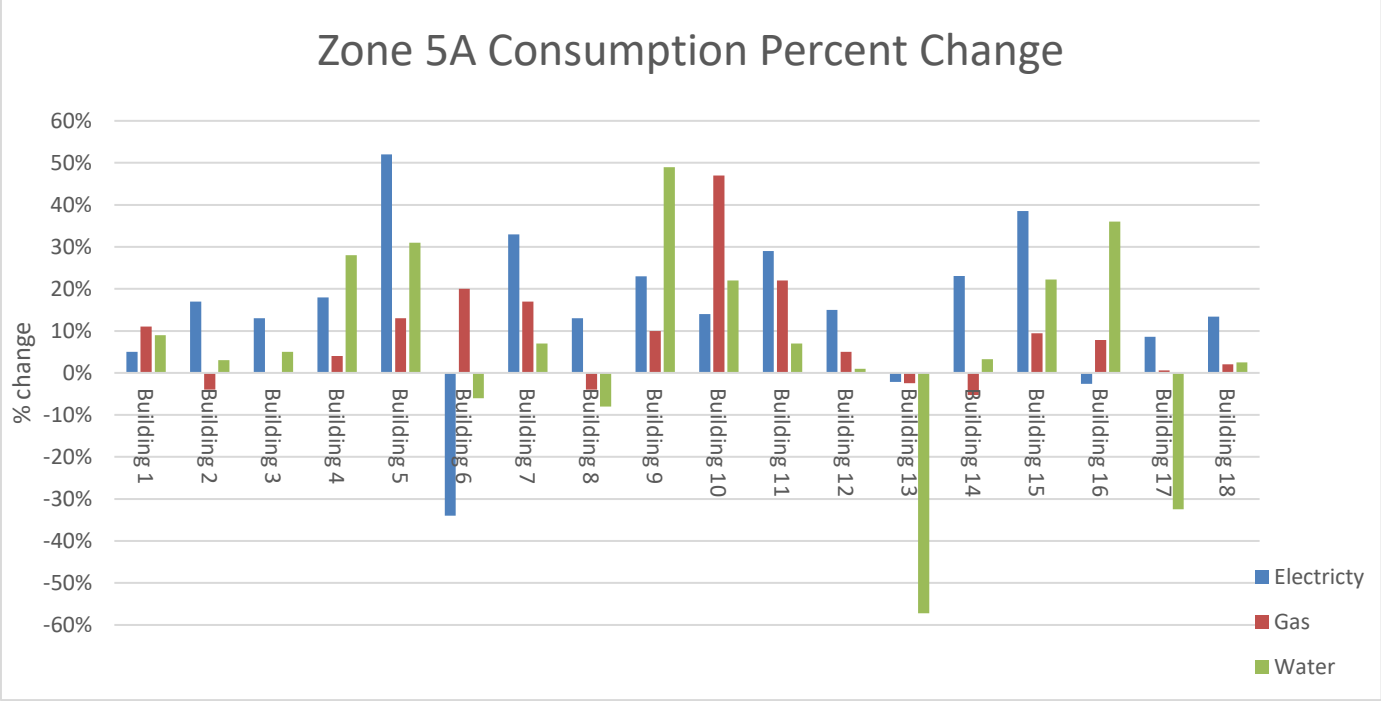

Figure 2: Zone 5A Consumption Percent Change

- Gas consumption percent change:

Furthermore, When considering the gas consumption, 4 buildings had a percent increase in the consumption ranging from 1% to 26%. 1 building had a 0% change in the consumption between the 2 years and 1 showed less than 4% reduction in the gas usage.

- Water consumption percent change:

Next, water consumption during COVID-19 year was less than pre-COVID-19 year for 4 buildings with a minor decrease ranging from 1.8% to 4.6%. While these buildings had a minimal percent decrease, the other 2 buildings saw a percent increase of 28% and 35% in water usage

C. Climate Zone 3A (1 building)

The total electricity, gas, and water percent change for Zone 3A buildings are plotted in figure 4.

- Electricity consumption percent change:

The building experienced a 26% increase in electricity usage when compared with pre-COVID-19 year.

- Gas consumption percent change:

Next, with regrads to the gas consumption, the building saw a 16% decrease.

- Water consumption percent change:

Also, the building water use was declined by 6% during COVID-19 year.

D. The Chosen Buildings

A comparison has been done between each average building that was selected; these buildings have been compared between each type of energy consumption which consisted of two approaches. The first one is comparing the total percent change of the buildings as shown in Figure 5. The second approach is relating the climate zone percent change to the four seasons of the year.

- Electricity consumption:

As shown in Table 1, climate zone 3A appeared to have the most percent increase in electricity consumption with a 26% increase. After that, climate zone 5A had the second most overall rise in electricity usage of 15%, and climate zone 4A took the last place with only a 2% increase. However, all of the climate zones experienced a percent increase in electricity consumption when compared with the pre-COVID-19 year.

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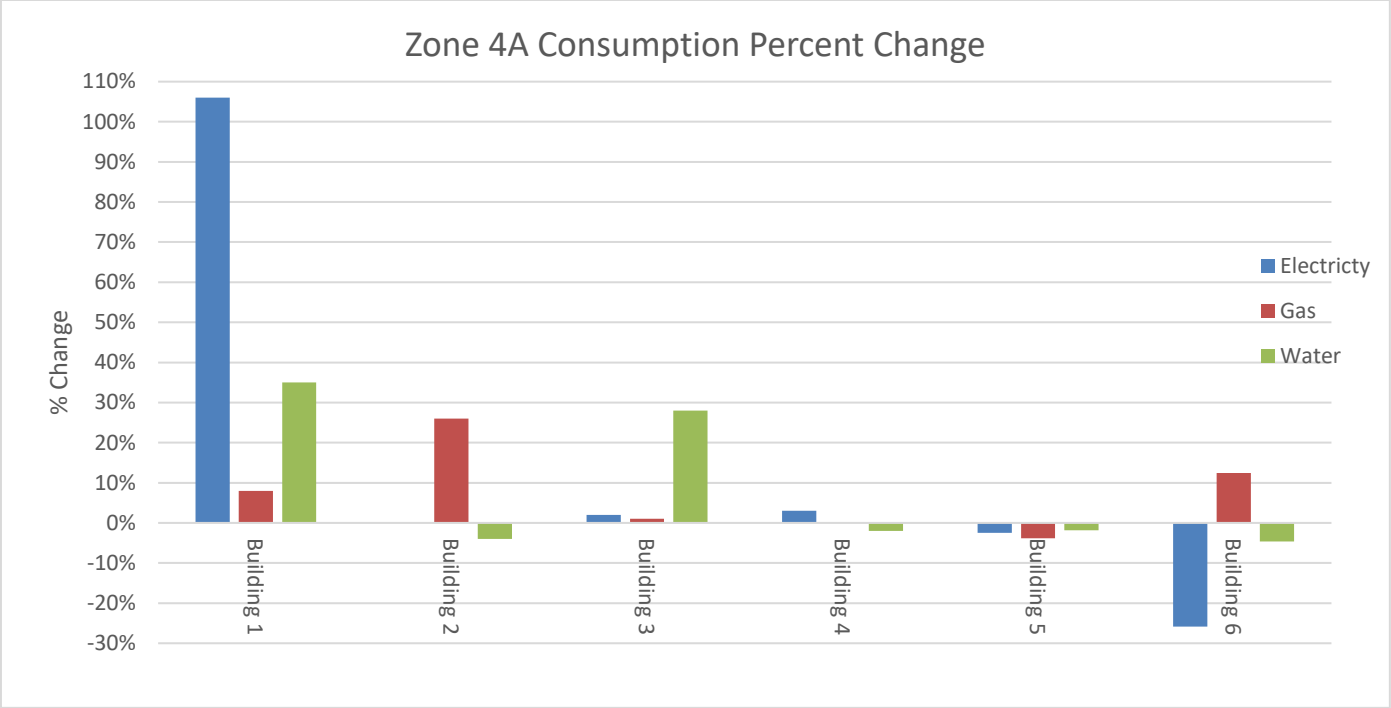

Figure 3: Zone 4A Consumption Percent Change

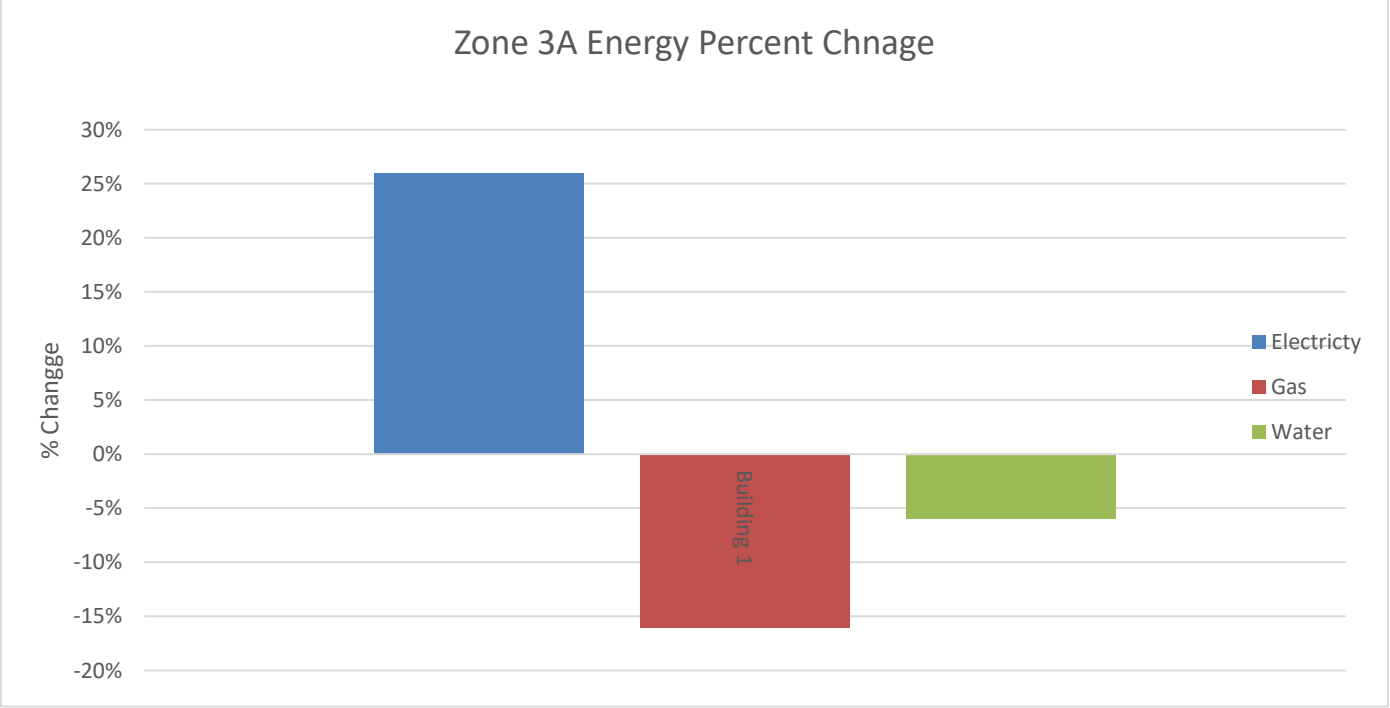

Figure 4: Zone 3A Consumption Percent Change

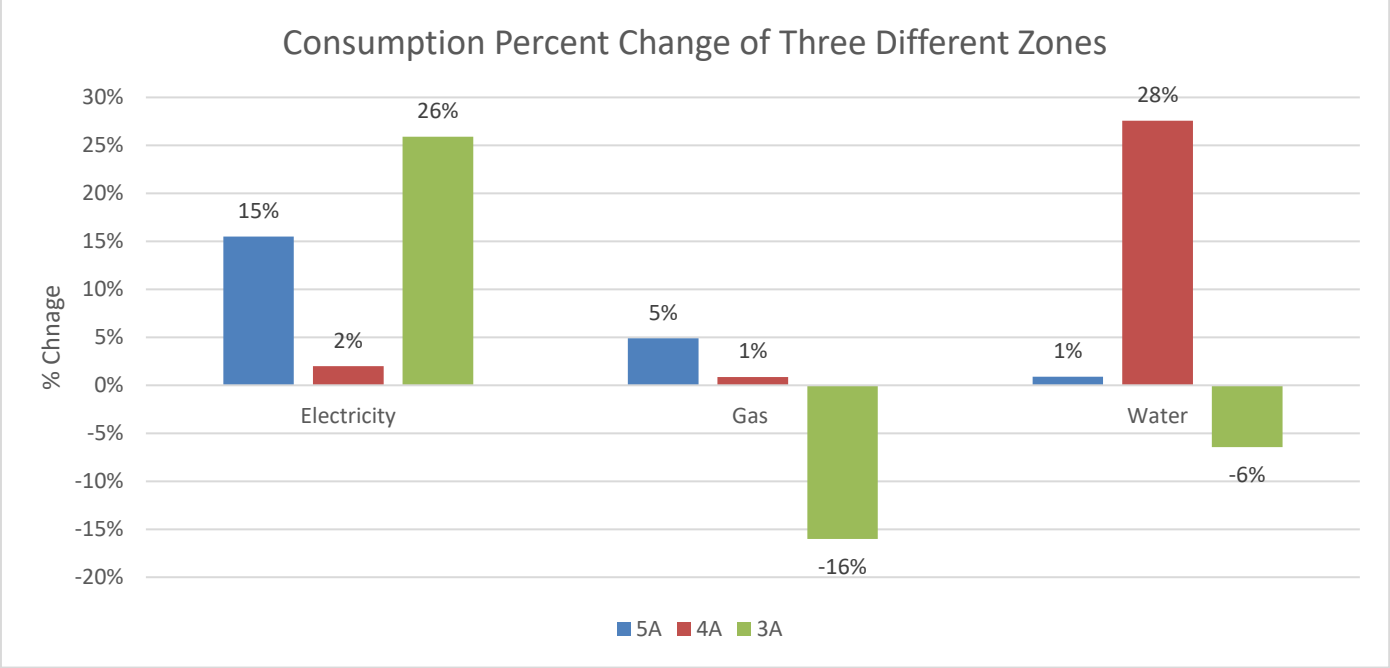

Figure 5: Consumption Percent Change of three different zones

When looking at the monthly percent changes for the 3 buildings in table 1, it can be seen that the building in climate zone 3A had the most electricity usage in the spring and summer seasons with excluding the month of June 2020, since the building for climate zone 3A was empty at that time. Also, the climate zone 5A building showed a constant percent increase during these two seasons with a percent increase ranging from 9% to 17%. Further, climate zone building 4A had an unsteady pattern in electricity consumption. Also, in the month of July, one of the hottest months of the year, the 3 buildings saw an increase in their electricity consumption. For the other 2 seasons, fall and winter, climate zone 3A building had a percent decrease in the consumption in September, October, and January and more than 25% increase for the rest of the 3 months. Climate zone 4A building had a decrease of 29% and 2% in October and December in consumption. It also had an increase in usage ranging between 4% and 20% for the four other months. Next, similarly to spring and summer seasons, climate zone 5A building kept having a monthly relativity monthly percent increase in consumption for the fall and winter.

- Gas consumption:

For the gas usage, unlike its percent increase in electricity, climate zone 3A had the lowest percent of gas consumption when compared with the other climate zones with a percent reduction of about 16% as shown in Table 2. Climate zones 4A and 5A buildings, on the other hand, showed a percent increase of 1% and 4% in their gas usage. Moreover, for the water consumption, the building in climate zone 3A showed a reduction of 6% percent in the total annual water consumption during COVID-19 year than in the pre-COVID-19 year. However, buildings in climate zones 4A and 5A showed an increase in their water usage. The building in climate zone 5A had a very minimal 1% increase, and zone 4A had the most increase of 28%.

Table 1

Electricity Consumption Percent Change			
Climate Zone	5A	4A	3A
1-Mar	9%	-11%	38%
1-Apr	10%	26%	93%
1-May	15%	14%	78%
1-Jun	17%	-1%	-10%
1-Jul	13%	9%	121%
1-Aug	15%	-8%	-1%
1-Sep	16%	13%	-5%
1-Oct	11%	-29%	-3%
1-Nov	7%	20%	62%
1-Dec	19%	-2%	27%
1-Jan	14%	4%	-6%
1-Feb	36%	13%	47%
Total	15%	2%	26%

When looking at the monthly percent change for the 3 buildings, it can be concluded that the climate zone 5A building had an increase in the gas consumption during the spring and summer seasons except in July. Whereas, the building at climate zone 3A experienced fewer gas consumptions during the spring and the first month of the summer with a percent decrease

ranging from 11% to 39%; however, it saw a sudden increase in the gas usage during the last 2 months of the summer with a 44% and 113% percent increase in July and August. Further, climate zone building 4A showed a 3 month incline in the gas consumption and 3 months decline in usage with a percent change ranging from -19% to 47%. Furthermore, when observing the other two seasons, fall and winter, it can be concluded climate zone 4A building had the greatest percent increase in gas consumption with a maximum percent increase of about 50% when comparing it with pre-COVID-19 year. However, it also had the most percent reduction in gas usage out of the 3 buildings; reaching a 26% reduction in gas usage in December. Next, the climate zone 5A building did not show any significant percent change from September to February. The maximum percent increase of 11% was in November, and the maximum percent decrease of 10% was in October. Furthermore, Unlike the 2 buildings in climate zones 4A and 5A, climate zone 3A buildings experienced more reduction in the gas consumption during the fall and winter, particularly in November with a percent decrease of 34%.

Table 2

Gas Consumption Percent Change			
Climate Zone	5A	4A	3A
1-Mar	16%	-19%	-29%
1-Apr	12%	-11%	-11%
1-May	3%	47%	-23%
1-Jun	19%	21%	-39%
1-Jul	-4%	8%	44%
1-Aug	8%	-7%	113%
1-Sep	5%	33%	8%
1-Oct	-10%	50%	6%
1-Nov	11%	-8%	-34%
1-Dec	1%	-26%	-11%
1-Jan	-1%	22%	-8%
1-Feb	6%	14%	-17%
Total	5%	1%	-16%

- Water Consumption:

Moreover, for the water consumption, the building in climate zone 3A showed a reduction of 6% percent in the total annual water consumption during COVID-19 year than in the pre-COVID-19 year. However, buildings in climate zones 4A and 5A showed an increase in their water usage. The building in climate zone 5A had a very minimal 1% increase, and zone 4A had the most increase of 28% as seen in Table 3.

Further, when observing the monthly percent changes, water use in buildings in climate zones 4A and 5A saw an increase in 5 out of the 6 months of the spring and summer seasons, but climate zone 4A building had a greater monthly percent increase reaching 126% in June. However, climate zone 3A building experienced the opposite. It showed an alarming increase of 236% in the first month of spring, and then water usage went down below the amount used in the pre-COVID-19 year of the similar months. For fall and winter seasons, climate zone building 4A water consumption stayed above the amount used from the year before. Further, climate zone building 5A water consumption remained close to the consumption from the pre-COVID-19 year. Finally, climate zone building 3A saw a booming percent increase in water consumption from November to February 2021 with a range of 77% to 170% increase.

Table 3

Water Consumption Percent Change			
Climate Zone	5A	4A	3A
1-Mar	3%	17%	236%
1-Apr	3%	10%	-18%
1-May	4%	17%	-17%
1-Jun	2%	126%	-90%
1-Jul	-8%	30%	-1%
1-Aug	0%	-26%	-18%
1-Sep	10%	12%	-5%
1-Oct	-1%	34%	-43%
1-Nov	1%	38%	170%
1-Dec	-2%	31%	155%
1-Jan	1%	13%	67%
1-Feb	9%	13%	77%
Total	1%	28%	-6%

V. Conclusion and Discussion

Out of the 25 buildings, a total of 19 buildings experienced an increase in electricity consumption, while 5 buildings saw a decline, and 1 had a similar consumption for the 2 years. This confirms that residential electricity demand has grown during the COVID-19 pandemic. Also, 17 buildings saw a percent increase in gas consumption, 6 saw a reduction, and 2 had 0% overall change in gas usage. These numbers emphasize that 76% of the buildings saw an increase in their electricity use and 68% had a higher gas consumption. Further, regarding water usage, 16 out of the 25 houses saw an increase in water consumption and the other 11 witnessed the opposite. Therefore, when looking at the overall picture, more buildings experienced an increase in consumption during COVID-19. That increase is understandable and logical since lockdowns and quarantines forced people to stay at home for longer periods of time compared to before the pandemic. For most people, their home became their workplace. This resulted in more time on electronics such as laptops and televisions, more home-cooked meals, more use of air conditioning during the cooling seasons, and more heating during heating seasons [12, 13].

Also, for the water consumption, almost 2/3 of the buildings show an increase in demand and 1/3 saw the opposite and this can be explained from a study done in Brazil which saw that residential water demands did actually rise more in apartments than houses, and some evidence also showed that people used even more residential water by washing hands as precautionary act before the governments applying lockdowns

[14]. This might be the case why some buildings in this study had fewer water consumptions during the pandemic than before.

Finally, from the 3 chosen buildings, a preliminary conclusion can be drawn that the climate zone can certainly have an influence on the degree of percent change in both electricity and gas consumptions during COVID-19. For instance, from the results, climate zone 3A building consumed more electricity, most likely for space cooling, than the other 2 colder climate zones. Another supporting example is that colder climate zones used more gas than the building at the warmer climate zone. Moreover, water consumption did indeed increase during COVID-19; however, the climate zone did not show any clear sign of its impact on residential water consumption. The reason behind the variation in the percent change of water consumption could be the result of severity of COVID-19 in the area, partial and full lockdowns, or the different levels of precautionary measures taken against the virus-like showers and handwashing [14]. These can be based on the individuals' level of fear of getting infected. Other factors affecting the water consumption trends are embracing spare time activities during lockdowns such as gardening and using inflatable pools [15]. Furthermore, other factors that may affect the percent change in energy consumption which should be explored are building residences' level of income and their level of awareness on their energy consumption. For instance, a person with a limited budget may sacrifice inside-temperature comfort and consume less energy just to be on a budget. Other things to look for are an individual's activity and behavior, and if the building is considered energy efficient.

Conflicts of Interest: The authors declare no conflicts of interest.

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