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The Effects of the COVID-19 Pandemic on American Utilities Usage

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Abstract— The COVID-19 pandemic has affected the ways many Americans live their daily lives, including the amount of time spent at home. This study seeks to address how much the assumed extra time spent at home has affected energy, gas, and water consumption. Preliminary research suggests that due to increased time indoors, utilities consumption increased between 2019 and 2021, when the COVID-19 pandemic (henceforth simply "pandemic") began. This study intends to look at a relatively new phenomena and show how the recent pandemic has changed the lives of average Americans. Because the pandemic is ongoing, this research could provide the baseline for future examinations of the effects of the pandemic in years to come. For this study, the University of Dayton MEE 420/RCL 569 class of Spring 2021 provided their last three years of utilities usage and graphed their 2019, 2020, and 2021 data against each other. From there, the data was analyzed in MATLAB using the energy consumption data as well as weather to determine if a significant change in usage occurred between 2019 and 2021 that was not caused by unusual temperatures. From MATLAB, the mean difference values and p-values for each energy source consumption was recorded along with the plots of pre-COVID-19 and post-COVID-19 utility consumption. With the mean difference values being mostly positive, they suggest that the energy usage during the pandemic was greater than before the pandemic. Although this is true, the p-values indicate there is not enough evidence to suggest that the energy usage was greater during the pandemic than before it. This implicates that our study does not have enough information to definitively conclude that energy consumption increased during the pandemic.

Keywords— Pandemic: when a disease becomes widespread across a country, continent, or the world

Sars-COV-2: The name of the virus responsible for the COVID-19 pandemic

COVID-19: Abbreviation of coronavirus disease 2019

Utilities: In this paper, referring to electricity, natural gas, and/or water supplied to a residence

Lockdown: a period of time from March to August where most commercial businesses were closed due to the pandemic and people were expected to remain in their homes to prevent the spread of COVID-19

CO2: Carbon dioxide

The Spanish Flu: a pandemic that hit America in 1918 caused by the H1N1 virus

I. INTRODUCTION

The COVID-19 pandemic, caused by the virus SARS-CoV-2, was first discovered in Wuhan, China in November of 2019. It was found to be extremely contagious and quickly spread to other parts of the world. The virus reached the United States of America in early 2020, and began affecting citizens en masse around March of 2020. Businesses shut down, people began working from home, schools and universities sent students out of their buildings to study remotely. The entire country stayed home for the first three months of the pandemic.

Due to people being home more often, as well as no one traveling for work and college students being forced to move back home, home energy and utility usage likely increased during the lockdown period. A study published in the Sigma: Journal of Engineering & Natural Sciences had evidence to the contrary, however. The study found that gross energy usage had decreased after lockdown went into effect [1]. However, this study only looked at the overall energy usage, which includes commercial spaces. The study did not separate commercial and residential usage, and it is likely their results were influenced heavily by commercial buildings like offices, shopping centers, and restaurants closing down during the first few months of lockdown. A study published in the Turkish Journal of Electrical Engineering & Computer Sciences found similar results in Turkey and surrounding areas [2].

This study aims to observe both the effects of the pandemic on energy consumption as well as natural gas and water consumption, expanding on the studies that have come before. Despite the assertion that overall energy usage went down over the pandemic period, it can be theorized that residential usage increased overall, due to factors such as working from home and lockdown procedures implemented by state and local governments.

II. LITERATURE REVIEW

In the modern period, energy has come to be a basic requirement for human life. With the birth of new technologies and increase in population, the world is already using an exorbitant amount of energy each day. Alarmingly, this energy use is subject to a significant decrease during periods of unrest/pandemics, such as the COVID-19 pandemic. There has been substantial research done on the increase in the global energy demand due to COVID-19. In the Appendix, Figure 1, the global energy-related to CO2 emissions between 1900-2020 can be seen. This figure illustrates that the pandemic caused the largest decrease to global energy use in more than seven decades, resulting in a record annual decline in carbon emissions of almost 8%[1]. In this global decrease of energy use, almost all non-renewable energy sources were hit hard due to the pandemic. In Figure 2 the impact of the pandemic on the decline of these energy sources can be seen, particularly with oil and coal. Furthermore in Figure 3 we see the global demand for coal was projected to fall by 8% in 2020, the largest decline since World War II. Following its peak in 2018, energy generated by coal was set to decline by more than 10% in 2020[1]. Besides looking at the impact the pandemic had on global energy use, other events were gathered by the author to see whether or not the global energy use was impacted negatively or positively. In Figure 4 between the Spanish Flu and World War II, the peak was observed to be during the Spanish Flu and the lowest value was observed to be in World War II. Since then, the trend of rate of change remained in the positive region until the COVID-19 pandemic, meaning the energy demand did not notably decrease between the years 1945-2018. Furthermore, for every period of unrest/pandemic, except the Spanish Flu, the rate of change in global energy use experienced a decrease. Moving to observing the electricity consumption alone, in Figure 5 the author reveals electricity consumption in Europe relative to 2019. The consumption of electricity exhibits a drastic change especially for the countries that struggled with the COVID-19 pandemic. One of these countries, Italy, experienced an exponential decrease in electricity consumption. In week one the consumption decreased by 1%, week 2 the consumption decreased by 6%, and then in week 3 the consumption decreased by 21% where Italy experienced its first COVID-19 death. Hence, this graph indicated that the pandemic enormously affected the electricity consumption of European Countries, which can serve as a sample for the whole world.

III. Materials and Methods

In order to gather results for this study, four steps were taken. The first step was to organize and clean the energy use data gathered from the University of Dayton MEE 420/RCL 569 class of Spring 2021. This data was collected for the study on a volunteer basis, resulting in possible volunteer bias. Each dataset was lightly analyzed for feasibility. For datasets that had extreme recordings for gas, water, and electricity consumption, they were removed from consideration. For the datasets that had feasible energy consumption, they were organized in a database to be used. The second step in this process was to observe weather patterns for each individual location (34 houses and 13 areas recorded). Using the National Climate Report to gather the average annual temperatures in the United States of America between 2019-2020, they were analyzed for any major change in temperature. This was done to provide background information on possible explanations for change in energy consumption besides the pandemic, as an increase/decrease in usual weather patterns could result in a drastic change in energy consumption. The third step was to place the house data into MATLAB to record and analyze each individual house automatically. The program created would perform statistics and generate statistics for each utility cost included by the students. Finally, the last step in this study's methods was to analyze the mean difference values and the p-values. Mean difference values were calculated by subtracting the energy use, for each energy source and house, of post-COVID-19 and of pre-COVID-19. Positive values indicate that the mean energy consumption was greater during the pandemic than before, while a negative value indicates that the mean energy consumption was smaller during the pandemic than before. P-values were calculated through the "ttest" function in MATLAB. P-values indicate the probability of our hypothesis being true, under the assumption that the original hypothesis is true.

IV. Results

From the National Climate Report, Figures 6 and 7 were obtained. These figures contain temperature ranks separated by state for 2019, seen in Figure 6, and for 2020, seen in Figure 7.

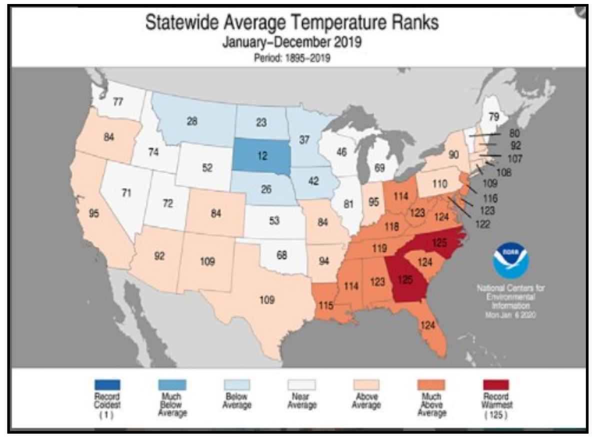

Figure 6: 2019 Statewide Average Temperature Rankings [4]

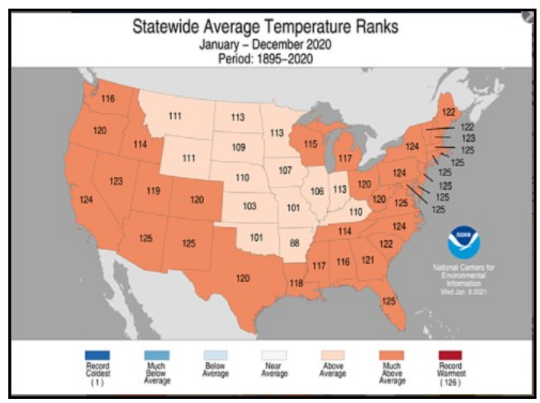

Figure 7: 2020 Statewide Average Temperature Rankings[5]

For 2019, based on the preliminary analysis, the United States of America's average annual temperature was 0.7°F, the nationally averaged maximum temperature was 0.1°F, and the nationally averaged minimum was 1.2°F above the 20th century average across the Southeast and Mid-Atlantic[4]. For 2020, based on the preliminary analysis, the United States of America's average annual temperature was 2.4°F, the nationally averaged maximum temperature was 2.3°F, and the nationally averaged minimum was 2.4°F above the 20th century average across the Southeast and Mid-Atlantic[5].

From MATLAB, the Figures 8-19 (with Figures 11-19 being in the Appendix) and values in the Table 1 in the Appendix were acquired. Figures 8-10 below portray the different utility usage throughout the years for the 17th house in our dataset located in Dayton, OH. The utilities include

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electricity (kWh), gas (CCF), and water (gallons) usage. Each figure portrays pre-Covid data as a dashed line, and post-Covid data as a solid colored line. The start date of Covid is defined as March, 2020. The colors on the figures represent different years with blue, red, and magenta signifying 2019, 2020, and 2021 respectively.

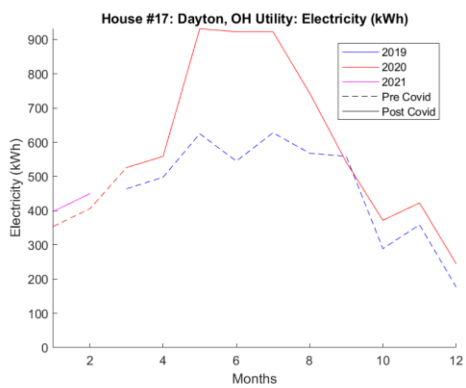

Figure 8: House 17 Electricity Usage Plot

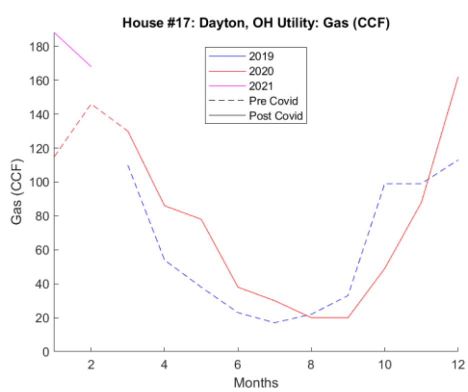

Figure 9: House 17 Natural GasUsage Plot

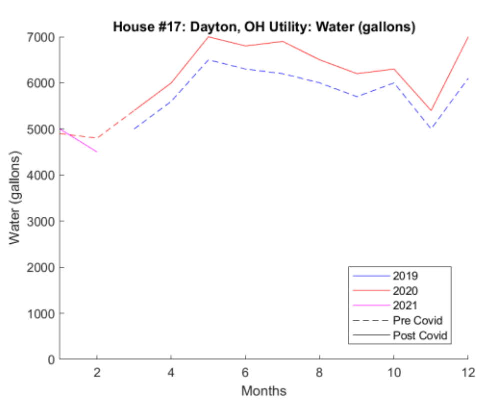

Figure 10: House 17 Water Usage Plot

From these figures above, the general trend observed is that the energy consumption for each utility is higher during the pandemic than before the pandemic. This observation is supported by the mean difference values found in Table 1, calculated by subtracting the mean energy consumption during the pandemic by the mean energy consumption before the pandemic. The equation used to calculate the difference values is shown:

$$diff = \frac{Average(postCovid - preCovid)}{Average(preCovid)} \times 100 \quad [1]$$

The postCovid variable represents the utility values after the COVID-19 outbreak in March 2020, while the preCovid variable is the time before. Out of 34 individual houses recorded, only 5 have two negative mean differences for energy uses and 11 have one negative mean difference. Furthermore, the p-values also recorded in Table 1 seems to indicate that there is no evidence to suggest that the energy consumption was greater during the pandemic than before it. Using the "ttest" function in MATLAB, the p-values were calculated with an alpha level of 5%, a null hypothesis equaling the mean energy consumption before the pandemic, and an alternative hypothesis being greater than the null hypothesis. This resulted in 9 houses with a single occurrence where the null hypothesis can be rejected due to its p-value being lower than the alpha level of 5%.

V. Discussion

As seen in Figures 6 and 7 above, the United States of America's annual average, minimum, and maximum temperatures increased from 2019 to 2020. The annual average temperature increased from 0.7oF to 2.4oF, the annual maximum temperature increased from 0.1oF to 2.3oF, and the annual minimum temperature increased from 1.2oF to 2.4oF. These increases are all significant enough to warrant an effect in energy consumption that's not related to the pandemic. Unfortunately, the effect of the increase in annual average temperatures on energy consumption can not be further studied due to the lack of specific information on the individual houses. Without this information, energy balances can not be done to study the heat transfer of each house.

As seen in Table 1: All Houses Summary, the difference between post-COVID-19 and pre-COVID-19 energy use can be seen. With a positive mean difference value appearing when the mean energy use for a house is higher during the pandemic than it was prior to the pandemic. Similarly, a negative mean difference value indicates that the mean energy use for a particular house was lower during the pandemic than before it. Out of 34 individual houses recorded, only 5 have two negative mean differences for energy uses and 11 have one negative mean difference. Considering if two energy sources have a negative mean difference value indicates that the house used less energy during the pandemic than before, then only 5/34 houses used less energy during the pandemic. Contradicting the findings made from the mean difference values, the p-values recorded in Table 1 for each house indicates the probability of obtaining test results at least as extreme as the results actually observed, under the assumption that the null hypothesis is correct. In other words, if the p-value is higher than the alpha level, we fail to reject the null hypothesis as it indicates the alternative hypothesis being true is less likely. From the table, we see that there are only 9 houses with a single occurrence where the null hypothesis can be rejected due to its p-value being lower than the alpha level of 5%. These cases indicate that there is enough evidence to suggest the mean consumption of energy was higher during the pandemic. This, unfortunately, still leaves 25/34 houses where we can not confidently say the mean energy use is higher during the pandemic than before it. The p-value can only give us the probability that an occurrence is true, so therefore, despite having the mean difference values indicating energy consumption was greater during the pandemic, there is not enough evidence to suggest that the average energy consumption for individual houses increased during the pandemic.

VI. Conclusion

The main aim of this study is to observe the change in energy use of water, gas, and electricity, before and during the COVID-19 pandemic. With the whole world being available for a sample population size, this study focused on 34 individual houses from the University of Dayton MEE 420/RCL 569 class of Spring 2021. Upon confirming/recognizing that there were radical changes in average outdoor temperature at each house location over the course of 2019-2020, the study moved forward with the energy values for each house and analyzed them through MATLAB. The results taken away from this analysis was driven by the mean difference values for each energy use for the individual houses and their respective p-values. With the p-values as an indicator, we can not confidently claim that the energy usage rose during the pandemic despite it being indicted through the mean difference values.

VII. Limitations and Directions for Further Study

The limitations of this study stem from questionable and lack of house data. Since the data used in this study was provided on a volunteer basis, all of the data provided can not be assumed true. In fact, there were multiple cases in which data had to be thrown out due to its questionability in results. Additionally, for future studies, more house information for each individual case would be preferred. Information such as square feet of the house, how many stories, how many windows, and more detailed information can provide this study with a specific heat transfer energy balance equation for each house. This will allow future studies to fully explore the effects temperature changes and the COVID-19 pandemic have together. Furthermore, future studies should include a more in-depth look at weather data on an individual basis as this study only took into account national trends. Future work would be benefitted by analyzing city or state trends instead of national averages. Lastly, a larger initial dataset should be looked at for future work. This study was limited by the information available in the initial survey. More utilities data spread out across multiple cities and states would greatly increase the likelihood of finding an accurate trend in utility usage before and during lockdown went into effect in the United States.

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

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VIII. Appendix

Table 1: All Houses Summary

City	State	Elec_diff	Gas_diff	Water_diff	Elec_p	Gas_p	Water_p
(-)	(-)	(kWh)	(CCF)	(Gallons)	(kWh)	(CCF)	(Gallons)
Springfield	IL	9.20	7.83	-34.25	0.04	0.40	1.00
Pittsburgh	PN	19.43	-6.45	0.00	0.06	0.62	0.00
Fort Wayne	IN	3.78	8.20	0.00	0.36	0.39	0.00
Pittsburgh	PN	17.27	10.35	0.21	0.03	0.36	0.49
Pittsburgh	PN	-10.08	10.98	0.00	0.84	0.36	0.00
Pittsburgh	PN	12.60	0.00	3.57	0.24	0.00	0.31
Milwaukee	WI	2.76	68.33	0.00	0.41	0.12	0.00
Kansas City	MO	-11.38	0.00	0.00	0.86	0.00	0.00
Indianapolis	IN	17.63	0.00	-22.30	0.16	0.00	0.65

Dayton	OH	-3.39	17.86	39.13	0.62	0.29	0.02
Dayton	OH	18.41	0.00	-14.88	0.20	0.00	0.80
Dayton	OH	16.72	0.22	-9.30	0.11	0.50	1.00
Dayton	OH	16.43	48.64	23.82	0.08	0.00	0.00
Dayton	OH	39.31	0.00	172.03	0.00	0.00	0.00
Dayton	OH	43.52	12.76	5.95	0.00	0.04	0.11
Dayton	OH	-33.28	17.80	-2.41	1.00	0.14	0.60
Dayton	OH	28.52	28.22	6.79	0.05	0.17	0.08
Dayton	OH	12.16	-17.65	-6.39	0.20	0.84	0.74
Dayton	OH	1.03	-7.19	-58.41	0.47	0.74	1.00
Dayton	OH	-14.64	0.00	22.58	0.98	0.00	0.05
Dayton	OH	18.53	-3.39	4.65	0.14	0.58	0.06
Dayton	OH	45.04	22.59	21.03	0.02	0.25	0.01
Dallas	TX	25.78	-13.33	-8.21	0.17	0.70	0.79
Cleveland	OH	14.23	9.09	1.73	0.03	0.38	0.44
Cincinnati	OH	13.47	-0.68	6.05	0.17	0.51	0.03
Cincinnati	OH	115.21	9.09	40.79	0.00	0.37	0.06
Cincinnati	OH	2.33	5.74	30.76	0.44	0.43	0.07
Cincinnati	OH	15.63	45.31	62.32	0.18	0.18	0.01
Cincinnati	OH	10.56	0.00	0.00	0.08	0.00	0.00
Cincinnati	OH	-22.56	7.00	-0.74	0.99	0.29	0.53
Chicago	IL	59.15	12.10	31.37	0.02	0.33	0.00
Buffalo	NY	19.26	6.11	30.87	0.16	0.37	0.01
Baltimore	MD	6.86	6.34	-0.65	0.22	0.43	0.53
Atlanta	GA	2.05	38.35	44.68	0.40	0.31	0.38

A. MATLAB Code and House Information Links

The MATLAB live script file used for this paper can be found here. The user will have to update the input variables as necessary to match the naming convention for the Excel document. The first section of the code focuses on calculations and figure generation for a single house. The second section of the code focuses solely on the calculations for all the houses included in the dataset. The Excel document containing the properly formatted house information used for this project can be found here.