RESIDENTIAL ELECTRICITY CONSUMPTION ANALYSIS: A CROSS-DOMAIN APPROACH TO EVALUATE THE IMPACT OF COVID-19 IN A RESIDENTIAL AREA IN INDIANA

by

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I dedicate my thesis to my parents and grandparents. They are the inspiration for my future endeavors.

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I would like to express my deepest gratitude to my mentor and guide, Dr. Eric Dietz. I owe him a lifelong debt, and without him, it would not have been possible for me to complete my master's thesis. He provided me with freedom, support, and encouragement in making my ideas a reality. More than an academic advisor, Dr. Dietz is a life guide on being a good human who treats everyone with love and respect. My sincere thanks to Dr. Matson and Dr. El Gamal for accepting to be on my committee and helping me shape my research by providing feedback.

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ABSTRACT

This research aims to measure the change in the electricity consumption of a residential urban area in the U.S. during the COVID-19 pandemic year. The research questions to be answered are:

1. What are the main changes in domestic electricity consumption during quarantine in comparison to regular activities?
2. How predictable are residential consumers based on specific appliances usage?
3. How much kWh/$-year does it cost to work remotely full time?

The pandemic scenario caused by COVID-19 is an event with no precedent. Therefore, it is a phenomenon that can be studied to observe how electricity loads have changed during the stay-at-home order weeks. The data collection process was done through online surveys and using publicly available data. This study is focusing on analyzing household energy units such as appliances, HVAC, lighting systems. However, collecting this data is expensive and time-consuming since dwellings would have to be studied individually. As a solution, previous studies have shown success in characterizing residential electricity using surveys with stochastic models. This characterized electricity consumption data allows the researchers to generate a predictive model, make a regression and understand the data. In that way, the data collection process will not be as costly as installing measuring instruments or smart meters. The input data will be the behavioral characteristics of each participant; meanwhile, the output of the analysis will be the estimated electricity consumption "kWh." After generating the "kWh" target, a sensitivity analysis will be done to observe the electricity consumption through time and examine how people evolved their load during and after the stay-at-home order.

This research can help understand the change in electricity consumption of people who worked at home during the pandemic and generate energy indicators and costs such as home office electricity cost kWh/year. In addition to utilities and energy, managers can benefit from having a clear understanding of domestic consumers during emergency scenarios as pandemics.

CHAPTER 1. INTRODUCTION

1.1 Introduction

The COVID-19 pandemic affected all society sectors, such as manufacturing, information technology, and healthcare. Private and Public institutions moved their efforts to mitigate the pandemic effects, which shifted people's consumption habits. Consequently, the energy sector was negatively affected; for instance, oil prices went down at historical prices, reaching minus zero costs, which meant producers paid the traders to buy oil (Desjardins, 2020). The electricity and fuel load profile changed within the biggest consumers: commercial, industrial, and residential. Globally, the electricity demand decreased between 2.5% - 4.5% in Q1 2020, not only because of COVID-19, since the weather conditions were milder than in 2019 (International Energy Agency, 2020). This reduction happened because most people stopped going out, and activities such as office work, education, or shopping continued online. Additionally, the energy demand per country in 2020 is associated with the governments' containment measures. Limited restrictions produced a shift of 10% in Korea's and Japan's energy consumption; partial stay-at-home orders account for a 17% reduction in Europe, and total stay-at-home order averaged 25 to 30% in some cases (International Energy Agency, 2020)

In most U.S. states, people had to stay at home between 6-8 weeks as part of the "stay at home order"; they could only go out for essential activities such as grocery or medical emergencies (U.S. News, 2020). The containment measure such as"stay-at-home-order" or stay-at-home volunteer order occurred between late March and early May. As a result of the containment measures and efforts to restrict people's mobility, the U.S Energy Information Administration estimated the residential electricity usage per customer increased by 6% in April 2020 compared to the previous five Aprils. On the other hand, the commercial and industrial sectors decreased by 10% and 9%, respectively (EIA, 2020).

1.2 Problem Statement

Although previous studies about electricity consumer patterns (Chicco, 2012),(Tsekouras et al., 2007),(Pan et al., 2017) researchers have not studied in deep these patterns under diverse containment scenarios or work-from-home policies. During pandemic scenarios, most employees

are requested to work from home for several weeks; that shifts electricity consumption drastically in urban areas, especially in the U.S, where most Americans' occupations occur at offices and buildings (U.S. Bureau of Labor Statistics, 2014).

Most COVID-19 electricity impact analyses and studies have shown a general increase in residential demand (International Energy Agency, 2020; MISO, 2020). However, there is little information about the specific or disaggregated demand, such as appliances usage and demographic correlations. In other terms, there are plenty of macro analyses but few disaggregated consumer analyses.

1.3 Significance

This study's findings will be reflected in the benefit of the energy sector, considering that this is a critical sector in any country. Nowadays, the electric grid's modernization is on-demand because it intends to leverage renewable energies and improve power systems' general efficiency. Thus, the comprehension of electricity during emergencies supports this transition. Utility companies can benefit from having a study that shows how predictive load demand is during containment scenarios. The government can also have a better way to know the primary necessities of people's electricity consumption.

Additionally, households account for roughly 40% of greenhouse gas emissions in developed countries (Wolske et al., 2020). This percentage is a big chunk of the energy matrix. Therefore, any effort to understand consumer behavior is helpful to contribute to the reduction of these emissions.

Without accurate forecasting, the operative management of the electric grid becomes costly and unstable during emergencies. In such scenarios, losses in the electricity market are dramatic (Perrier et al., 2013), leading to increased nominal electricity prices (Sahebi et al., 2012). Until August 2020, the COVID-19 crisis cost nearly 10 billion dollar losses to electricity utilities (Cash, 2020). Experts agree that a second quarantine or wave of cases can negatively affect the operation of utilities. The Independent System Operator's director in Texas agreed about the impact adding that one of the most significant issues is that they do not know how this will affect utilities (Tomich et al., 2020).

This proposal is relevant because most organizations and companies have made a general exploration of electricity consumption (International Energy Agency, 2020) (MISO, 2020); however, this study explores the appliances in more detail.

1.4 Purpose Statement

This quantitative research aims to construct a sensitivity analysis to understand the domestic electricity consumption during the COVID-19 quarantine in an urban population in the United States. In addition, this study looks to analyze historical data of household electricity consumption during the first ten months of 2020.

This research intends to describe how people change electricity habits consumption in three different periods during 2020. People use diverse loads in a house such as appliances, lighting systems, heating/cooling, and even produce their energy. Therefore, it is expected to observe various loads during the weeks of the "stay-at-home-order" and Fall 2020. One of the objectives is to explore consumers according to their load usage and have profiles or consumption patterns.

A quarantine can produce a significant shift in the domestic electricity load; therefore, it is hypothesized that there is a strong correlation between the number of quarantine weeks and domestic electrical consumption. Another tentative assumption is that the electricity load will increase during the stay-at-home order in the residential sector since people do more home activities.

The problem addressed by this study is providing an estimation of how did the quarantine change consumer behavior in residential clients. This proposal can help with the consumer's profiling and understand more about people's electricity load behavior.

1.5 Research Questions

1. What are the main changes in domestic electricity consumption during quarantine in comparison to regular activities?
2. How different is the electricity consumption during the first weeks of quarantine compared to the last weeks of the stay-at-home order? How it evolved?
3. How much kWh/$-year does it cost to work remotely full time?

1.6 Assumptions

- Residential consumers are only consumers. Some people produce their electricity (solar panels or diesel generators), but this sample will consider all subjects as consumers.
- The residential sector consumption does not include personal transportation such as electric vehicles or internal combustion engine cars.

1.7 Delimitations

- The population selected are students and staff of Purdue University. The sample will be chosen as a random selection.
- The target value is kWh and hours of usage.
- The timeframe of the manipulated data is from January to December of 2020.

1.8 Deliverables

- A stochastic load simulator of how the electricity (kWh) consumption changes when varying the number of weeks.
- A descriptive statistical analysis of the surveys during the three different periods of quarantine.

1.9 Limitations

- The data collected comes from a relatively small population.
- People's responsiveness to answer online surveys is a limitation. The rate of responses is expected to be low since there is no direct incentive for the subjects.
- Peoples' answers are subjective since they will answer their electricity consumption based on their beliefs.

1.10 Definitions

- Load Curve: It is a graph that shows the electricity consumption in time. (Operational definition)

- Demand Response: It's a voluntary change in the consumer's electric consumption to adjust the demand with the demand to get a better price and more efficient transmission. (Operational definition)
- Independent System Operator: An independent organization that coordinates, controls, and monitors the operation of the electric power system within a state or multiple states (FERC, 1996)
- Pattern: A pattern is a sequence of daily electricity consumption reads that are similar in time. For example, if a house uses up to 150 kWh every day for a month, consumption would be a pattern.
- Supplier: Generators of electricity who provide electricity in the energy market. (Operational definition)
- Consumer**:** Any person, house, or load that uses electricity for their use. It can be a residency, a retail store, or even a factory.
- Residential area: land use in which housing predominates instead of industrial and commercial areas. The housing may vary significantly between and through residential areas. These include single-family housing, multi-family residential, or mobile homes.

CHAPTER 2. LITERATURE REVIEW

2.1 Classification of Consumers

Electricity customers are usually classified into three macro-categories: commercial, industrial, and residential. This classification is based on the electric power load range in kW (EIA, 2015).

- Residential: 3-20kW
- Commercial: 75-1000kW
- Industrial: 1000kW- More

Each of the customers has different consumption profiles. For instance, Figure 1 shows different general electricity consumption load curves during a hot day in California. As shown, residential customers have more activity at night when people return home, while industrial users tend to stabilize production to avoid peak hours.

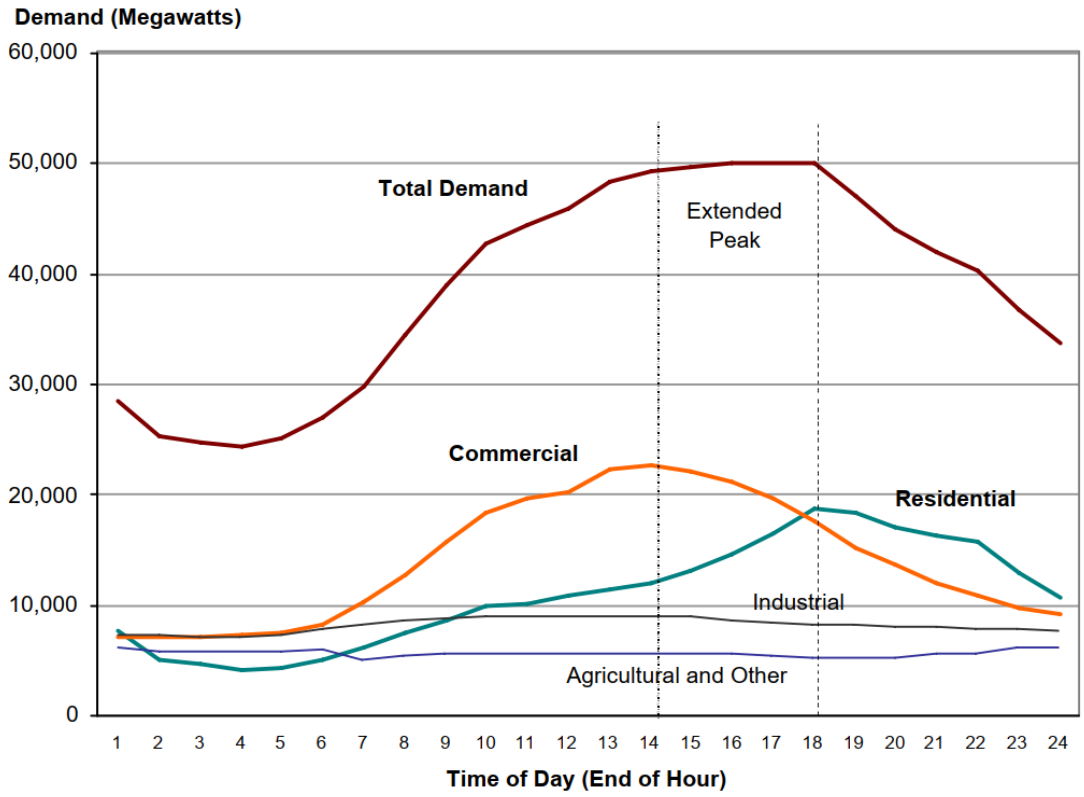


Figure 1. Total California load profile for a hot day in 1999(Rubinstein et al., 2001)

Classifying customers in those macro-categories might be helpful for utilities and generators. However, further segmentation should be done in residential customer's loads to understand people's energy consumption. Previous research tried to cluster residential consumers into more complex profiles according to their behavior, demographics, or psychographic (Diamantopoulos et al., 2003), (Diaz-Rainey & Ashton, 2011). Table 1 shows a couple of authors who segmented consumers into more detail.

Table 1. Previous Consumer Segmentation Studies

Author	Classification	Description
(Yao & Steemers, 2005)	Behavioral determinants	Related to human factor actions, people's habits, and seasonality
	Physical Determinants	Correlated with the house's physical attributes, such as building design and dwelling size.
(Sütterlin et al., 2011)	The idealistic	Show most energy-savings effort based on behavior restriction driven by idealistic thoughts
	The selfless inconsequent	A small effort for behavior restriction in food demonstrate energy-saving measures by accepting policy regulation
	The thrifty	Involve energy savings efforts if they do not involve expenditure or disadvantages.
	The materialistic	Less energy-saving efforts in mobility and food. If considered energy-saving is for financial considerations
	The convenience-oriented indifferent	Ignores the consequences of energy consumption increase.
	Problem aware well-being-oriented	They consider a limited energy-saving behavior and do not believe their action can make a difference.

2.2 Probabilistic Characterization of residential load patterns

Household electricity consumption has many variations since it is strongly tied to the number of people living in a dwelling and their lifestyle (Cagni et al., 2004). Consequently, measuring or disaggregating the electric load of any dwelling is a complicated task that would require many power meters. Electric companies measure total power usage; however, this is not informative enough to understand people's specific demands.

A probabilistic analysis approach is helpful to estimate the load power distributions at different dwellings without power meters. This analysis consists of asking survey questions to residential consumers and asking them about their primary power appliances usage. Once usage data is collected, a probabilistic or stochastic analysis can characterize the load data in kWh (Carpaneto & Chicco, 2008; Sandwell et al., 2016). This approach has been used previously in low-income countries where utilities need to quantify the aggregated demand from a given micro-population (Boait et al., 2015). For instance, the following statements are questions that can be asked in each survey.

1. The family unit (number of people, sex, age, activity, and frequency of presence at home).
2. The characteristics of the houses (size, number of rooms)
3. Electrical appliances (type number electrical data and usage)
4. Electricity bills

(Carpaneto & Chicco, 2008) demonstrated that gamma, normal, and log-normal are the most suitable distributions to fit the data with the actual load patterns. Figure 2 compares the distributions used to characterize a residential house's data compared to the actual measured data graphed in the staircase line.

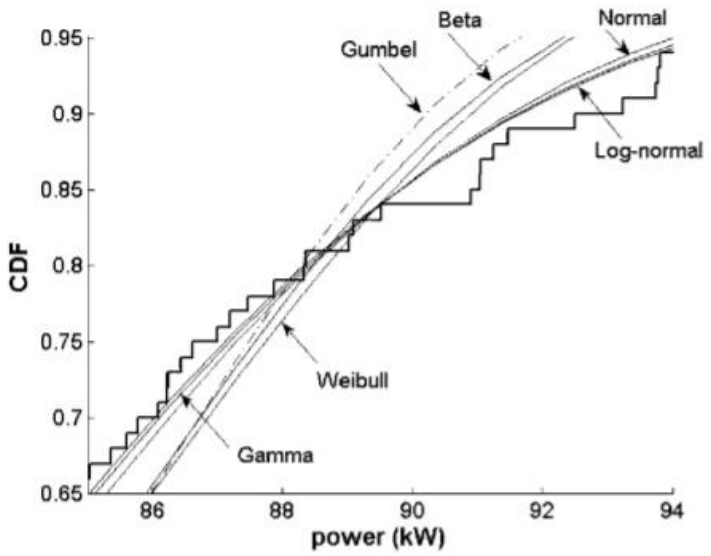


Figure 2. Comparison of cumulative distributions frequency with the read power (staircase line) (Carpaneto & Chicco, 2008)

2.3 Impact of Social Distancing and Public Health on Residential Electricity Consumption

Three potential factors affected electricity consumption in 2020:

- Public Health: Number of COVID-19 Cases
- People's Mobility in Tippecanoe County
- Stay-at-home population in Lafayette.

These factors represent a complex dependency between the COVID-19 cases, people's mobility, social distancing, and electricity consumption, as shown in

Figure 3. The increase of COVID-19 cases results in the rise of the social distancing population, which affects the business to close. This can be observed in the mobile location data and reduction of the visit of retailers.

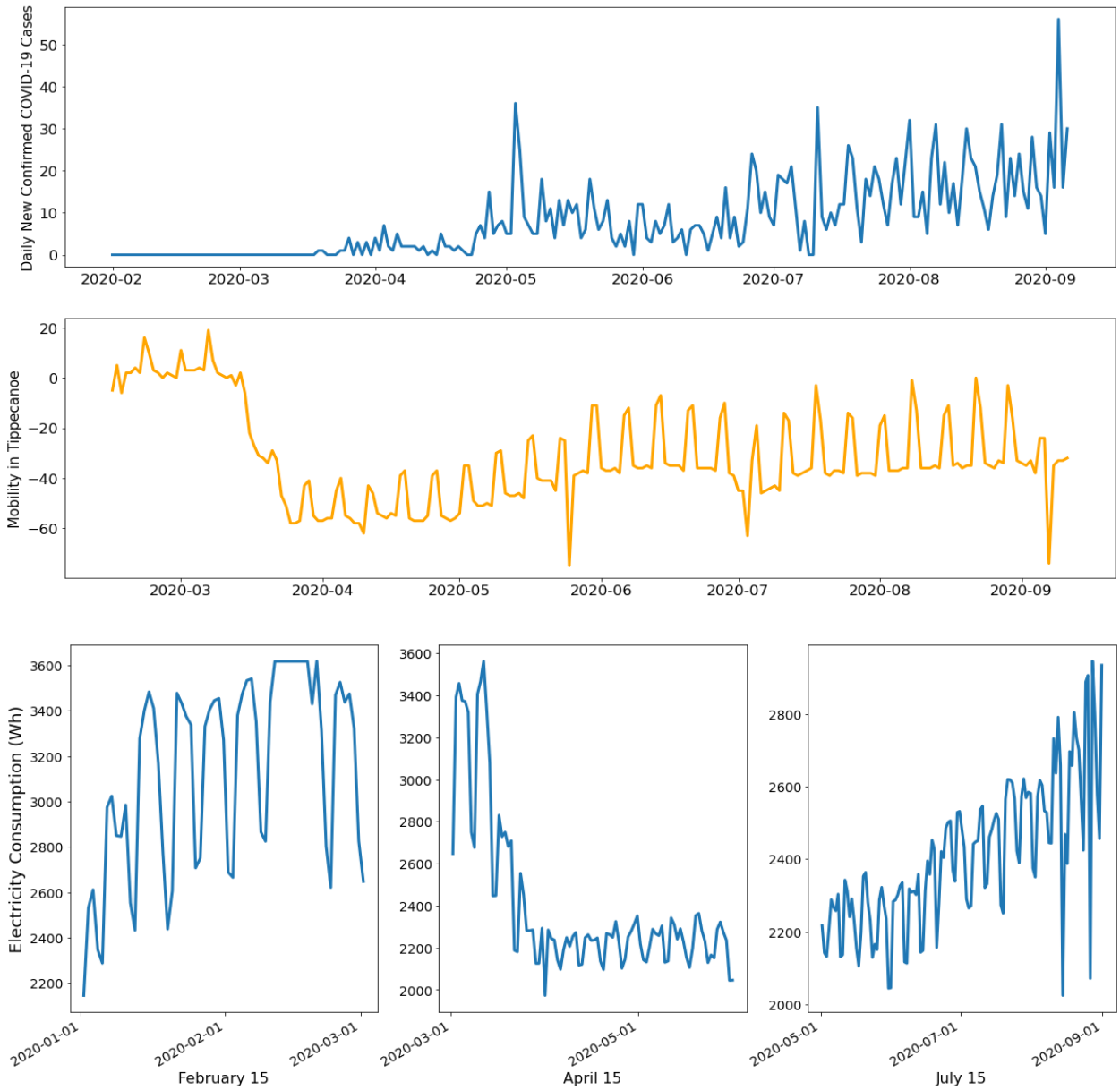


Figure 3. Mobility and COVID infected cases from mid-February to September

CHAPTER 3. METHODS

3.1 Research type

This is quantitative and applied research since it focuses on solving a real problem, and it is going to be conclusive in the results with different numerical values. The data collected will come from publicly available sources and surveys sent to 54 Purdue students and staff. The collected data will then be tabulated and processed. This study aims to produce generalizable knowledge about residential electricity consumption during 2020.

3.2 Data Set

The data analyzed for this research were collected from public sources such as the Midcontinent Independent System Operator (MISO), Energy Information Administration (EIA), Purdue University Utilities, COVID-19 Cases, and Energy Surveys (EIA, 2015; MISO, 2020). In the Surveys, Purdue University students and staff were asked about different consumption activities related to their daily electricity consumption during 2020. In addition, another dataset was created based on the regional electricity consumption per capita, which comes from the EIA surveys done in 2015 in the U.S. The EIA dataset will serve to compare the results from the electricity profile of the participants. Only annual electricity was considered for this research. The total sample of participants is n=54. The survey questions can be found in the Appendix I

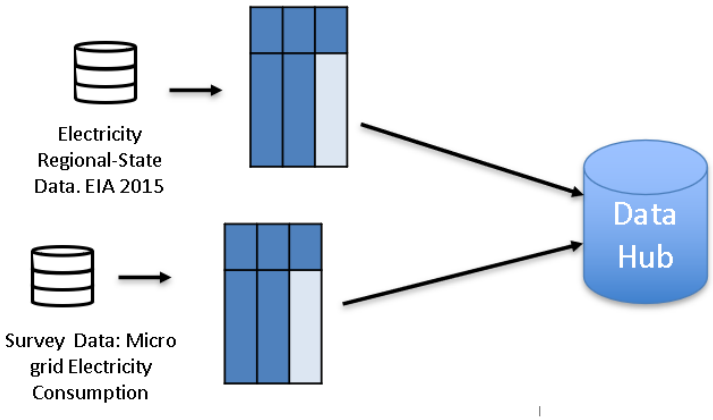


Figure 4.Data hub construction

3.3 Variables

3.3.1 Independent Variables

This section explains the variables used as predictors for the final model. Table 2 shows the physical variables and their frequencies. Note that the number of people that selected each option is between parentheses.

Table 2. Overview of physical variables and their frequencies

Variable (abbreviation)	Categories
Floor area in square foot (Floor Area)	100-400 ( ), 400-700 ( ), 700-1000 ( ), 1000-1300 ( ), 1300 or more ( )
Household type (	House ( ), Apartment ( ), Other ( )
People in dwelling	1 ( ), 2 ( ), 3 ( ), 4 ( ), 5 ( )
People at home	1 (X) 2(Y)
Appliances	TV ( ), Laptop( ), Microwave ( ), Dishwasher ( ), Water Heater ( ), Stove ( ), Washing Machine ( ), Refrigerator ( ), Toaster ( ), Blender ( ), Dryer ( ), Vacuum Cleaner( ), Electric Fan ( ), Rice Cooker ()
HVAC	Air conditioning, Heater
Lightning	LED ( ), Bulbs ( ), Incandescent ( ), Fluorescent ( )

Table 3. Overview of socio-demographics

Variable (abbreviation)	Categories
Age	18-24 ( ), 25-34 ( ). 35-44 ( ), 45-54 ( ), 55-64 ( ), 65 or over
Gender	Male (X) Female(Y)
Status	Student ( ), Staff ( ), Faculty ( ), Undergraduate Student ( ), Graduate Student with RA or TA ( ), Graduate Student ( ), Other ( )

Table 4.Overview of daily activities variables PRE-COVID-19, Stay-at-home, and Fall 2020

Variable (abbreviation)	Categories
Hours in Campus daily	1-24
Hours at home daily	1-24
Appliances usages daily	
Appliances usage per hour weekly	1-24
Campus Activity	Study( ), Exercise ( ), Research ( ), Eat ( ), Take Classes ( ), Teach
Lights on	1-24
Building	Purdue Building List

3.3.2 Dependent Variables

The dependent variable is weekly electricity consumption in kilowatt-hours (kWh), and it was sectioned into three parts: PRE-COVID, Stay-at-home-order, and Fall 2020 consumption.

3.4 Statistical Analysis

First, a descriptive analysis will be done with the survey dataset to observe the patterns and trends of appliances usage during 2020. After that, correlation analysis will be performed to observe how appliances are related and whether the usage of some devices increased during the pandemic. Finally, linear regression will be performed on the load simulator to observe which appliances have more weight in the final energy consumption of each participant.

3.5 Survey

The characteristics of this survey will be based on the Energy Information Administration (EIA) previous survey. The survey will be given to household residents, and the content of it will have (not limited) these questions. The household unit's identification and description are key to understand the behavior of consumer patterns. Therefore residents will provide information that has to be characterized. (Cagni et al., 2004; Carpaneto & Chicco, 2008) Recommend manipulating the following information:

- Appliances at home: T.V.s, computers, washing machine, kitchen, toaster, microwave.
- Lightning system: LED, incandescent.
- Heating Cooling System: Brand of the system and source of energy
- Usage of appliances, heating/cooling, lights
- Remote Work: Y/N
- Characteristics of the house: Wood, Brick, insulation windows, among other characteristics
- Number of People living in the apartment/house, sex, age.

Since there is a lack of smart meters in houses, the previous information from the surveys will serve to make the probabilistic Characterization (as shown in the

Probabilistic Characterization of residential load patterns section) and finally have the load profile of consumers. The validation of this will be done by comparing the total of electricity consumption of the electricity bills. All the survey questions can be found in Appendix I.

3.6 Load Simulator

A code was created in python to do a Monte Carlo simulation process to model the system's load composed of several devices. It relies on binomial statistics to simulate the number of devices of each type on and off at a specific month of 2020. This is used to estimate the variation in load demanded as part of this mini-grid system. This code can be found in Appendix I.

A stochastic approach was used to estimate overall power consumption based on some power given to each appliance. Figure 5 has all the power given to each appliance based on each device's average power.

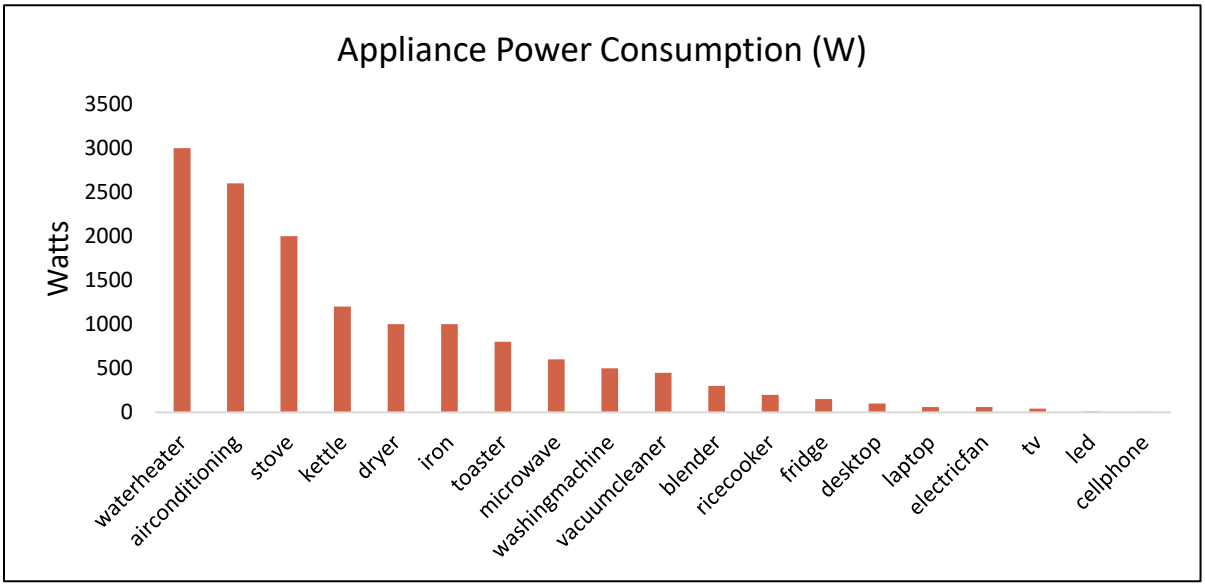


Figure 5. Appliance Power Consumption for Load Simulator

3.7 Predictive Models and Cost Analysis

After processing all the data and building a ready-to-use table, two algorithms were used to process EIA 2015 dataset, which contains information about U.S. residential consumers. The first one was a K-neighbors algorithm to predict electricity consumption based on appliances usage as features and the second one was a Multilayer Perceptron or neural network to evaluate whether this data set has a non-linear behavior.

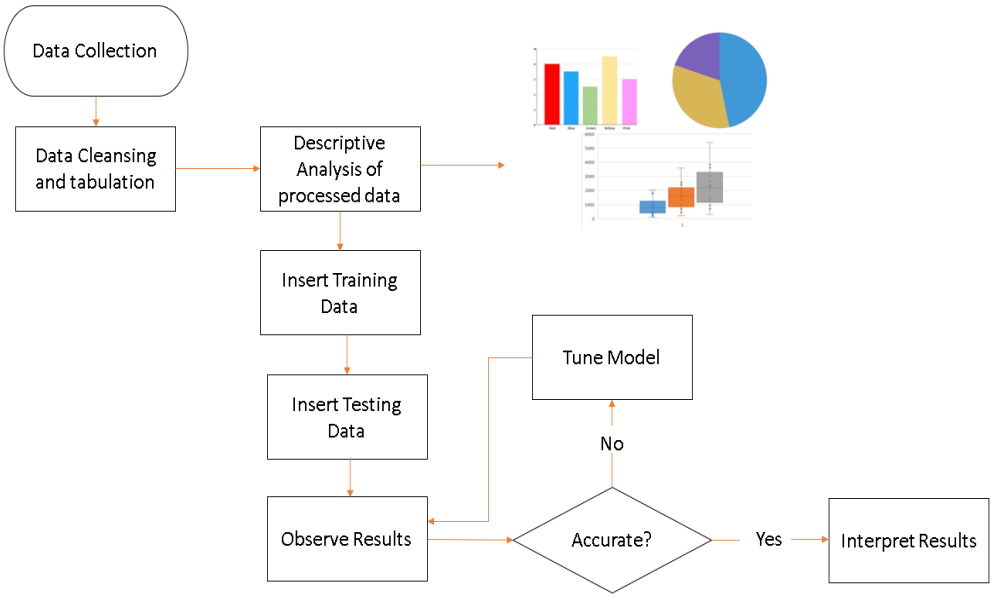


Figure 6. Data Treatment flow chart

CHAPTER 4. RESULTS AND ANALYSIS FROM SURVEY

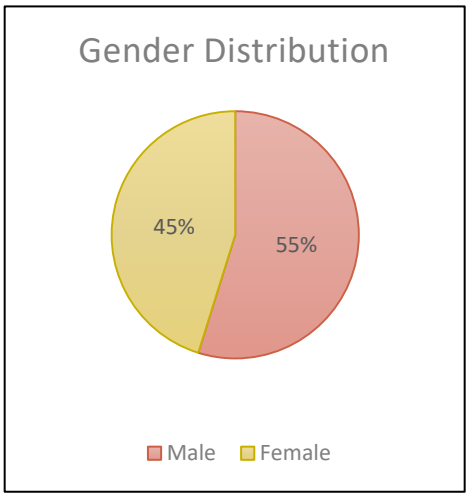
In order to understand the surveys' collected data, the answers were divided into three different periods, PRE-COVID 19, Stay-at-home order, and Fall 2020. The dates for each period are shown in Figure 7.

Figure 7. Research Timeline

4.1 Demographics and Static Data

Participants' demographics are shown in three charts in Figure 8. Most participants live in apartments with at least one roommate from these figures, where 41 out of 59 participants live in apartments. In a) Male was more responsive, having 54% of all total answers. In c), the most common dwelling size is between 700-1000 sqft, an average apartment size.

a.



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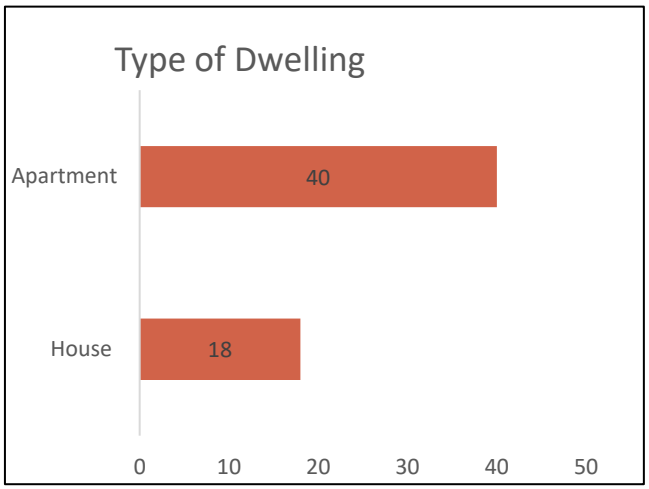

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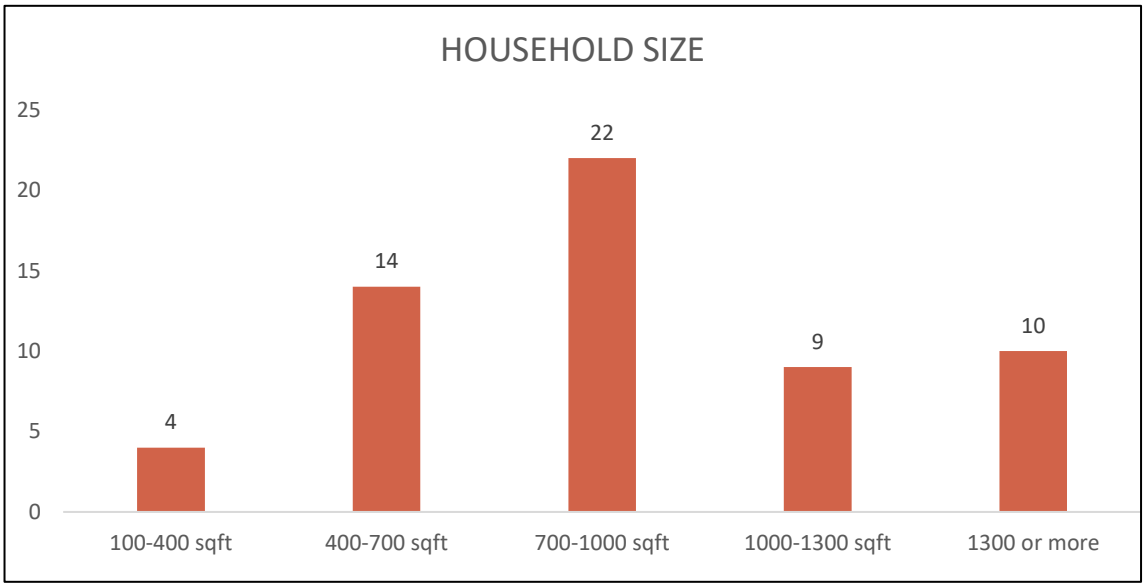

Figure 8. a. Gender Distribution; b. Type of Dwelling c. Household size of individual people.

Figure 9 shows the number of people who live with each participant. Most people live with one or two people in the same dwelling.

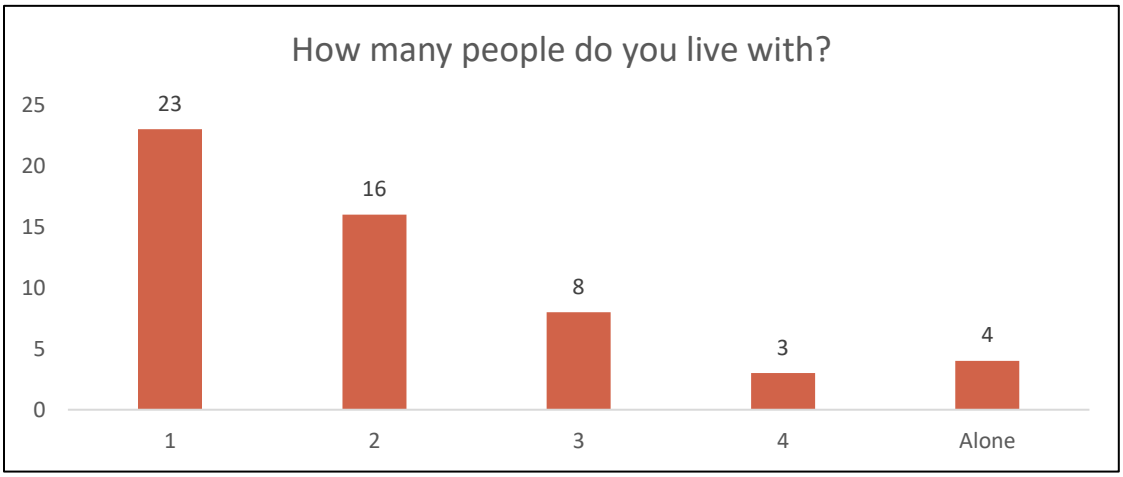

Figure 9. Number of roommates per participant

4.2 Pre-COVID

This section asked subjects about their consumption behavior before Indiana's government announced the stay-at-home order. The survey's questions can be found in appendix II, and they are split into three sections: people's activities on Campus, at home, and their appliance usage during a week.

Figure 10 shows the most frequented activities that participants partook in. This data consists of activities done on Campus between Monday to Friday. As expected, most participants, students, and professors have meetings, study, do research, and do different campus activities. These activities involve energy consumption in different ways. For example, during study sessions or research, people use computers, lab equipment such as microscopes or oscilloscopes. Indeed, eating contributes to electricity consumption too; students and professors bring their food, and that food is sometimes heated in microwaves that consume an average of 800 watts per hour.

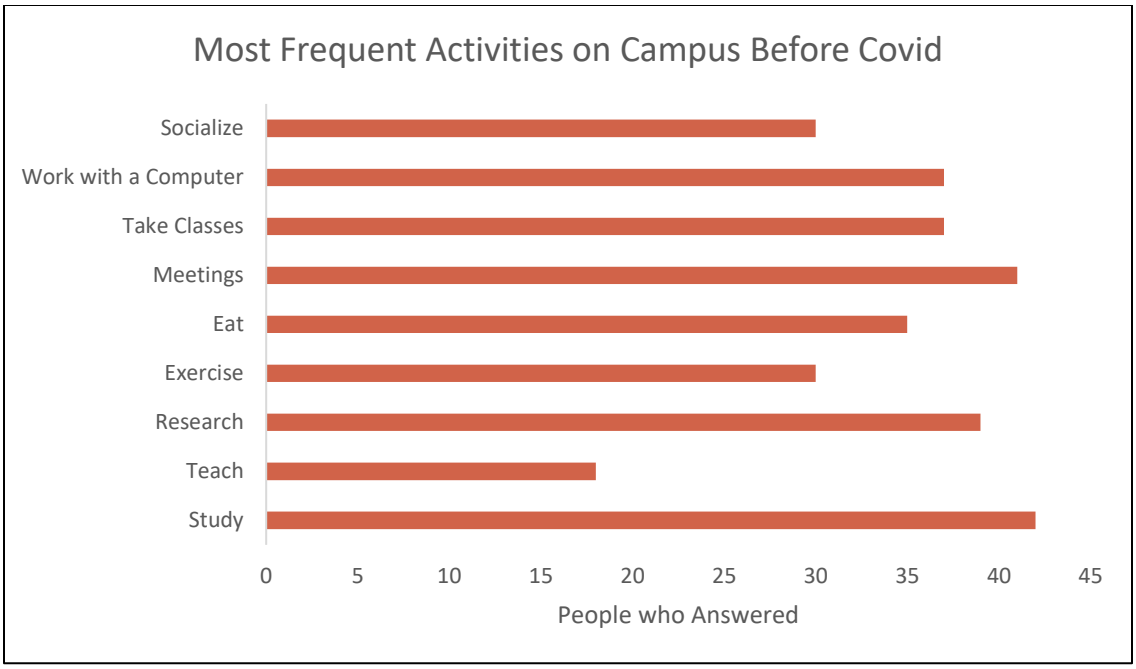

Figure 10. Most Frequented Activities Pre-Covid 19 on Campus

In Figure 11, the data shows participant's time expenditure on Campus and their homes. Time at home was separated between Monday through Friday days and Saturday and Sunday days. Before the stay-at-home order, at least 72% of people spend between 5-15 hours on Campus during weekdays. Also, 82% spend between 10-24 hours at home during weekends while 70% spend about 10-24 hours on weekdays. Those numbers suggest that even before the COVID-19 pandemic, most participants already spent a decent amount of time at home. According to the Environmental Protection Agency, the average American spends 87% indoors, 6% in the automobile, and 7% outdoors. Therefore the given times can be corroborated with this data. It is essential to mention that indoor activities involve electricity consumption which implied CO2 emissions by electric appliances.

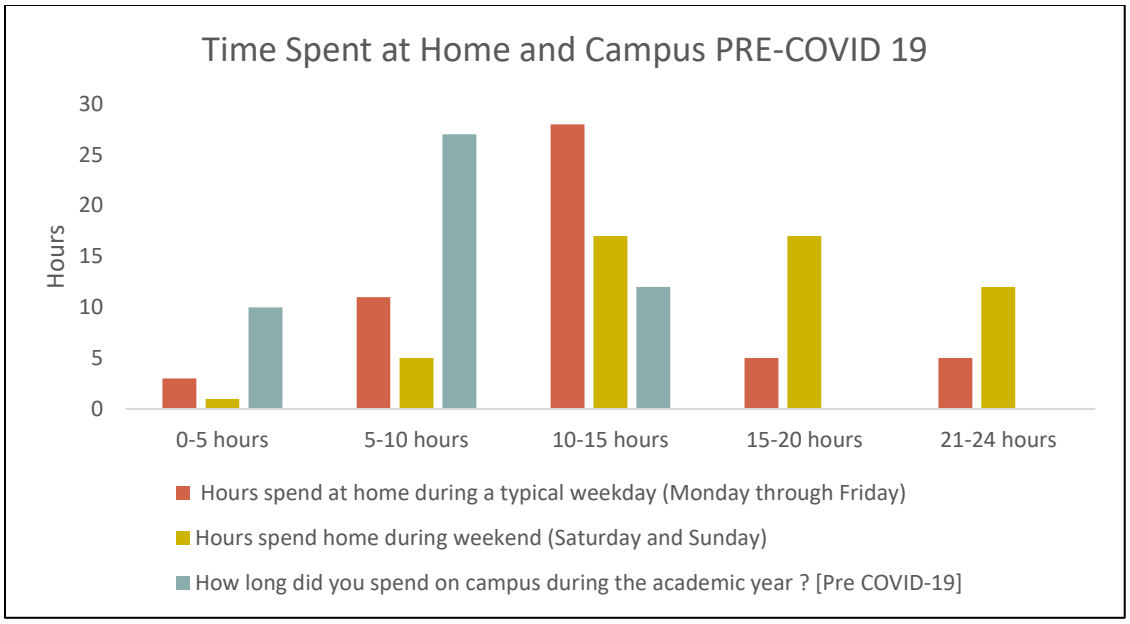

Figure 11. Time Spent at Home and Campus PRE-COVID 19

Figure 12 shows participants' energy consumption on a weekday of specific appliances. Due to appliance demand and characteristics, this graph shows overall consumption. For example, devices that generate heat consume the most, such as electric stoves, water heaters, dryers, and others. On the other hand, laptops, televisions, or desktop appliances do not generate that much heat. Thus they demand less electricity in kWh.

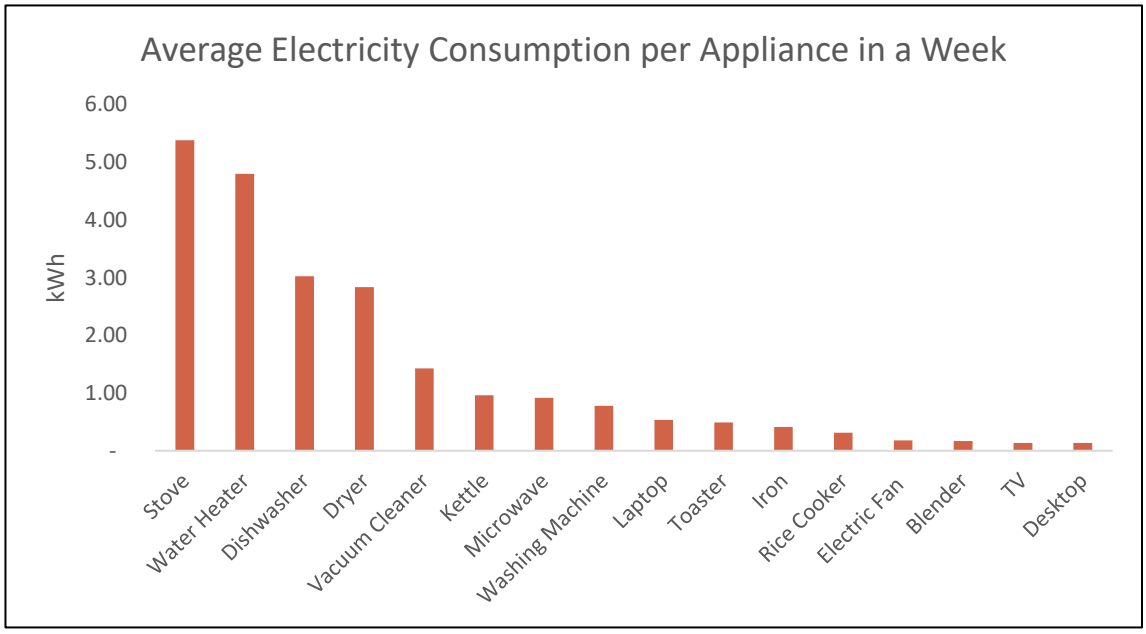

Figure 12. Average electricity consumption per appliance PRE-COVID-19

Appliances and Lightning sum up the average load a participant has when working at an office or home office. Since most campus jobs require using a computer, people used laptops for about 8 hours a day during PRE-COVID, as observed in Figure 13. Lights and desktops are widely used by university workers and have between 3-7 hours of average usage. Also, fan usage and air conditioning are associated with seasonality, mainly used during summer.

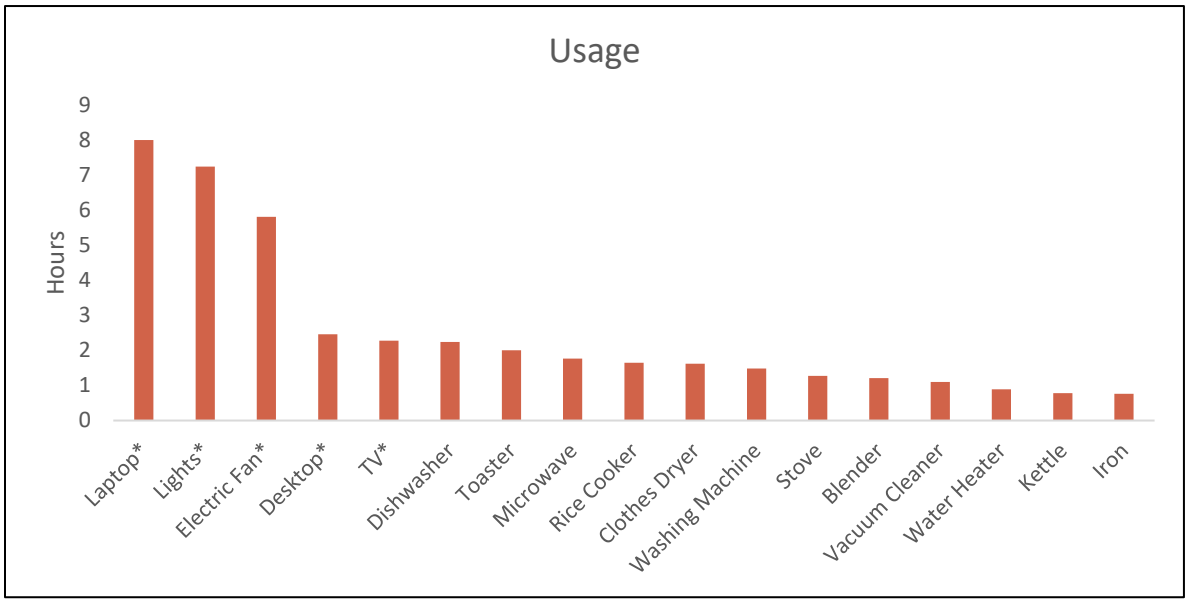

Figure 13. Usage of appliance per hour and duty cycles during a week.*Appliances that consume in hours

4.3 Stay at home order

During the stay-at-home order, most people spent between 0-5 hours at the Campus. Simultaneously, only 5% of participants stayed on Campus for more than 5 hours during a weekday. About 85% spend more than 10 hours at home during stay-at-home order, and 50% spend at least 21 hours at home, which means that at least 50% of people started to work at home full time, therefore, using more appliances at their homes.

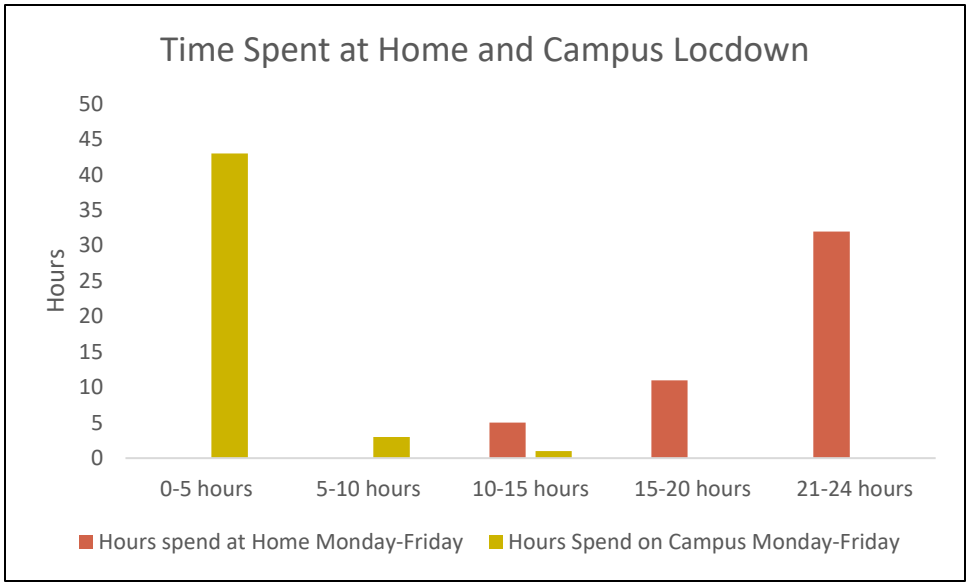

Figure 14. Time Spent at Home and Campus – stay-at-home order

Energy consumption is mainly significant in the electric devices that generate heat or cool. During the stay-at-home order, there was an increase in kitchen appliances consumption; for example, stove usage increased 25% compared to PRE-COVID, as shown in Figure 13. In general, people's weekly consumption increases by about 15-20%, as observed in Figure 15.

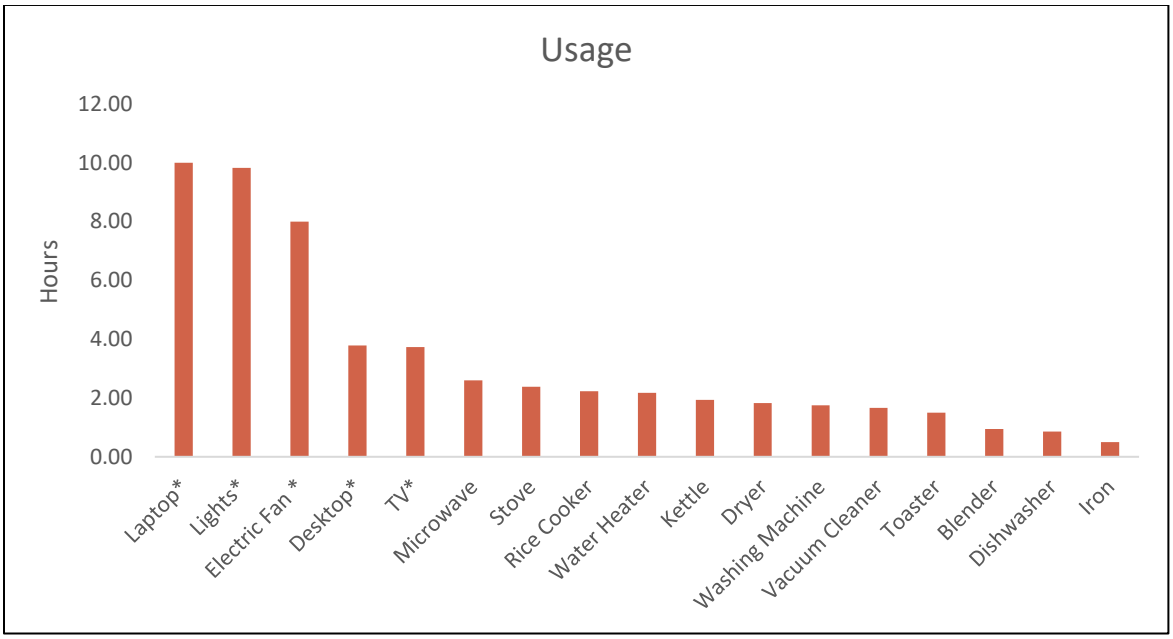

Figure 15. Usage by duty cycle and hours per appliance - stay-at-home order

Due to remote work, laptop and lights usage increased from 8 to 10 hours of average daily usage. Besides, desktops and televisions increased from two to roughly four hours. Kitchen devices seem to increase their duty cycle, having twice as much usage per day.

4.4 Fall 2020

In Fall 2020, people started to go back to Campus, leaving full-time remote work. However, subjects can be divided between those who return Campus smoothly without any alteration in their schedule; others just went for less than 2 hours a day occasionally, and some people did not need to go to Campus at all. As shown in Figure 16, 60% of the participants stayed on Campus less than 5 hours per day on a weekday. Also, hours spend at home remained similar with more than 80% of participants staying at home between 10-24 hours, which shows the social distancing policy lasted on fall 2020.

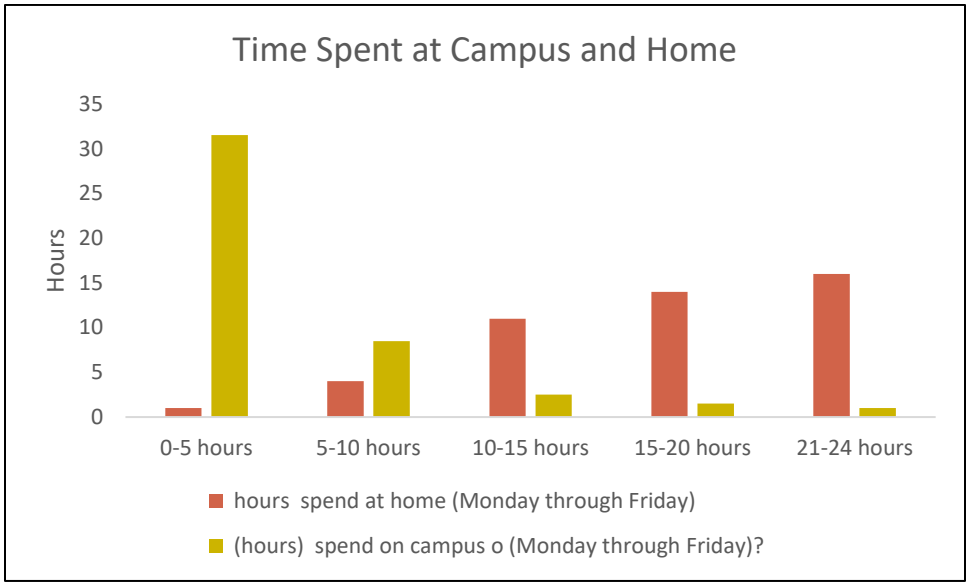

Figure 16. Time spent at home and Campus – Fall 2020

The activities performed at Campus during Fall 2020 changed in comparison to the Spring. Figure 17 shows which activities were the most performed by participants. Research is the most common, and it involves working with a computer in a laboratory where the space is limited. Then taking classes and study were allowed at Campus with restriction. All other leisure activities such as exercise or socializing on Campus were prohibited as well.

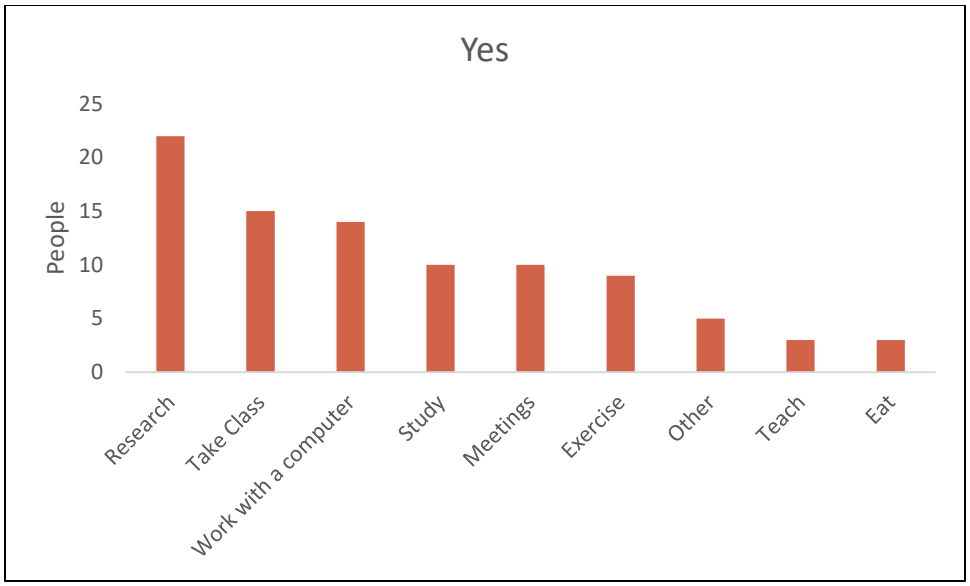

Figure 17. Activities spend at Campus – Fall 2020

During the Fall of 2020, appliance usage did not change much compared to the stay-at-home order appliance usage. Laptops, lights, and stoves are among the most used in hours/day. Nonetheless, desktop usage slightly reduces to 1 hour per day. This reduction might be associated with people's mobility; since laptops are more portable than desktops, students and staff who move between dwelling or Campus buildings are more likely to use laptops.

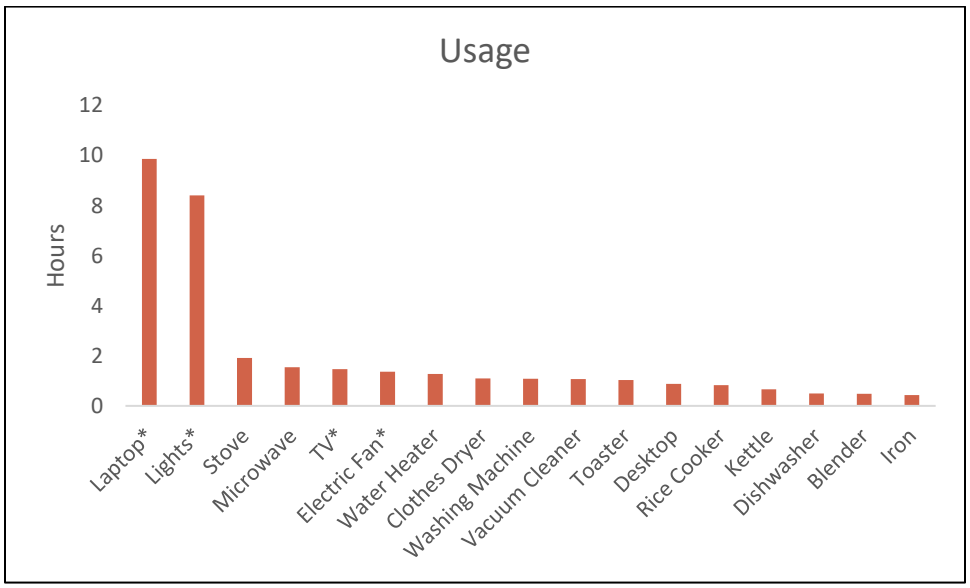

Figure 18. Usage of appliance per hour – Fall 2020

4.5 Correlation Analysis Between Appliances

Appliance usage is correlated with other appliances. For instance, when people use laptops to work, they will have a router or modem on simultaneously, or when using the dishwasher, people are very likely to use the stove or oven. Because of those correlations, some correlations matrix or heat maps were done in the following figures.

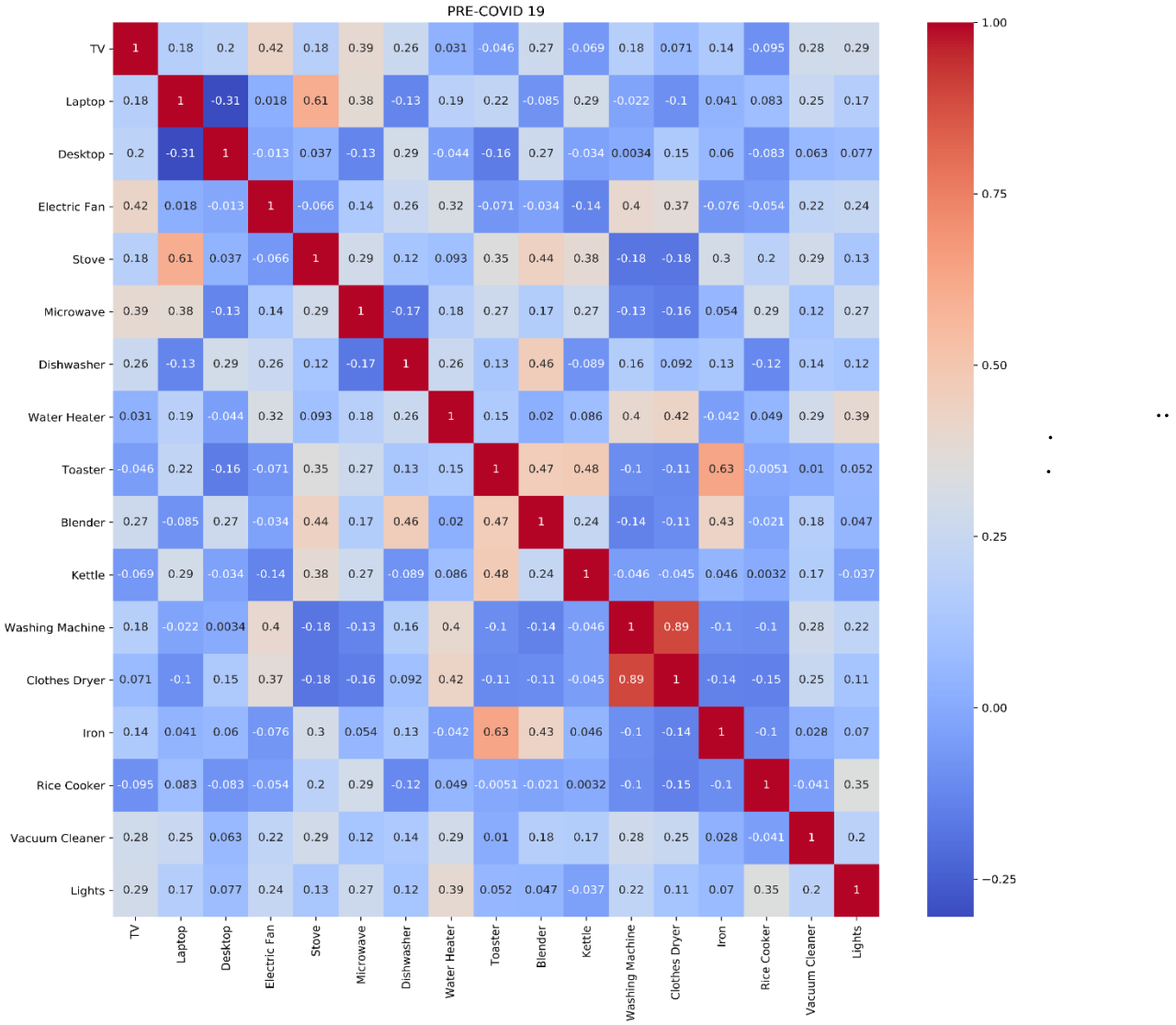

Figure 19. Appliance Correlation Matrix – PRE-COVID

Figure 19 shows the usage correlation between appliances. This chart is called a heat map, and it highlights the values that are more correlated with the less correlated values. The red intensity represents a Pearson value of 1, and the intense blue is close to 0, which means it is not correlated. Some appliances are highly correlated to each other such as the clothes dryer and the washing machine (r=0.95), kettle and microwave (r=0.55), or laptop and lights (r=0.47). Nevertheless, there are opposing pairs, such as laptops and desktops (r=-0.34) or toasters with almost all the appliances.

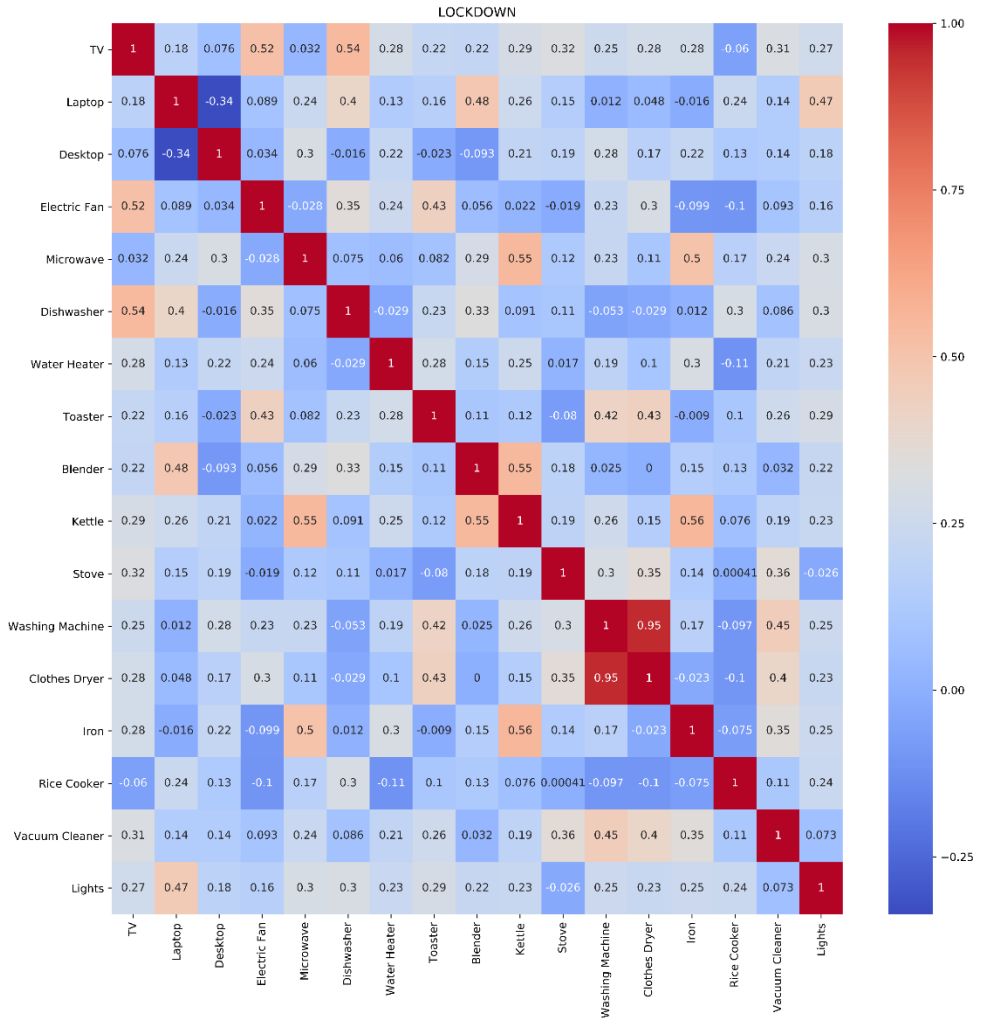

Figure 20. Appliances correlation matrix - stay-at-home order

Figure 20 has the same purpose as Figure 19, but it shows the stay-at-home order. In this case, more pairs showed up. For instance, kettles are more associated with other appliances such as blenders, iron, and microwave (r=0.55). On the other hand, the vacuum cleaner correlates with other appliances such as iron, stove, washing machine, and clothes dryer. These changes could have increased because people spent more time at home and used more appliances. Meanwhile, the washing machine and dryer still have the same Pearson value (r=0.95). In general, negative r values were reduced due to usage increases.

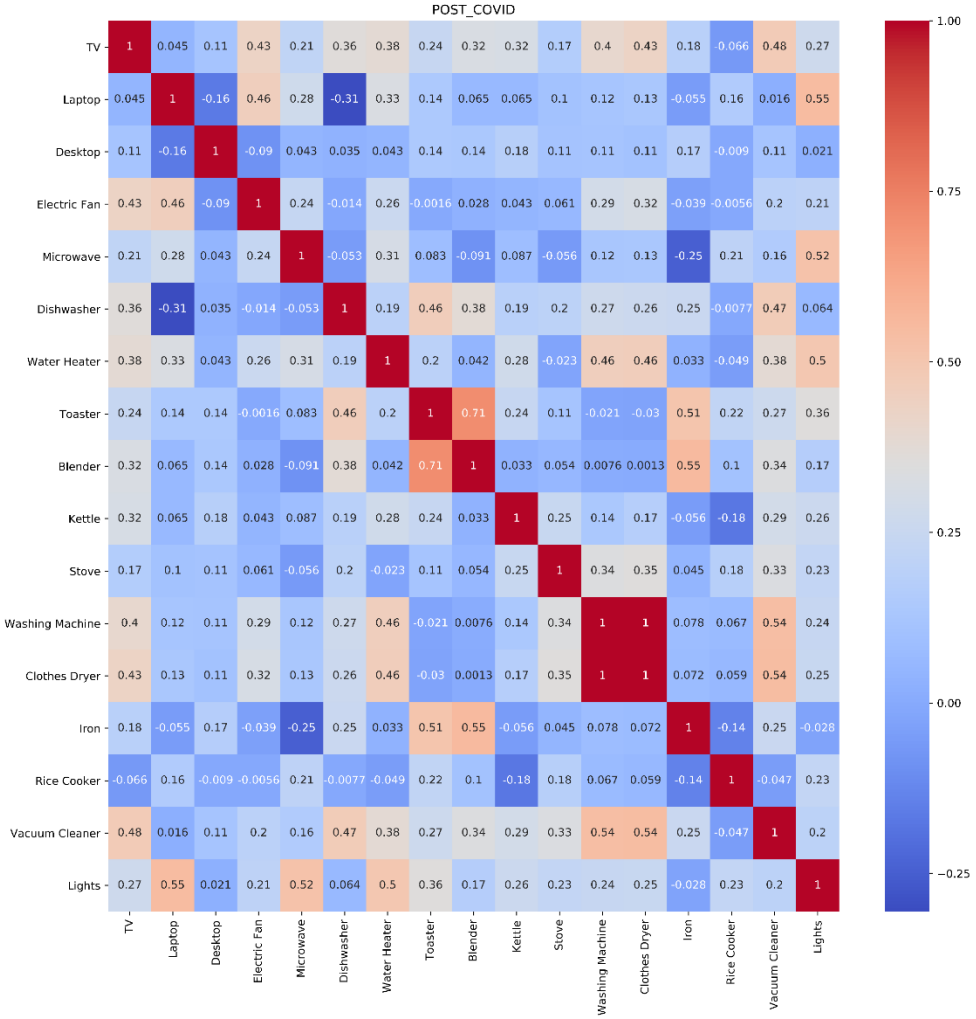

Figure 21. Appliance Correlation Matrix Fall-2020

During the Fall of 2020, appliances kept at a similar usage rate compared to stay-at-home order responses. Nevertheless, some appliance correlation increases and decreases significantly; for example, the washing machines and dryer usage were 100% correlated (r=1). In addition, vacuum cleaners are associated with other appliances such as dishwashers and T.V.s (r=<0.45). One interesting fact is that laptop usage is always kept very uncorrelated with other appliances except for lights. This fact might explain that people who use their laptops for long hours tend to use fewer other appliances. For instance, vacuum cleaners and laptops are aFigure 21lmost negatively correlated (r=0.016). This might indicate that more laptop usage reduces the likelihood of using vacuum cleaners.

These heatmaps have shown participants' behavior towards the usage of certain appliances. For example, from Figure 21, there is a clear pattern with less correlation between appliance usage; on the other hand, Figure 22 and Figure 23 changed, showing a clear shift in people habits during the stay at home order and after it.

4.6 Overall Comparison

4.6.1 Usage Comparison

Figure 22 shows the appliance usage change during the PRE-COVID months, stay-at-home order, and fall 2020 semester. The PRE-COVID usage is in red dots in the middle because it shows usage at normal conditions before the pandemic with 100%. Meanwhile, the other blue and green sky shows the change in appliances usage percentage during stay-at-home order and fall 2020.

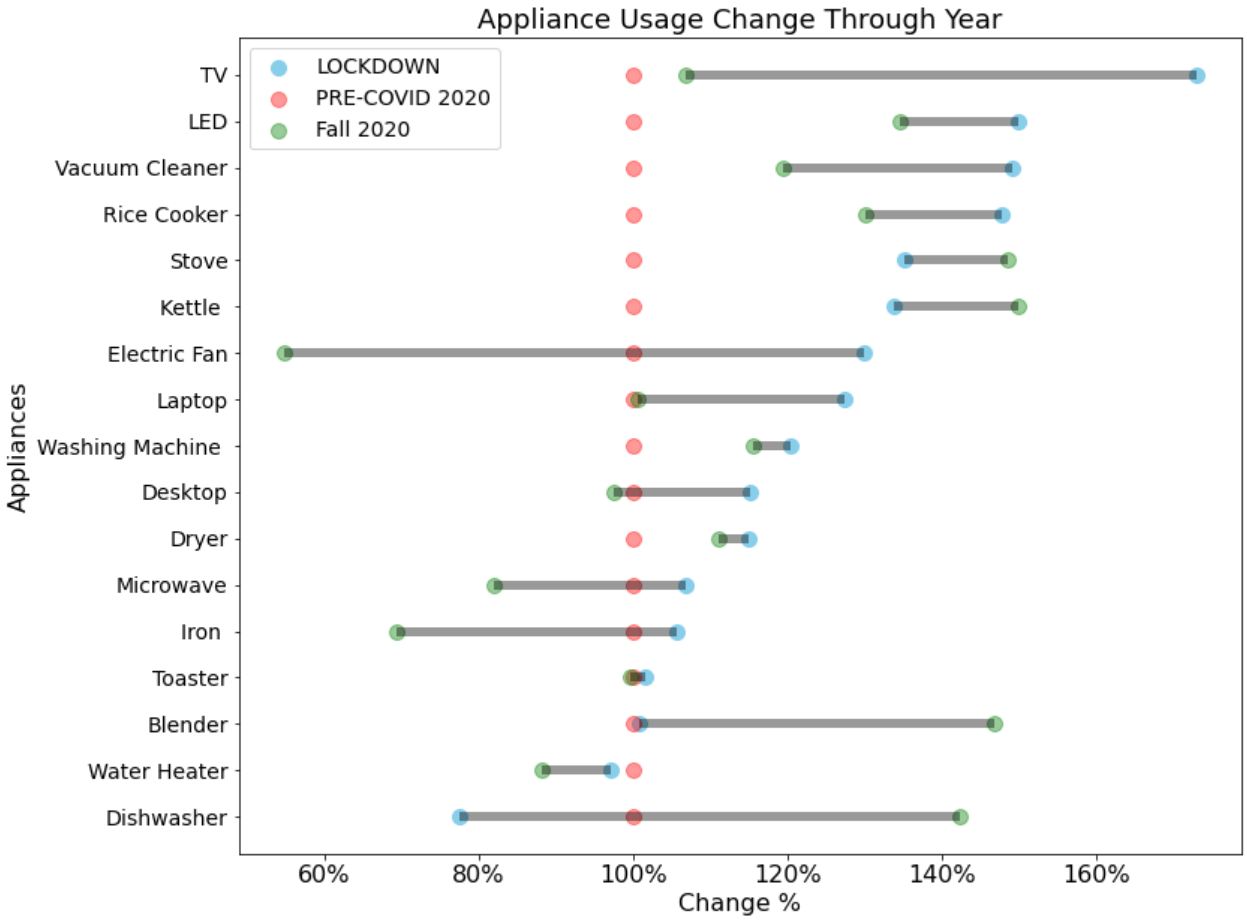

Figure 22.Appliance Usage Change through the year

Appliances such as the Laptop, T.V., Vacuum cleaner, lights increased overall usage after the spring semester of 2020. Other appliances such as the microwave, iron, or dishwashers increased after Spring; however, when the stay-at-home order ended, and fall 2020 started, usage decreased or got back to the same. Seasonality might have an impact on the usage, no matter if a pandemic exists. For instance, the electric fan is mainly used during the hot months; after that, its usage decreased as shown in the previous figure.

4.6.2 Load Simulator Results

The load simulator showed an iteration of the daily electricity consumption established each month of the academic year, which is part of the participant's appliances usage results. Figure

23 shows a boxplot of the daily electricity consumption of participants at three different moments: Pre-COVID, stay-at-home order, Fall_2020.

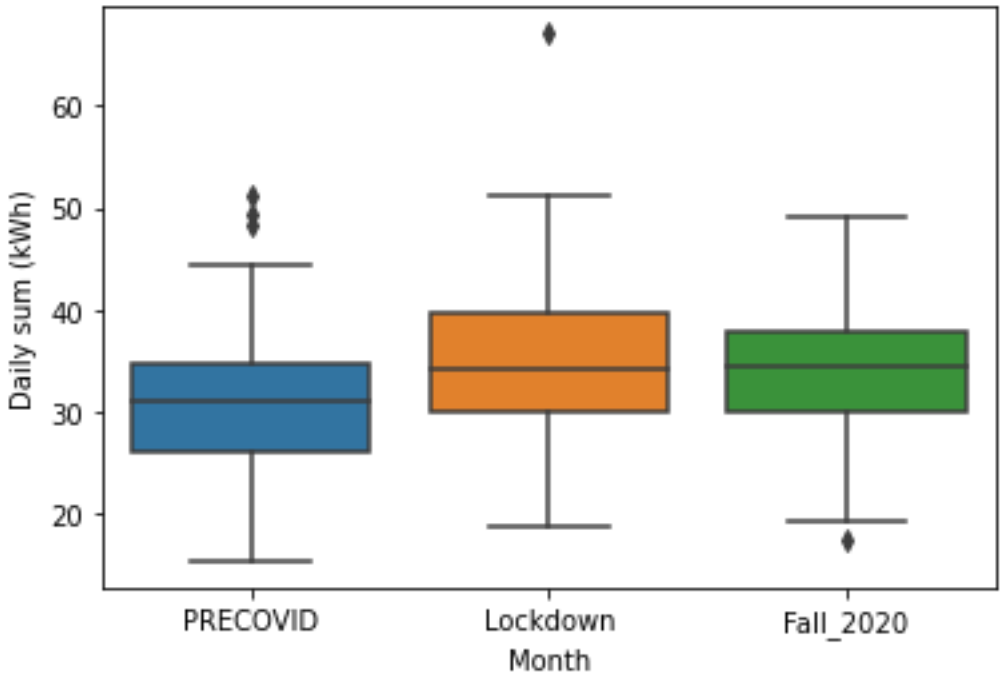

Figure 23. Daily Electricity Consumption during PRE_COVID, stay-at-home order, and Fall 2020

The average daily consumption during pre-COVID was 31.1 kWh/day, then during the stay-at-home order, the electricity consumption increased by 3kWh, having an average of 34.8 kWh during any month between April and May. In this case, the stay-at-home order consumption is positively skewed, showing more cases close to the Q2-Q3 of 38kWh/day. Finally, during the Fall 2020 semester, the average consumption was around 34.4kWh, very close to stay-at-home order months, but with minor variation. Thus, during Fall 2020, results show more evenly distributed values with very few outliers. In addition, most of the participants who were located on Campus did hybrid work hours causing Fall 2020 consumption to become similar.

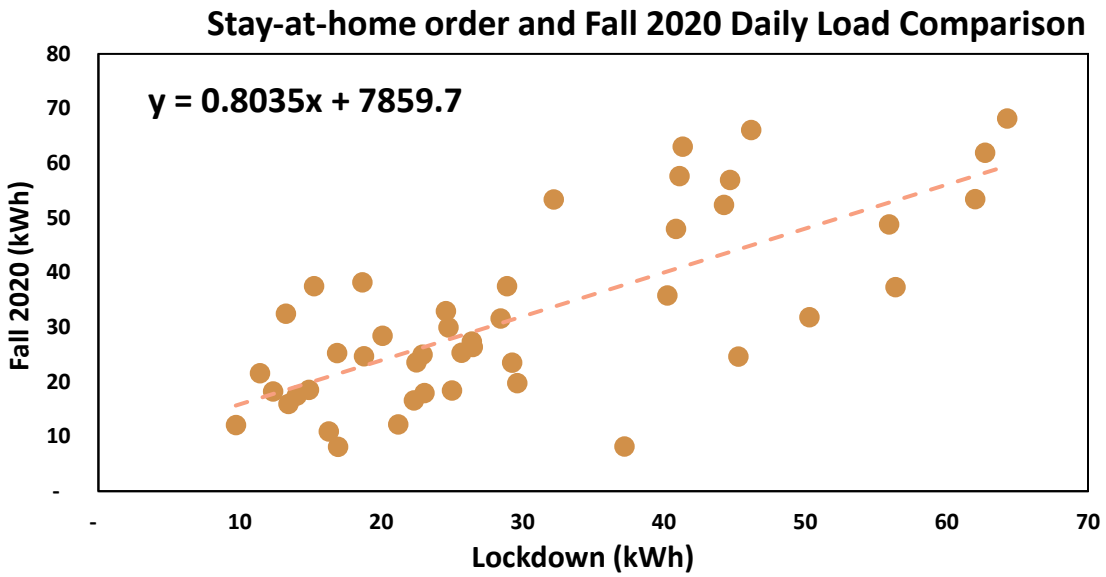

Figure 24. Stay-at-home order and Fall 2020 energy consumption correlation.

Electricity consumption in the stay-at-home order and Fall 2020 did not vary a lot between each other. Consumption from participants keeps the similar as shown in Figure 24. The R Pearson coefficient is 0.8, which shows a high correlation in both electricity consumption in kWh. This relationship between both loads shows that after pandemic appliance consumption increased and even with a hybrid work schedule, it has not returned to the previous state.

CHAPTER 5. REGRESSION ANALYSIS, COSTS, AND COMPARISON

5.1 Statistics Comparison between Survey data and EIA 2015

Table 5 shows a statistical comparison between the survey created for this research project and the survey made by the Energy Information Administration in 2015 to all residential consumers in the U.S. The EIA 2015 dataset validated the self-made survey results and developed a predictive model using the more extensive data set.

Yearly average electricity consumption before COVID is approximately 2000kWh less than the stay-at-home order and Fall 2020. In the previous chapters, data showed that people used more appliances during the pandemic, which increased. On the other hand, the EIA 2015 shows a more kWh year consumption due to several reasons. One of them is because participants are from all parts of the USA, and the dwelling types vary more. In contrast with the self-made survey, the EIA survey interviewed many more houses, which increases the average kWh year consumption. In the self-made survey, almost 70% of the dwelling were apartments.

Table 5. Statistics Summary of Survey and EIA 2015 data

	Survey			
	PRE_COVID	Stay-at-home order	Fall 2020	**EIA 2015 Survey**
Average Electricity Consumption (kWh)	8,468	10,031	10,659	11,055
Standard Deviation	4,620	4,892	5,661	7,039
Max	23,821	21,496	23,564	63,217
Min	3,049	3,209	2,528	1,058
Median	7,200	8,870	8,446	9,559
Observations	54	46	45	5,672

5.2 Regression Analysis for EIA 2015 Data

The EIA 2015 dataset provides a comprehensive understanding of the residential electricity consumption of people in all climates in the U.S. Generalizing this dataset by doing a predictive model with Machine Learning or Deep Learning will allow researchers to understand better the differences or errors between residential electricity consumption at regular times and confinement scenarios. That is why in this section, two different regression analyses were performed to the EIA 2015 dataset. One of them is a classic K-Neighbors Regression, and the other is the multilayer perceptron regressor.

5.2.1 K-Neighbors Regression

The objective variable is "kWh," which is the total electricity consumption by a participant. This model tries to predict this variable by understanding other features such as T.V.s, computers, fridges, lights, among other appliances usage. Figure 25 shows the prediction error plot from the K-neighbors regression; it shows an R square value of 0.761. Additionally, this graph shows that residents whose energy consumption is below 30 000kWh are more predictable than larger values from more significant residential consumers.

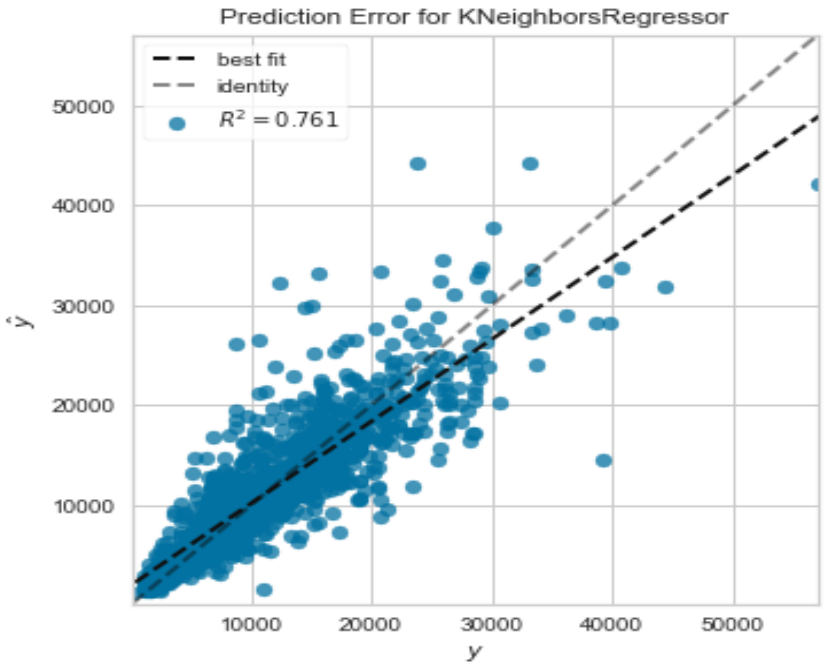

Figure 25. K_neighbors Regression Analysis for 2015 EIA Survey

Furthermore, a residual plot is shown in Figure 26 to analyze the distribution of error of this regression algorithm. A clear error divergence is seen in this graph which increases almost linearly in both directions, but it is more accentuated after 30 000kWh consumption. This is because this dataset does not have a linear behavior; instead, the data shows a non-linear behavior. Nevertheless, more than 70% of the predictions are within a short error, which finally gives a reasonable estimation of electricity consumption in a year without any intrusive electricity measurement device.

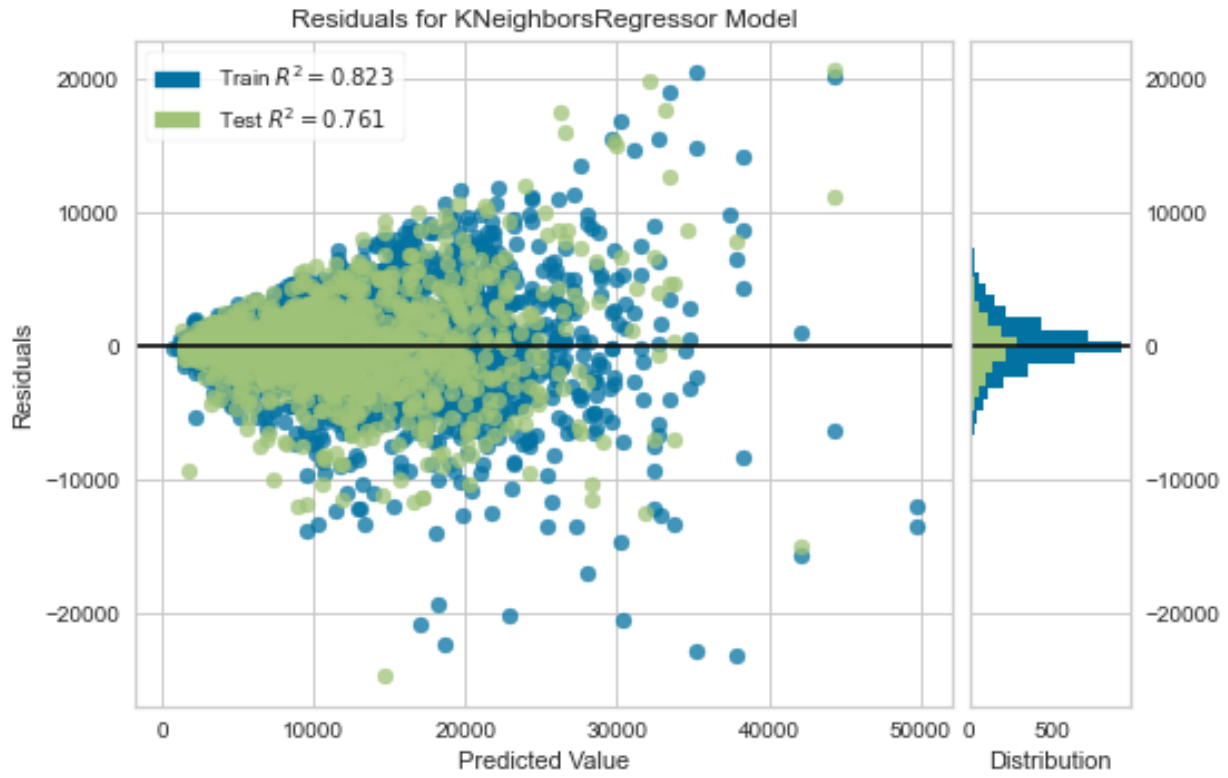

Figure 26. Residuals for KNeighbors Regressor Model

5.2.2 Multilayer Perceptron Regressor

Since the dataset showed a non-linear response, a multilayer perceptron regressor was used to predict people's electricity consumption with a more accurate response. Figure 27 showed an accuracy of 79% when trying to predict energy in kWh. Even though this accuracy is better than

the previous K-neighbors approach, still prediction is non-consistent with loads that still have much error.

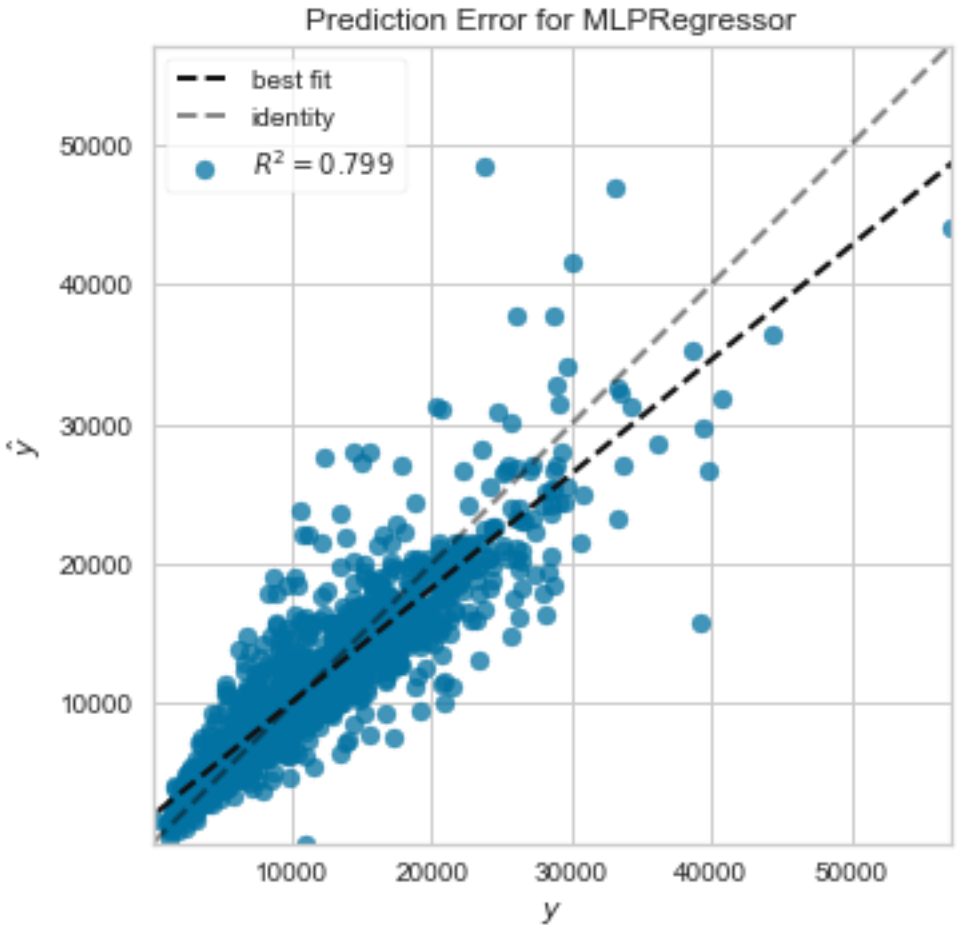

Figure 27. Multilayer Perceptron Regressor

In Figure 28, the divergence of the error results has not been solved or understood by the MLP algorithm. This might indicate that the non-linear behavior of this dataset corresponds mainly to more significant residential consumers with more unpredictable loads, such as big houses with, e.g., pools or electric vehicles at home.

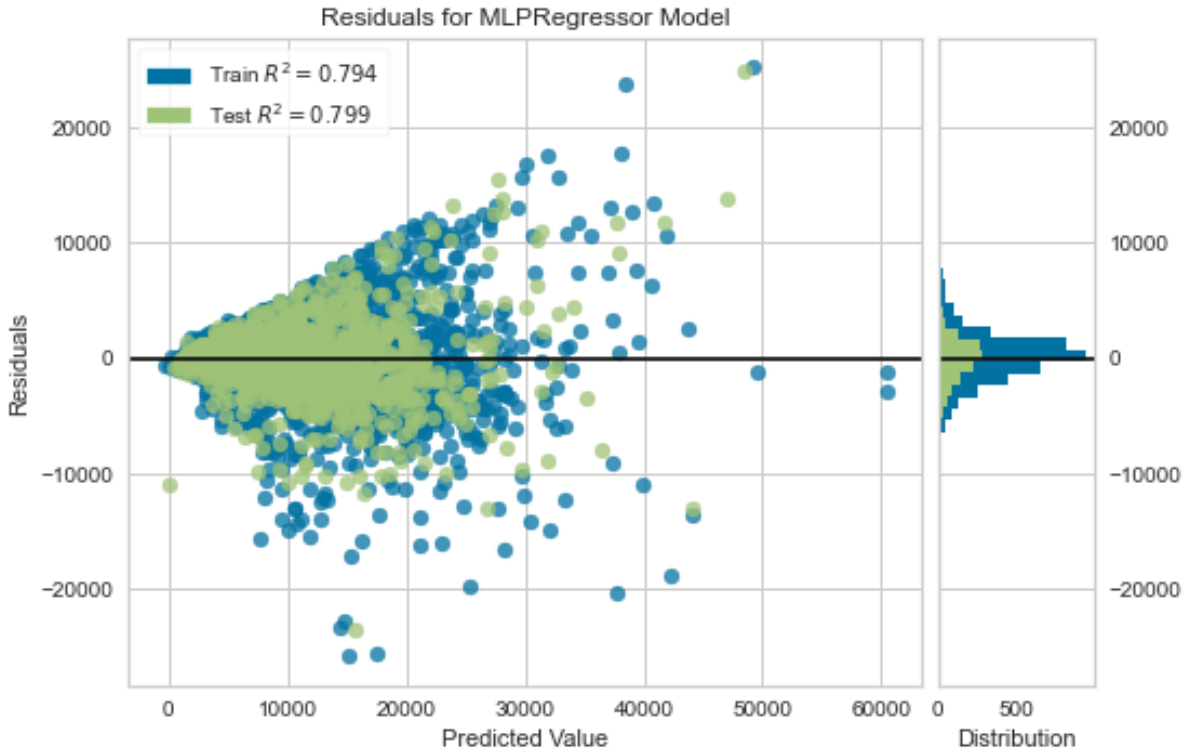

Figure 28. Multilayer Perceptron Regressor Residuals Values

5.2.3 Survey Data Multiple Regression Analysis

Equation 1 shows the total electricity consumption by adding individual appliances to daily life usage for each appliance. This equation shows the impact of certain appliances on total electricity consumption in kWh.

$$y(kWh) = 33.6\,x_1 + 25.2\,x_2 + 75.6\,x_3 + 21.8\,x_4 + 1176x_5 + 352.8\,x_6 + 1663.2\,x_7 + 1176\,x_8 + 193.2\,x_9 + 109.2\,x_{10} + 756\,x_{11} + 257x_{12} + 856.8\,x_{13} + 470\,x_{14} + 110.8x_{15} + 588\,x_{16}$$

Equation 1. Multiple Regression Analysis of the Appliance Consumption for Residential Consumers

X1: T.V.

X2: Laptop

X3: Desktop

X4: Fan

X5: Stove

X6: Microwave

X7: Dishwasher

X8: Waterheater

X9: Toaster

X10: Blender

X11: Kettle

X12: Washing Machine

X13: Clothes Dryer

X14: Iron

X15: Rice Cooker

X16: Vacuum Cleaner

From this regression, it can be concluded that heating appliances represent the most significant consumption; nonetheless, in a home office environment, these heating appliances are hardly ever used.

5.3 Results for Home Office Consumption Stay at Home Order and Fall 2020

The following tables show a summary of the office appliances' energy consumption and cost divided into three tables for each different period of the 2020 academic year. The devices included in an office setup are laptops, desktops, modems, and lights only. Table 6 shows an average electricity consumption of 362 kWh of the PRE_COVID time in an office on Campus without considering HVAC. In a year of 260 working days, the average cost of using those appliances would be 39.87 USD. The electricity cost was put in a fixed value of 0.11c/kWh (Indiana Energy, 2018).

Table 6. PRE_COVID_19 Office Energy and Cost Analysis

PRE_COVID_19 Office kWh Consumption	Results
Average Electricity Consumption (kWh) Survey	362
Average Cost in a Year ($)	$ 39.87
Max	$ 93.67
Min	$ 8.29
Median	$ 34.61
Standard Deviation	$ 46.00
Observations	47

Table 7 summarizes the total electricity consumption of home office appliances and the total cost per participant during the stay-at-home order. This analysis represents an individual electricity consumption for either student or Staff at Purdue. The average electricity consumption for a year of home office would be 506 kWh which is 55.71USD that each worker would have to pay.

On-Campus, there are approximately 10 000 graduate students enrolled per year, 5800 staff. During the stay-at-home order, between 60-80% worked remotely. Out of this range of graduates and staff, at least half of them work in an office. In a full academic year, the total cost of remote work would range between 300 000 and 500 000 USD dollars of total electricity cost for all graduate students and staff, without considering undergraduate students. It is essential to highlight that the 55.5 USD per year increases 25% more than PRE_COVID. The confinement and remote work consequence was a higher usage appliance such as laptops, desktops, lights, and other home office appliances.

Table 7. Stay-at-home order Home Office Energy and Cost Analysis

Stay-at-home order Home Office kWh Consumption	Results
Average Electricity Consumption (kWh) Survey	506
Average Cost in a Year ($)	$ 55.71
Max	$ 117.26
Min	$ 19.73
Median	$ 53.20
Standard Deviation	$ 46.00
Observations	47

The results from Fall 2020 showed similar results of the PRE COVID appliances consumption. In general, workers returned to Campus and started to work in a hybrid schedule consisting of remote work and campus work. The average electricity consumption was 360 kWh/year with a cost of 39 USD. These results big down from the stay-at-home order where people started to use less

Table 8. Fall_2020 Home Office kWh Consumption

Fall_2020 Home Office kWh Consumption	Results
Average Electricity Consumption (kWh) Survey	360
Average Cost in a Year ($)	$ 39.58
Max	$ 86.94
Min	$ 18.73
Median	$ 36.61
Standard Deviation	$ 46.00
Observations	47

CHAPTER 6. CONCLUSIONS

The first hypothesis was that people used more appliances during a pandemic scenario, corroborating the data shown in chapter four. Overall appliance usage increase between 20-30% during the stay-at-home order and 10-15% during the Fall semester of 2020. One of the main reasons for this is the rapid swift from working at office and then working from home. As a result, people started to use laptops as part of their work; they passed from 7-8 hours to almost 10 hours per day. At the same time, laptop usage affected other appliances positively and negatively. For instance, vacuum cleaners and laptops are negatively correlated, which means people who work more on their computers cleaned the lessor did not use cleaning appliances.

In addition, the load simulator based on a stochastic iteration showed a monthly electricity consumption at different times. In pre-pandemic, an average of 31kWh, during stay-at-home order 34.8 kWh/day and 32 kWh/day for fall 2020. The impact of office appliances such as laptops, desktops, or printers is minimal compared to other heating appliances such as water heaters, air conditioning systems, or stoves. For example, the ratio between a stove and a laptop is 33:1, which means using for one hour a stove is equivalent to using 33 laptops for the same time.

Even though offices appliances have a relatively minimal consumption, they account for hundreds of dollars when adding those values in a kWh/year period. Indeed during pandemics, the amount increases. For instance, pre-pandemic, a home-office worker could pay roughly 40USD; during the stay-at-home order, this amount goes to 55.71 USD, and in fall 2020, it goes down to 39 USD. These numbers are relatively low cost compared to the average salary of a worker in Indiana. However, when multiplying this number, remote workers can add to hundreds of thousands of dollars. For example, Purdue University can save between 300k to 500k USD annually by sending 60% of graduate students and staff to work from home. This amount can go up to a couple of million dollars if undergraduate students and other devices are considered in the total count of consumption.

People's behavior towards appliances usage increases when staying at home for extended hours; there are correlated appliances. Stoves, vacuum cleaners, iron, and other chores appliances seem to depend on each other. On the other hand tv, laptops which are office and leisure appliances are related as well. Those two groups tended to grow, Table 9 shows overall pros and cons of stay-

at-home order. Finally, during fall 2020, consumption stabilized, but office appliances did not go back to normal.

Table 9. Pros and Cons of Stay at Home Order

Pros	Cons
Electricity savings to any large company where there is a considerable amount of office workers	Much cost for people who work long hours in an office
Less commuting means less expenditure on transportation and carbon footprint reduction.	People's habits tend to change to more appliance usage and therefore increase the electricity bill.
Less usage of appliances on Campus means less maintenance, therefore, fewer maintenance costs.	Degrading of specific devices when using them more such as computer or kitchen appliances

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APPENDIX A. SURVEY QUESTIONS

Q100

Demographics and General Information

Q64 Please provide your preferred email

_____

Q14 What is your gender?

Male (1)

Female (2)

Other (specify) (3) _____

Q1 How old are you?

18-24 (5)

25-34 (6)

35-44 (7)

45-54 (8)

55-64 (9)

65 or over (10)

Q39 Select your Status at Purdue University

▼ Faculty (1) ... Other (9)

Display This Question:

If Select your Status at Purdue University = Other

Q108 Specify what is your position

_____

Q3 What type of housing do you live in?

House (1)

Apartment (2)

Other Specify (3) _____

Q7 How large is your living space in square feet? *You may find for this information in the webpage of your residence building.*

100-400 sqft (1)

400-700 sqft (2)

700-1000 sqft (3)

1000-1300 sqft (4)

1300 or more (5)

Q8 How many other people do you live with ?

1 (1)
2 (2)
3 (3)
4 (4)
5 or more (5)

Q16 Do you have smart meters? *A smart meter is an electronic device that records information such as consumption of electric energy, voltage levels, current, and power factor.*

Yes (1)
No (2)

End of Block: Demographics

Start of Block: Appliances, HVAC, and Ligthning

Q76 Select the appliances you have at home

- [ ] TV (1)
- [ ] Microwave (2)
- [ ] Laptop (3)
- [ ] Desktop (4)
- [ ] Dishwasher (5)
- [ ] Water Heater (6)
- [ ] Stove (7)
- [ ] Washing Machine (8)
- [ ] Dryer (9)
- [ ] Refrigerator (10)
- [ ] Toaster (11)
- [ ] Iron (13)
- [ ] Blender (14)
- [ ] Electric Fan (15)
- [ ] Rice cooker (16)
- [ ] Vacuum Cleaner (17)
- [ ] Electric Kettle (18)
- [ ] Air Conditioner (19)

- [ ] Heating (20)

Q18 What type of lights do you have at home? Select all that apply

- [ ] Fuorescent (1)
- [ ] LED Bulbs (2)
- [ ] Mercury Lamp (3)
- [ ] Tube Fluorescent (4)
- [ ] Incandescent Lamp (6)
- [ ] Other (7) _____

Q63 When you set up your workspace in your **OFFICE**, what electric objects do you use? Select all that apply

- ☐ Laptop (1)
- ☐ Desktop (CPU) (2)
- ☐ 1 Monitor (3)
- ☐ 2 Monitors (4)
- ☐ 3 Monitors (5)
- ☐ 3 or more monitors (13)
- ☐ TV (6)
- ☐ Lamp (7)
- ☐ Cellphone (9)
- ☐ Wireless Mouse (10)
- ☐ Wireless headphones (11)
- ☐ Wireless keyboard (12)
- ☐ Modem-Router (14)
- ☐ Speakers (15)
- ☐ Heater (16)
- ☐ Humidifier (17)
- ☐ Fan (18)

☐ Other (specify) (20) ____

☐ N/A (22)

Q61 When you set up your workspace at **HOME**, what electric objects do you use? Select all that apply

- ☐ Laptop (1)
- ☐ Desktop (CPU) (2)
- ☐ 1 Monitor (3)
- ☐ 2 Monitors (4)
- ☐ 3 Monitors (5)
- ☐ 3 or more monitors (13)
- ☐ TV (6)
- ☐ Lamp (7)
- ☐ Spotlight (8)
- ☐ Cellphone (9)
- ☐ Wireless Mouse (10)
- ☐ Wireless headphones (11)
- ☐ Wireless keyboard (12)
- ☐ Modem-Router (14)
- ☐ Speakers (15)
- ☐ Heater (16)
- ☐ Humidifier (17)

☐ Fan (18)

☐ Other (specify) (20) _____

Page Break

End of Block: Appliances, HVAC, and Ligthning

Start of Block: PRE COVID-19

Q101

PRE COVID-19 Routine

Answer this information related to your routine during the semester previous COVID-19 stay at home order (before mid-March).

Q4 On average, how many hours did you spend at home during a typical weekday (Monday through Friday)? [Pre COVID-19]

0-5 hours (1)
5-10 hours (2)
10-15 hours (3)
15-20 hours (4)
21-24 hours (5)

Q98 On average, how many hours did you spend at home during a typical day over the weekend (Saturday and Sunday)? [Pre COVID-19]

0-5 hours (1)
5-10 hours (2)
10-15 hours (3)
15-20 hours (4)
21-24 hours (5)

Q43 On average, how long did you spend on Campus during the academic year on a daily basis? [Pre COVID-19]

▼ 0 (28) ... 22-24 (10)

Q38 Which building did you spend most of your time in? [Pre COVID-19]

▼ KNOY (1) ... Other (18)

Q55 On average, how many hours did you spend in the building selected in the previous question on a daily basis? [Pre COVID-19]

0-3 (1)
3-6 (2)
6-9 (3)
9-12 (4)
12- or more (5)

Q46 Before COVID-19, what activities did you used to partake in on Campus? [Pre COVID-19]

- ☐ Study (1)
- ☐ Teach (2)
- ☐ Research (3)
- ☐ Exercise (4)
- ☐ Eat (5)
- ☐ Meetings (8)
- ☐ Take classes (9)
- ☐ Work with a computer (11)
- ☐ Socialize (15)
- ☐ Other (14) _____

Q80 On average, how long (HOURS) did you use the following appliance/device on a given weekday (Monday through Friday)? [Pre COVID-19]

Display This Choice:

If Select the appliances you have at home = T.V.

Display This Choice:

If Select the appliances you have at home = Laptop

Display This Choice:

If Select the appliances you have at home = Desktop

Display This Choice:

If Select the appliances you have at home = Electric Fan

Display This Choice:

If Select the appliances you have at home = Stove

Display This Choice: *If Select the appliances you have at home = TV* TV (1)	▼ 0 (1) ... 24 (64)
Display This Choice: *If Select the appliances you have at home = Laptop* Laptop (2)	▼ 0 (1) ... 24 (64)
Display This Choice: *If Select the appliances you have at home = Desktop* Desktop (3)	▼ 0 (1) ... 24 (64)
Display This Choice: *If Select the appliances you have at home = Electric Fan* Electric Fan (4)	▼ 0 (1) ... 24 (64)
Display This Choice: *If Select the appliances you have at home = Stove* Stove (6)	▼ 0 (1) ... 24 (64)

Q79 On average, how often (times) did you use the following appliance/device on a given weekday (Monday through Friday)? [Pre COVID-19]

Display This Choice:

If Select the appliances you have at home = Microwave

Display This Choice:

If Select the appliances you have at home = Dishwasher

Display This Choice:

If Select the appliances you have at home = Water Heater

Display This Choice:

If Select the appliances you have at home = toaster

Display This Choice:

If Select the appliances you have at home = Blender

Display This Choice:

If Select the appliances you have at home = Electric Kettle

Display This Choice: *If Select the appliances you have at home = Microwave* Microwave (2)	▼ 0 (1) ... 20 (28)
Display This Choice: *If Select the appliances you have at home = Dishwasher* Dishwasher (4)	▼ 0 (1) ... 20 (28)
Display This Choice: *If Select the appliances you have at home = Water Heater* Water Heater (10)	▼ 0 (1) ... 20 (28)
Display This Choice: *If Select the appliances you have at home = Toaster* Toaster (17)	▼ 0 (1) ... 20 (28)
Display This Choice: *If Select the appliances you have at home = Blender* Blender (18)	▼ 0 (1) ... 20 (28)
Display This Choice: *If Select the appliances you have at home = Electric Kettle* Kettle (19)	▼ 0 (1) ... 20 (28)

Q81 On average, how often (times) did you use the following appliance/device per WEEK? [Pre COVID-19]

Display This Choice:

If Select the appliances you have at home = Washing Machine

Display This Choice:

If Select the appliances you have at home = Dryer

Display This Choice:

If Select the appliances you have at home = Iron

Display This Choice:

If Select the appliances you have at home = Rice cooker

Display This Choice:

If Select the appliances you have at home = Vacuum Cleaner

Display This Choice: *If Select the appliances you have at home = Washing Machine* Washing Machine (7)	▼ 0 (1) ... 8 (16)
Display This Choice: *If Select the appliances you have at home = Dryer* Clothes Dryer (8)	▼ 0 (1) ... 8 (16)
Display This Choice: *If Select the appliances you have at home = Iron* Iron (16)	▼ 0 (1) ... 8 (16)
Display This Choice: *If Select the appliances you have at home = Rice cooker* Rice Cooker (17)	▼ 0 (1) ... 8 (16)
Display This Choice: *If Select the appliances you have at home = Vacuum Cleaner* Vacuum Cleaner (18)	▼ 0 (1) ... 8 (16)

Q82 On average, how long (hours) did you keep your lights on per day on a given weekday (Monday through Friday)? [Pre COVID-19]

▼ 0 (1) ... 24 (39)

Page Break

End of Block: PRE COVID-19

Start of Block: LOCKDOWN

Q102

Stay at Home Order Section

Answer this section with information related to your routine during the stay at home order or Lockdown established in Indiana in mid March until May 1st.

Q5 On average, how long (hours) did you spend at home during the Lockdown on a given weekday (Monday through Friday)? [LOCKDOWN]

0-5 hours (1)
5-10 hours (2)
10-15 hours (3)
15-20 hours (4)
21-24 hours (5)

Q93 On average, how long (hours) did you spend on Campus on a daily basis? [LOCKDOWN]

▼ 0 (28) ... 22-24 (10)

Q83 On average, how long did you use the following appliance/device on a given weekday (Monday through Friday)? [LOCKDOWN]

Display This Choice:

If Select the appliances you have at home = T.V.

Display This Choice:

If Select the appliances you have at home = Laptop

Display This Choice:

If Select the appliances you have at home = Desktop

Display This Choice:

If Select the appliances you have at home = Electric Fan

Display This Choice:

If Select the appliances you have at home = Stove

Display This Choice: *If Select the appliances you have at home = TV* TV (1)	▼ 0 (40) ... 24 (66)
Display This Choice: *If Select the appliances you have at home = Laptop* Laptop (2)	▼ 0 (40) ... 24 (66)
Display This Choice: *If Select the appliances you have at home = Desktop* Desktop (3)	▼ 0 (40) ... 24 (66)
Display This Choice: *If Select the appliances you have at home = Electric Fan* Electric Fan (4)	▼ 0 (40) ... 24 (66)
Display This Choice: *If Select the appliances you have at home = Stove* Stove (6)	▼ 0 (40) ... 24 (66)

Q84 On average, how often (times) did you use the following appliance/device on a given weekday (Monday through Friday)? [LOCKDOWN]

Display This Choice:

If Select the appliances you have at home = Microwave

Display This Choice:

If Select the appliances you have at home = Dishwasher

Display This Choice:

If Select the appliances you have at home = Water Heater

Display This Choice:

If Select the appliances you have at home = toaster

Display This Choice:

If Select the appliances you have at home = Blender

Display This Choice:

If Select the appliances you have at home = Electric Kettle

Display This Choice: *If Select the appliances you have at home = Microwave* Microwave (2)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Dishwasher* Dishwasher (4)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Water Heater* Water Heater (10)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Toaster* Toaster (17)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Blender* Blender (18)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Electric Kettle* Kettle (19)	▼ 0 (1) ... 8 (15)

Q85 On average, how often (times) did you use the following appliance/device per WEEK? [LOCKDOWN]

Display This Choice:

If Select the appliances you have at home = Washing Machine

Display This Choice:

If Select the appliances you have at home = Dryer

Display This Choice:

If Select the appliances you have at home = Iron

Display This Choice:

If Select the appliances you have at home = Rice cooker

Display This Choice:

If Select the appliances you have at home = Vacuum Cleaner

Display This Choice: *If Select the appliances you have at home = Washing Machine* Washing Machine (7)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Dryer* Clothes Dryer (8)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Iron* Iron (16)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Rice cooker* Rice Cooker (17)	▼ 0 (1) ... 8 (15)
Display This Choice: *If Select the appliances you have at home = Vacuum Cleaner* Vacuum Cleaner (18)	▼ 0 (1) ... 8 (15)

Q86 On average, how long (hours) did you keep your lights on per day throughout the whole week? [LOCKDOWN]

- 0-2 (1)
- 2-4 (2)
- 4-6 (9)
- 6-8 (10)
- 8-10 (3)
- 10-12 (4)
- 12-14 (5)
- 14-16 (6)
- 16-18 (7)
- 18-24 (15)

Page Break

End of Block: LOCKDOWN

Start of Block: POST COVID-19

Q103

Fall 2020 Section

Answer this section with information related to your routine during the semester of Fall 2020 until now.

Q91 On average, how many hours do you current spend at home on a given weekday (Monday through Friday)? [FALL SEMESTER 2020]

0-5 hours (1)
5-10 hours (2)
10-15 hours (3)
15-20 hours (4)
21-24 hours (5)

Q92 On average, how long (hours) do you spend on Campus on a daily basis during a given weekday (Monday through Friday)? [FALL SEMESTER 2020]

▼ 0 (28) ... 22-24 (10)

Q94 What activities do you partake in on Campus currently?

- ☐ Study (1)
- ☐ Teach (2)
- ☐ Research (3)
- ☐ Exercise (4)
- ☐ Eat (5)
- ☐ Meetings (8)
- ☐ Take class (9)
- ☐ Play (10)
- ☐ Work with a computer (11)
- ☐ Move around campus (12)
- ☐ Other (14) _____

Q87 On average, how long (hours) do you use the following appliance/device on a given weekday (Monday through Friday)? [FALL SEMESTER 2020]

Display This Choice:

If Select the appliances you have at home = T.V.

Display This Choice:

If Select the appliances you have at home = Laptop

Display This Choice:

If Select the appliances you have at home = Desktop

Display This Choice:

If Select the appliances you have at home = Electric Fan

	0 (1)	1-2 (30)	2-3 (34)	3-4 (32)	4 -5 (36)	5-6 (38)	6-7 (39)	7 + (40)	(18)
Display This Choice: If Select the appliances you have at home = TV									
TV (1)									
Display This Choice: If Select the appliances you have at home = Laptop									
Laptop (2)									
Display This Choice: If Select the appliances you have at home = Desktop									
Desktop (3)									

Display This Choice:

If Select the appliances you have at home = Electric Fan

Electric Fan (4)

Q88 On average, how often (times) do you use the following appliance/device on a given weekday (Monday through Friday)? [FALL SEMESTER 2020]

Display This Choice:

If Select the appliances you have at home = Microwave

Display This Choice:

If Select the appliances you have at home = Dishwasher

Display This Choice:

If Select the appliances you have at home = Water Heater

Display This Choice:

If Select the appliances you have at home = toaster

Display This Choice:

If Select the appliances you have at home = Blender

Display This Choice:

If Select the appliances you have at home = Electric Kettle

	0-1 (1)	1-2 (7)	2-3 (2)	3-4 (3)	4-5 (4)	5-6 (5)	7+ (6)
Display This Choice: *If Select the appliances you have at home = Microwave* Microwave (2)							
Display This Choice: *If Select the appliances you have at home = Dishwasher* Dishwasher (4)							
Display This Choice: *If Select the appliances you have at home = Water Heater* Water Heater (10)							
Display This Choice: *If Select the appliances you have at home = toaster* Toaster (17)							

Display This Choice:

If Select the appliances you have at home = Blender

Blender (18)

Display This Choice:

If Select the appliances you have at home = Electric Kettle

Kettle (19)

Q89 On average, how often (times) do you use the following appliance/device per WEEK? [FALL SEMESTER 2020]

Display This Choice:

If Select the appliances you have at home = Stove

Display This Choice:

If Select the appliances you have at home = Washing Machine

Display This Choice:

If Select the appliances you have at home = Dryer

Display This Choice:

If Select the appliances you have at home = Iron

Display This Choice:

If Select the appliances you have at home = Rice cooker

Display This Choice:

If Select the appliances you have at home = Vacuum Cleaner

	0-1 (1)	0-2 (2)	2-3 (3)	3-4 (4)	4-5 (5)	5-6 (6)	7+ (7)
Display This Choice: *If Select the appliances you have at home = Stove* Stove (6)							
Display This Choice: *If Select the appliances you have at home = Washing Machine* Washing Machine (7)							
Display This Choice: *If Select the appliances you have at home = Dryer* Clothes Dryer (8)							
Display This Choice: *If Select the appliances you have at home = Iron* Iron (16)							

Display This Choice:

If Select the appliances you have at home = Rice cooker

Rice Cooker (17)

Display This Choice:

If Select the appliances you have at home = Vacuum Cleaner

Vacuum Cleaner (18)

Q90 On average, how long (hours) do you keep your lights on per day? [FALL SEMESTER 2020]

- 0-2 (1)
- 2-4 (2)
- 4-6 (9)
- 6-8 (10)
- 8-10 (3)
- 10-12 (4)
- 12-14 (5)
- 14-16 (6)
- 16-18 (7)

End of Block: POST COVID-19