Energy Forecasting: Phase 1 – Exponential Smoothing and Seasonal ARIMA Models

VOLT Analytics (Orange 12)
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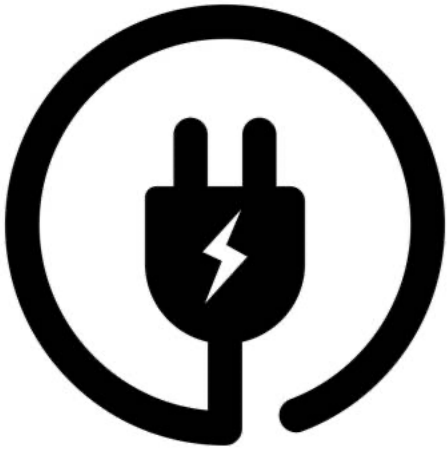

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Overview

American Electric Power Co. (AEP) partnered with VOLT Analytics to develop a model to best forecast the hourly energy load in megawatts (MW) for the Appalachian Power territory. We constructed both exponential smoothing and seasonal ARIMA models from the provided data. According to our findings, the best model was a seasonal ARIMA model, which accounts for inclement weather. This model had a mean absolute percent error (MAPE) value of 6.81% and 4.06% on the two validation data sets. The corresponding mean absolute error (MAE) values were 251.11 and 162.27 megawatts.

VOLT Analytics recommends using seasonal ARIMA models for hourly forecasting due to consistently lower MAE and MAPE values. This model will improve forecasting ability and better meet the customers' needs while reducing operational expenses. In the future, consider using more advanced models and accounting for additional extreme weather to improve forecasts. Finally, we recommend exploring external variables that may further enhance predictive value.

Methodology

Data Used

The data provided contains information about the hourly megawatts (MW) load for the Appalachian Power territory of AEP from 2016 to 2023. We subset the data from January 1, 2020, to September 22, 2023, comprising 32,951 hourly observations. Figure 1 shows the subsetted data regarding its energy use.

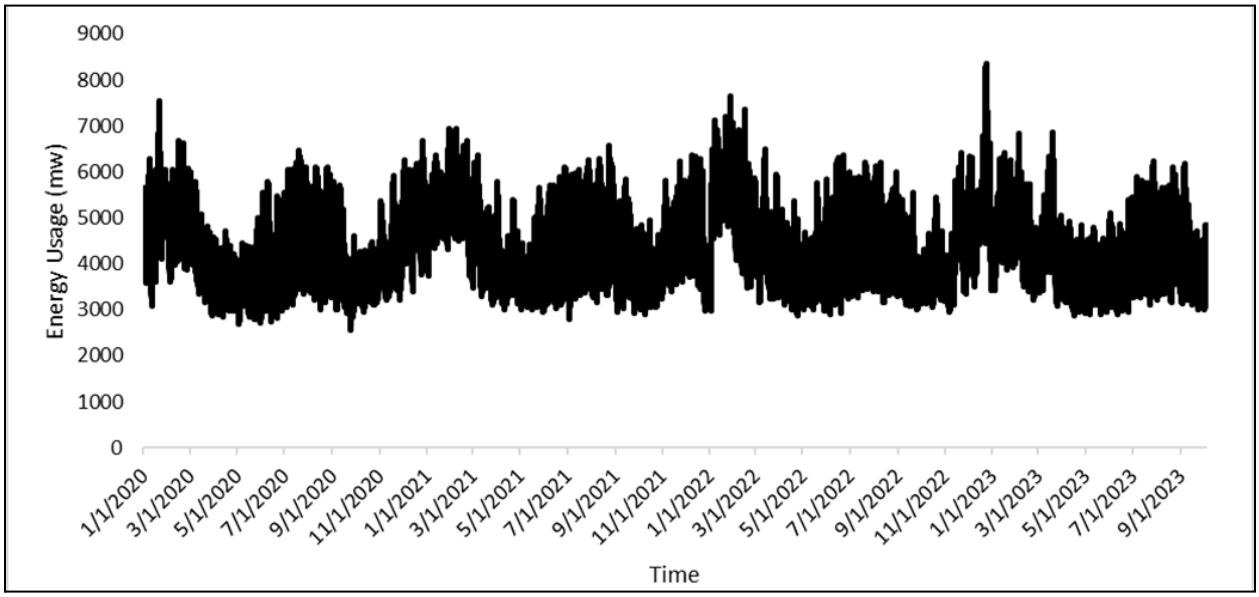

Figure 1: Hourly energy usage for data in megawatts from January 1, 2020, to September 22, 2023.

We used two different validation sets to assess our models. The first (hereafter, "validation 1") encompassed 144 hourly observations from September 22, 2023, to September 27, 2023. It is worth mentioning that this validation set contained missing observations, specifically for Thursday, September 21, 2023, which we accommodated by adjusting the forecast. The second validation set (hereafter, "validation 2") consisted of 168 hourly observations from September 28, 2023, to October 4, 2023.

Exponential Smoothing Modeling

Our team began the analysis process with an exponential smoothing model. Due to the seasonality within the data, we chose to analyze both Holt-Winters additive and multiplicative models. We forecasted and compared results to the two validation sets upon model creation. We concluded that the multiplicative method performed best due to a lower MAPE and MAE compared to the additive model.

ARIMA Modeling

We initially conducted the Canova-Hansen test for the ARIMA model, which confirmed the need for seasonal differences. However, after taking seasonal differences, additional differencing was unnecessary. Subsequently, we established a stochastic solution and proceeded to analyze the model.

We decided to implement an intervention in response to an increase in energy consumption around December 24, 2022, due to an extreme weather event causing unforeseen energy usage. To account for the daily seasonality, we employed a lag of 24, corresponding to the 24 hours within each day. We explored various ARIMA models after determining our lag and seasonally differencing the data (visualized by Figure A.1 and Figure A.5 in the appendix).

Although the selected model did not have complete white noise, the residuals were normal and had constant variance (supported by Figure A.3 and Figure A.6 in the appendix). We forecasted their future values, compared them to our validation sets, and calculated their MAE and MAPE values to assess their performance.

Results

Our team found that the seasonal ARIMA(2,0,2)(3,1,2)[24] model outperformed the multiplicative Holt-Winters model when evaluating on MAPE and MAE. Tables 1 and 2 show the MAE and MAPE values for the multiplicative Holt-Winters and seasonal ARIMA models.

Table 1: MAE and MAPE for multiplicative Holt-Winters models.

Multiplicative Holt-Winters	MAE	MAPE
Validation 1	247.29	6.64%
Validation 2	269.21	6.64%

Table 2: MAE and MAPE for the seasonal ARIMA model.

Seasonal ARIMA	MAE	MAPE
Validation 1	251.56	6.81%
Validation 2	163.73	4.06%

Figure 2 and Figure 3 illustrate the predicted and actual energy usage observed from September 28, 2023, to October 4, 2023. The predicted values are gray, while the actual values are blue. The figures demonstrate that the seasonal ARIMA model better captures the nuances in the seasonality pattern, as seen with the slight dip during each period's increase. The multiplicative Holt-Winters and seasonal ARIMA model forecast for September 22, 2023, to September 28, 2023, is illustrated in Figure A.2 and Figure A.4 in the appendix.

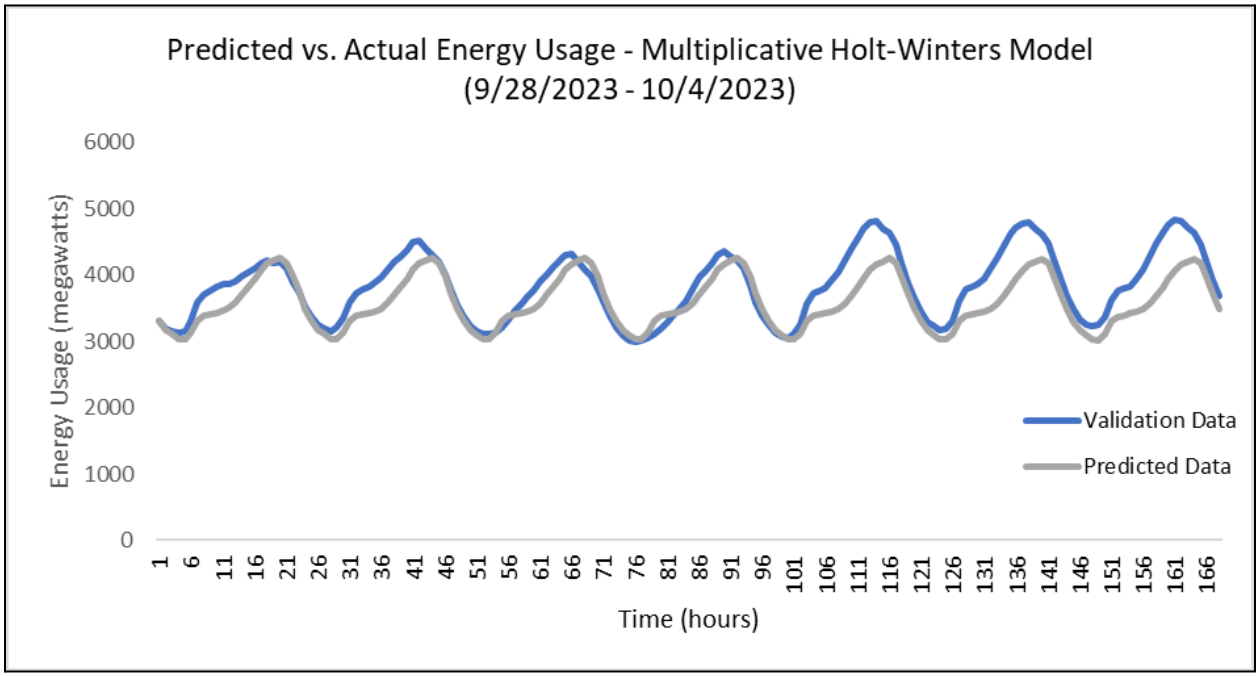

Figure 2: Time plot for the predicted energy usage of the Multiplicative Holt-Winters model and the actual energy usage from September 28, 2023 to October 4, 2023.

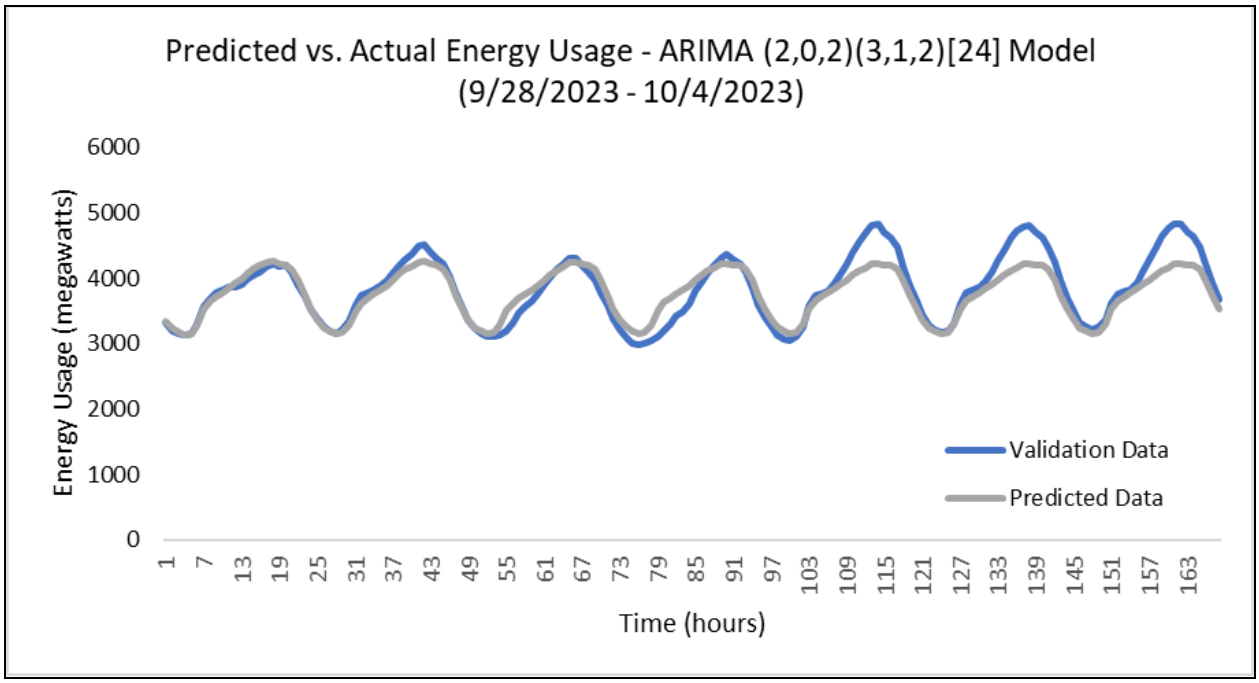

Figure 3: Time plot for the predicted energy usage of the seasonal ARIMA model and the actual energy usage from September 28, 2023 to October 4, 2023.

Recommendations

Based on the results of our analysis, we recommend that AEP take the following next steps:

- Use the seasonal ARIMA model for near-term forecasting as it has the most predictive power.
- Apply more advanced models in the future, such as neural networks or Facebook's prophet model, to further increase the prediction accuracy.
- Incorporate weather/temperature forecasts as blizzards can create periods of increased energy usage.
- Research any other external variables that may provide predictive value.

Conclusion

Our team developed two models to predict energy consumption for AEP. We found the seasonal ARIMA(2,0,2)(3,1,2)[24] to with the pulse intervention for the rare weather event to be the best model. It had validation MAPEs of 6.81% on the first validation set and 4.06% on the second. The Holt-Winters model was comparable when analyzing the first validation set, with a MAPE of 6.64%, but had a much higher MAPE, 6.64%, on the second validation set.

Going forward, we recommend using the seasonal ARIMA while incorporating weather forecasts to predict energy usage. In the future, we advise exploring more advanced models, such as neural networks, and researching additional external variables to increase predictive power.

Appendix

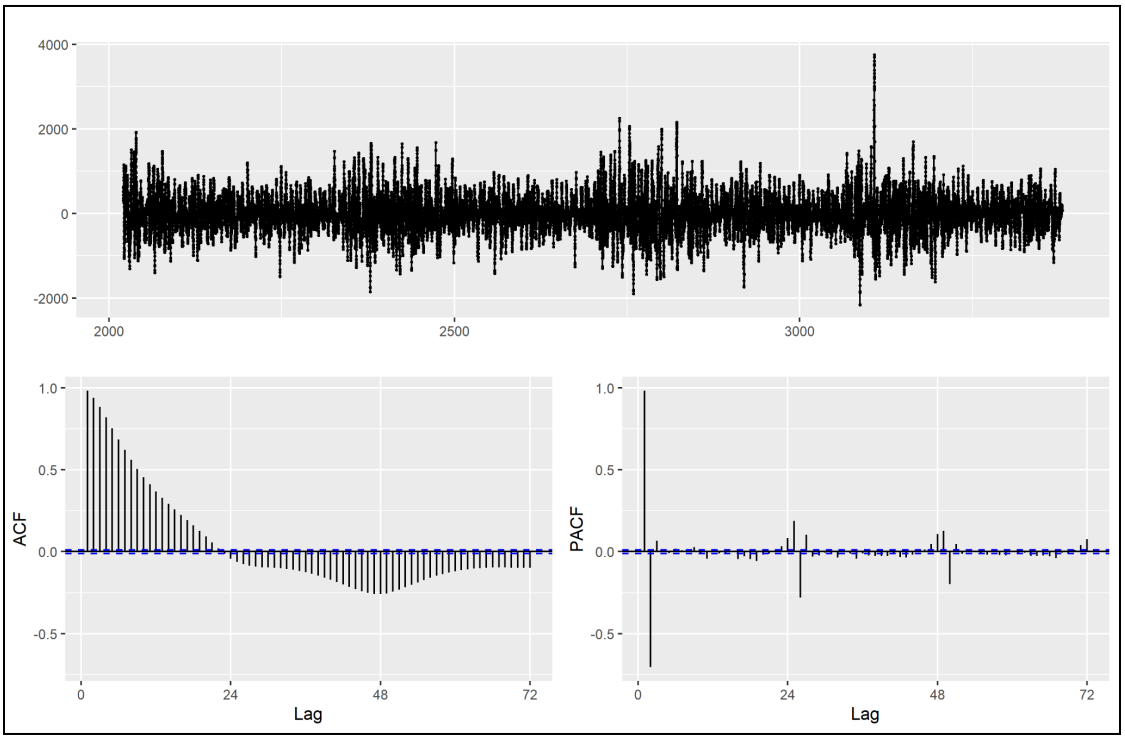

Figure A.1: Energy usage over time after taking seasonal differences as well as corresponding ACF/PACF plots January 1, 2020, to September 22, 2023.

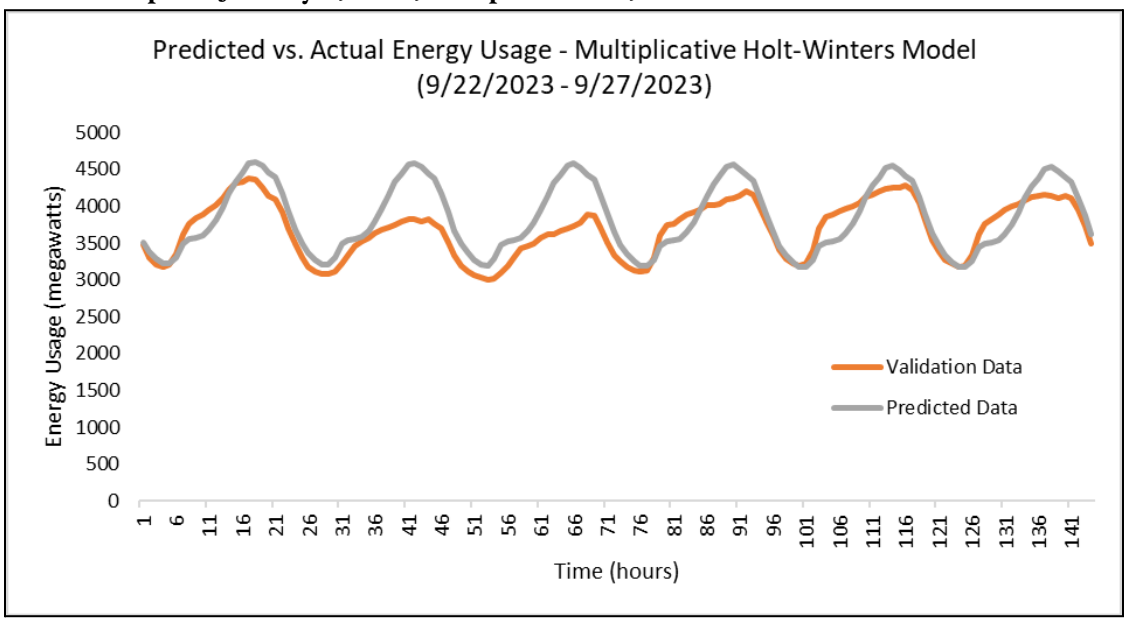

Figure A.2: Time plot for the predicted energy usage of the multiplicative model and the actual energy usage from September 22, 2023 to September 28, 2023.

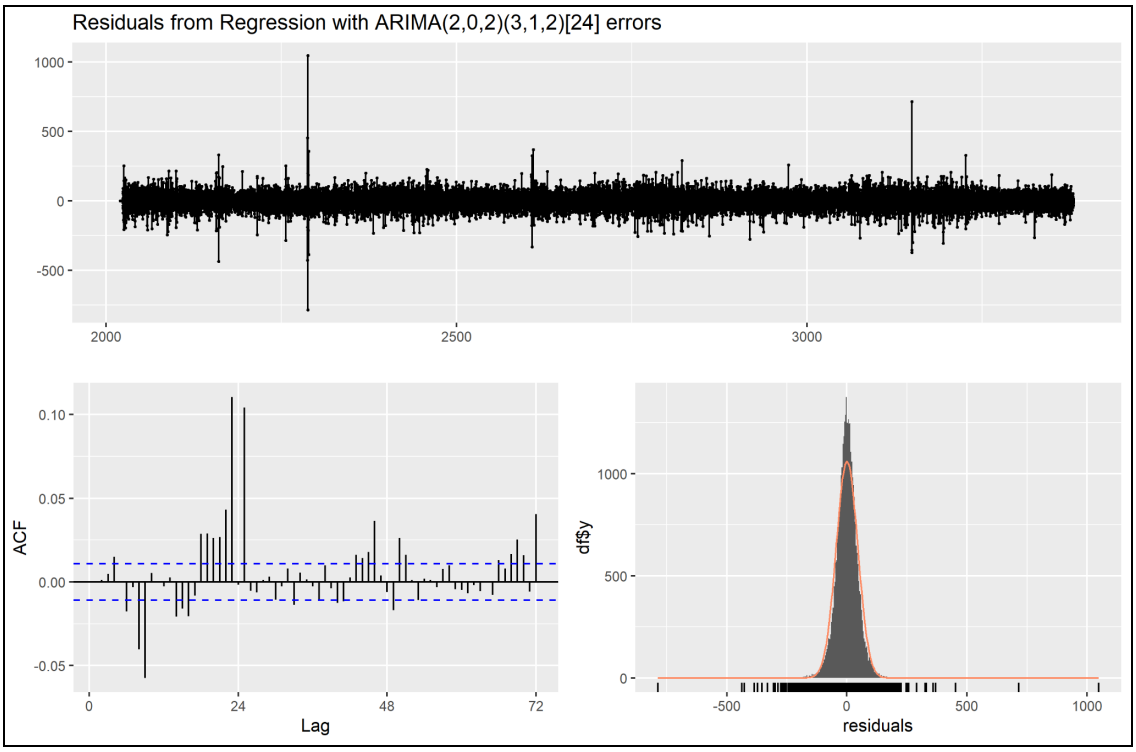

Figure A.3: Residual plot of ARIMA(2,0,2)(3,1,2)[24] for validation 1; No white noise but normal residuals.

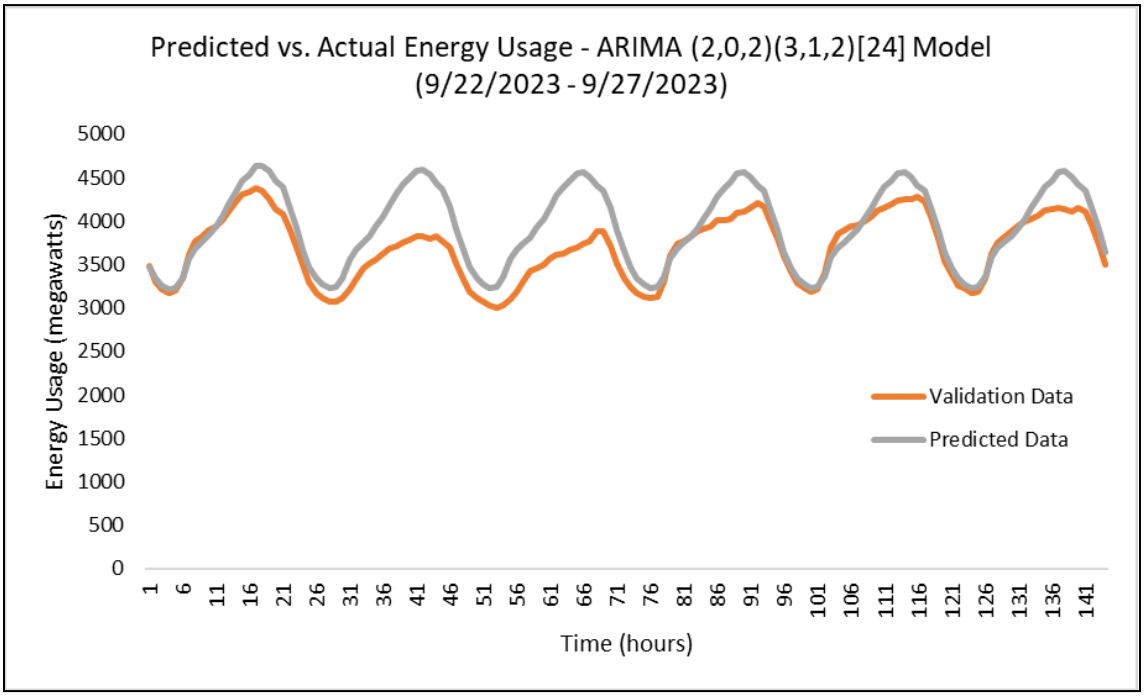

Figure A.4: Time plot for the predicted energy usage of the seasonal ARIMA model and the actual energy usage from September 22, 2023 to September 28, 2023.

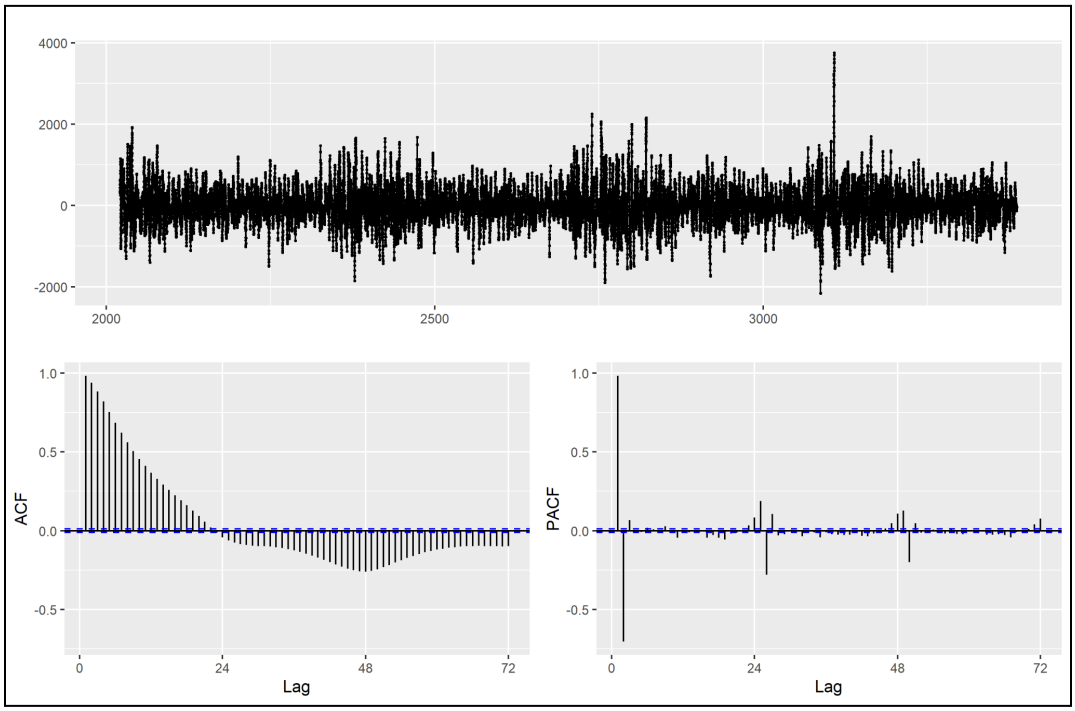

Figure A.5: Energy usage over time after taking seasonal differences as well as corresponding ACF/PACF plots January 1 2020, to September 27, 2023.

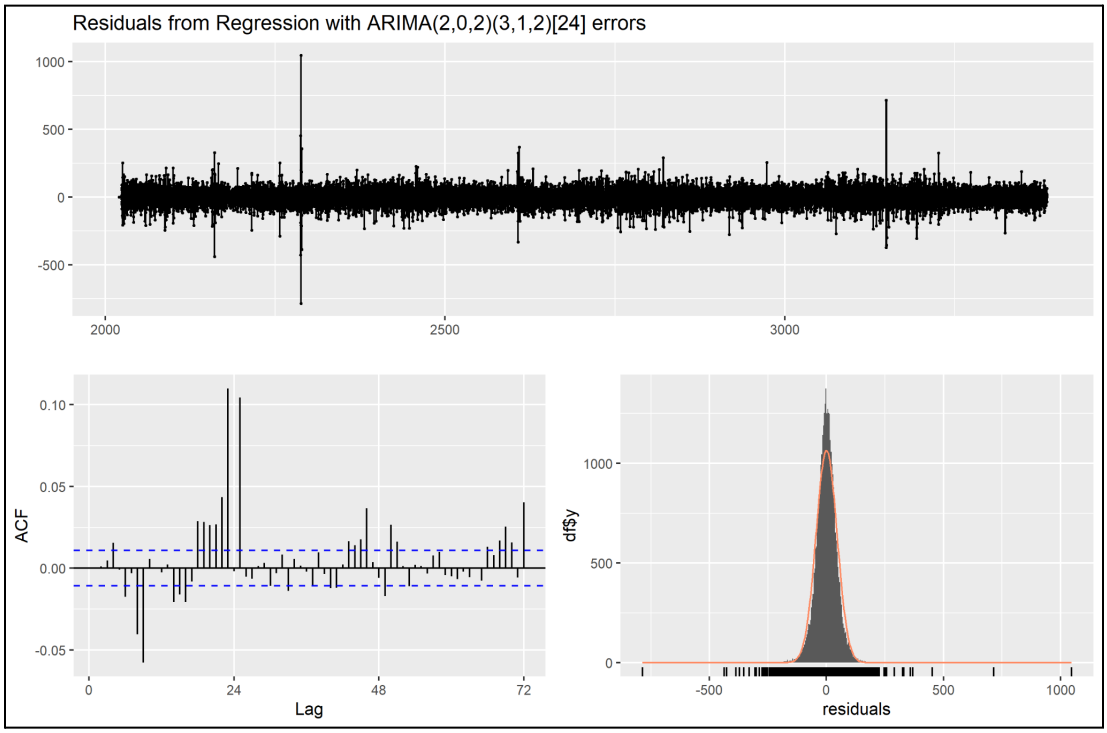

Figure A.6: Residual plot of ARIMA(2,0,2)(3,1,2)[24] for validation 2; No white noise but normal residuals.

Homework Report Checklist

As instructed by Dr. Egan Warren, the team member(s) responsible for checking each item should enter their initials in the field next to each question. All items should be addressed before submitting the assignment with the initialed checklist attached.

Sections & Structure

Overview

OB	Is the overview concise?
OB	Does it provide context about the business problem? <Content>
OB	Does it briefly address your team's work, quantifiable results, and recommendations? <Action>
OB	Does it offer audience-centered reasons for recommendations? <Context>

Body Sections

TF	Does the report body include information on methods, analysis, quantifiable results, and recommendations?
TF	Is content grouped into appropriate sections (*methodology*, *analysis*, *results*, *recommendations*)?

Conclusion

TF	Does the report have a conclusion?
TF	Does the conclusion sum up the report and emphasize relevant takeaways?

Structure

TF	Does each major section have a heading?
TF	Are sections, subsections, and paragraphs organized logically for easy navigation?

Visuals

Introduction, Discussion, and Captions

LS	Is each visual introduced in the text before it appears?
LS	Is each visual close to where it is introduced?
LS	Does each visual include a title with the following information: type (*table* or *figure*), number, and a descriptive caption?
LS	Is each visual discussed and interpreted in the text?
LS	Are figures and tables numbered separately?
LS	Are table captions above the table? Are figure captions below the figure?

Visual Design

LS	Do figures/tables use audience-friendly labels rather than variable names?
LS	Are the visuals easy to interpret?
LS	Are the visuals appropriately sized?
LS	Do tables appear on one page (*not split between 2 pages*)?
LS	Are legends and axis labels included for figures?

LS	Are numbers in tables right aligned?
LS	Are the visuals designed well (*ex*: *re-created in Word or Excel*, *not blurry or stretched*,...)?

Document Design

Title Page Design

VC	Does it include a descriptive title?
VC	Does it state the team name, team members' names, and the submission date?

Table of Contents Design

VC	Does it list all the major sections of the report with corresponding page numbers?
VC	Do the page numbers and sections in the Table of Contents match the report?

Document Design for Entire Report

VC	Is a standard typeface (*Calibri*, *Arial*, *etc.*) used?
VC	Is the size of the body text between 10-12 pt.?
VC	Are headings and subheadings used to organize information?
VC	Are distinctive text styles (*bold*, *italic*, *etc.*) used to distinguish between heading levels?
VC	Are text styles for headings used consistently (*ex*: *all level-one headings are bold*)?
VC	Are all paragraphs an appropriate length (*fewer than 12 lines*)?
VC	Is white space used to indicate paragraph breaks?
VC	Are bullet lists used for a series of items and numbered lists to show a hierarchy?

Writing Style and Mechanics

Spelling and Capitalization

TY	Are spelling errors located and corrected?
TY	Is spelling consistent throughout (*no switching between acceptable spellings*)?
TY	Is capitalization used appropriately (*proper nouns*, *etc.*)?
TY	Is capitalization of words consistent throughout the report?

Grammar and Punctuation

TY	Are verb tenses used appropriately?
TY	Are marks of punctuation used appropriately?
TY	Is subject-verb agreement used in every sentence?
TY	Is the grammar checker updated and are underlined grammar issues addressed?

Writing Style

TF	Are all sentences in the report easy for your audience to understand quickly?
OB	Are most sentences written in active voice?
OB	Are idioms and vague words eliminated from the report?

OB	Are acronyms introduced before being used?
TF	Are well-written topic sentences included at the beginning of each paragraph?
OB	Are lists parallel?
OB	Is the appropriate point of view used when addressing your audience or describing team actions?