

CUNY MSDS Capstone Project

COMMERCIAL BUILDING ENERGY CONSUMPTION

ANALYSIS AND PREDICTION

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Abstract

Commercial Building Energy Consumption accounts for approximately 25%¹ of the United States energy production profile. Many economical and sociological factors are pushing owners of these buildings to reduce energy consumption and optimize performance. However, it is difficult to say whether a building is operating efficiently or not. Using publicly available data, models can be constructed to predict major fuel consumption. Keywords: building energy consumption, predicted energy consumption, baseline energy model.

Introduction

Building owners, local governments, and utility providers are all looking for ways to reduce energy consumption. Reasons for doing so can vary all the way from social responsibility to economic gain. Some want to show off an efficient structure, others want to identify building properties that are in need of improvement. However, this concept of evaluating performance typically requires someone to measure the buildings's consumption and then compare it to a standard practice equivalent. Evaluating summary statistics between buildings, such as energy use per square foot, is not as simple as it seems because there are a multitude of factors that affect a building's energy consumption profile. Factors such as building type, number of employees, etc., can have critical importance for some buildings and not others. This complexity of making similar comparisons creates a situation where it is difficult to determine whether a building is performing consistent with, or better than, similar standard practice buildings.

Commercially, using the most popular example, ENERGY STAR² has implemented a benchmarking algorithm that scores buildings on a scale from 1 – 100 using market-available data. The output of this benchmarking algorithm is a unit-less score, as well as a reference ‘baseline’ building. However, the methodology is not released and it is unclear what factors are important to influence the energy consumption of the building. These barriers make it difficult to provide custom comparisons and nearly impossible to make batch predictions from a set of buildings, or variations of buildings to test what impactful improvements could be made.

Every few years, the U.S. Energy Information Administration (EIA) conducts a survey attempting to record pertinent features of these buildings, known officially as the Commercial Buildings Energy Consumption Survey (CBECS)³. While the survey is expansive (i.e. more than 600 tracked features), it is useful to identify predictors that significantly affect consumption and that can be attained by building operators. This study will focus on creating a series of models to extract the most important survey questions and then use these values as predictors to train a final model that predicts fuel use consumption.

¹EIA - https://www.eia.gov/energyexplained/index.php?page=us_energy_commercial

²ENERGY STAR - <https://www.energystar.gov/>

³EIA Microdata

Research

Related Work

The idea of determining building energy efficiency is not a novel concept in itself. As previously mentioned, ENERGY STAR has a building benchmarking tool⁴. Additionally, the United States Green Building Council has created the Arc Platform⁵ which provides benchmarking and active monitoring features. While these platforms provide building comparisons in the form of an overall score, it is beneficial to explore the space around various building attribute inputs themselves as well as compare consumption of a specific building to its equivalent standard practice building in a programmatic way.

Literature Review

There are a variety of texts that are dedicated to the analysis of building energy consumption, and determining operating efficiency. For example, ASHRAE Guideline 14⁶ provides a standardized set of energy, demand, and water savings calculation procedures. Also, there are guidelines that must be followed for buildings undergoing new construction or major renovation, which have energy compliance sections (ASHRAE Guideline 90.1, 189.1, and International Energy Conservation Code)⁷. Particularly, there is a well thought out process for auditing commercial buildings, known as ASHRAE Audits, which start at the lowest level (I) and progress to the highest level (III) as the opportunity for energy and cost savings increases⁸.

Theory and Hypothesis

Commercial buildings are complex and encompass a wide variety of purposes. In order to be functional, they all must be powered, and require a considerable amount of energy to operate properly, which can be costly. In fact, there is a whole industry dedicated to ensuring the proper operation of a structure. The most direct example is the ASHRAE energy audit process. As part of the initial audit process, an assessment of the building's overall operational efficiency is gauged. Typically, an auditor will walk through the building, analyze utility bills, and make the closest energy consumption comparisons they can. This takes years of experience and sometimes requires highly tuned spreadsheets that have been developed over a long period of time. It can take a surprising amount of effort just to determine if a building is operating efficiently or not, which demonstrates how useful it could be to have a model at hand which predicts building consumption based on easily attainable features.

The CBECS data set provide some insight as to what building attributes most greatly affect building energy consumption. Over 400 survey questions are recorded and coupled with major fuel consumption. These fuel sources are Electricity, Natural Gas, District Heat, and Fuel Oil.

⁴<https://www.energystar.gov/buildings/about-us/how-can-we-help-you/benchmark-energy-use/benchmarking>

⁵<https://arcskoru.com/>

⁶-https://www.techstreet.com/standards/guideline-14-2014-measurement-of-energy-demand-and-water-savings?product_id=1888937

⁷<https://www.energycodes.gov/status-state-energy-code-adoption>

⁸<http://aea.us.org/3143-2.html>

However, it would not be useful to construct a model with a large number of predictors, as it would require a large amount of time and effort to compile the necessary information in order to provide a prediction. Therefore, one of the main focuses for this study will be to extract the fewest amount of predictors necessary in order to make accurate predictions.

Given the complex nature, it is unlikely a linear regression will provide the best prediction accuracy. This point is especially highlighted by the fact the the goal of this study is produce a parsimonious set of predictors, which means a small subset must be selected. Therefore, an investigation into more complex, nonlinear, algorithms will be performed in order to keep the number of necessary predictors as low as possible while still capturing complex interactions.

Data and Methods

General Process

Due to the large number of features in the survey responses, it is not possible to analyze each one individually. Therefore, the first steps in the process will be centered around selecting smaller subsets from various feature extraction algorithms. The magnitude and contribution percentage of each variable will be considered in selecting features from this model. In order to try and normalize the data, the response variable was divided by the gross floor area of the building and reported in units of BTU per square foot (e.g. ELBTU/PerSF, NGBTU/PerSF).

A neural network model will be built to take the subset of extracted features and make predictions for the selected major fuel use. A variety of hyperparameters will be tested, using cross-validation, and compared on a common error metric. This step will reveal the optimal hyperparameter combination to use for the model. The prospective model will then be retrained on the entire training and validation data. This model's selected error metrics will then be compared to the preliminary feature extraction models in order to assess performance. The response variable will also be transformed to units of total consumption and have the resulting metrics re-reported so that an approximation on actual consumption can be made. Due to time restrictions, only electricity and natural gas fuel uses will be studied.

Data Pre-Processing

The raw data set consists of 6,720 records and 1,119 features based on a stratified sample of commercial buildings. Multiple steps of preprocessing were required in order to prepare the data. Note, there are many columns which are being used as imputation flags and statistical weights (for aggregation) which, when removed, reduced the number of features down to approximately 400. While these columns are useful to indicate where values have been imputed into the dataset by the source's own methodologies, rather than try to change back the data to the original records it has been determined that the imputed values were sufficiently applied and the dataset will not be imputed any further.

After evaluating the reduced data set, some feature engineering efforts were taken. First, very specific cases which resulted in many null responses (e.g. buildings less than 1,000 gross square feet, buildings open for less than a year, etc.) were removed. Second, some null entries were converted to zero when logically appropriate. For example, if a building was indicated to not be cooled, then a follow up question asking what percentage of the building is cooled was not asked,

resulting in an null. In this instance, the null value was replaced with a zero. Third, some values were removed as they simply did not apply to the study (e.g. expenditure for energy sources in USD). Fourth, nominal categorical values that had null responses were encoded to a special value. The logic for this approach is that if a null value for a feature ends up being a significant predictor, then it can be analyzed what factors make this situation occur. Fifth, the categorical features were then one-hot encoded to separate columns. The preprocessed data set was transformed to 6661 rows and 456 features (before one-hot encoding).

Electricity

General

The preprocessed data was passed to the feature extraction algorithms in order to determine the best possible set of candidate predictors with some additional adjustments. Only buildings that indicated electricity being used ELUSED were included in the samples for this major fuel use. Then, one of each pair of predictors with correlations above 0.75 were removed, to avoid model selection issues. Additionally, the other major fuel consumption values were removed from the set of possible predictors. Also, the numeric predictors were transformed via BoxCox methodology as well as centered and scaled.

Two potential outlier was found in the analysis. A public assembly space reported an energy consumption of 1E09 BTUs whereas the next highest consumption for this building type, with similar area was 3E08 BTU (less than one third of the value), and the 3rd quartile value of this subset is 5.5E06. While it is noted that there were significantly higher indications of refrigeration use than other comparables, the inclusion of this data point still vastly skews most models due to its high leverage. Similarly, an 'Other' space type has a reported energy consumption of 7E08 BTU whereas the next highest value is 2E08 BTU and the third quartile value is 2E06. While this building is large (1.4 mmSF), and has a lot of server equipment (more than 500), it is still greatly beyond the next closest category and seems to be causing instability in the models due to lack of similar data points. Therefore, these points have been removed and the caveat of instability past a maximum limit will be instituted (more than 5E08 BTU), due to lack of additional information.

Response Analysis

The response data appear to be unimodal and have a heavy right skew. After filtering for this model's end-use, there are 6499 samples in the data set. The energy use was converted to units BTU/SF and the log was taken in an attempt to maintain homoscedacity as the variance of the energy used also scales with the magnitude. [Appendix](#)

Variable Selection - PCA

RMSE: NA, R-squared: NA

Top 5: COOK.2[NO], LAUNDR..1[NA], ELCPLT..1[NA], PBA.14[EDUCATION], BLDPLT.2[NO]

The principle component analysis indicates that only About 4.2% of the variance in the data can be explained in the first principle component, which then drops to about 1.7% for the second principle component. These results reveal that there does not appear to be a clear set of axes that can explain the variance of the data very well, which indicates there may be some very complex

interactions taking place in the predictors. *Appendix*

Variable Selection - PLS

RMSE: 46880, Rsquared: 0.548

Top 5: NWKERPerSf, RGSTRNPerSf, FDSEATPerSf, RFGWINPerSf, PCTERMNPerSf

This model returned a promising result; however, it must be noted that all predictors were used in this process. Looking at the output thus far, it appears that the number of workers, receptical equipment, and refrigeration equipment, influence electrical consumption. *Appendix*

Variable Selection - Random Forest

RMSE: 163434, Rsquared: 0.173

Top 5: RFGWINPerSf, RGSTRNPerSf, NWKERPerSf, RFGICNPerSf, PCTERMNPerSf

The resulting error metrics were much less promising. However, similarly selected variables are picked for this model when compared to the PLS. *Appendix*

Variable Selection - Lasso

RMSE: NA, Rsquared: NA

Top 5: NA

This algorithm returned an error on many simulations, which is not unexpected. Lasso models typically work when a few variables can be used to predict the response, which does not appear to be the case in this instance. Due to the lack of fit, this model will not be used in the variable selection process. Due to the number of reported errors, no metrics have been provided for this model.

Variable Selection - Forward Selection

RMSE: 90503, Rsquared: 0.315

Top 5: NWKERPerSf, RFGWINPerSf, RFGWI.1[YES], RFGICNPerSf, PCTERMNPerSf

This model was building using the leaps package which iteratively selected the best predictor variable up to a limit of 100. Unsurprisingly, the best model turned out to be the maximum setting. Large refrigeration equipment load and typical office space attributes dominated this analysis, as appears to be the case in previous models. It seems that in order to capture energy use for all buidling types, much more than 5 variables will be necessary. *Appendix*

Variable Selection - Recursive Feature Elimination

RMSE: 48022, Rsquared: 0.517

Top 5: RGSTRNPerSf, RFGICNPerSf, NWKERPerSf, PBAPLUS.32[FAST FOOD], RFGWINPerSf

A more direct approach was taken with this model, which is specifically used to extract useful features from data sets. *Appendix*

Variable Selection - Simple Neural Network

RMSE: 48644, Rsquared: 0.499

Top 5: FDSeatPerSf, PBAPLUS.32 [FAST FOOD], RFGWINPerSf, RFGWI.1 [YES], RGSTRNPerSf

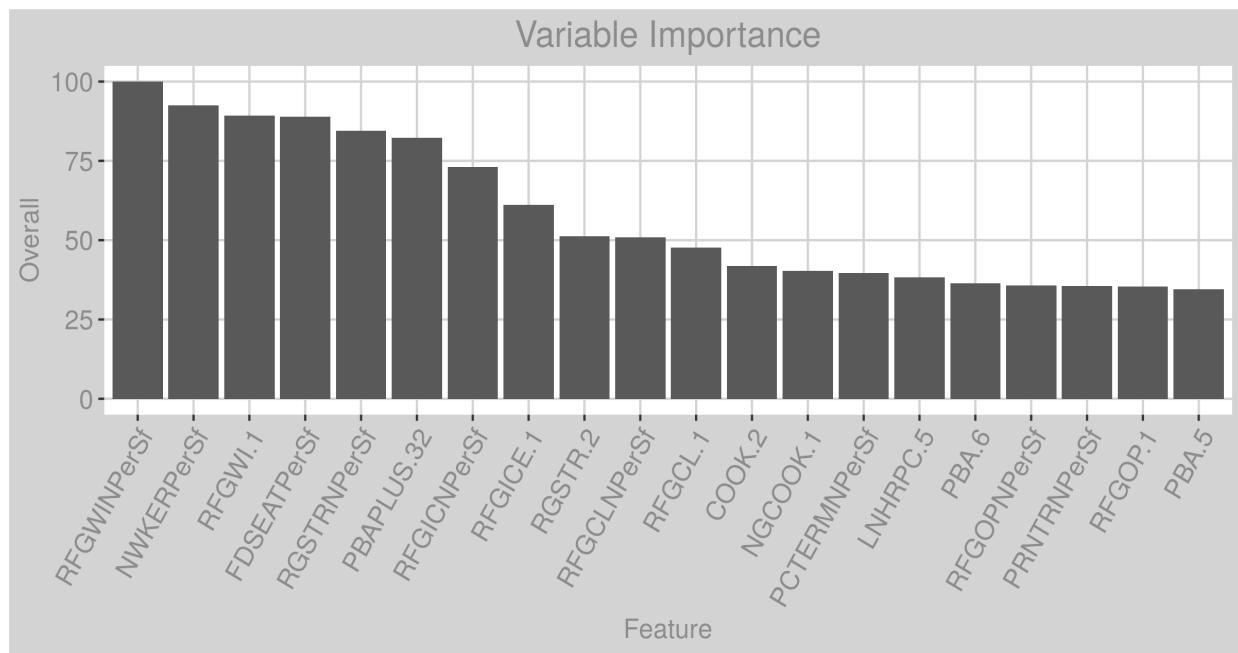
Given that the final model will be a neural network, it made sense to try a simple out-of-the-box training model to see if any particular features work better with this process. As can be seen, there are some new attributes that surface which were not indicated to be of high importance previously.

Appendix

Variable Selection - Selected Variable Analysis

Feature Extraction Model Results

Model	RMSE	R2	MAE	MAPE
leaps	90503.65	0.3149572	59157.08	100.2384
partialLeastSquares	46880.41	0.5475726	24461.50	585.9408
neuralNetwork	48644.23	0.4990216	28964.80	1754.0299
recursiveFeatureExtraction	48022.21	0.5168333	29511.04	2227.8453
randomForest	163434.65	0.1731248	141674.66	11208.6082



In order to rank the most impactful features, the variable importance metrics from the selected models were all set to the same scale then summed. As a preliminary check, the top 20 predictors are plotted in the appendix and are generally discussed here. It seems the attempts to create

stratified random samples may have been beneficial in this case since there are some building type specific end-uses that are highly ranked. As previously noted, there are many attributes associated with refrigeration, office, and food sales equipment. Also, the attribute identifying one of the more atypical building types, speaking in an energy intensity sense, has made it into the top 20 (PBA .5 [NON-REFRIGERATED WAREHOUSE]). Additionally, some occupancy features (NWKERPerSf, FDSEATPerSf) have been included which is expected given that they impact interior space cooling and ventilation loads. In an attempt to truly follow the important predictors, no variables have been removed from this set and the order of importance remains unchanged. *Appendix*

Natural Gas

General

As previously noted, only buildings that indicated natural gas being used NGUSED were included in the samples for this major fuel use. Then, one of each pair of predictors with correlations above 0.75 were removed, to avoid model selection issues. Numeric predictors were transformed via BoxCox methodology as well as centered and scaled. Note, no further commentary will be made in the following sections unless it differs from previous sections.

Response Analysis

After filtering for this model's end-use, there are 6662 samples in the data set. The same transformations were applied to this response variable as electricity. *Appendix*

Variable Selection - PCA

RMSE: NA, Rsquared: NA

Top 5: EDSEATPerSf, PBA .14 [EDUCATION], STRLZR .1 [YES], MCHEQP [NA], ACT2PCT *Appendix*

Variable Selection - PLS

RMSE: 73076, Rsquared: 0.293

Top 5: FDSEATPerSf, HEATP, RFGWINPerSf, NWKERPerSf, RGSTRNPerSf

The Rsquared and RMSE values are still on the poorer side compared to those in the electricity study, which suggests there is either a more complex relationship, or there is greater variance in response, given the available data. However, the presence of attribute which indicates the percent of the building that is heated (HEATP) is promising. *Appendix*

Variable Selection - Random Forest

RMSE: 175808, Rsquared: 0.193

Top 5: DRYCL .1 [YES], FDSEATPerSf, RFGWINPerSf, LAUNDR .3 [OFF-SITE], STRLSZR .1 [YES]

Again, the error values are much lower; however, the presence of notable fuel-using equipment have been indicated to be of high importance. *Appendix*

Variable Selection - Lasso

RMSE: NA, Rsquared: NA

Variable Selection - Forward Selection

RMSE: 100385, Rsquared: 0.246

Top 5: FDSEATPerSf, TVVIDEONPerSf, NGWATR.2 [NO], RGSTRNPerSf, RFGWINPerSf *Appendix*

Variable Selection - Recursive Feature Elimination

RMSE: 59212, Rsquared: 0.523

Top 5: NWKERPerSf, RFGICNPerSf, RFGWINPerSf, FDSEATPerSf, RGSTRNPerSf *Appendix*

Variable Selection - Simple Neural Network

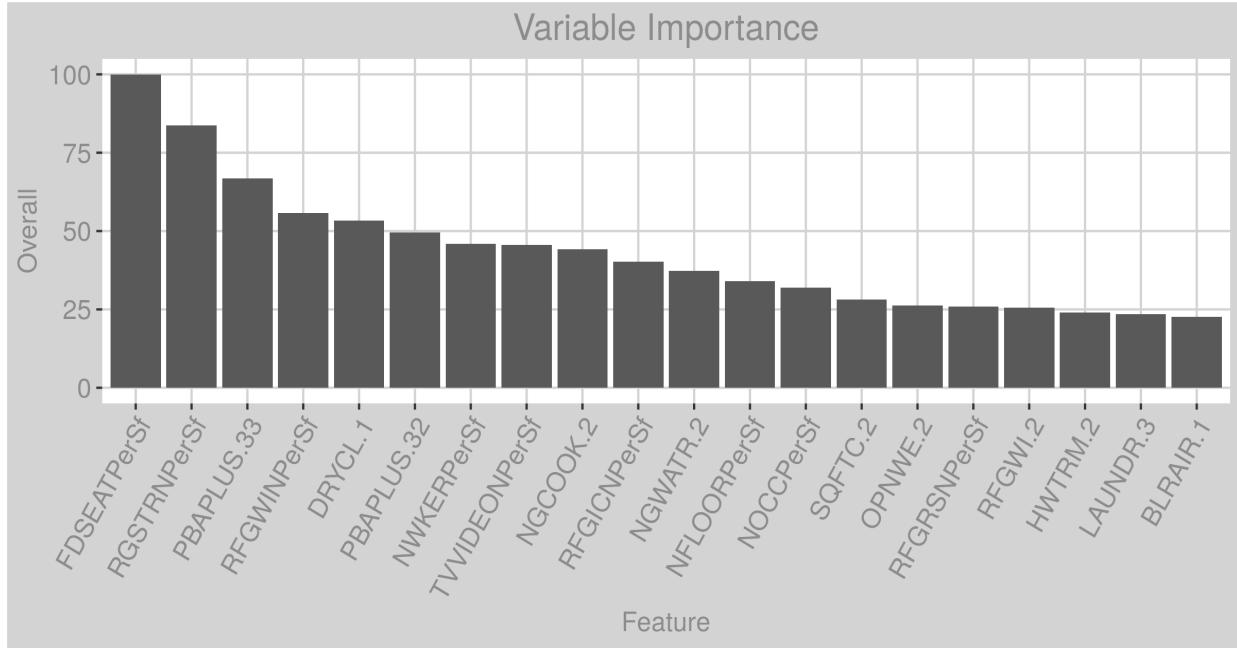
RMSE: 69784, Rsquared: 0.334

Top 5: FDSEATPerSf, RGSTRNPerSf, DRYCL.1 [YES], PBAPLUS.33 [RESTAURANT/CAFETERIA], PBAPLUS.32 [FAST FOOD] *Appendix*

Variable Selection - Selected Variable Analysis

Feature Extraction Model Results

Model	RMSE	R2	MAE	MAPE
leaps	100385.86	0.2462162	53658.33	99.67084
partialLeastSquares	73075.99	0.2934536	32068.61	254.60825
neuralNetwork	69784.67	0.3336745	35642.13	1116.47039
recursiveFeatureExtraction	59212.72	0.5230241	34203.37	2148.20709
randomForest	175808.23	0.1930417	147144.46	9354.99778



As with the electricity model, attributes related to occupancy seem to have made a large impact, possibly due to the need to heat ventilation air, especially given some of these occupancy types are associated with 24/7 operation. Also as expected, cooking and large heating equipment attributes are high on the list. Surprisingly, the number of floors per gross floor area has shown some importance, perhaps due to building shape and its relationship with heating needs (i.e. volume to area ratio). [Appendix](#)

Neural Network Models

General

The choice to use neural networks for the final model was multi-faceted. First, these types of models are very good at capturing complex non-linear interactions. This appears to be the case with the data set given the failure of lasso models as well as the low percentage of variance capture for the first few dimensions of the principal component and partial least squares analyses. Secondly, neural networks have the ability to select different loss functions. This is beneficial because it is important to highlight practicality of the results returned. As the estimated energy consumption grows, it is somewhat acceptable for the error rate to grow proportionally if it results in better fits for the low estimates. As an example, a large datacenter may use a lot of energy so a slightly higher absolute error rate may be acceptable since it could be a small relative error compared to the overall consumption; conversely, if a non-heated warehouse, which uses very little energy, would be wildly inaccurate with a similar absolute error rate. Therefore, importance should be placed on minimizing the relative error rates. To reflect this reasoning, the loss function for this set of models was chosen to be the mean absolute percentage error (MAPE).

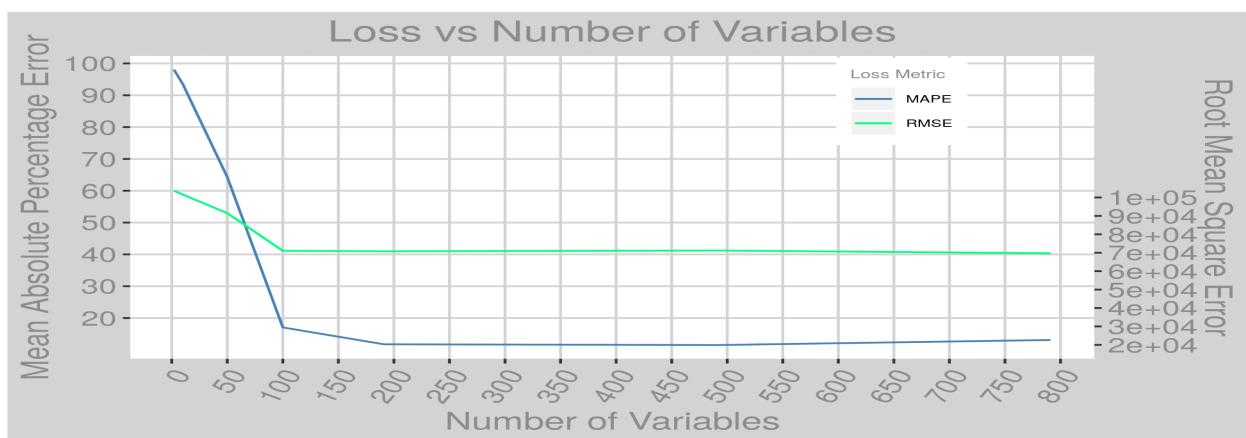
Hyperparameter Training

In order to select the most optimized set of parameters, some hyperparameter training was performed. Some standard searches were made, such as varying the dropout rate, regularization, learning rate, and batch size; however, one additional training set was incorporated to highlight the goals of this study. A series of models were tested which had an incrementally decreasing number of variables, by least importance, in order to test the loss of accuracy.

Electricity

Summary

The final selected model consisted of a 3 hidden layers, 200 hidden layer nodes, a dropout rate of 0.6, no regularization, batch sizes of 150, using the rmsprop() algorithm with a learning rate of 0.001, and 100 predictors. As can be seen in the graph below, the number of variables needed to obtain near-peak performance, is much less than the full set.



The final selected model, after re-training, has a MSLE of 0.875 and RMSE of 15357. Comparing this model ('Full Neural Network') to the previous feature extraction models, which used many more variables, the performance is competitive. Additionally, the results were then multiplied by their respect gross floor area and then compared to the set of feature extraction models, with the same transformation, in order to evaluate the total consumption prediction error. Again, it can be seen that this neural network model has shown to be competitive in this manner and, in fact, has a better R-squared value.

The residuals indicate that the variance scales with the response variable; however, since neural network models do not operate on a principle of homoscedascity, only underlying patterns are of concern. Additionally, the noted error pattern is by design since the loss function (MAPE) allows for higher error in higher consumption projects. [Appendix](#)

Variable Selection Summary

The final model chosen uses 100 variables. Many of the features within the set have to do with the amount of receptacle equipment within the building as well as major electrical devices (e.g. MRI machines) and essential equipment (e.g. data center servers, refrigeration). Also, building type identifiers have been included for various categories. [Appendix](#)

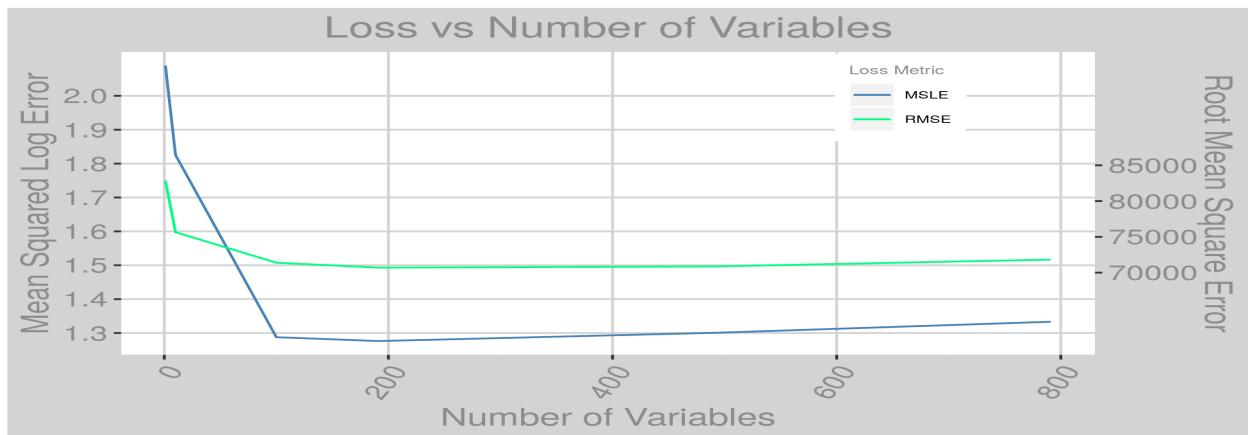
Per SF Model Comparison [BTU/SF]					Total Consumption Prediction vs. Feature Extraction Models [mmBTU]				
Model	RMSE	R2	MAE	MAPE	Model	RMSE	R2	MAE	MAPE
Full Neural Network	58067.72	0.4412603	30116.51	69.46956	Full Neural Network	1.385147e+04	0.7078063	3.724740e+03	69.46956
leaps	90503.65	0.3149572	59157.08	100.23838	leaps	2.630494e+10	0.6996219	8.841972e+09	100.37495
partialLeastSquares	46880.41	0.5475726	24461.50	585.94075	partialLeastSquares	1.174690e+10	0.7777011	3.163009e+09	771.21278
neuralNetwork	48644.23	0.4990216	28964.80	1754.02993	neuralNetwork	1.137476e+10	0.8018569	3.401298e+09	2353.57370
recursiveFeatureExtraction	48022.21	0.5168333	29511.04	2227.84533	recursiveFeatureExtraction	1.202321e+10	0.7654496	3.428939e+09	2799.73266
randomForest	163434.65	0.1731248	141674.66	11208.60823	randomForest	5.206360e+10	0.7250761	2.117227e+10	15257.42369

The automated selection process does seem to have included some highly correlated pairs, such as the number of workers per square foot as well as the categorical bin of workers. This does reduce the number of necessary questions, but it is unclear if both are necessary and/or if they are possibly detrimental. Also, there are a number of questions that may be automatically known just based on the usage type as some questions do not apply to all buildings. It is possible take the steps used in asking questions in the survey in order to build a live form that can automatically parse out the meaningful questions based on building type, which could reduce the need to enter a value for all the selected variables.

Natural Gas

Summary

The final selected model consisted of a 4 hidden layers, 400 hidden layer nodes, a dropout rate of 0.9, no regularization, batch sizes of 50, using the rmsprop() algorithm with a learning rate of 0.001, and 100 predictors. As can be seen in the graph below, the number of variables needed to obtain near-peak performance, is much less than the full set.



Variable Selection Summary

The final selected model, after re-training, has a MSLE of 0.875 and RMSE of 58528. Comparing this model ('Full Neural Network') to the previous feature extraction models, which used many more variables, the performance is actually better. Additionally, the results were then multiplied by their respect gross floor area and then compared to a set of feature extraction models that were trained on total consumption. Again, it can be seen that this neural network model is the best performing out of the set and has a better Rsquared value than the per SF model. Much like the electricity data set, there appears to be heteroscedacity in the residuals, but may be due to the selected loss function.

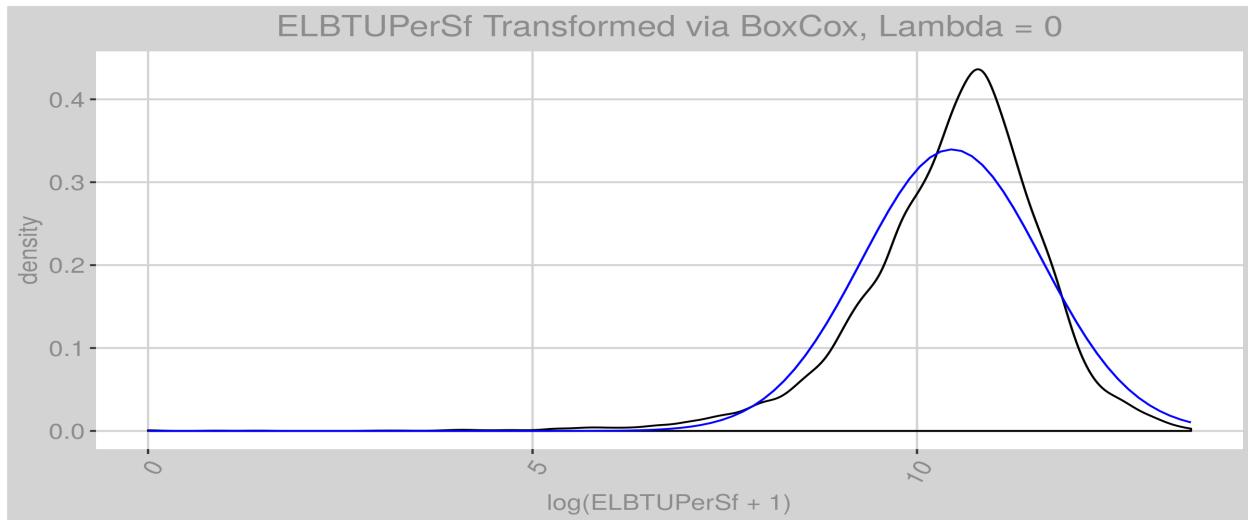
Per SF Model Comparison [BTU/SF]					Total Consumption Prediction vs. Feature Extraction Models [mmBTU]				
Model	RMSE	R2	MAE	MAPE	Model	RMSE	R2	MAE	MAPE
Full Neural Network	74979.18	0.1828881	39355.65	98.23479	Full Neural Network	16573139791	0.7153157	5296888857	98.23479
leaps	100385.86	0.2462162	53658.33	99.67084	leaps	33637119391	0.2516121	7547240108	99.67084
partialLeastSquares	73075.99	0.2934536	32068.61	254.60825	partialLeastSquares	22991871263	0.5463794	4652875873	254.60825
neuralNetwork	69784.67	0.3336745	35642.13	1116.47039	neuralNetwork	24388281086	0.4544703	5136893873	1116.47039
recursiveFeatureExtraction	59212.72	0.5230241	34203.37	2148.20709	recursiveFeatureExtraction	19390028626	0.7036661	4788148767	2148.20709
randomForest	175808.23	0.1930417	147144.46	9354.99778	randomForest	55444836980	0.3182149	19997397023	9354.99778

Future Work

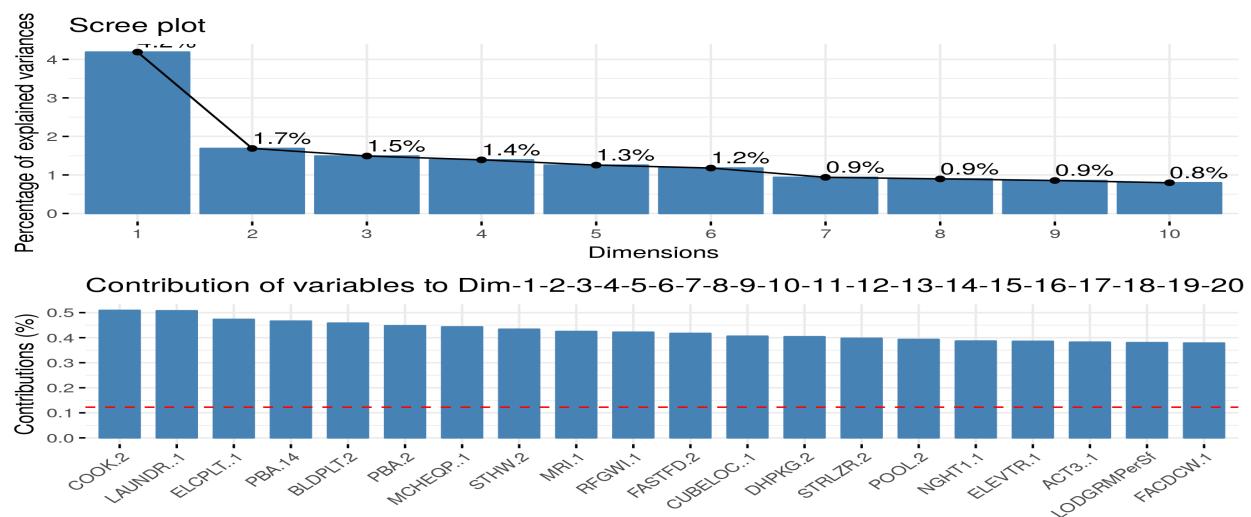
While it was determined that some heteroscedacity would be acceptable, there does appear to be area for improvement. Additionally, as mentioned at the beginning of this report, the sampling of this data set was stratified to reflect the building population. However, it is noted that there are some building classes that have greater variance than others. Therefore, it may be useful to use this stratification as a weighted method, based on PBAPLUS, in order to try and emphasize accuracy on the most prevalent building types. Also, there was not a lot of attention paid to the actual transformations of the predictors given the large quantity of them. It is possible a better fit can be obtained with more intelligent transformations applied to the features after further analysis. Finally, the neural network model was trained on the original (untransformed) response variable, rather than taking the log transformation, as was done in some of the feature extraction models. This was done because it was assumed that the neural network would pick up on the skewness of the data without further preprocessing. Also, testing transformations on the response would result in further hyperparameter training which could not be done due to time constraints. It is possible a better fit could be obtained by experimenting with further transformations of the response.

Appendix - Electricity

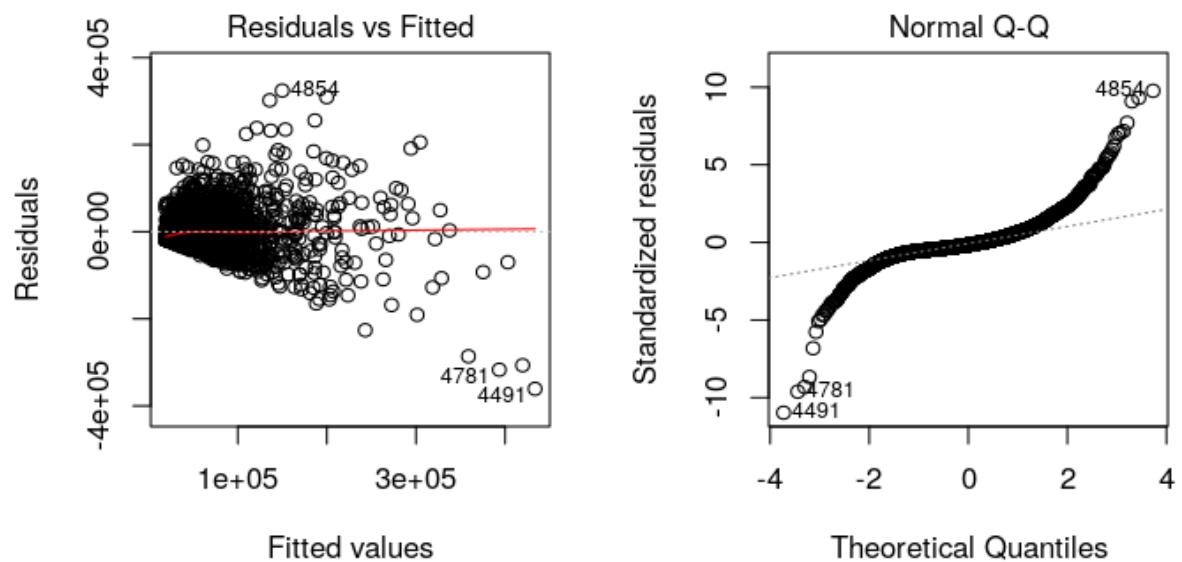
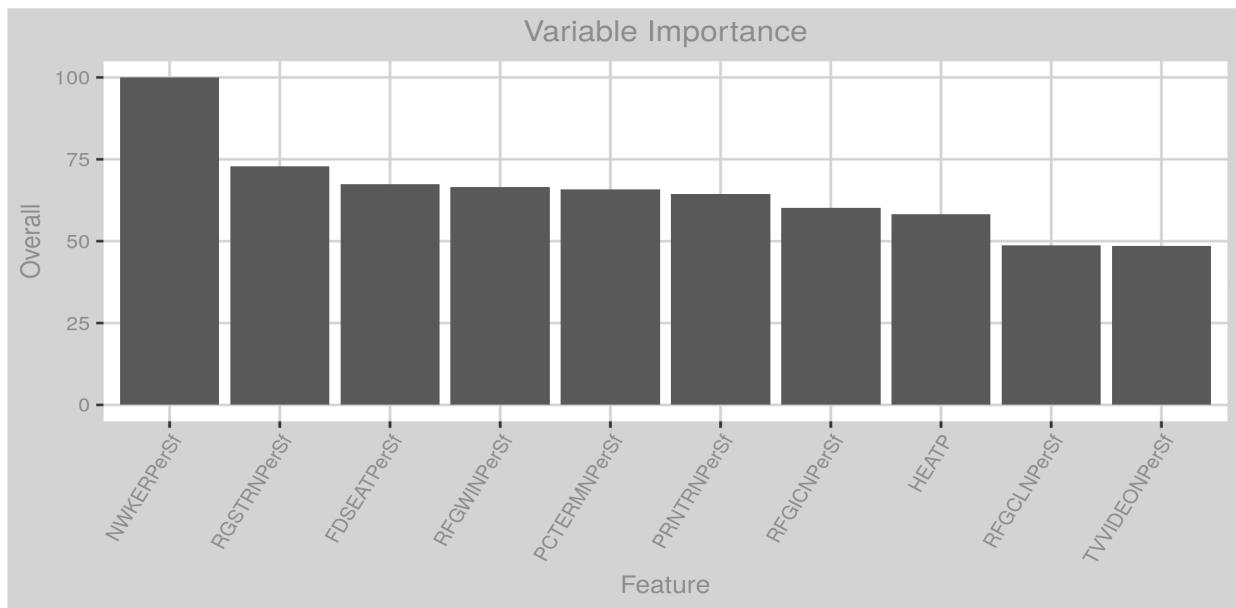
Response

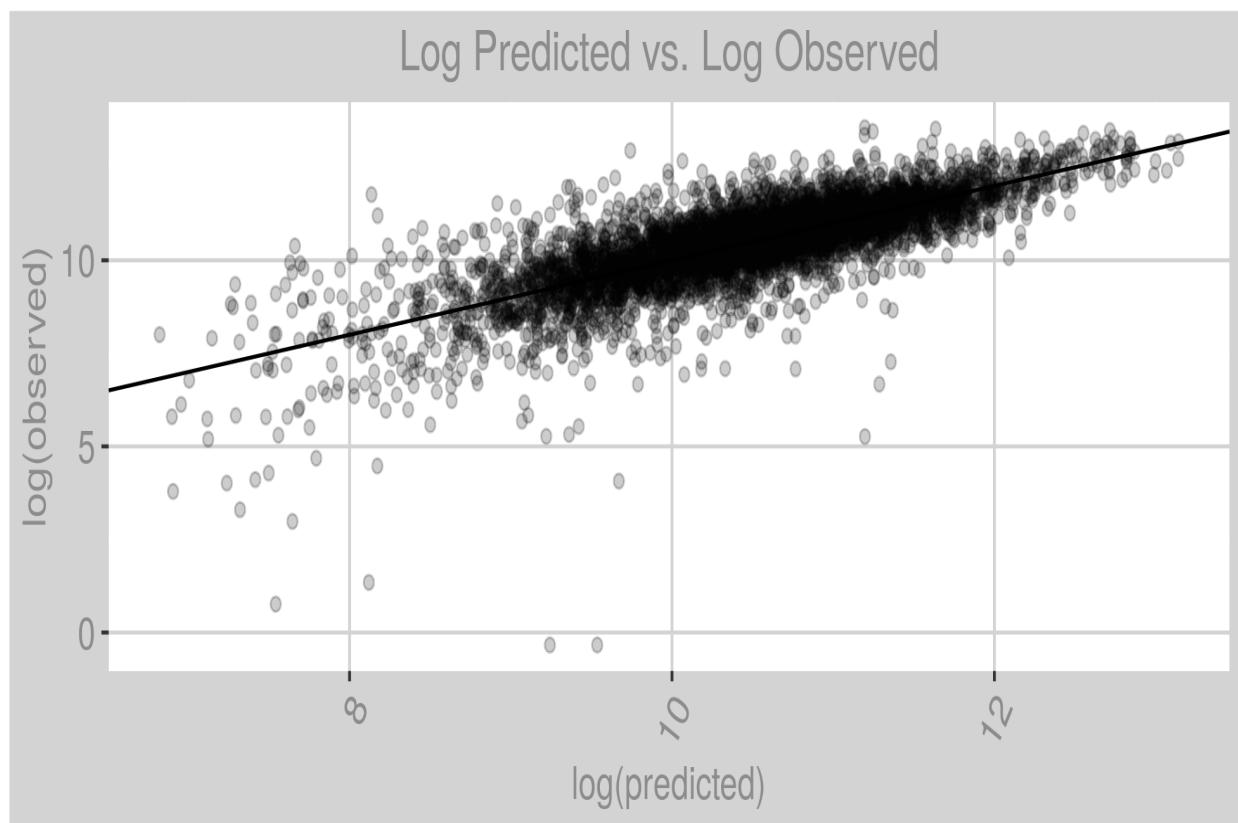
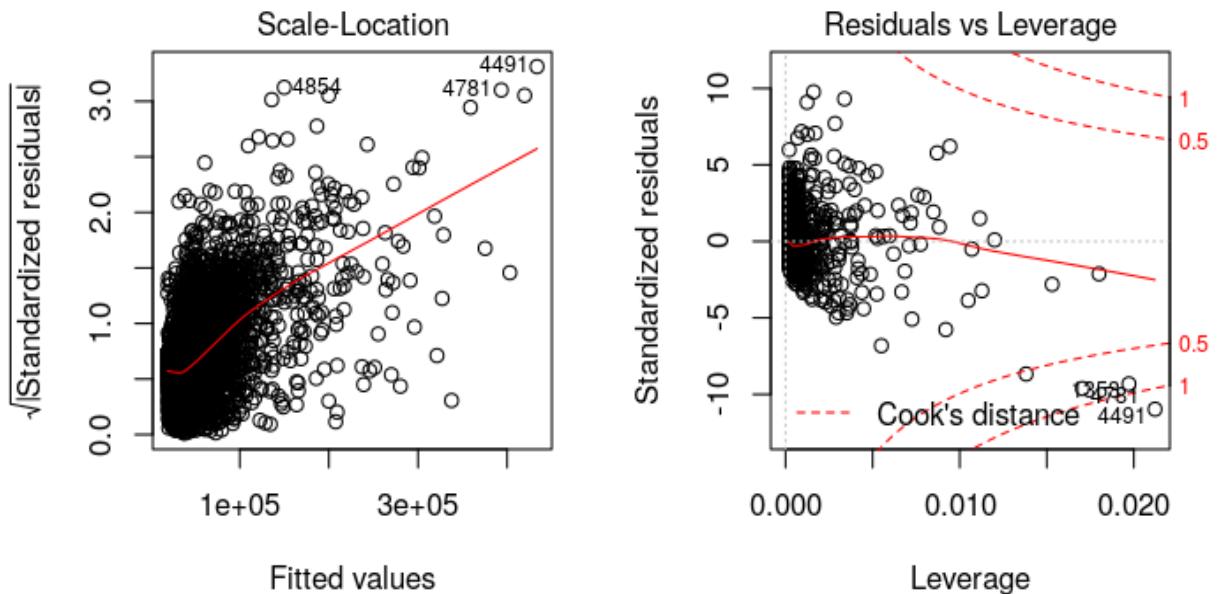


PCA

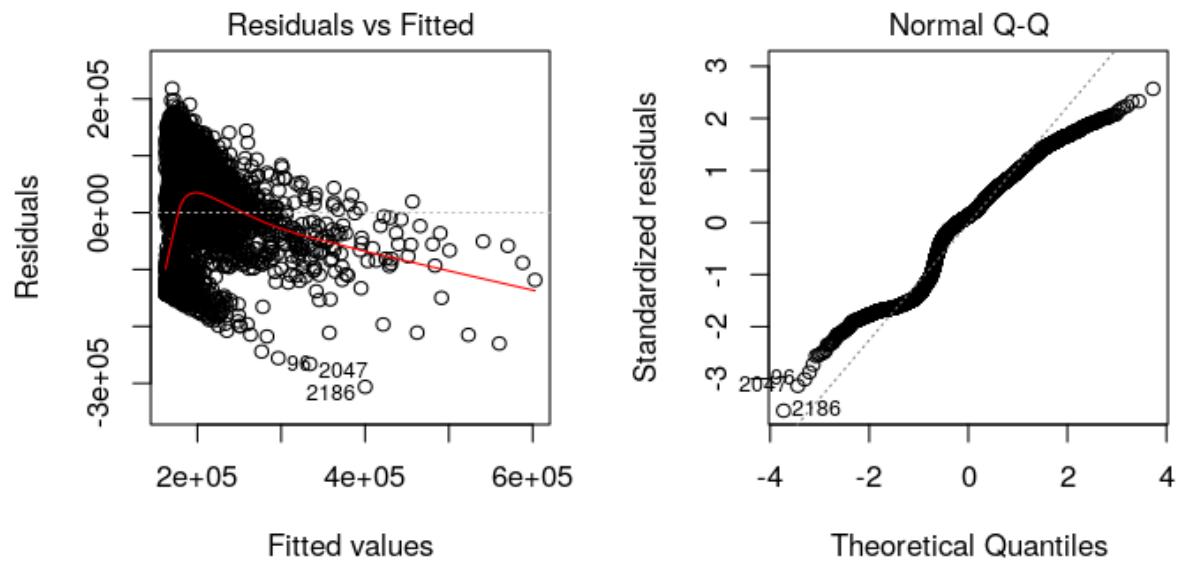
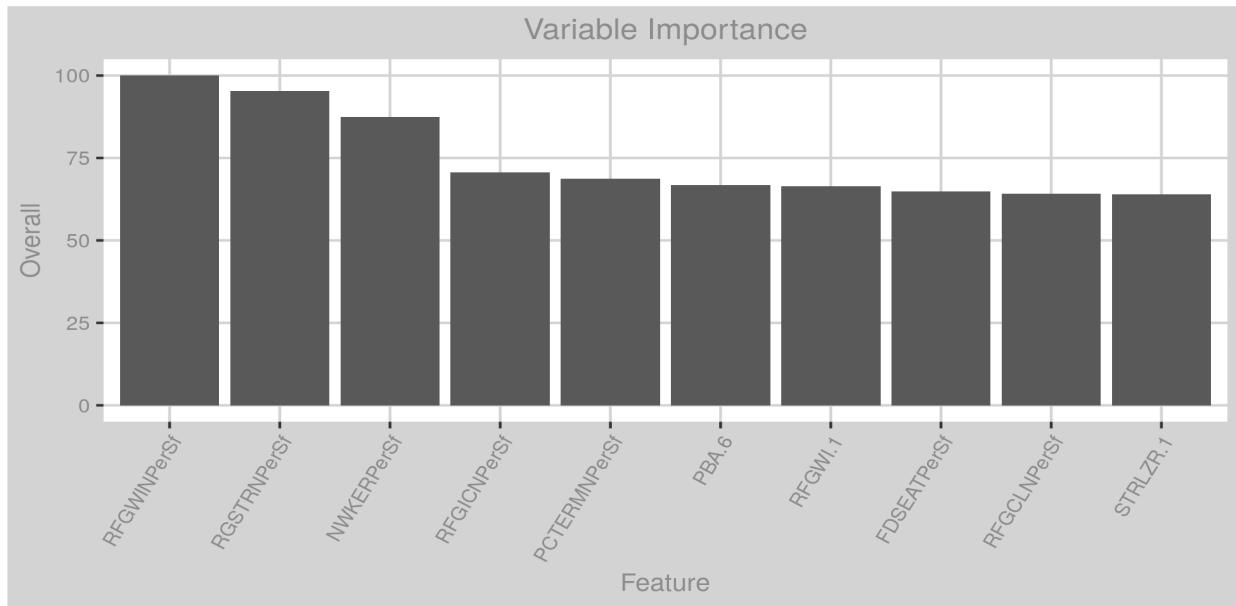


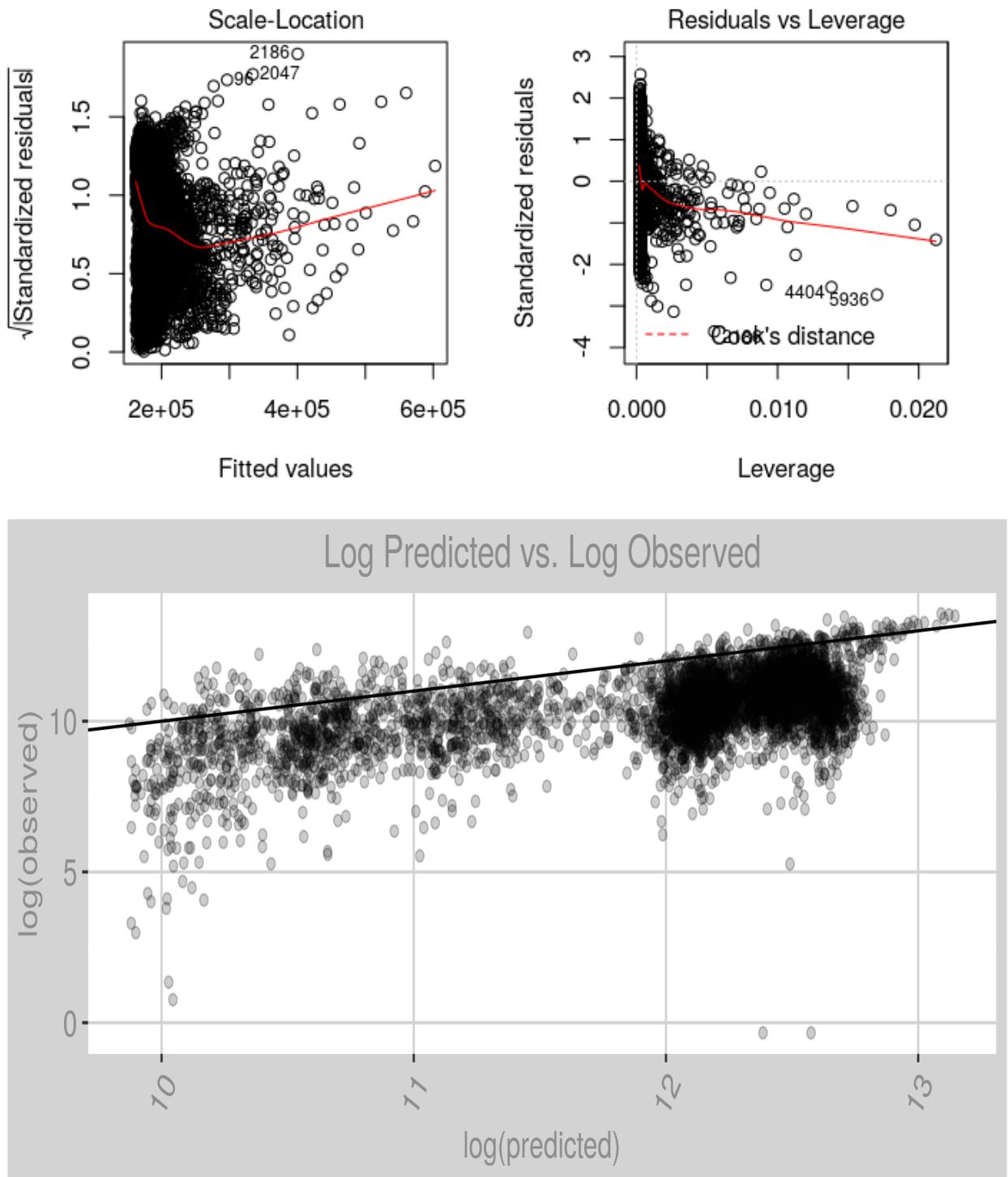
PLS



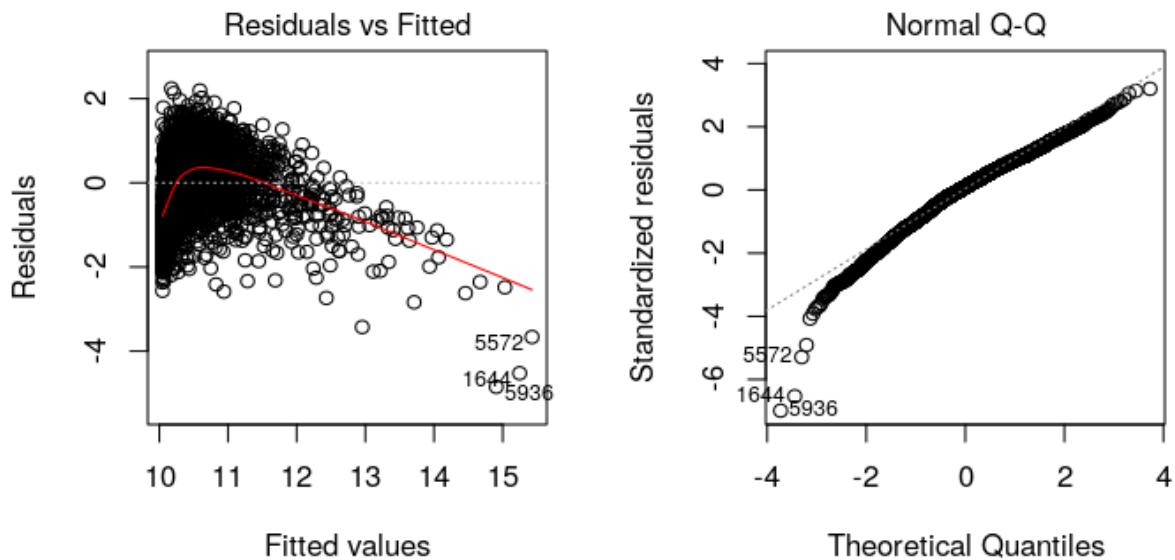
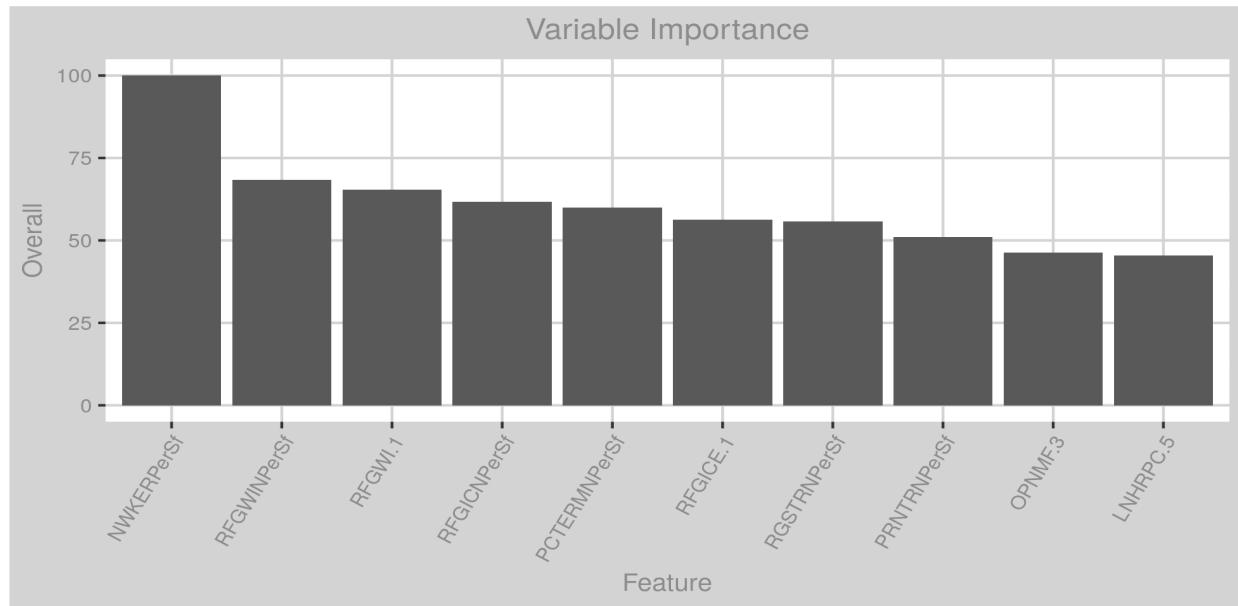


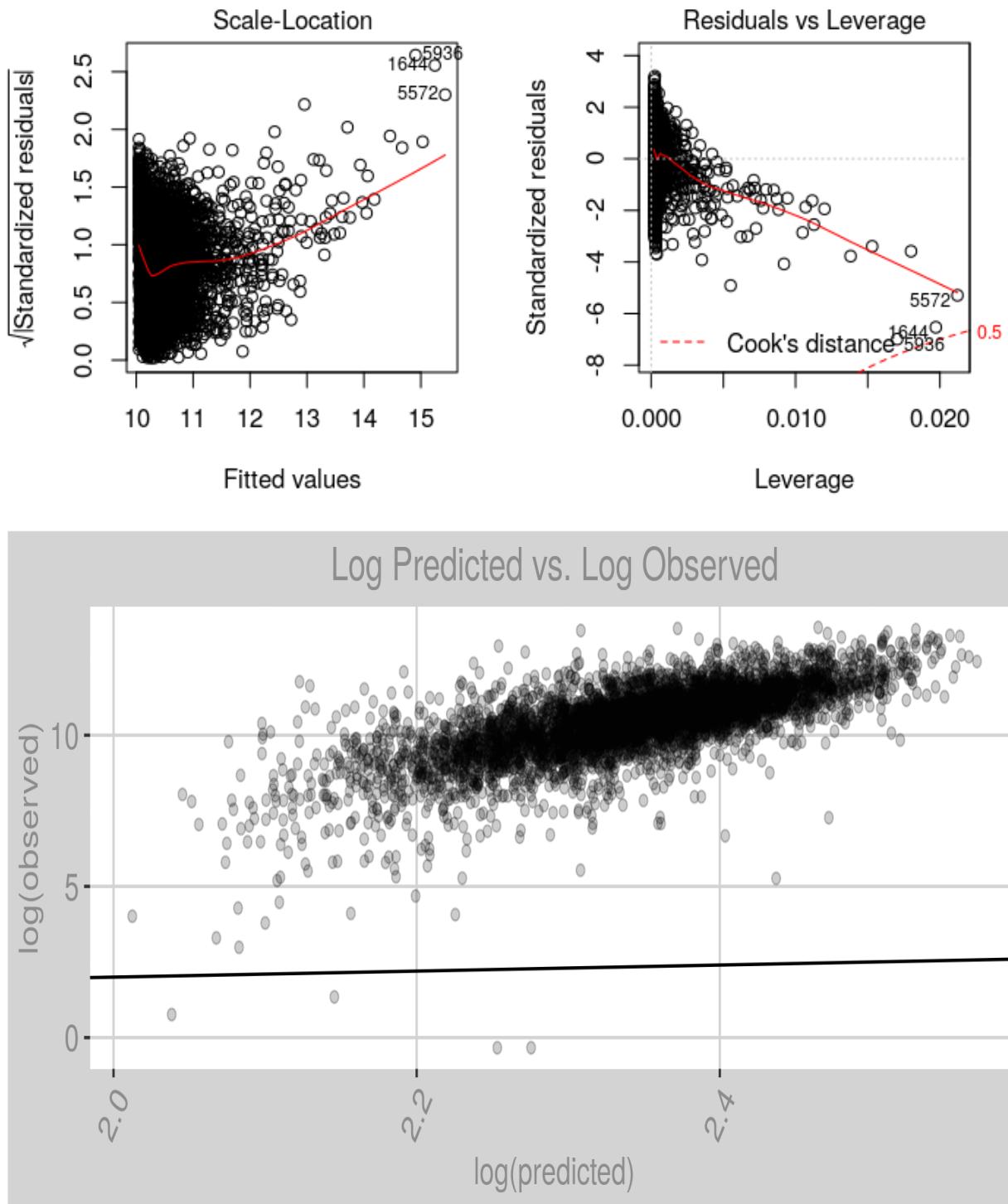
Random Forest



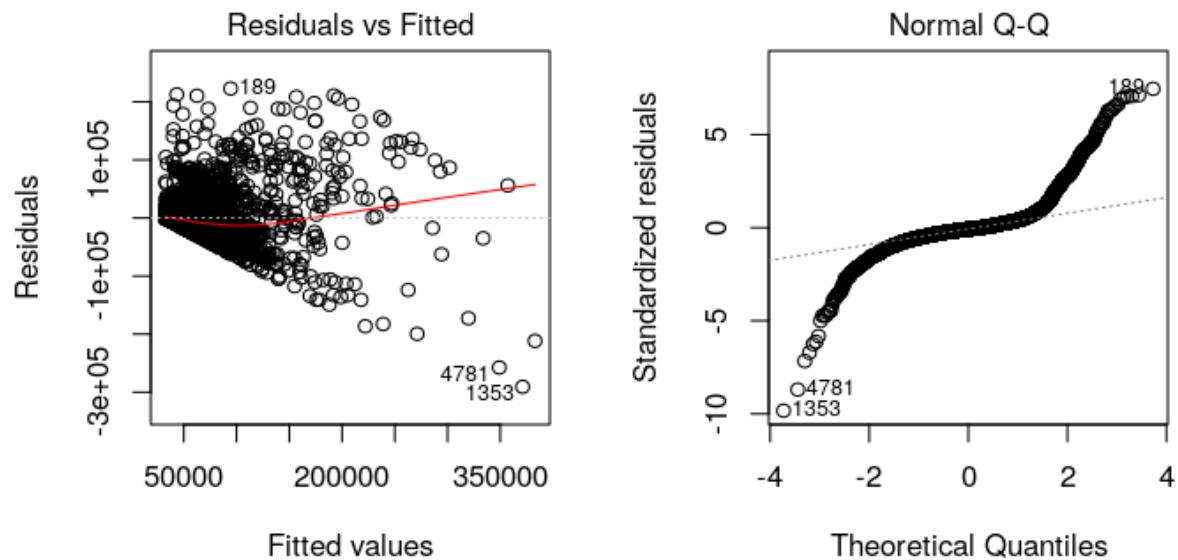
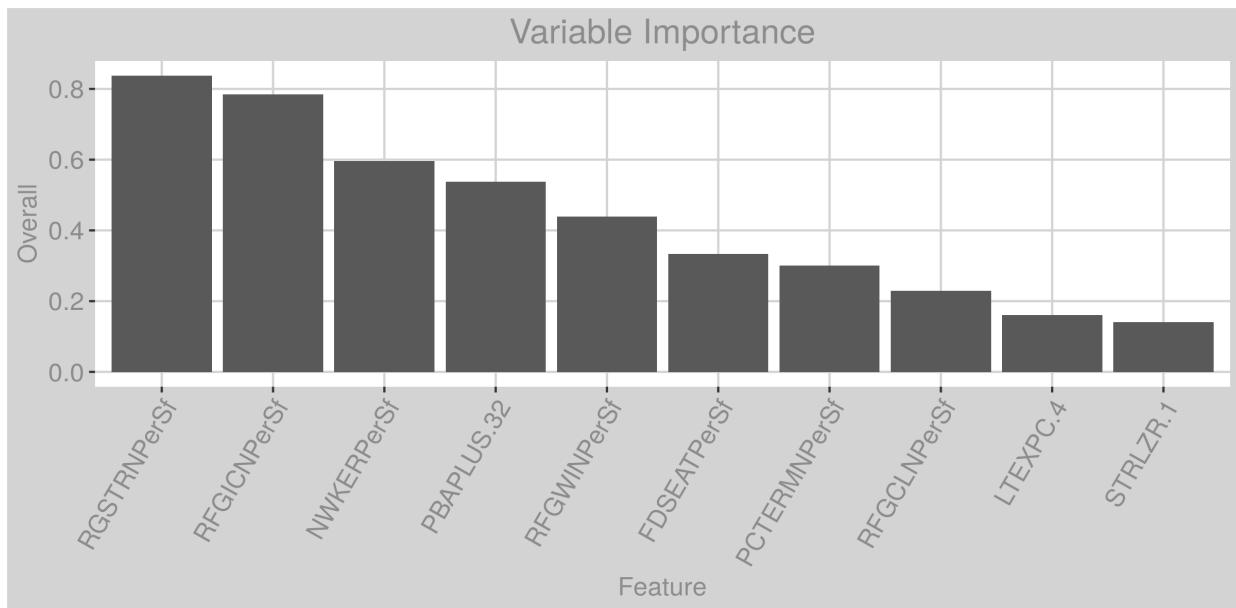


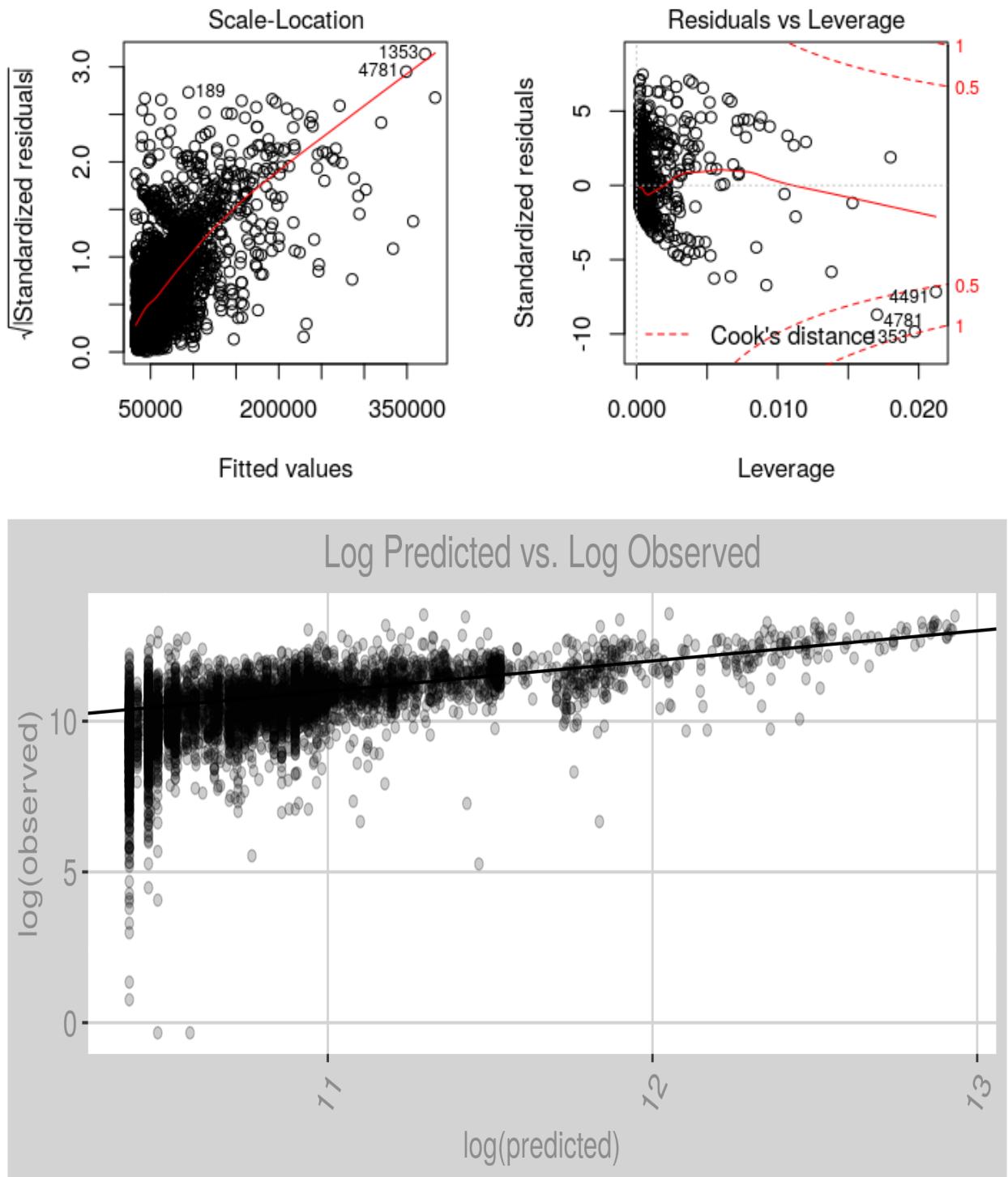
Forward Selection



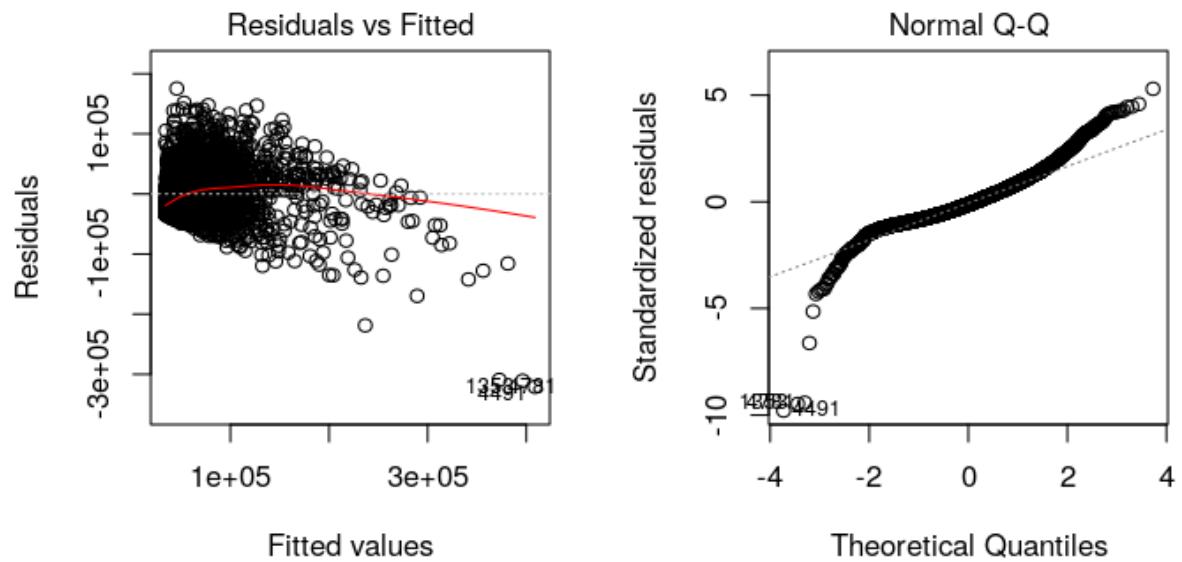
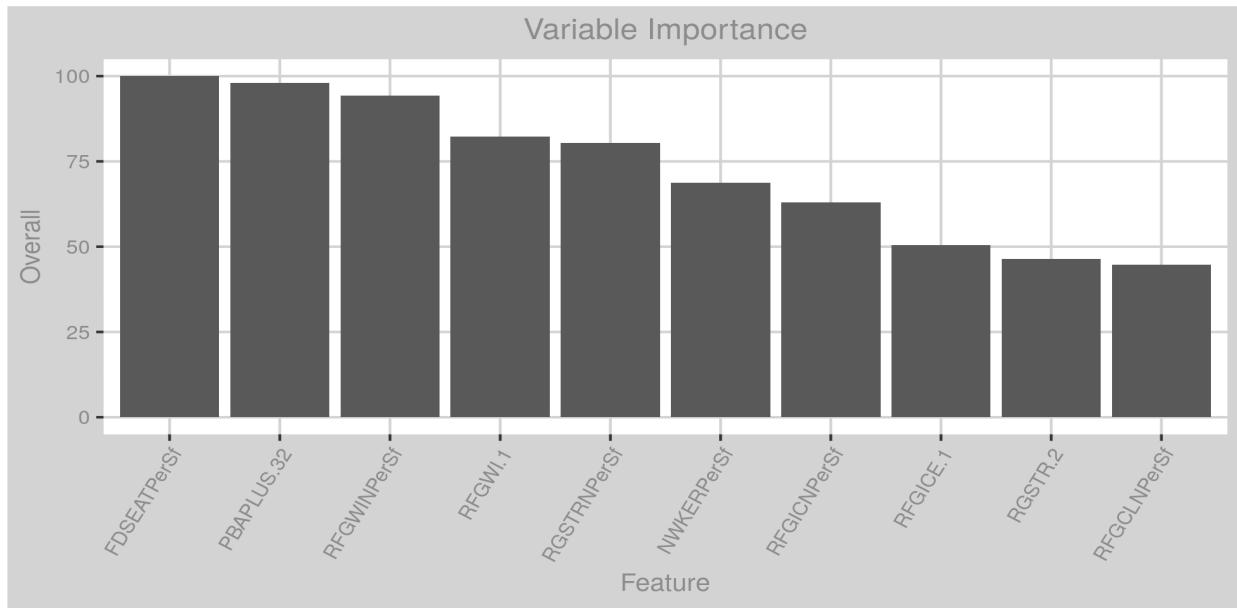


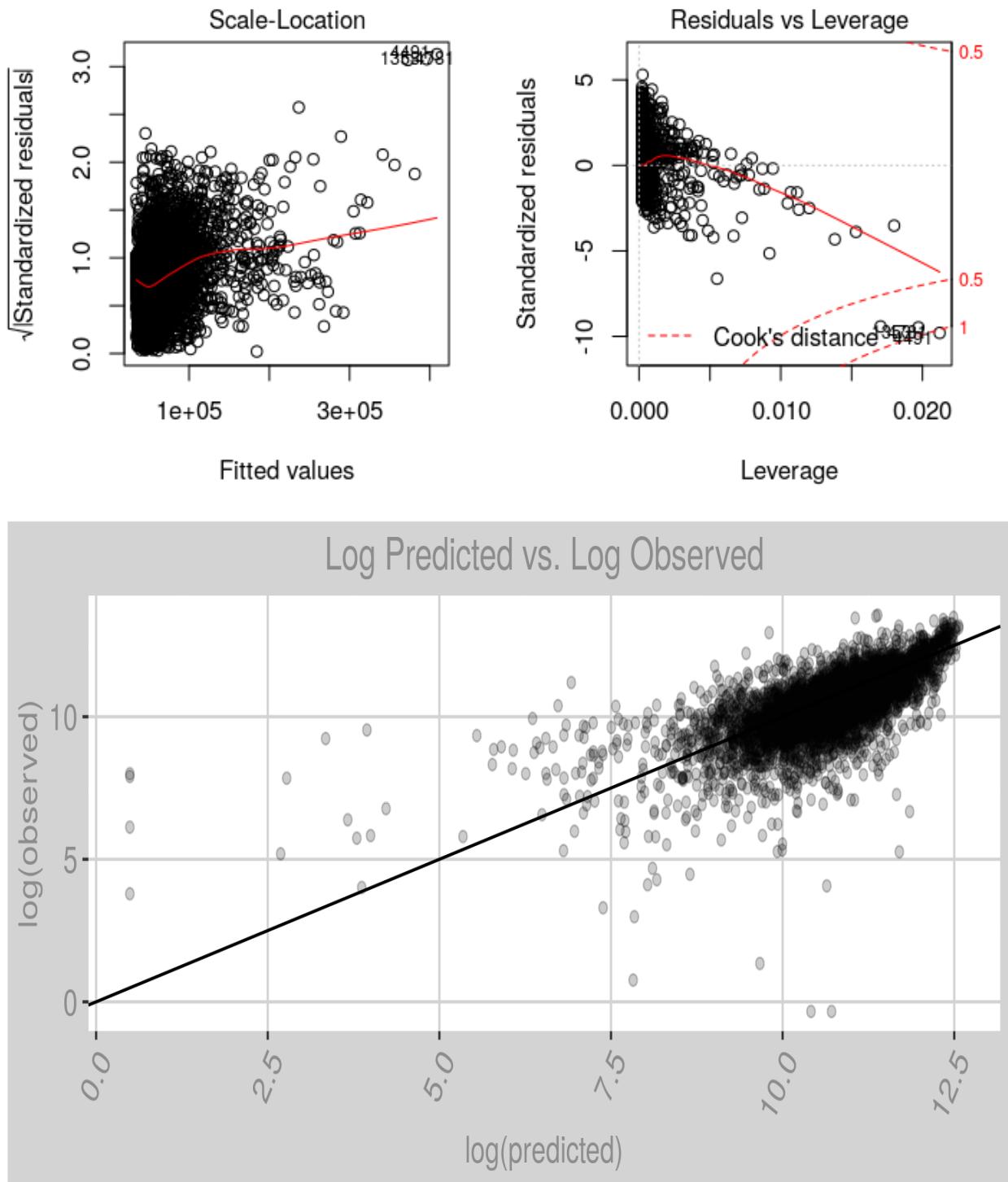
Recursive Feature Extraction





Simple Neural Network

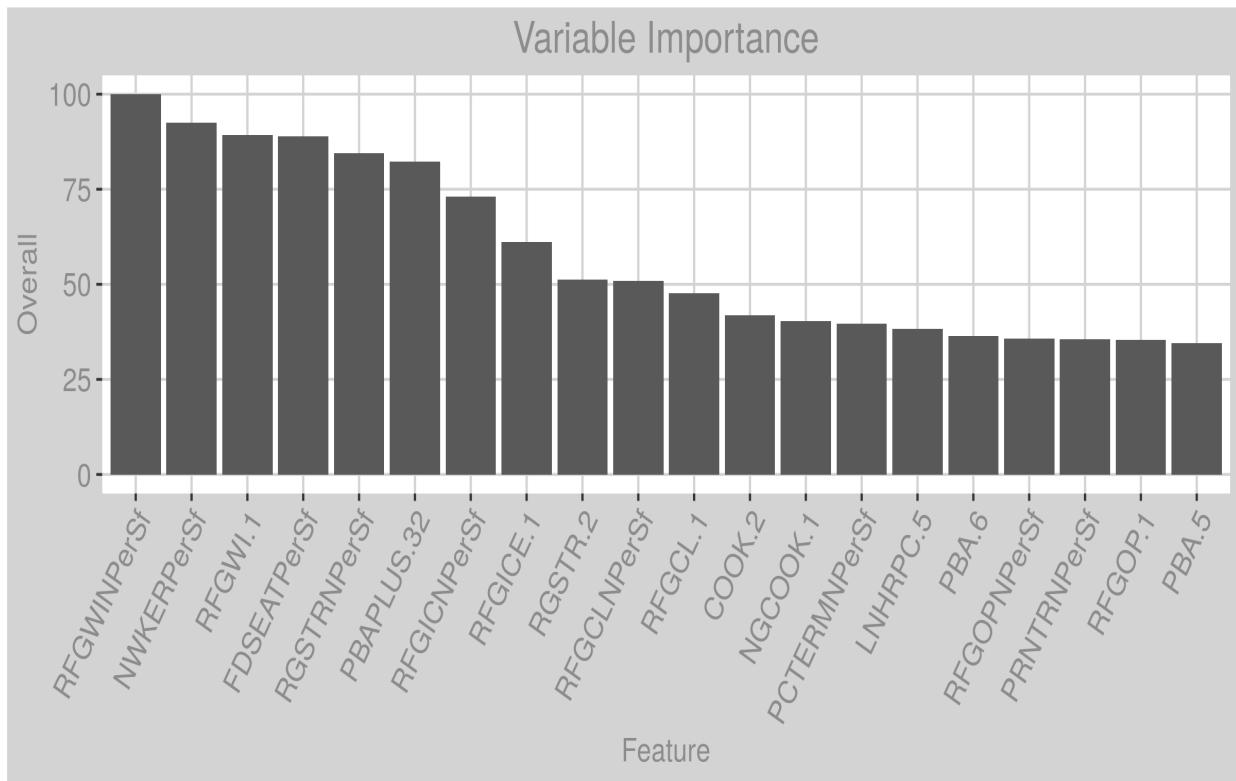


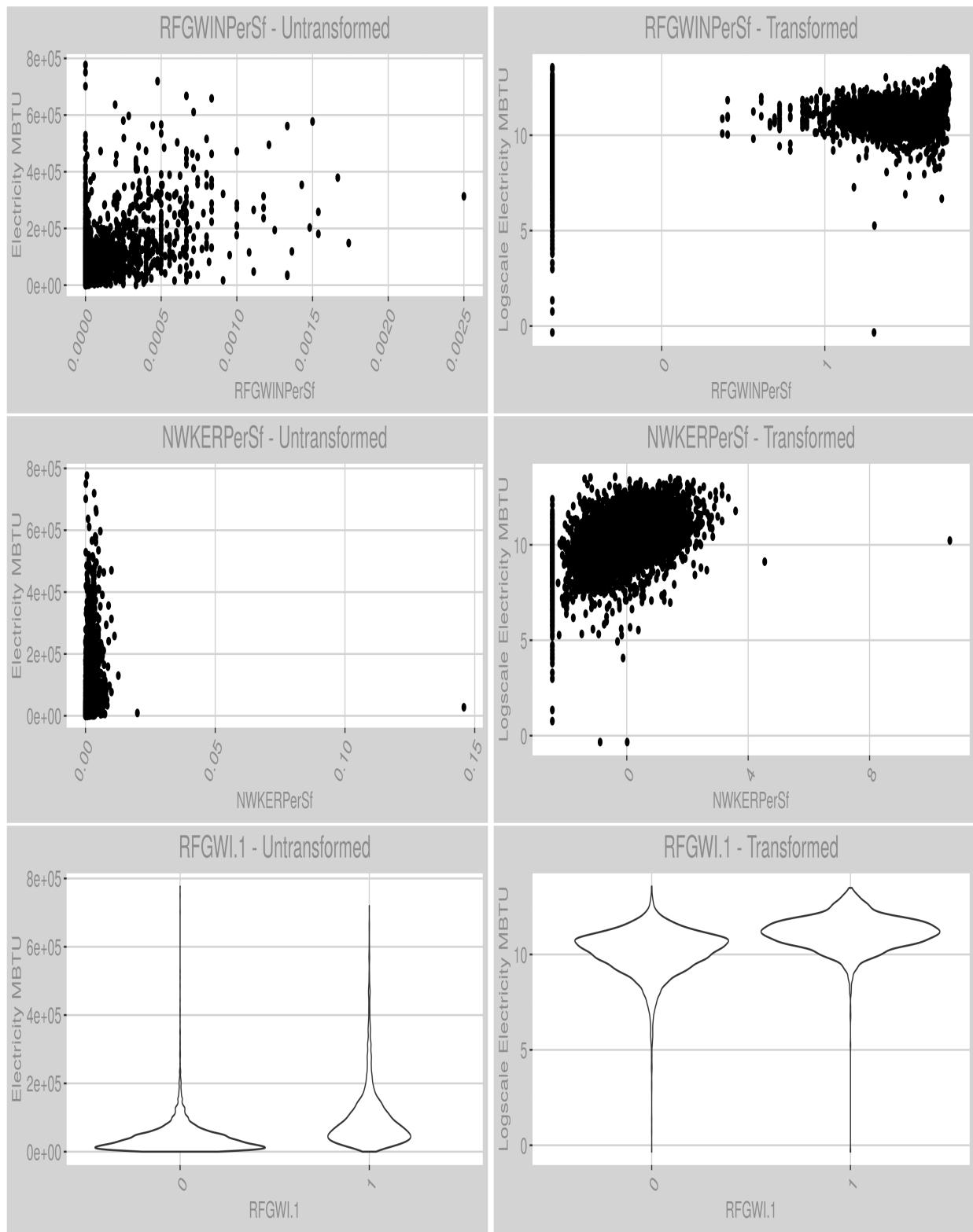


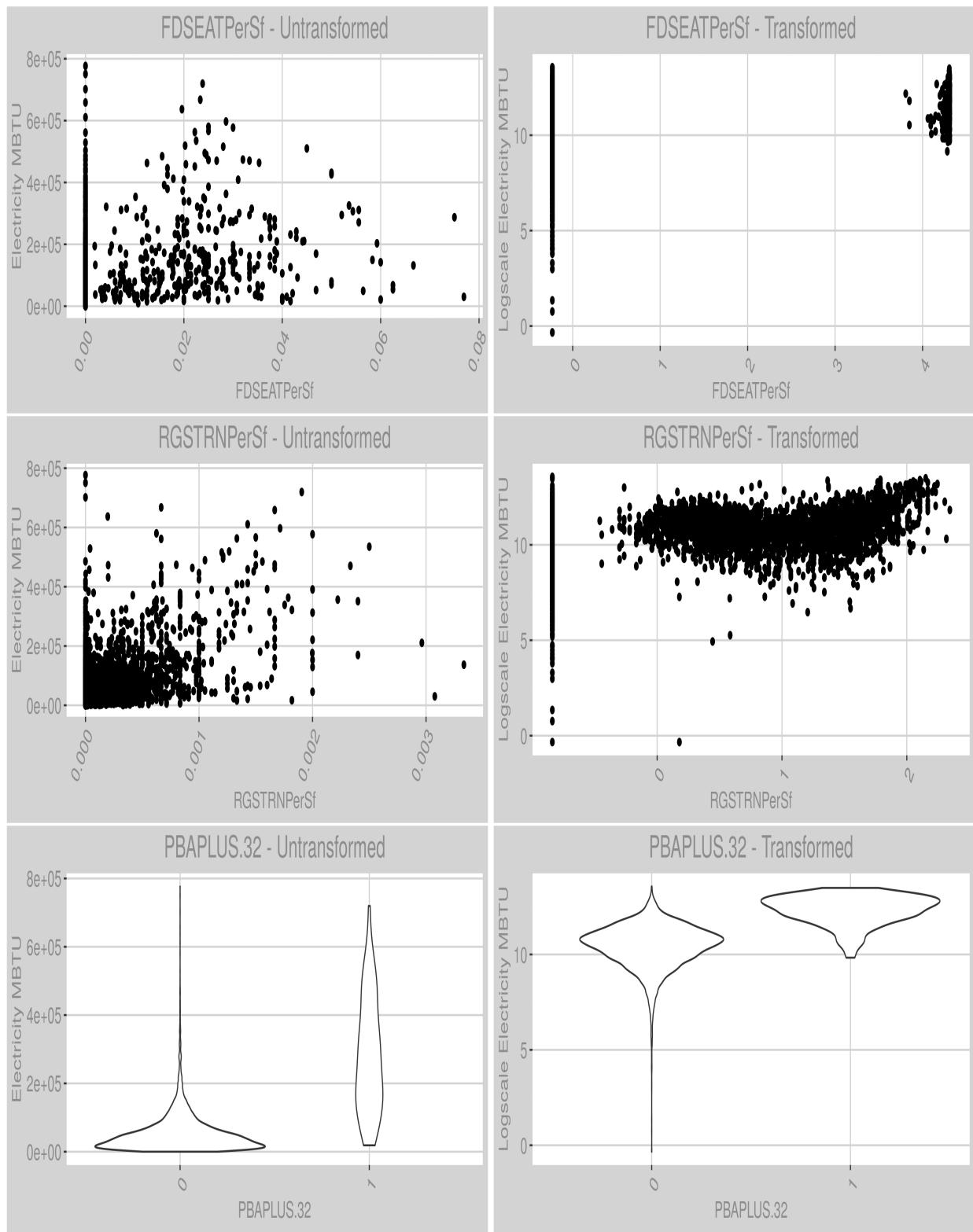
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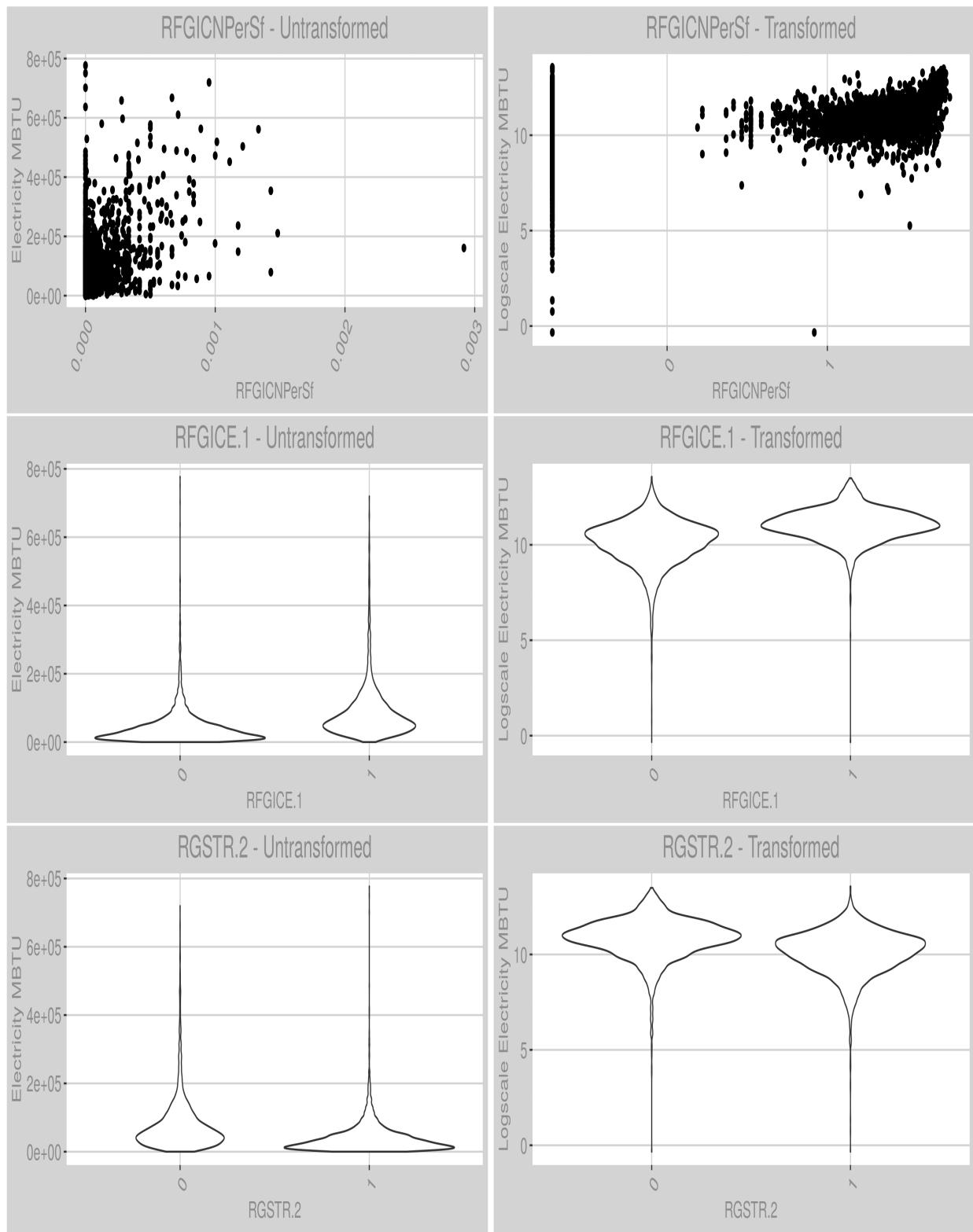
Feature Extraction Model Results

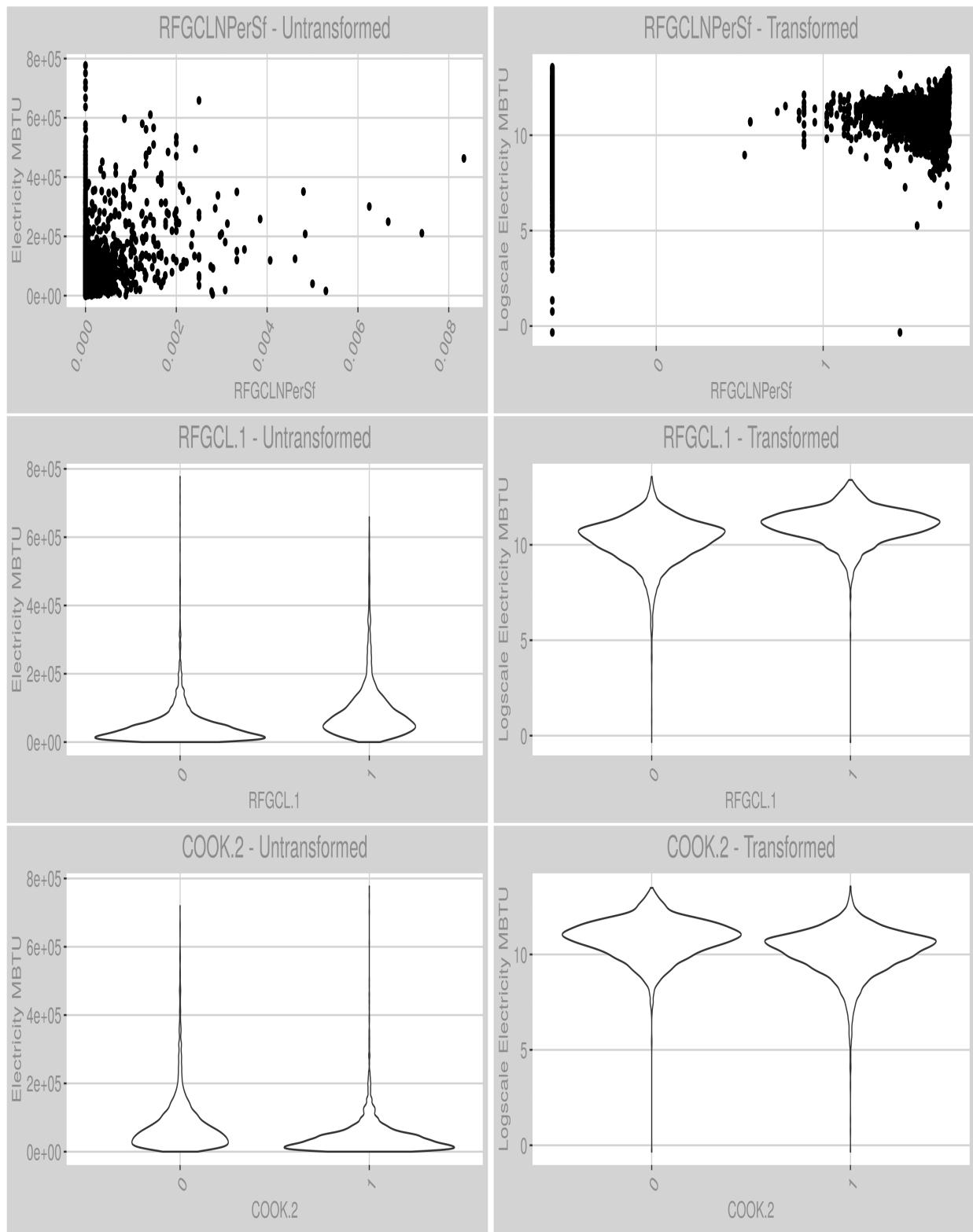
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partialLeastSquares	46880.41	0.5475726	24461.50	585.9408
neuralNetwork	48644.23	0.4990216	28964.80	1754.0299
recursiveFeatureExtraction	48022.21	0.5168333	29511.04	2227.8453
randomForest	163434.65	0.1731248	141674.66	11208.6082

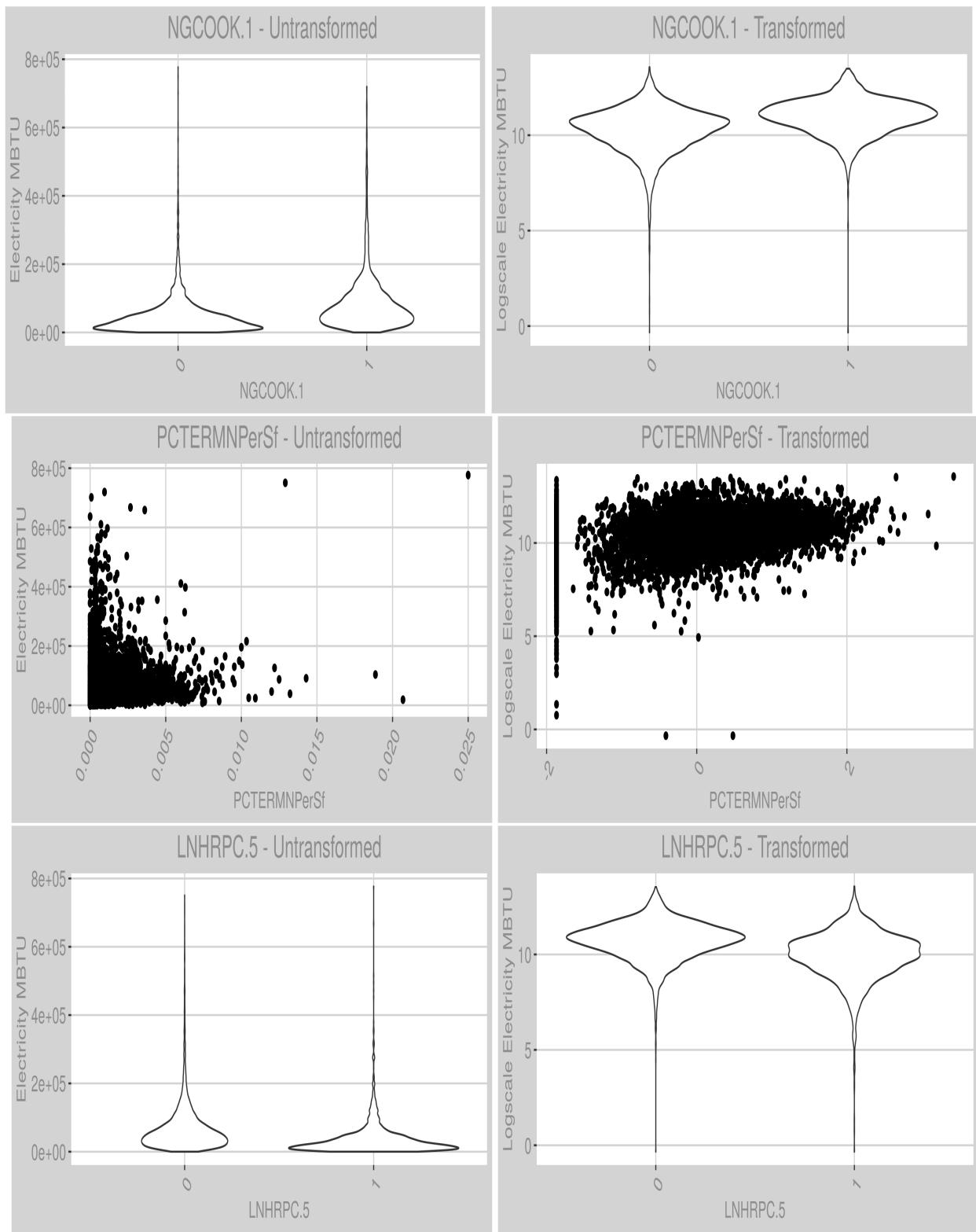


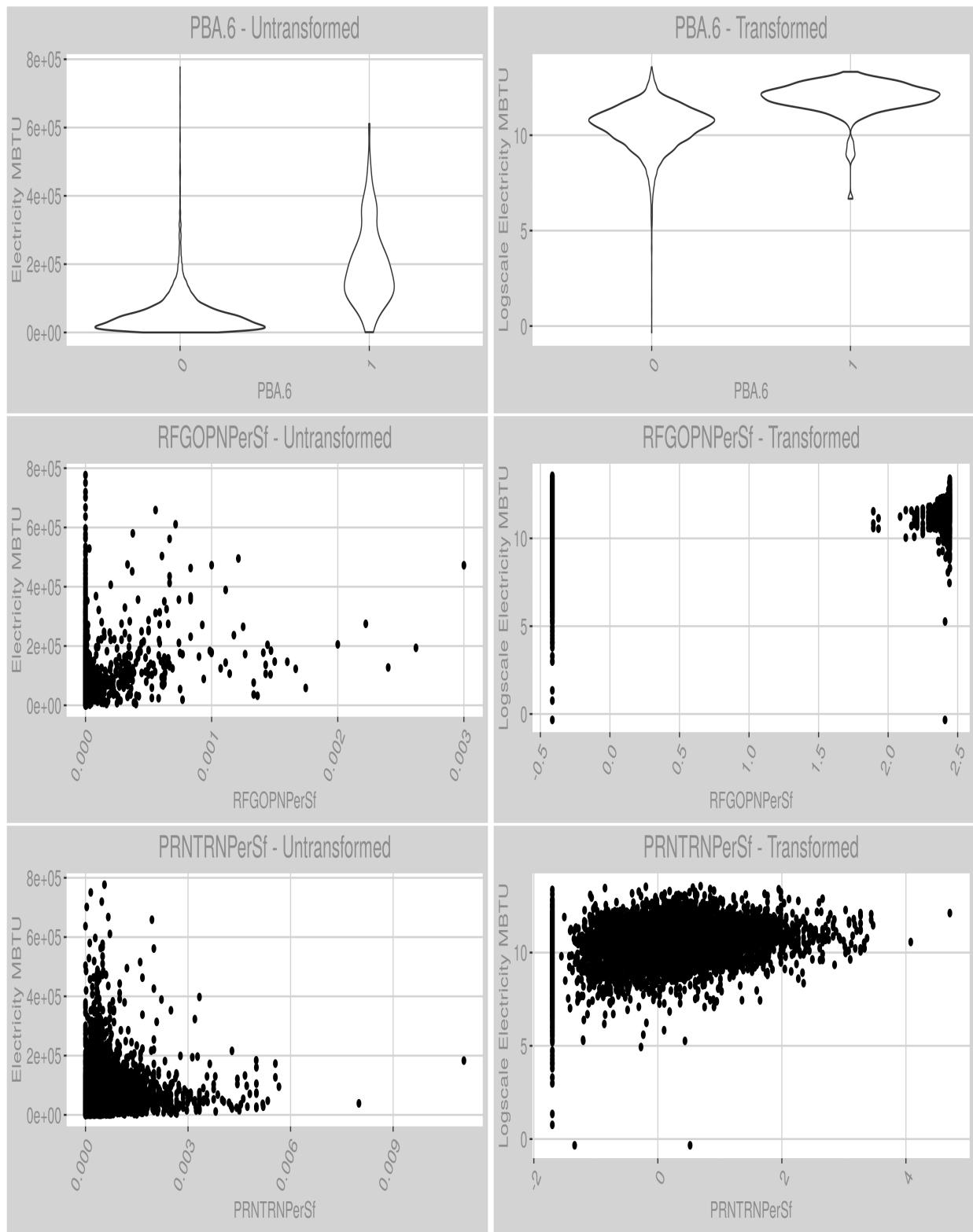


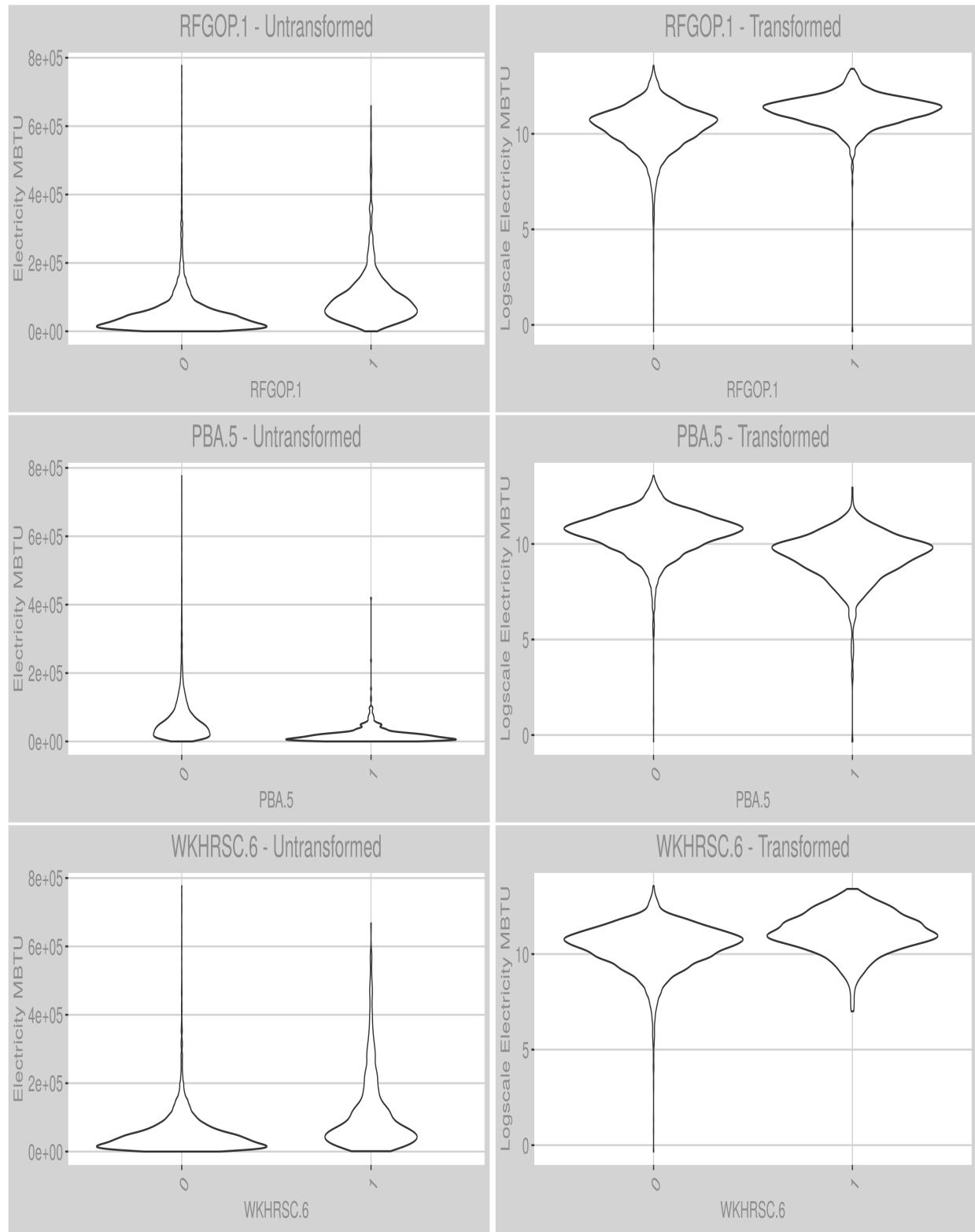




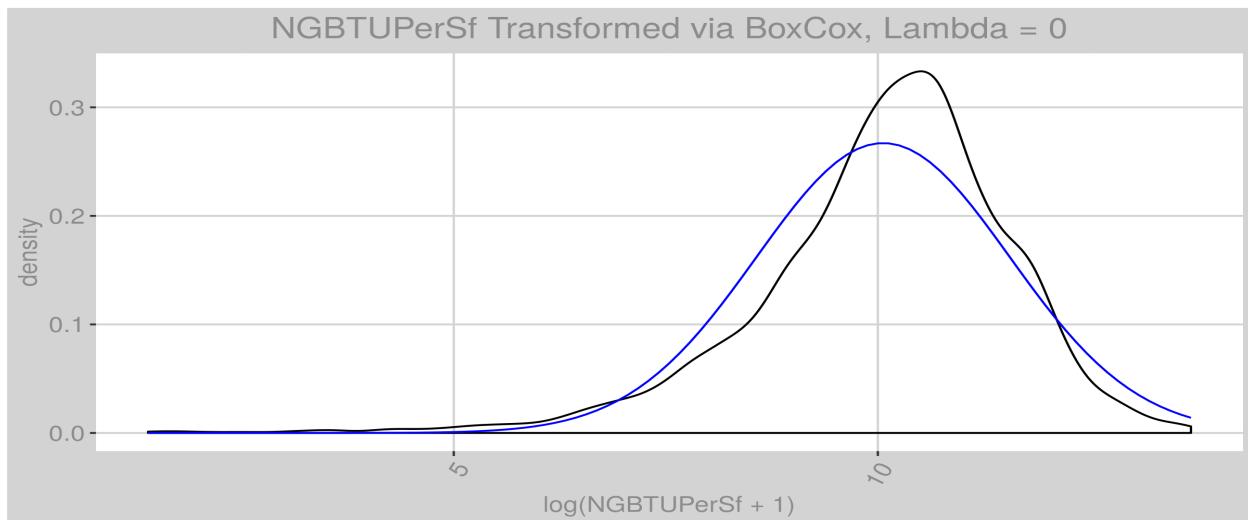




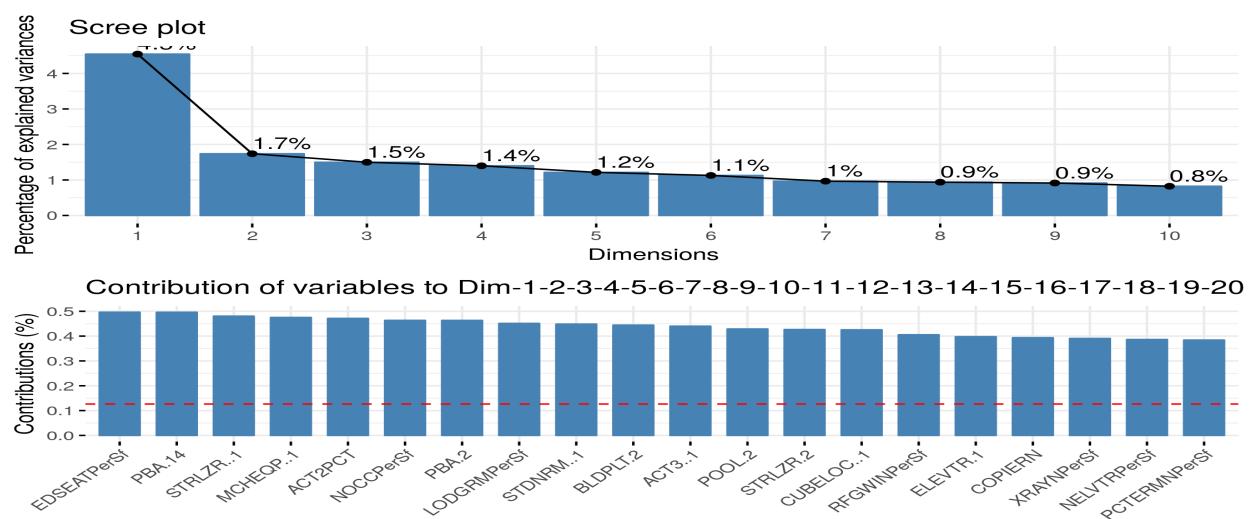




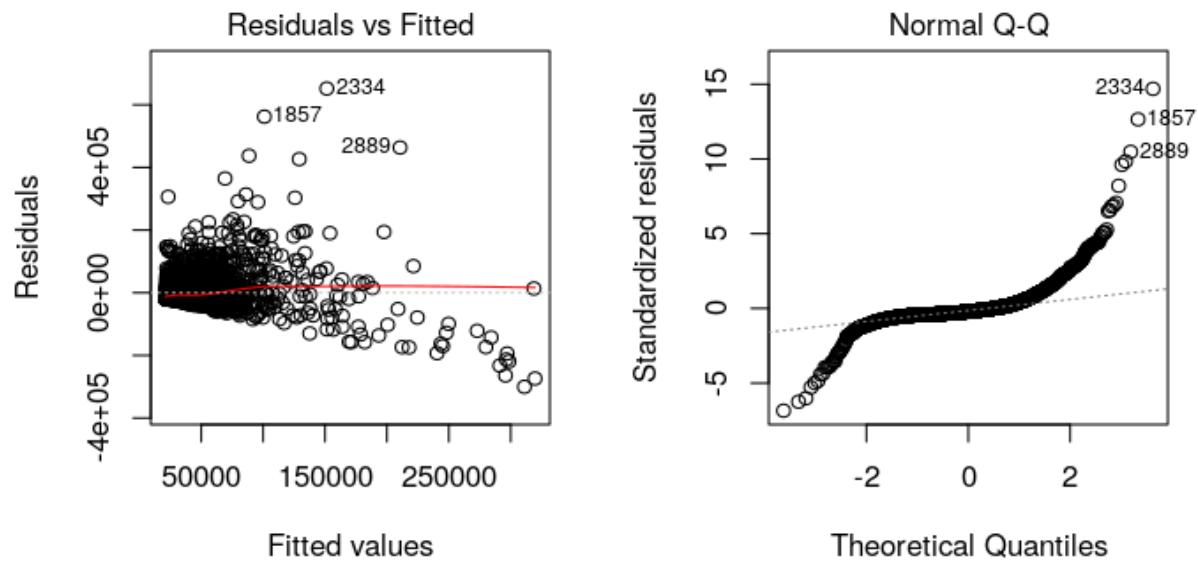
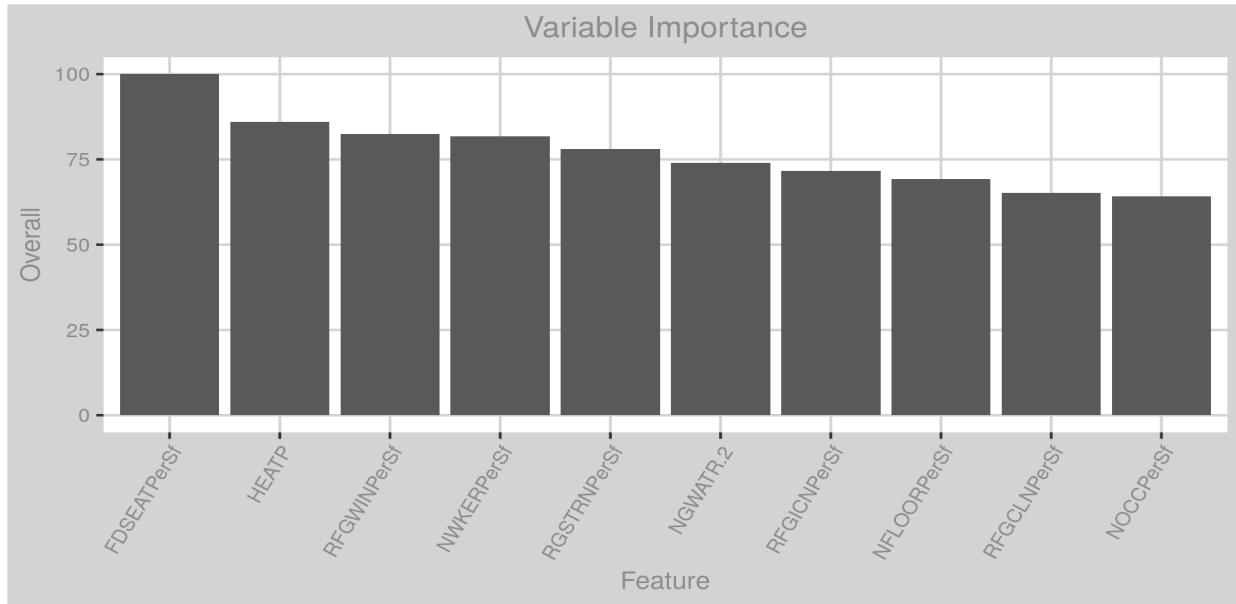
Appendix - Natural Gas Response

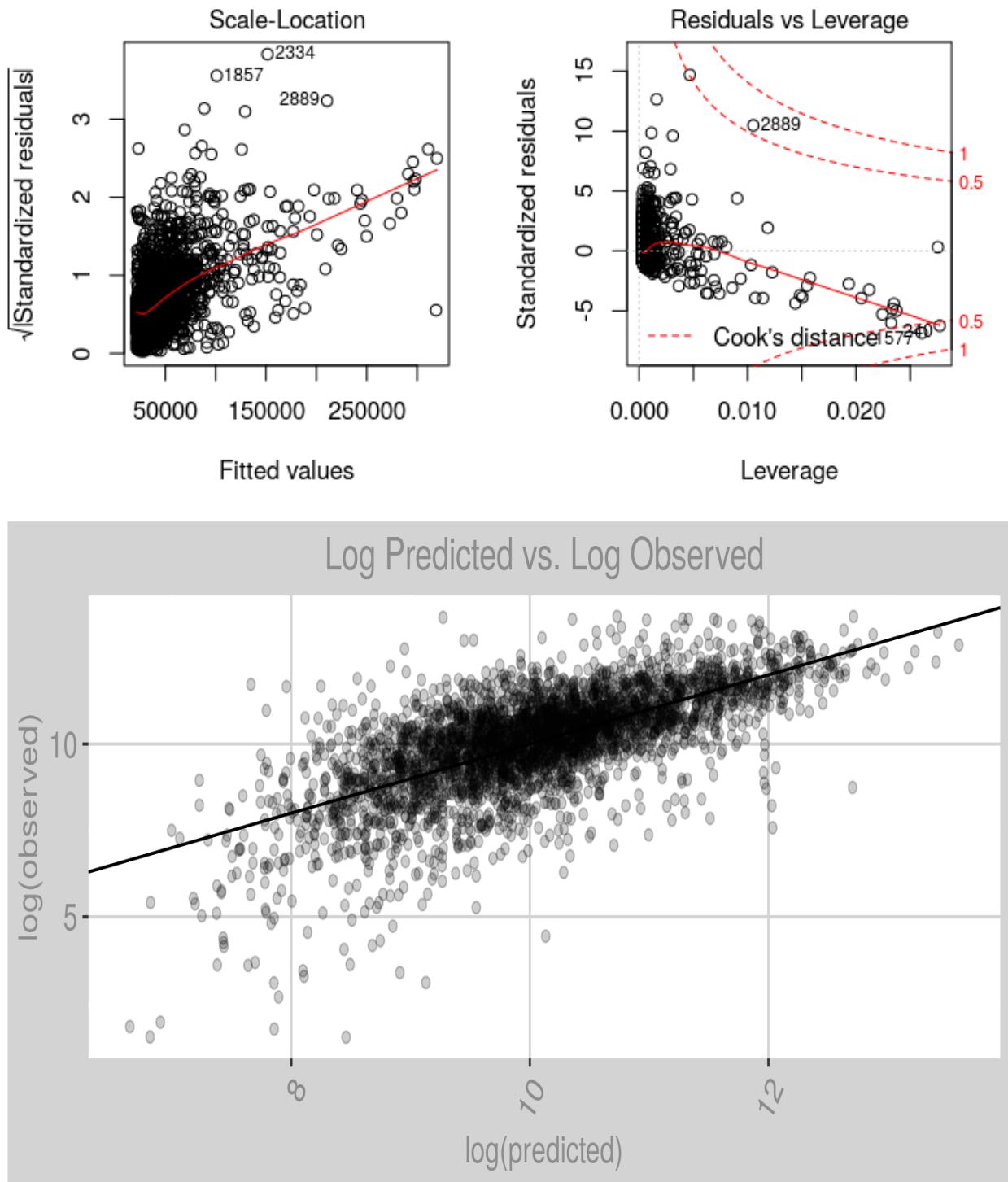


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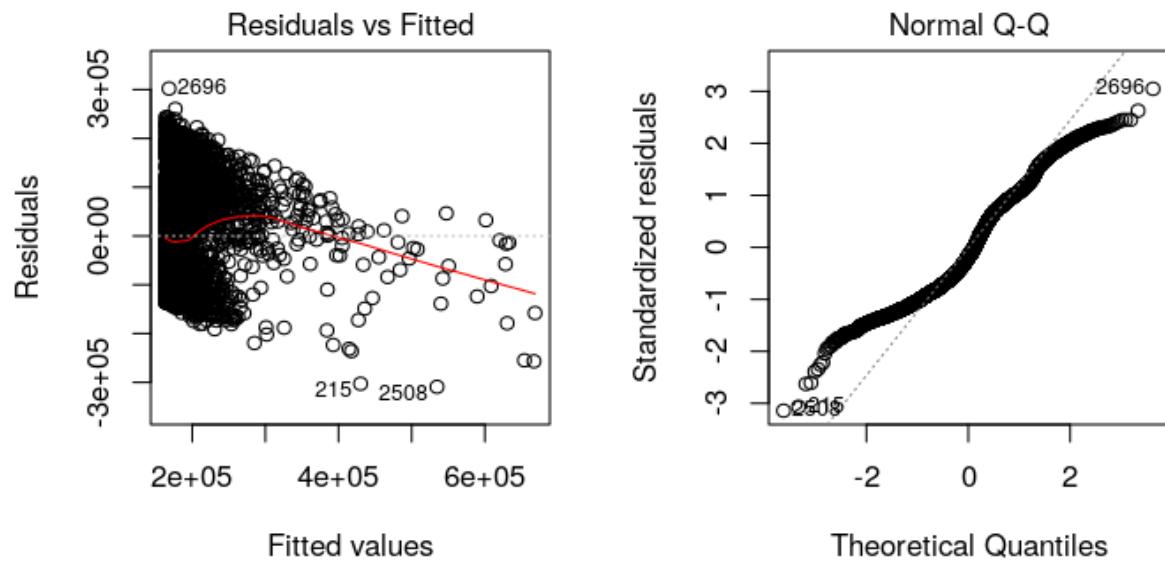
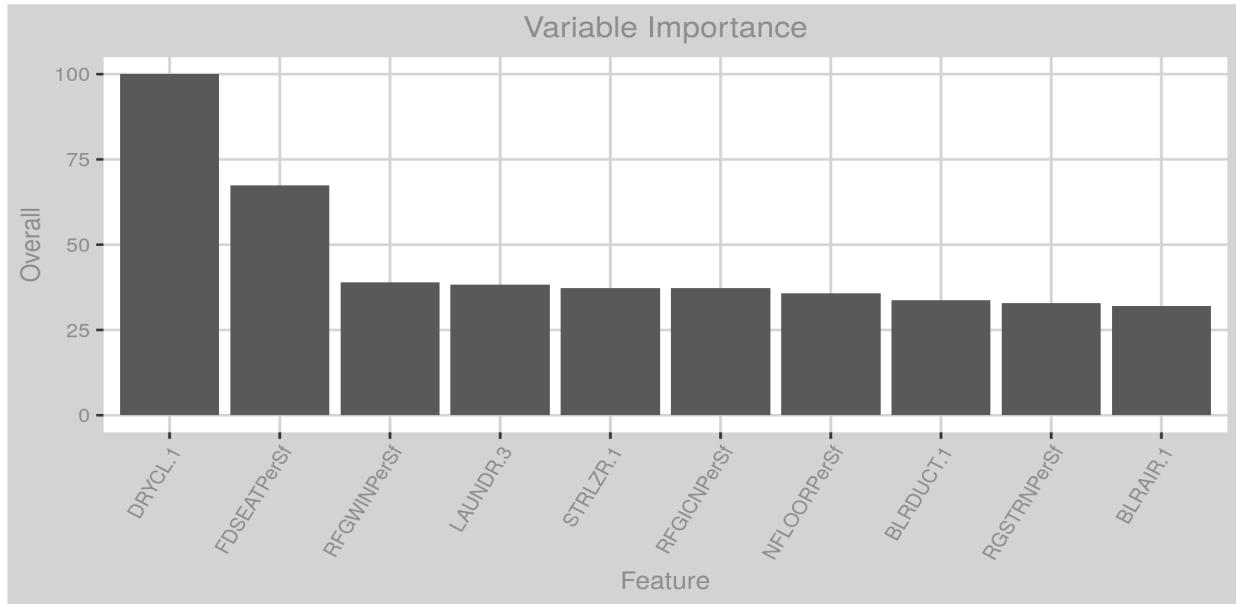


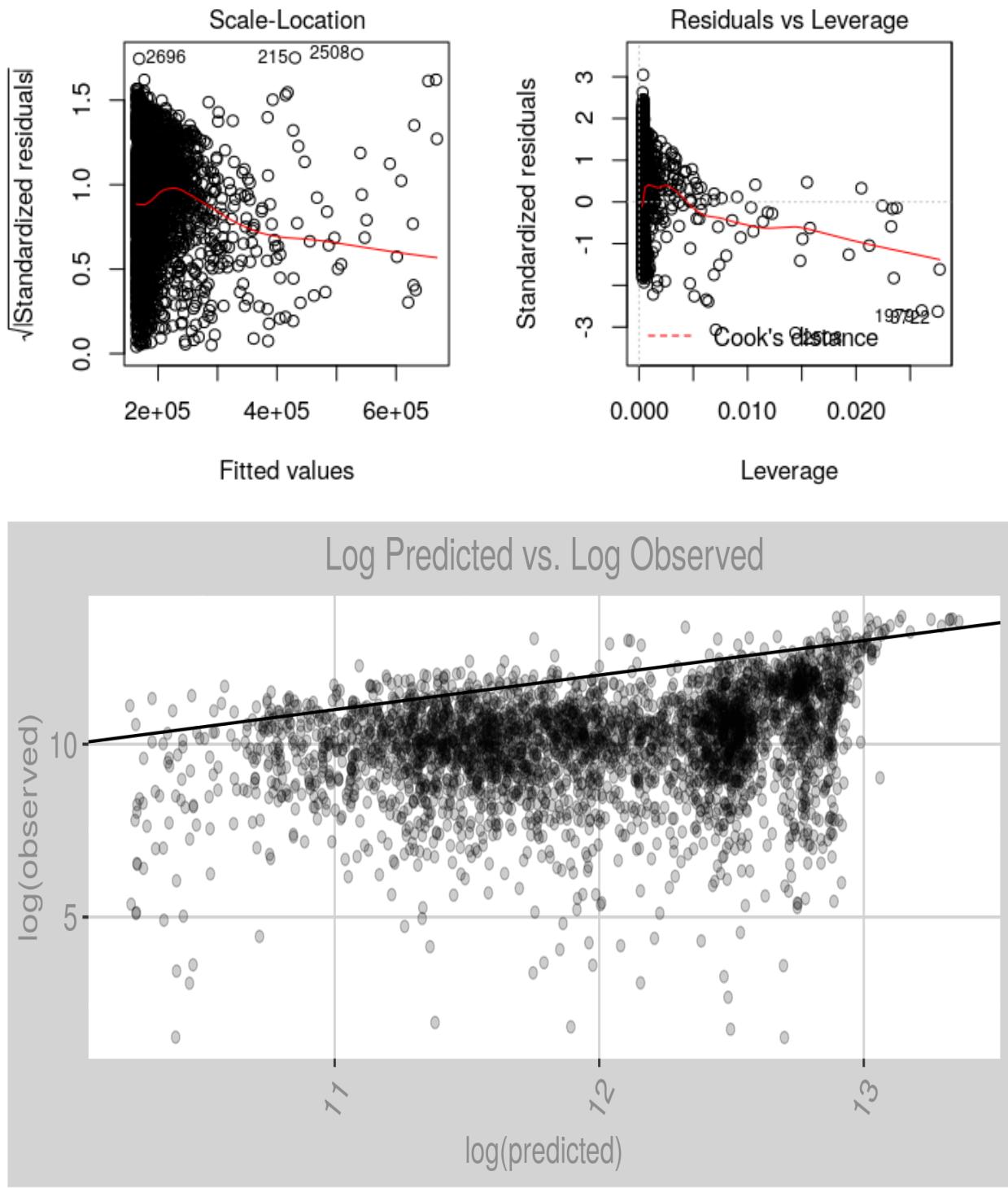
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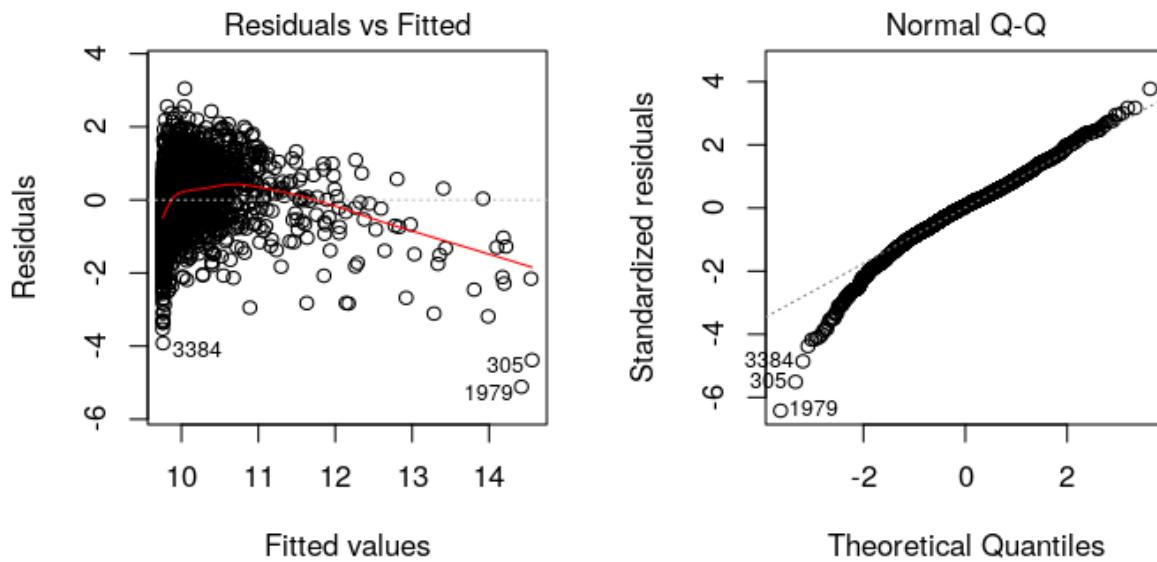
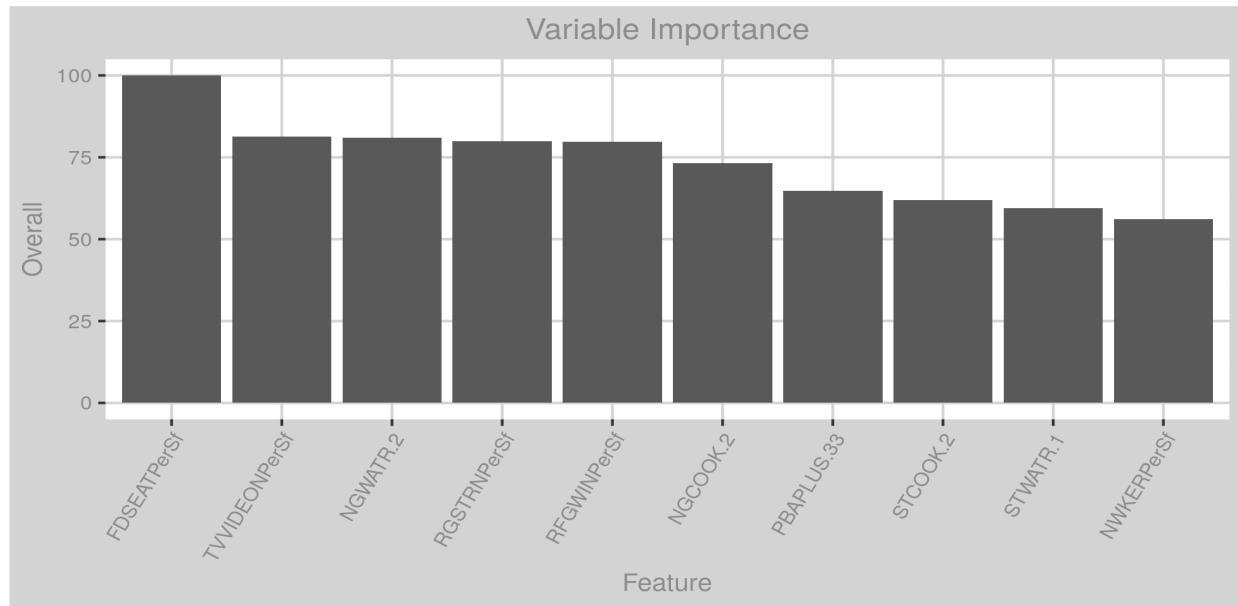


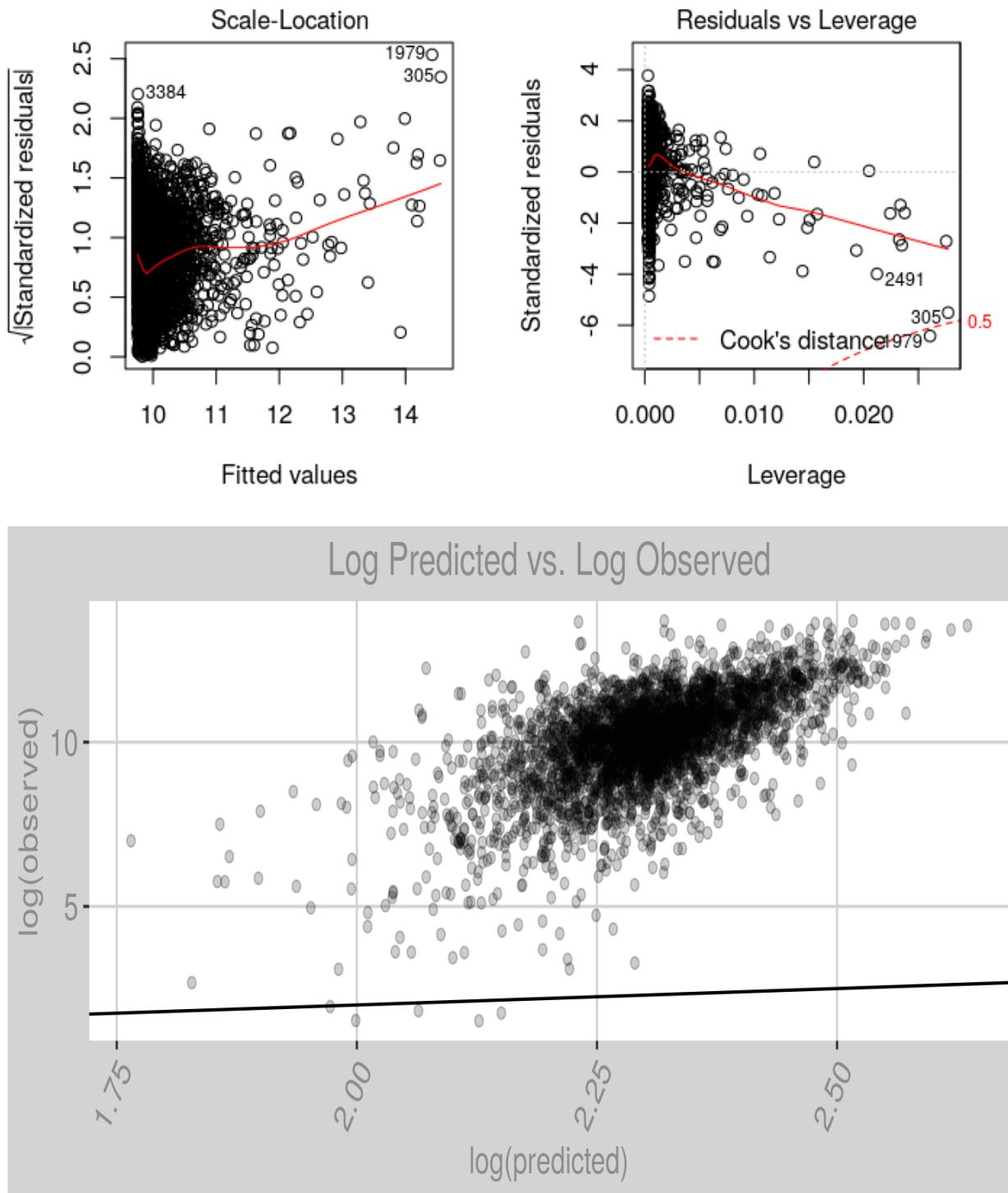
Random Forest



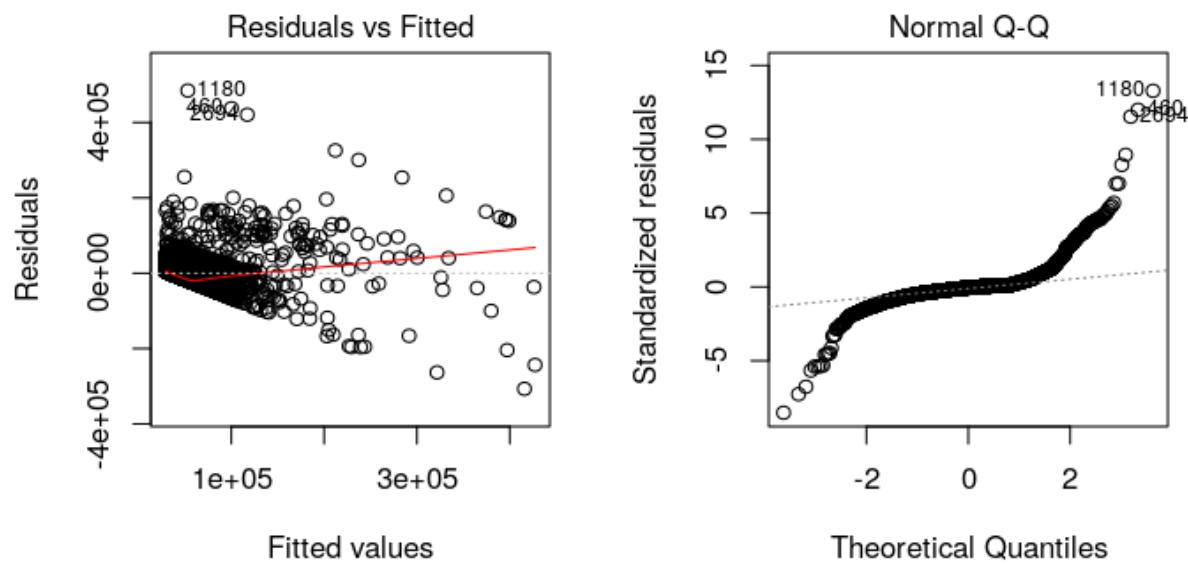
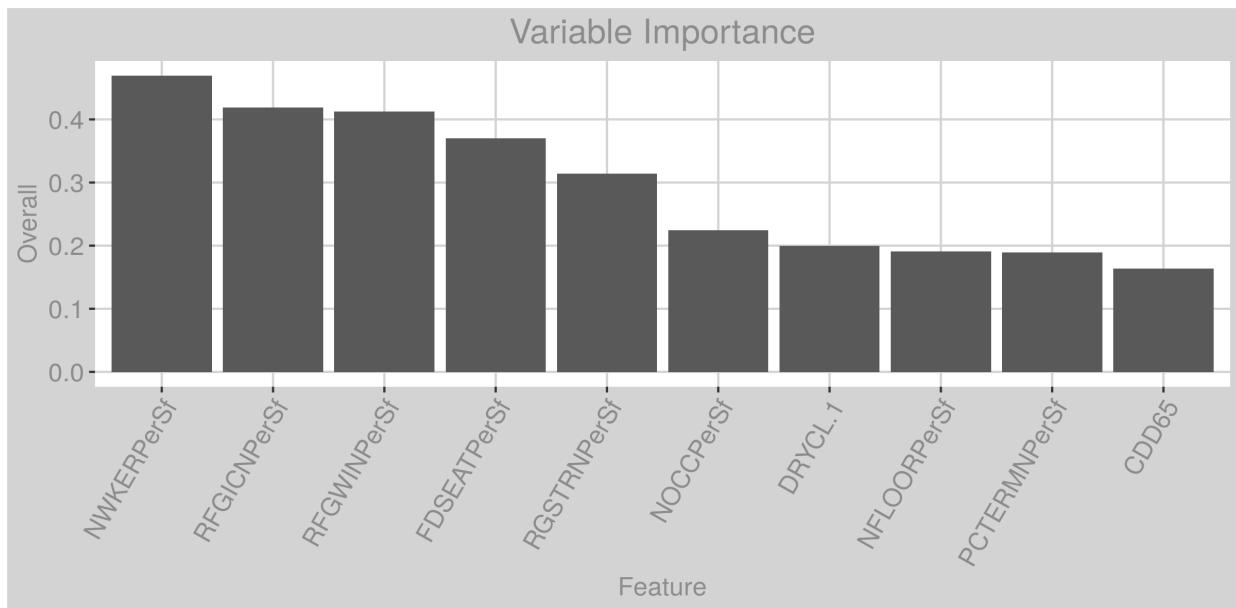


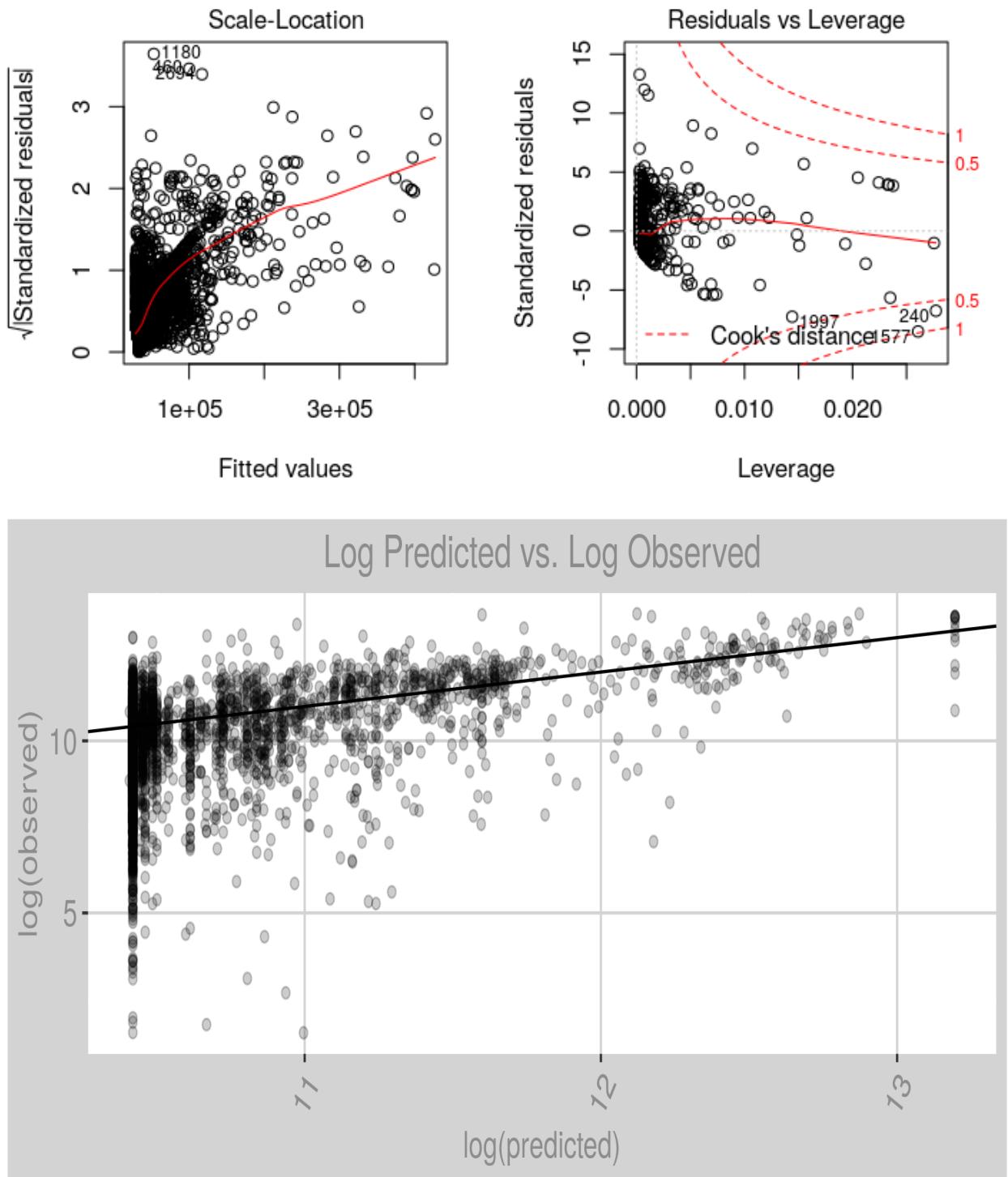
Forward Selection



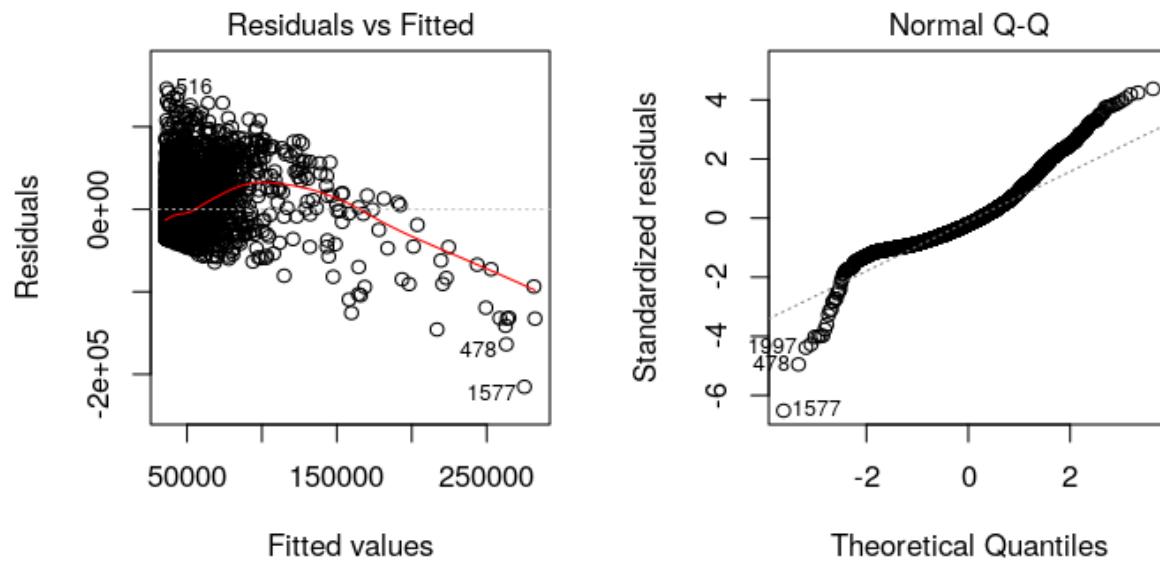
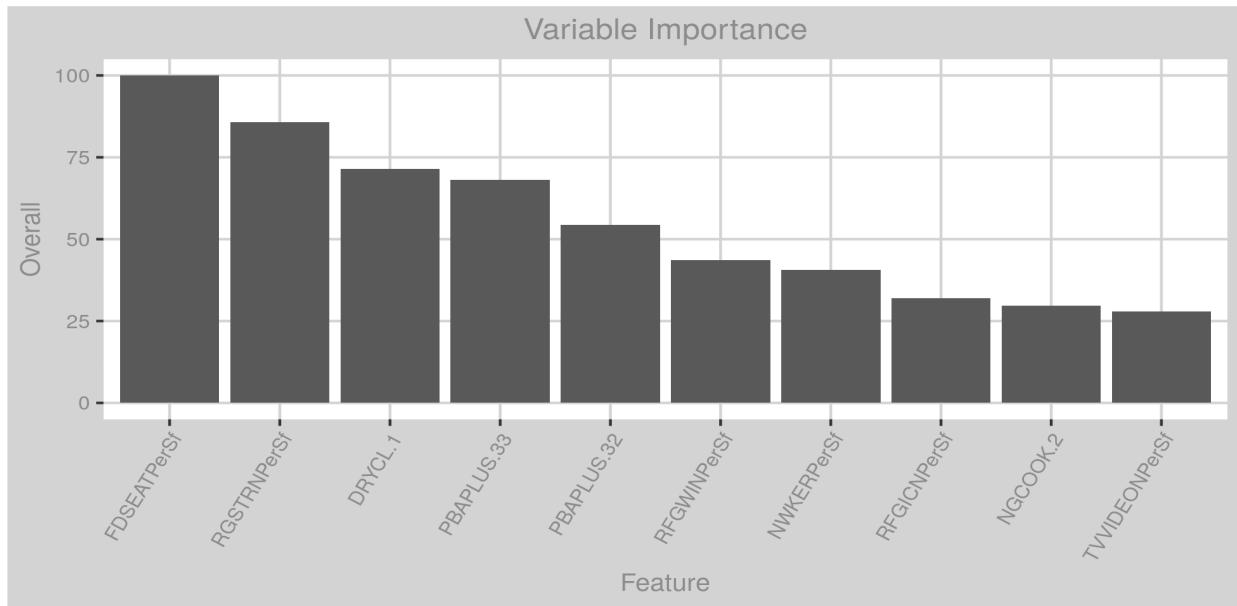


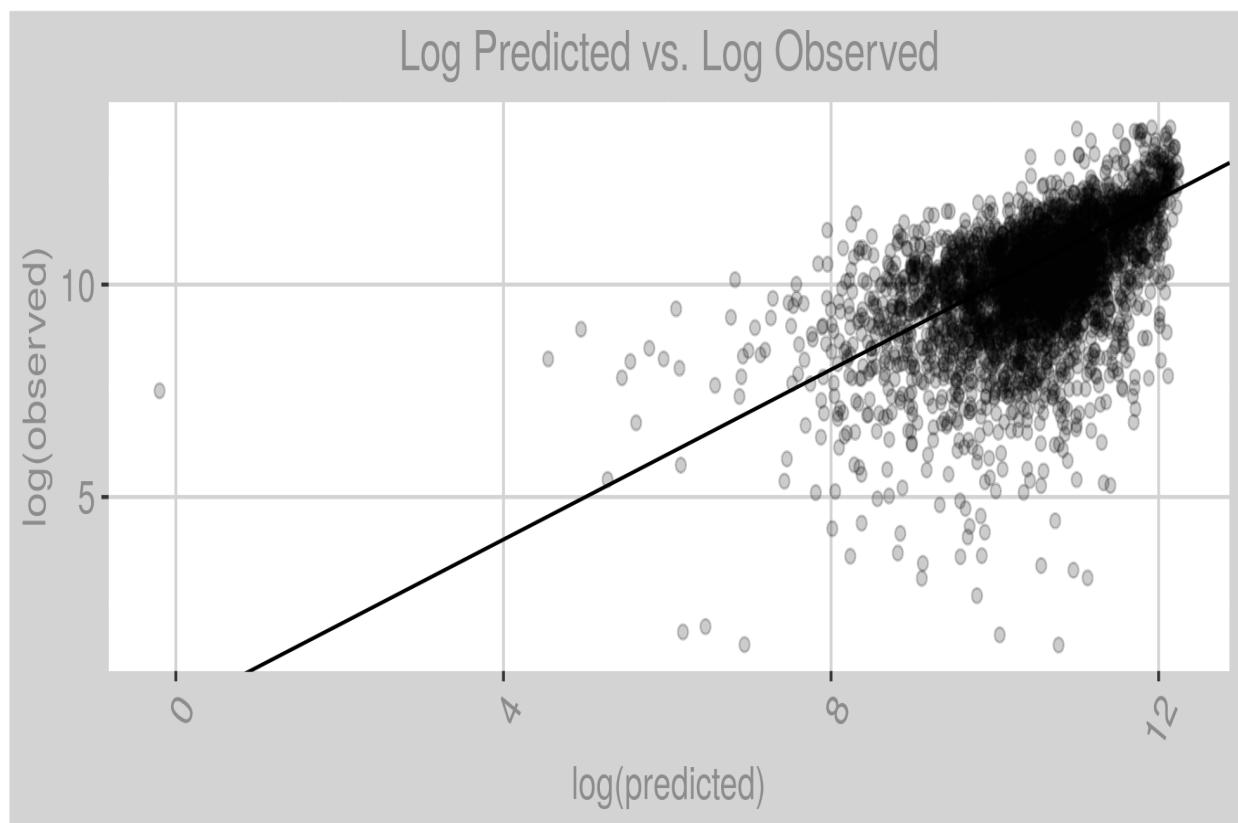
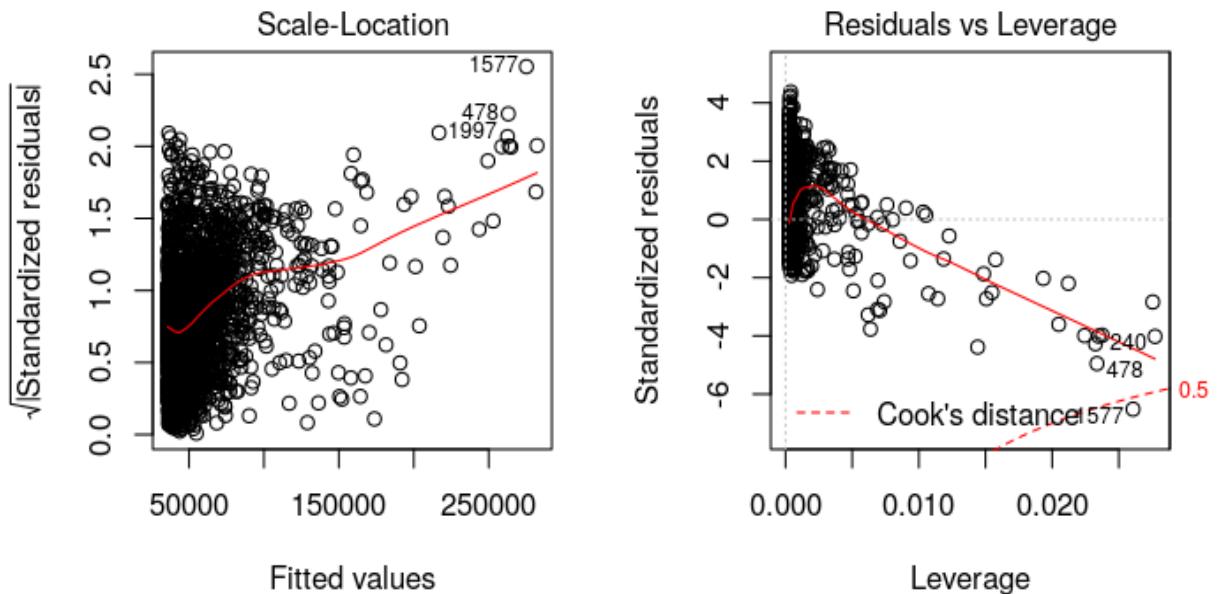
Recursive Feature Extraction





Simple Neural Network

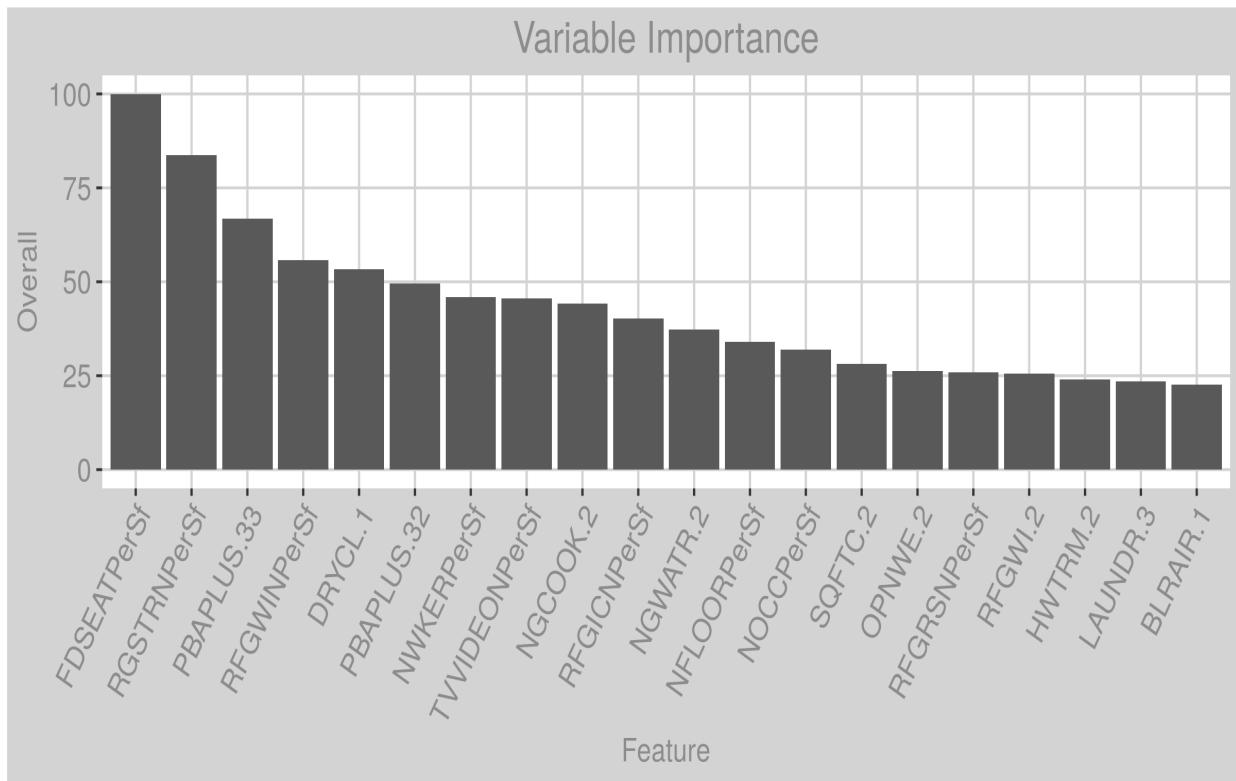


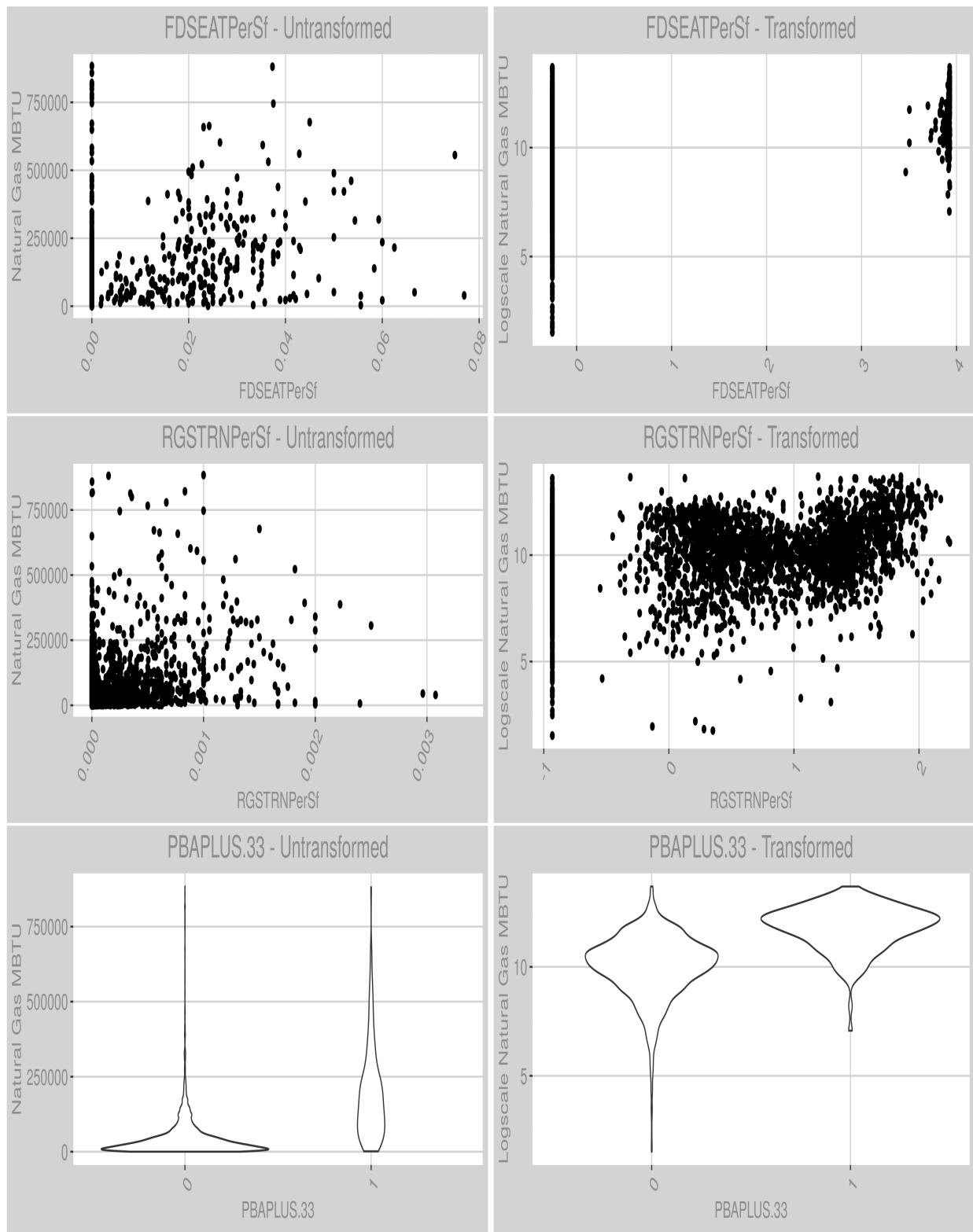


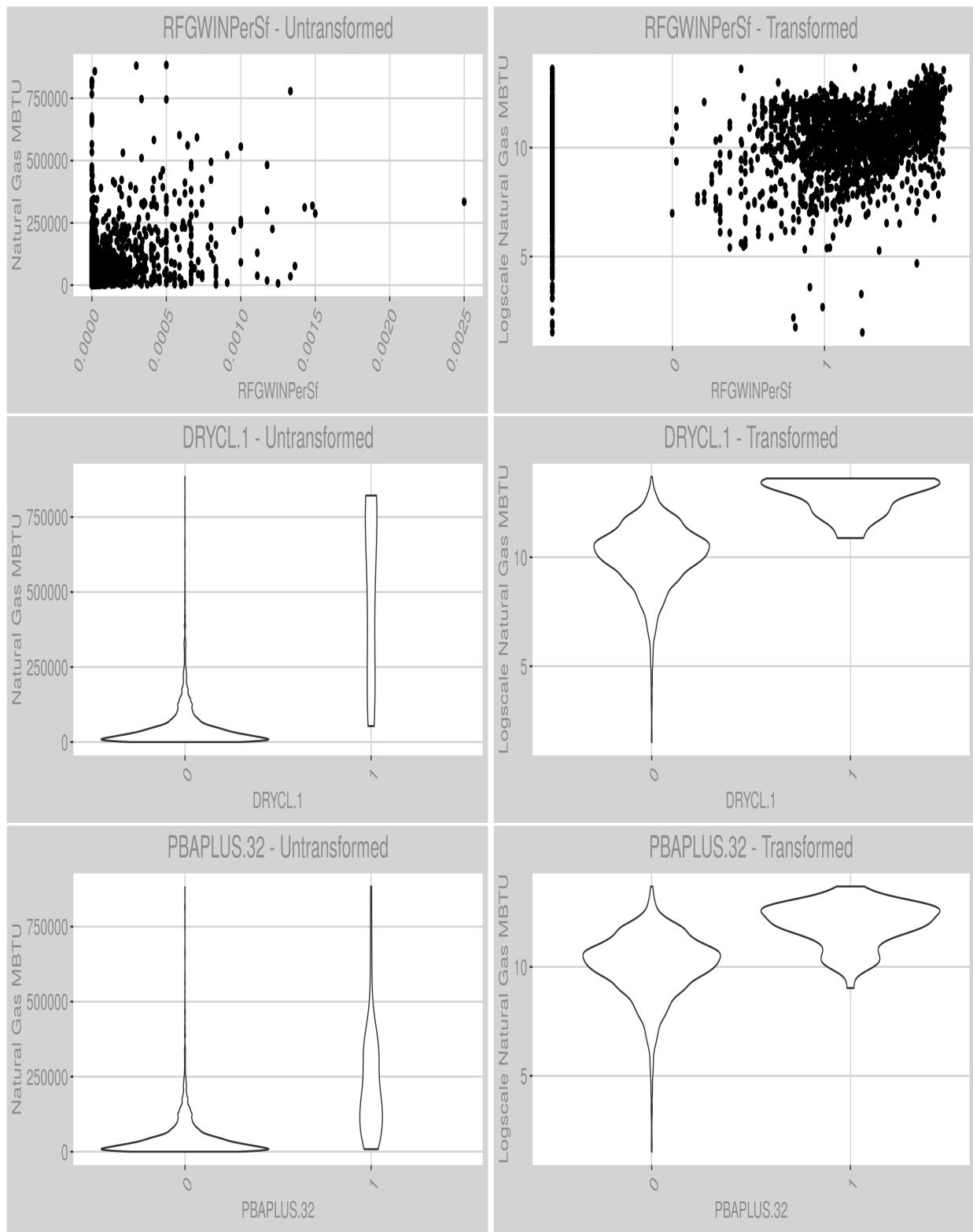
Select Variable Analysis

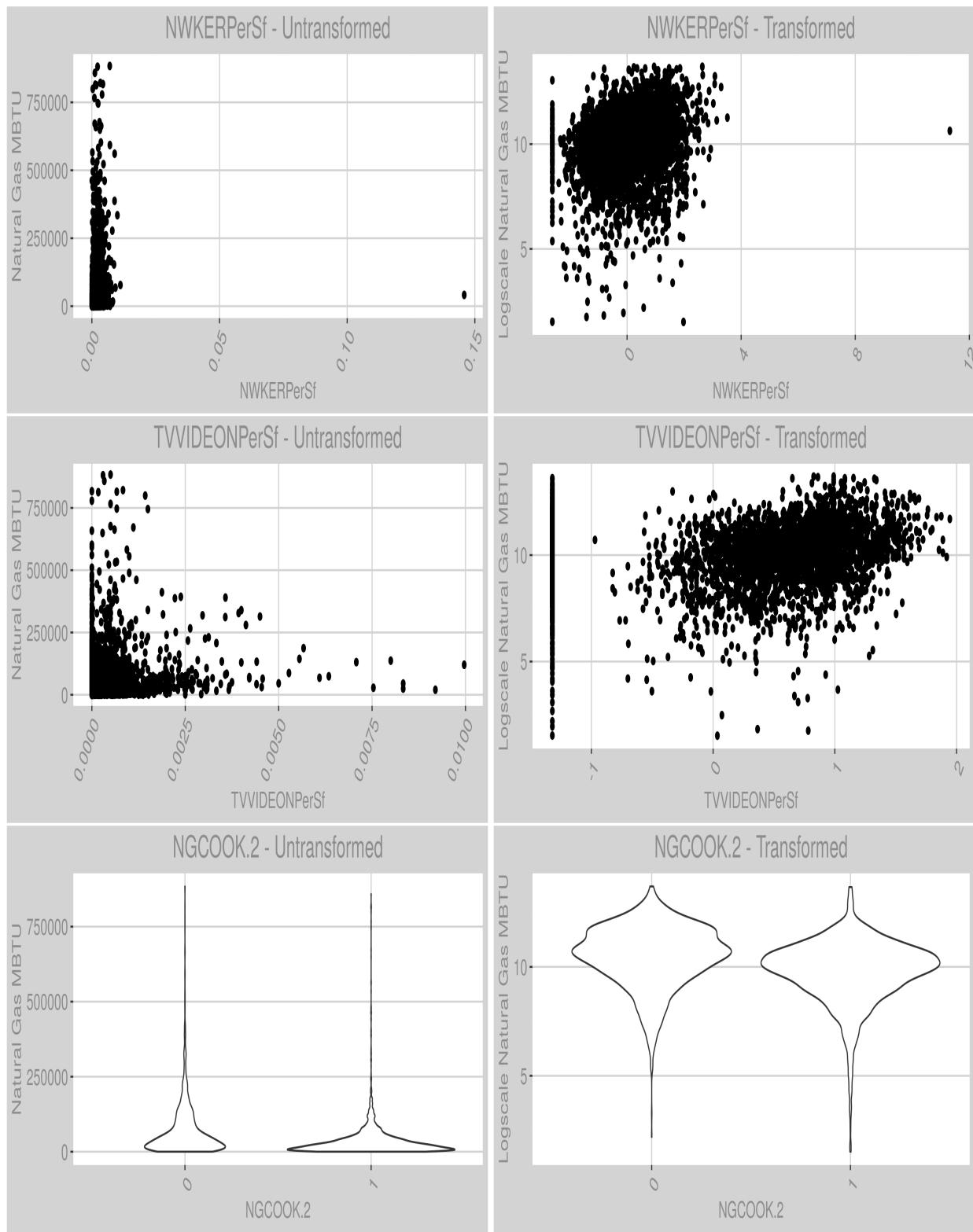
Feature Extraction Model Results

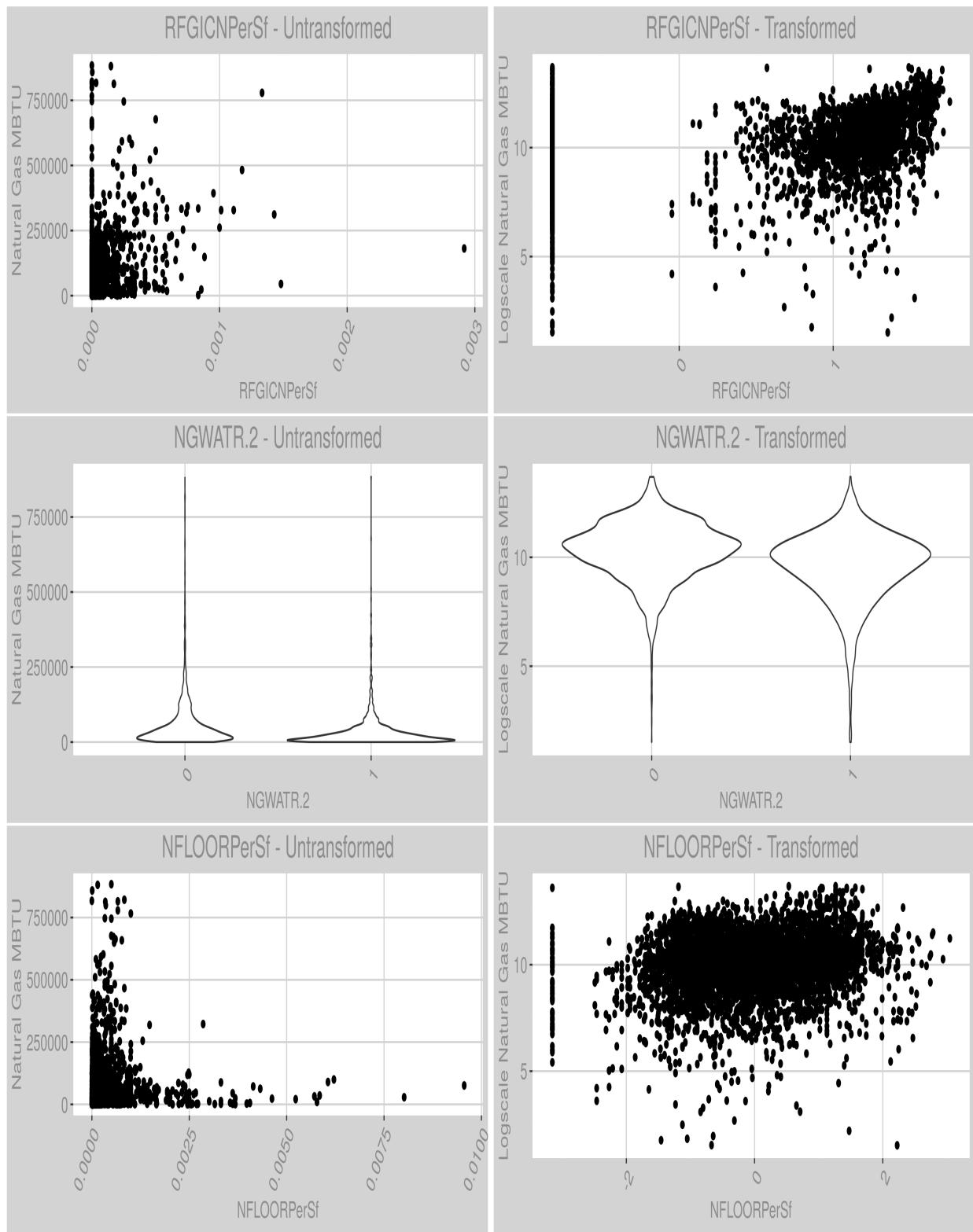
Model	RMSE	R2	MAE	MAPE
leaps	100385.86	0.2462162	53658.33	99.67084
partialLeastSquares	73075.99	0.2934536	32068.61	254.60825
neuralNetwork	69784.67	0.3336745	35642.13	1116.47039
recursiveFeatureExtraction	59212.72	0.5230241	34203.37	2148.20709
randomForest	175808.23	0.1930417	147144.46	9354.99778

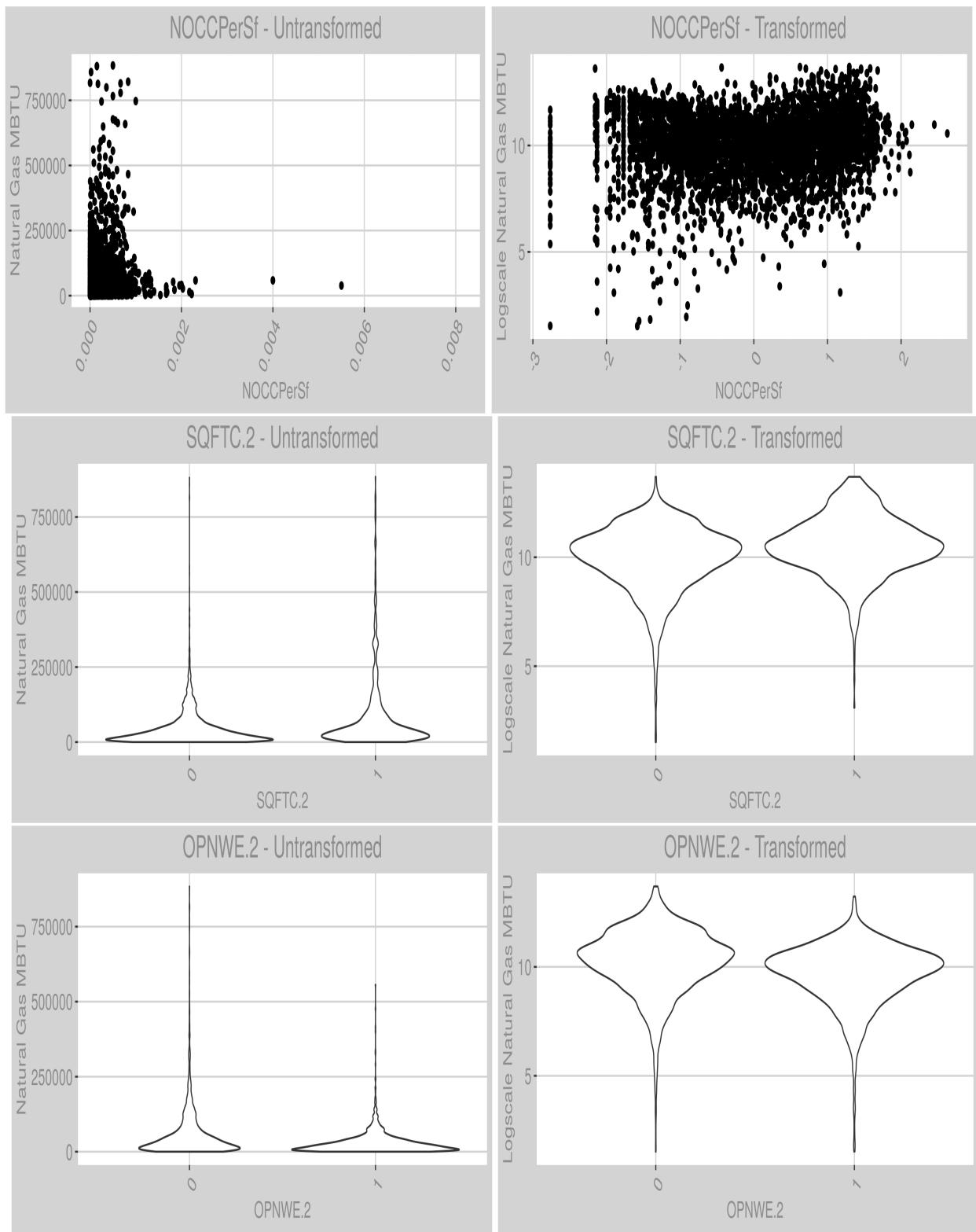


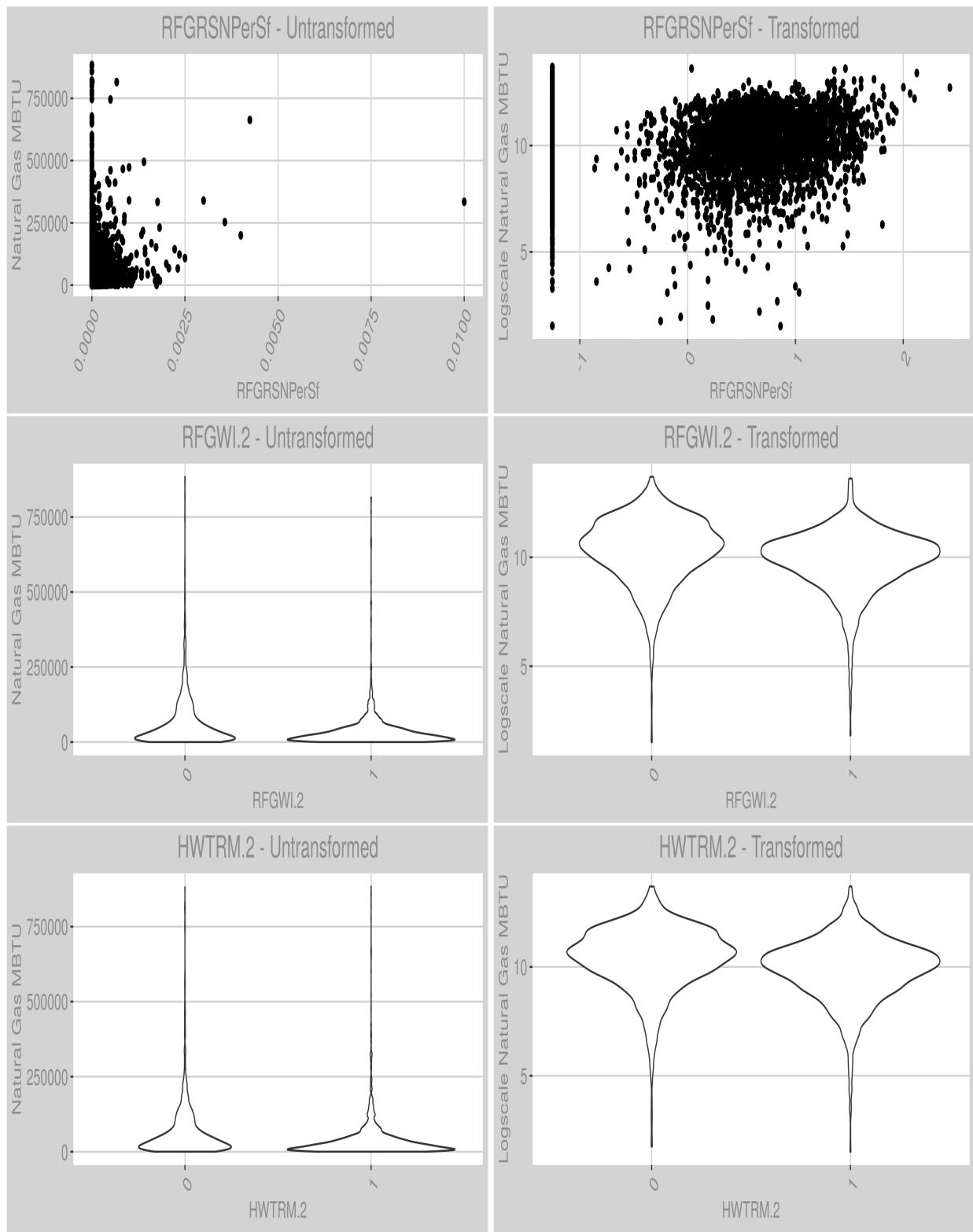


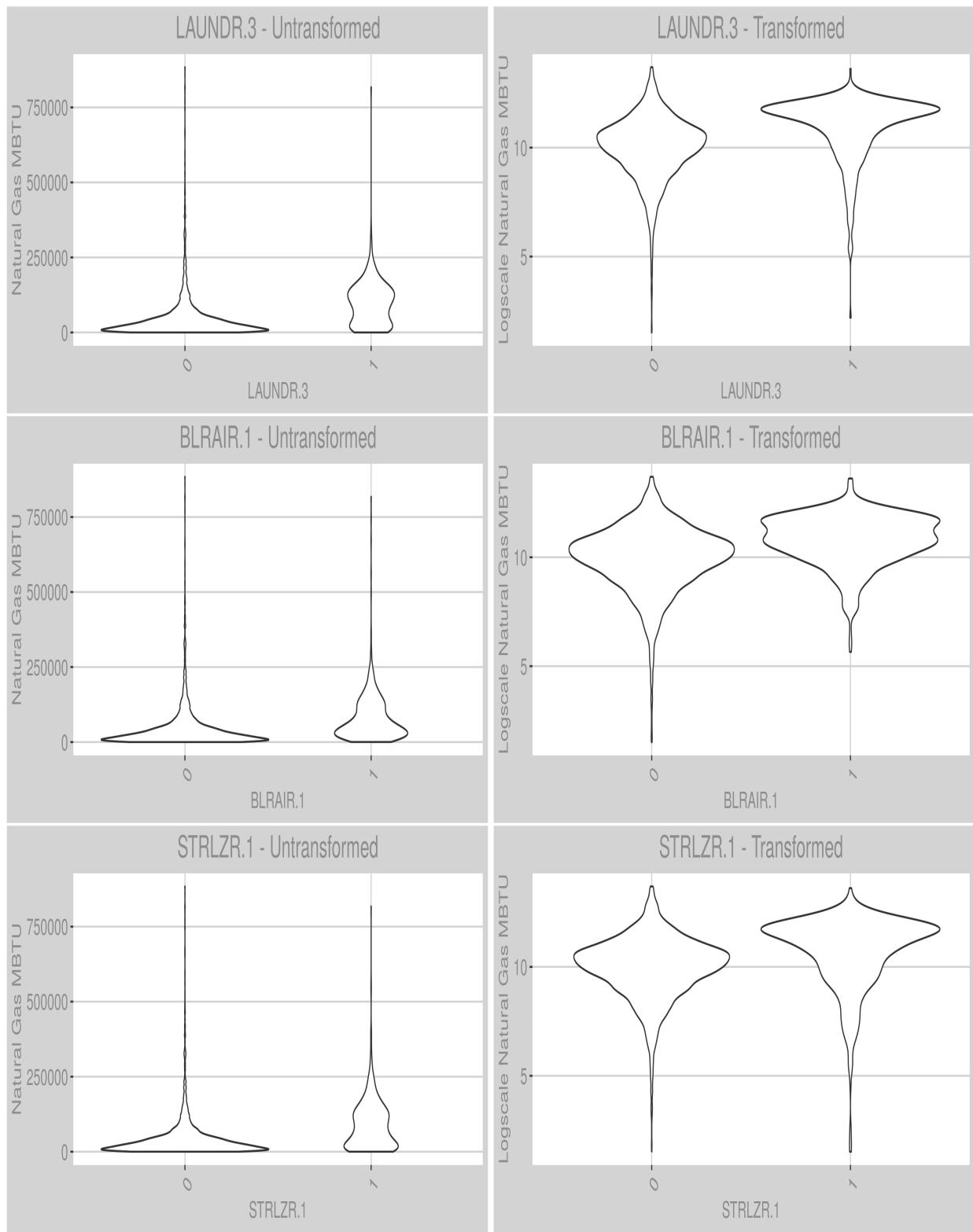






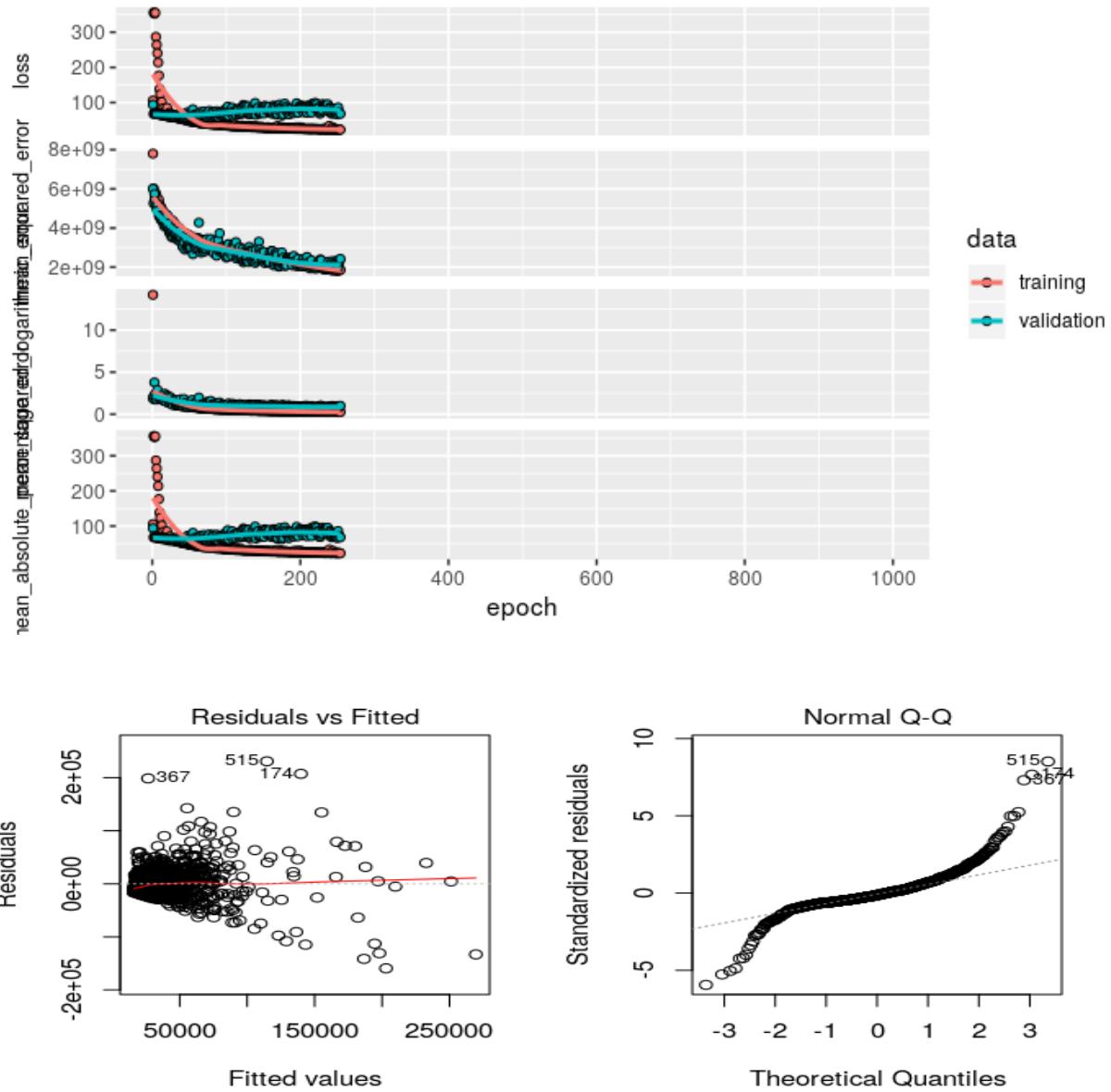


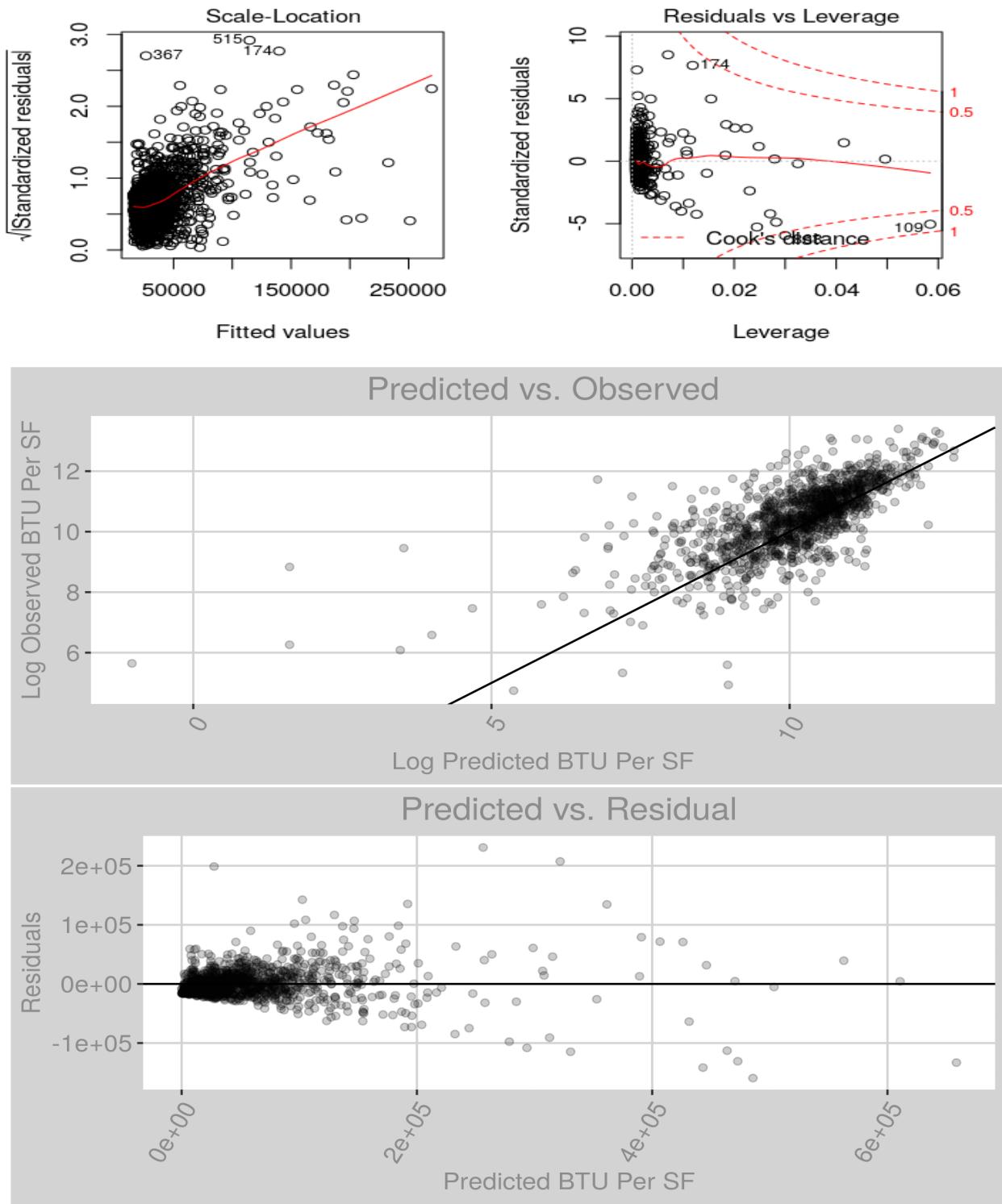


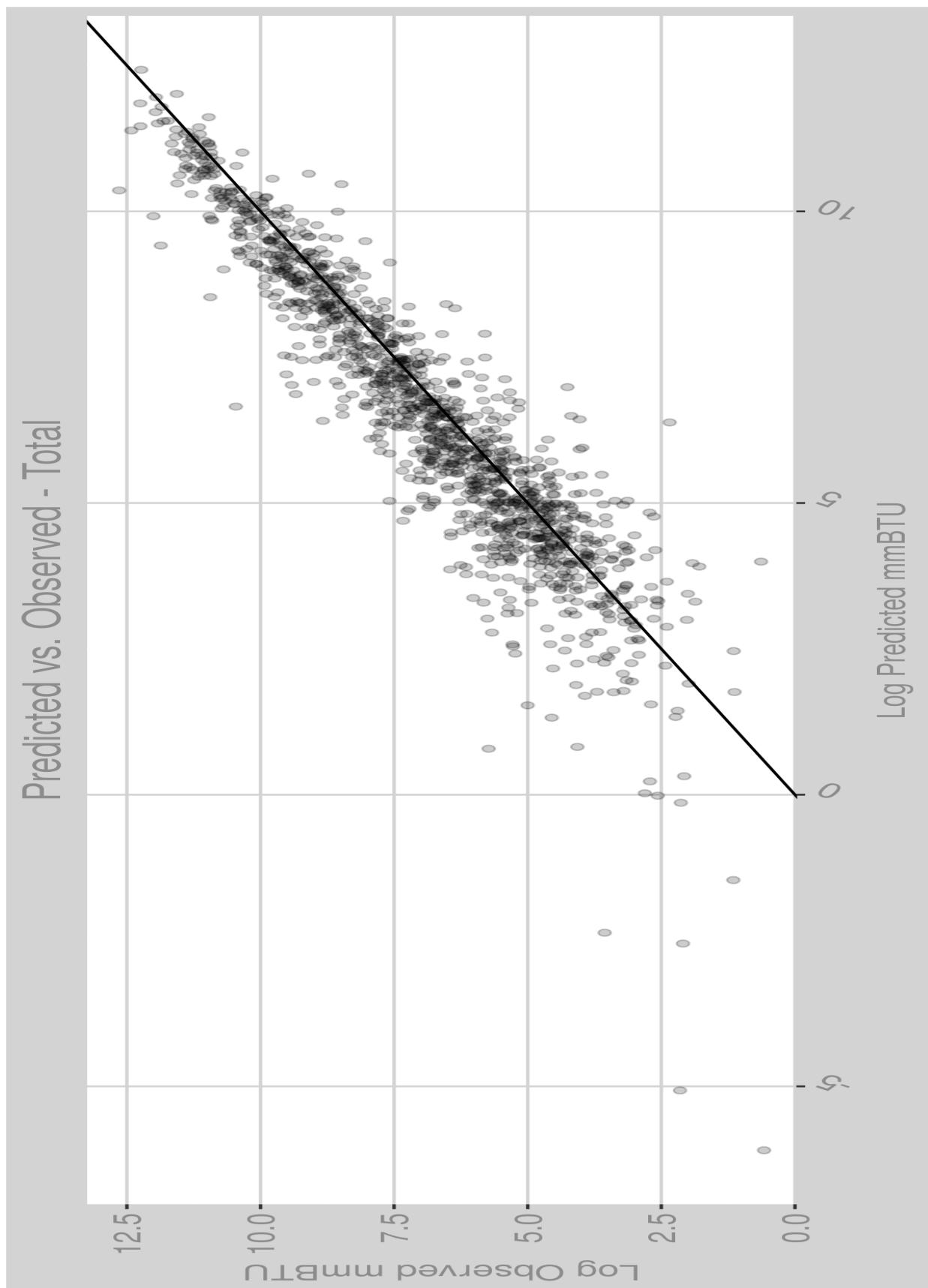


Appendix - Neural Networks

Electricity



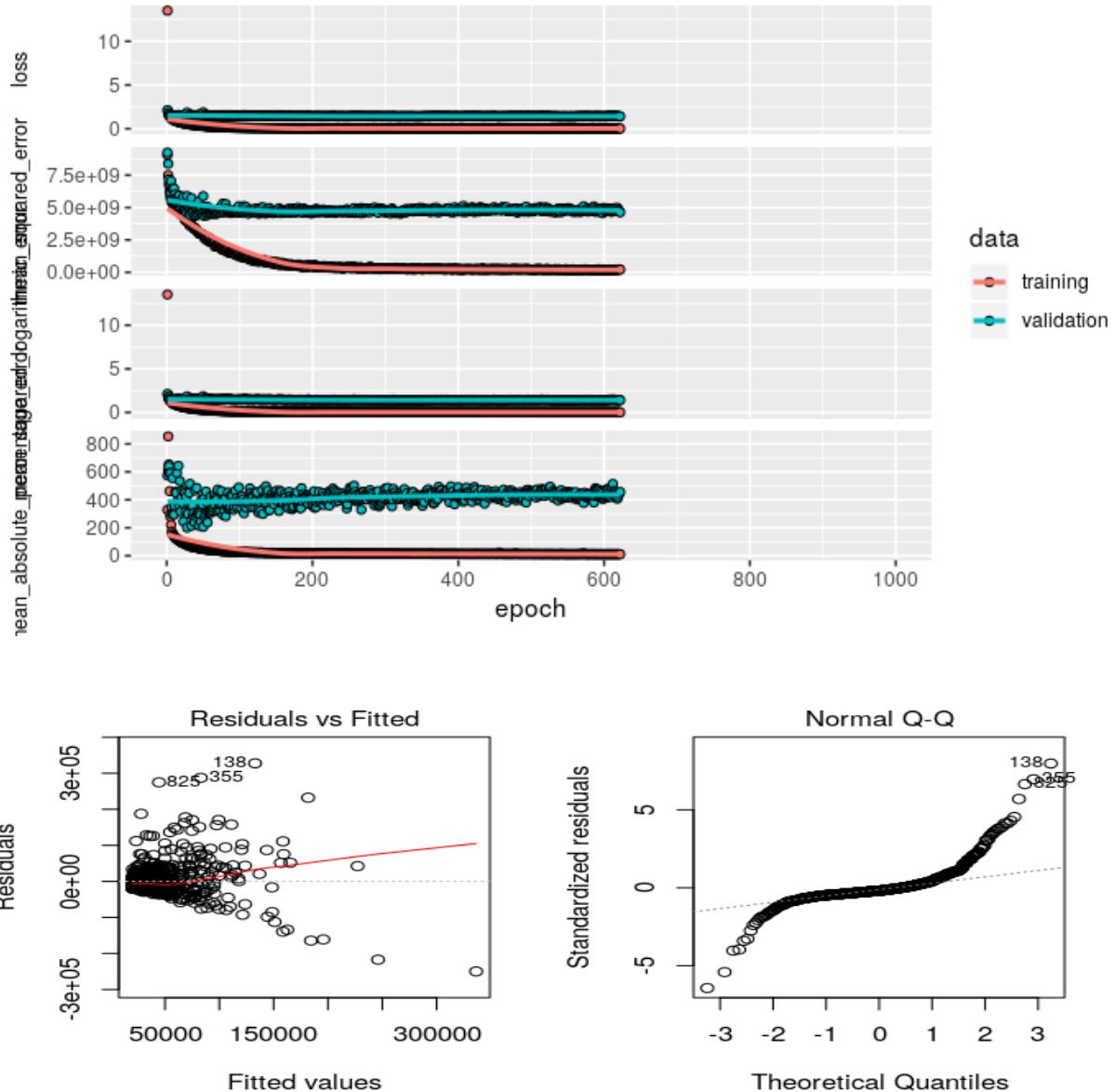


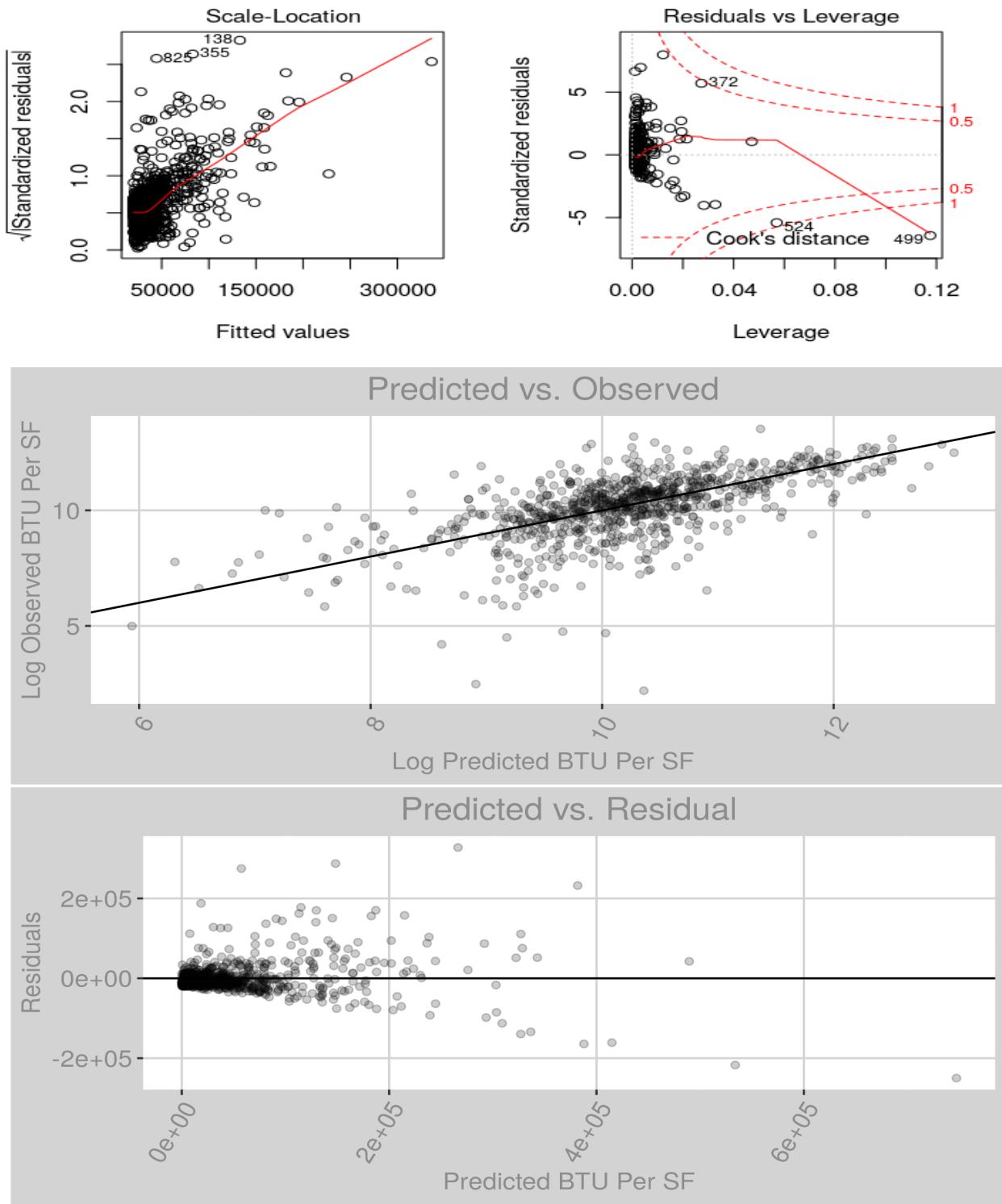


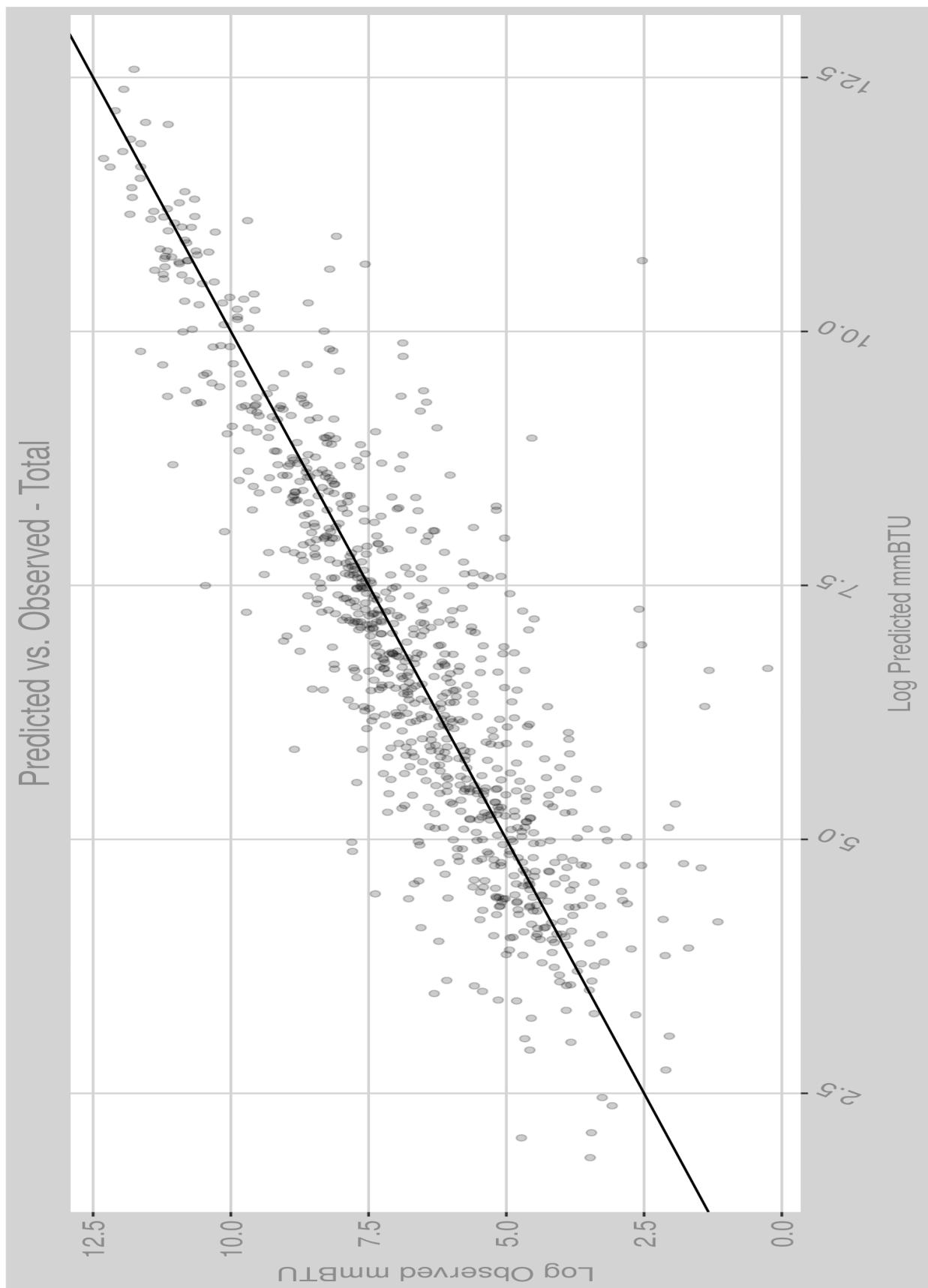
Selected Variables

RFGWIN	Number of walk-in units	TVIDEO	Number of TV or video displays	WKRSC	Weekly hours category	PKLT	Lighted parking area
NWKER	Number of employees	HWTRM	Large amounts of hot water	GLSSPC	Percent exterior glass	FAX	FAX machines
RFGWI	Walk-in refrigeration units	RFGWI	Walk-in refrigeration units	CLVOAS	Cooling ventilation: Dedicated outside air system	OPNMF	Open during week
FDSEAT	Food service seating capacity	OPNMF	Open during week	LAUNDR	Laundry onsite	NGCOOK	Natural gas used for cooking
RGSTRN	Number of cash registers	EVAPCL	Evaporative or swamp coolers	CFLRP	Percent lit by compact fluorescent	RFGCOMP	Number of compact refrigerators
PBAPLUS	More specific building activity	NWKERC	Number of employees category	RFGVEN	Refrigerated vending machines	FKHT2	Fuel oil used for secondary heating
RFGICN	Number of ice makers	ELCOOK	Electricity used for cooking	PBAPLUS	More specific building activity	COPIERN	Number of photocopiers
RFGICE	Commercial ice makers	STRLZR	Sterilizers or autoclaves	FACACT	Type of complex	FKTYPE	Specify fuel oil, diesel, or kerosene
RGSTR	Cash registers	MAINT	Regular HVAC maintenance	PCTERM	Computers used	LNHRPC	Lit off hours category
RFGCLN	Number of closed case refrigeration units	WKRSC	Weekly hours category	VACANT	Completely vacant	NWKERC	Number of employees category
RFGCL	Closed case refrigeration units	TVIDEO	TV or video displays	OTLT	Other type of bulbs	HCBED	Licensed bed capacity
COOK	Energy used for cooking	RFGRES	Full-size residential-type refrigerator	FASTFD	Fast food or small restaurant	CFLR	Compact fluorescent bulbs
NGCOOK	Natural gas used for cooking	GENUSE	Use of generated electricity	DCNTR5FC	Data center or server farm sqft category	ELEVTR	Elevators
PCTERMN	Number of computers	HEATP	Percent heated	RFTILT	Roof tilt	CHLPKG	Chiller system: Packaged unit
LNHRPC	Lit off hours category	MRI	MRI machines	TVIDEO	Number of TV or video displays	CHLAIRCL	Chiller type: Air-cooled
PBA	Principal building activity	BOOSTWT	Booster water heaters	PBAPLUS	More specific building activity	LTEXPC	Percent of exterior lighted
RFGOPN	Number of open case refrigeration units	LTNR24	Lights off during 24 hours	LINACC	Linear accelerators	RFGCOMP	Half-size or compact refrigerators
PRNTRN	Number of printers	SERVERN	Number of servers	LABEQP	Laboratory equipment	KITCHN	Small kitchen area
RFGOP	Open case refrigeration units	XRAYN	Number of X-ray machines	WHRECOV	Waste heat recovery	TRIM	High-end trimming or light-level tuning
PBA	Principal building activity	ANYEGY	Any energy used	RFGICE	Commercial ice makers	GLSSPC	Percent exterior glass
WKRSC	Weekly hours category	LEDP	Percent lit by LED	MCHEQP	Machine equipment	RFGSTO	Large cold storage areas
OPNWE	Open on weekend	RFGVNN	Number of refrigerated vending machines	MONUSE	Months in use	CHLFNCL	Chiller system: Fan coil units in rooms
LOHRPC	Lit when open category	PBAPLUS	More specific building activity	OWNTYPE	Building owner	HTVWAV	Heating ventilation: Central air handling with VAV
PBAPLUS	More specific building activity	RWSEAT	Religious worship seating capacity	RFGSTO	Large cold storage areas	NELVTR	Number of elevators
MCHEQP	Machine equipment	PBAPLUS	More specific building activity	LAUNDR	Laundry onsite	NGHT1	Natural gas used for main heating

Natural Gas







Selected Variables

FDSEAT	Food service seating capacity	FACACT	Type of complex	HCBED	Licensed bed capacity	CDD65	Cooling degree days (base 65)
RGSTRN	Number of cash registers	RGSTR	Cash registers	DHPKG	District heat system: Packaged unit	WTHTEQ	Water heating equipment
PBAPLUS	More specific building activity	PBA	Principal building activity	BLRRAD	Boiler system: Radiators	LNRPC	Lit off hours category
RFGWIN	Number of walk-in units	XRAYN	Number of X-ray machines	STRLZR	Sterilizers or autoclaves	DHFNCL	District heat system: Fan coil units in rooms
DRYCL	Dry cleaning onsite	BLRFNCL	Boiler system: Fan coil units in rooms	PBAPLUS	More specific building activity	WTHTEQ	Water heating equipment
PBAPLUS	More specific building activity	BLRDUCT	Boiler system: Duct reheat	WKHRSC	Weekly hours category	NGCOOL	Natural gas used for cooling
NWKER	Number of employees	PRNTRN	Number of printers	PCTRM	Number of computers category	LINACC	Linear accelerators
TVVIDEO	Number of TV or video displays	RFGCLN	Number of closed case refrigeration units	DHDUCT	District heat system: Duct reheat	BLRRAD	Boiler system: Radiators
NGCOOK	Natural gas used for cooking	LTNR24	Lights off during 24 hours	BLDPLT	Central plant in building	NGOTH	Natural gas for some other use
RFGICN	Number of ice makers	COPIER	Photocopiers	MCHEQP	Machine equipment	WKHRSC	Weekly hours category
NGWATR	Natural gas used for water heating	HCBED	Licensed bed capacity	NGSRC	How purchase natural gas	ELHT1	Electricity used for main heating
NFLOOR	Number of floors	BLRPKG	Boiler system: Packaged unit	DATACTR	Data center or server farm	BLRINDC	Boiler system: Induction units
NOCC	Number of businesses	HEATP	Percent heated	PCTERMN	Number of computers	RFGOPN	Number of open case refrigeration units
SQFTC	Square footage category	DHRAD	District heat system: Radiators	STDNRM	Student or public computer center	TRNGRM	Computer-based training room
OPNWE	Open on weekend	WKHRSC	Weekly hours category	BOOSTWT	Booster water heaters	PBAPLUS	More specific building activity
RFGRSN	Number of residential refrigerators	LINACC	Linear accelerators	RFGCOMP	Number of compact refrigerators	ELCOOK	Electricity used for cooking
RFGWI	Walk-in refrigeration units	BLRLOOP	Boiler system: Water loop heat pump	WBOARDS	Interactive whiteboards	RFGOP	Open case refrigeration units
HWTRM	Large amounts of hot water	ELWATR	Electricity used for water heating	PUBCLIM	Building America climate region	CUBELOC	Location of open plan
LAUNDR	Laundry onsite	CUBELOC	Location of open plan	RFGRES	Full-size residential-type refrigerator	GLSSPC	Percent exterior glass
BLRAIR	Boiler system: Central air handler	PBAPLUS	More specific building activity	DHFNCL	District heat system: Fan coil units in rooms	FDPREP	Commercial or large kitchen
STRLZR	Sterilizers or autoclaves	BOOSTWT	Booster water heaters	SERVERN	Number of servers	STDNRM	Student or public computer center
STCOOK	District steam used for cooking	RFGICE	Commercial ice makers	LABEQP	Laboratory equipment	DHDUCT	District heat system: Duct reheat
PBA	Principal building activity	LAPTPN	Number of laptops	PBAPLUS	More specific building activity	LAPTPC	Number of laptops category
BOOSTWT	Booster water heaters	TVVIDEO	Number of TV or video displays	CHLDUCT	Chiller system: Duct reheat	CHLFNCL	Chiller system: Fan coil units in rooms
STWATR	District steam used for water heating	LABEQP	Laboratory equipment	LNRPC	Lit off hours category	CUBEC	Percent open plan