

Problem Statement

The Energy Information Administration (EIA) has a plethora of hourly electricity demand data for different regions in the lower 48 states. Energy companies rely on accurate forecasts to predict upcoming demand. The goal of this project is to train a machine learning model on weather/electricity data to generate a more nuanced energy-demand forecast. The client for this type of project would be any energy company looking to better understand how the demand for their electricity varies hour to hour. An improved forecast helps energy companies take next steps to fully capitalize on and perhaps better brace for large spikes in electricity demand. Additionally an improved predictive model will shed insight on the features that most heavily affect electricity demand.

Data Cleaning and Wrangling

My project consists of primarily two data sets: (1) electricity data from the EIA, i.e., electricity demand, and (2) hourly, local climatological data (LCD) [downloaded from the National Oceanic and Atmospheric Administration \(NOAA\) website](#). To limit the scope of the project, I retrieved both data sets from the city of Los Angeles and the city of Seattle (specifically, Los Angeles Department of Water and Power data from EIA and the Los Angeles Downtown LCD data and Seattle City and Light from EIA and Seattle Tacoma International Airport LCD data). Electricity data were retrieved using EIA's API and then unpacked into a pandas `DataFrame`. Since LCD data are not available via NOAA's API, I manually downloaded LCD data from the NOAA website as a CSV file which I imported to a pandas `DataFrame`. Electricity data contain hourly entries from July 2015 to present. To align the data correctly, I downloaded the LCD data from July 2015 to September 2018 and later cut the electricity data to fit the date range.

The electricity data required some cleaning--there were very few null values in the set, however there were a very small number of outliers where data was either entered in as zero or a large negative number. Removing outliers cut only $\sim .01\%$ of the data. LCD data on the other hand required more cleansing. Throughout the cleaning of the LCD data, I frequently referred to the [LCD documentation](#) for guidance on how to treat the features. Firstly, all features (except daily cooling/heating degrees) that did not record hourly entries, i.e., monthly and daily records, were dropped. I kept hourly heating and cooling degrees because they are very relevant to energy consumption. I used `bfill` to fill the hourly entries of a specific day with that day's heating/cooling degrees. Additionally I added hourly heating and cooling degrees to get higher granularity on a metric which is relevant to energy consumption. The hourly heating/cooling degree days are the number of degrees below/above 65 degrees Fahrenheit (wet bulb temperature) (negative values are set to zero) respectively and represents the amounting heating/cooling necessary for that temperature. I dropped a number of hourly columns with excessive null entries compared to the size of the data set and those with low predictive power. I dropped hourly pressure tendency and change because we of excess null values and because measures of pressure were already present, hourly wind direction and gust speed for the same reasons, and hourly present weather type because of excess null values and the dispersity of possible values, indicating low predictive power.

One of the main challenges in cleaning the LCD data was that there were in some cases multiple entries for the same hour. I wanted to have just one entry per hour such that I could eventually align LCD data with the hourly entries in the electricity data. I wrote a function that goes through the weather data and for each instance where there are multiple hourly entries, I keep the hourly entry closest to the hour and drop the remaining rows. For instance, if there are entries at 11:05, 11:36, and 11:56, I kept the entry corresponding to 11:05 and dropped the

other rows. I performed the cleaning this way because the data closest to the hour is most representative for that hour. I then renamed the date such that the minute column is set to 00 to once again align with the electricity data. Either way, the values for multiple, per-hour entries are very similar, so the choice of which entry to keep doesn't make a huge difference.

The hourly sky condition feature required additional cleaning. The hourly sky condition feature contains information about each cloud layer (up to three) using six different categories to describe the cloud coverage. As stated in the documentation, the full state of the sky can be best determined by the category of the last (i.e., highest) layer. With this in mind, I replaced the sky condition feature with the condition of the upper most layer to make the feature consistent. This feature also included some information about the cloud layer height which I excluded because these data were only present for a small number of entries. There were also a number of features of mixed float and string types. After looking at their unique values, I saw that some values were string and floats arbitrarily. I simply converted strings to floats to make the features consistent. Finally, I convert our categorical value to numeric using Pandas' `get_dummies` function to be used for analyzing correlations among and performing learning.

Next we deal with null values and outliers. To determine whether to fill null values with median of `ffill`, I plotted histograms, violin plots, and printed stats for each feature. These plots can be found [here](#) (for LA) and [here](#) (for Seattle). Features where the median was close to the mean suggests few outliers and that the median is an appropriate statistic to fill null entries. Conversely, null values in features with outliers present were filled using `ffill`, assuming that previous values have some predictive value for subsequent values since we are dealing with time-stream data. For outliers, because there was not a single feature where the presence of outliers significantly shifted the median from the mean and because the data is such high granularity, outliers were kept without further cleaning. Lastly, we cut both data sets to fit the

same date range as mentioned above, and combine the electricity and weather data into a single `DataFrame` on date index. Tables of summary statistics for both Seattle and LA can be seen in **Figure 1**.

To obtain more training data, I performed the same analysis described above with weather and electricity data from Seattle. With both data sets (LA and Seattle), we are left with ~54K data points from July 2015 to September 2018 to perform statistical analysis and predictive modeling. The code for this process can be found [here](#).

	mean	median	std
demand	3317.094400	3191.00	785.756576
hourlyrelativehumidity	62.482905	66.00	20.829641
hourlydewpointtempf	51.144188	54.00	11.886757
hourlydrybulbtempf	66.454703	66.00	9.638729
hourlywetbulbtempf	58.249122	59.00	7.749118
hourlyheatingdegrees	7.371355	6.00	6.932305
dailycoolingdegreedays	4.866420	2.00	5.595377
dailyheatingdegreedays	1.971355	0.00	3.554354
hourlywindspeed	1.623656	0.00	2.415391
hourlyvisibility	9.220403	10.00	1.796501
hourlycoolingdegrees	0.651968	0.00	1.617127
hourlyskyconditions_CLR	0.709222	1.00	0.454130
hourlyskyconditions_OVC	0.179856	0.00	0.384074
hourlyskyconditions_BKN	0.051155	0.00	0.220318
hourlyskyconditions_SCT	0.031196	0.00	0.173850
hourlyskyconditions_FEW	0.026649	0.00	0.161060
hourlyaltimetersetting	29.967976	29.96	0.110782
hourlystationpressure	29.772348	29.76	0.108847
hourlysealevelpressure	29.964036	29.95	0.106616
hourlyprecip	0.000552	0.00	0.007481

	mean	median	std
demand	1110.918797	1108.00	202.371059
hourlyrelativehumidity	71.809753	75.00	17.561429
hourlydrybulbtempf	54.625480	54.00	12.272807
dailyheatingdegreedays	11.074687	10.00	9.714834
hourlywetbulbtempf	49.385309	50.00	9.047850
hourlyheatingdegrees	15.641228	15.00	8.983962
hourlydewpointtempf	44.533922	46.00	8.816830
hourlywindspeed	7.910760	7.00	4.465327
dailycoolingdegreedays	1.271269	0.00	3.071634
hourlyvisibility	9.466663	10.00	1.814851
hourlyskyconditions_OVC	0.477192	0.00	0.499489
hourlyskyconditions_BKN	0.240786	0.00	0.427569
hourlycoolingdegrees	0.040656	0.00	0.330297
hourlyskyconditions_CLR	0.097495	0.00	0.296636
hourlyskyconditions_SCT	0.092282	0.00	0.289428
hourlyskyconditions_FEW	0.089132	0.00	0.284939
hourlystationpressure	29.564245	29.58	0.206405
hourlyaltimetersetting	30.031201	30.04	0.191500
hourlysealevelpressure	30.057155	30.06	0.189585
hourlyprecip	0.002953	0.00	0.013927

Figure 1. Summary statistics for all the features in the data set for both LA (top) and Seattle (bottom). As discussed, since the median is not too far away from the mean for almost all of these features, filling null values with either the median of `fillna` is an appropriate procedure.

Exploratory Data Analysis

Here we perform some initial exploratory data analysis (EDA) for both the Seattle and Los Angeles weather/electricity data sets. One of the first questions we ask is what is the relationship between the independent variables (the weather features) and the dependent variable (electricity demand measured in MWh). Pandas has a nice method (the `.corr()` method) for finding the Pearson correlation coefficients between all the different variables. **Figure 2** shows the sorted Pearson correlation coefficients for both Seattle and Los Angeles. The results from the Pearson correlation coefficients between Seattle and Los Angeles are interesting. Namely that cooling degree days (CDD) are a significant, positive correlation and heating degree days (HDD) are a significant, negative correlation for LA, whereas the exact opposite is true for Seattle. **Figure 3** shows how the electricity demand varies in time for both LA and Seattle and sheds light on why we observe this behavior. Seattle's electricity demand spikes in the winter months, indicating that the majority of power is used for heating, whereas LA's electricity demand spikes in the summer months, indicating that the majority of power is used for cooling. This is consistent with the computed Pearson correlation coefficients, but a more thorough multivariate regression would be informative.

DEMAND CORRELATIONS (PEARSON) FOR LA		DEMAND CORRELATIONS (PEARSON) FOR SEATTLE	
dailycoolingdegreedays	0.572275	hourlyheatingdegrees	0.582695
hourlydewpointtempf	0.383226	dailyheatingdegreedays	0.574442
hourlyrelativehumidity	0.365116	hourlyrelativehumidity	0.269787
hourlywetbulbtempf	0.302208	hourlyskyconditions_OVC	0.125060
hourlycoolingdegrees	0.192912	hourlyprecip	0.061526
hourlydrybulbtempf	0.044278	hourlyskyconditions_CLR	0.040436
hourlyskyconditions_CLR	0.034075	hourlywindspeed	0.030342
hourlyvisibility	0.009670	hourlysealevelpressure	0.005554
hourlyskyconditions_FEW	-0.011283	hourlyaltimetersetting	-0.027498
hourlyskyconditions_BKN	-0.013311	hourlyskyconditions_SCT	-0.027725
hourlyskyconditions_OVC	-0.014977	hourlystationpressure	-0.034864
hourlyprecip	-0.022645	hourlyvisibility	-0.068125
hourlyskyconditions_SCT	-0.029785	hourlycoolingdegrees	-0.079621
dailyheatingdegreedays	-0.221475	hourlyskyconditions_FEW	-0.091991
hourlywindspeed	-0.232047	hourlyskyconditions_BKN	-0.097800
hourlystationpressure	-0.265702	dailycoolingdegreedays	-0.115990
hourlysealevelpressure	-0.266134	hourlydewpointtempf	-0.519638
hourlyaltimetersetting	-0.267439	hourlydrybulbtempf	-0.552038
hourlyheatingdegrees	-0.290998	hourlywetbulbtempf	-0.580742

Figure 2. Pearson correlation coefficients for both LA (left) and Seattle (right). As discussed, CDD are positive correlations for LA, while they are negative in Seattle, and vice versa for HDD.

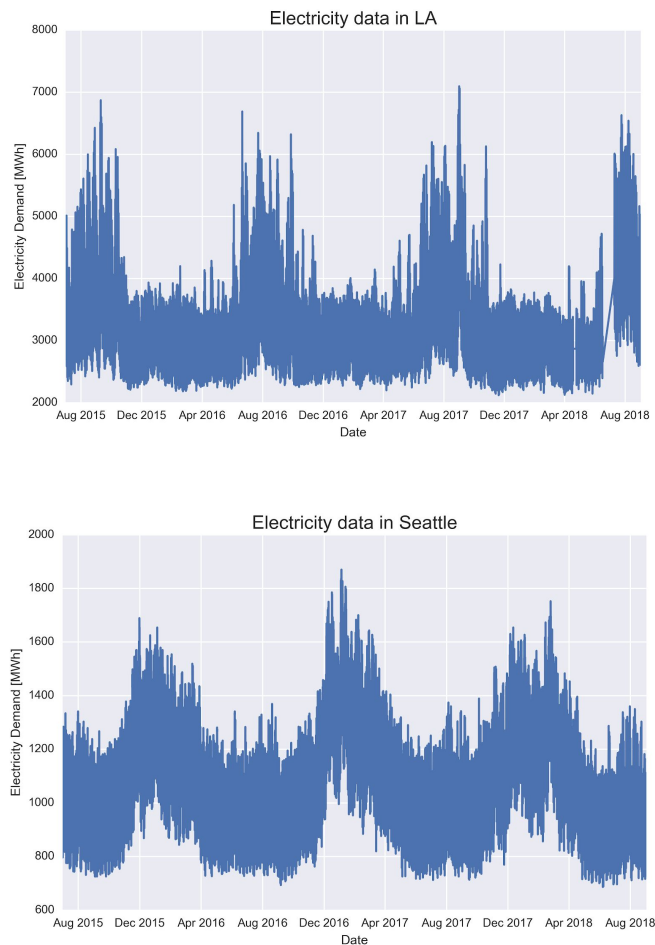


Figure 3. Electricity demand versus time for both LA (top) and Seattle (bottom). Demand peaks in the winter in Seattle, whereas it peaks in the summer in LA.

Additionally, **Figure 4** shows computed r^2 values for both the Seattle and Los Angeles data sets. Here we can see the relative power of each of the features for both data sets. Once again, HDD is a significant feature for Seattle while CDD is a significant feature for LA.

DEMAND CORRELATIONS (r^2) FOR LA			DEMAND CORRELATIONS (r^2) FOR SEATTLE		
	col	r^2		col	r^2
13	dailycoolingdegreedays	0.327499	2	hourlyheatingdegrees	0.339533
11	hourlydewpointtempf	0.146862	8	hourlywetbulbtempf	0.337261
18	hourlyrelativehumidity	0.133310	14	dailyheatingdegreedays	0.329984
8	hourlywetbulbtempf	0.091330	6	hourlydrybulbtempf	0.304746
2	hourlyheatingdegrees	0.084680	11	hourlydewpointtempf	0.270023
0	hourlyaltimetersetting	0.071524	18	hourlyrelativehumidity	0.072785
5	hourlysealevelpressure	0.070827	9	hourlyskyconditions_OVC	0.015640
17	hourlystationpressure	0.070597	13	dailycoolingdegreedays	0.013454
15	hourlywindspeed	0.053846	1	hourlyskyconditions_BKN	0.009565
14	dailyheatingdegreedays	0.049051	7	hourlyskyconditions_FEW	0.008462
10	hourlycoolingdegrees	0.037215	10	hourlycoolingdegrees	0.006340
6	hourlydrybulbtempf	0.001961	3	hourlyvisibility	0.004641
16	hourlyskyconditions_CLR	0.001161	12	hourlyprecip	0.003785
4	hourlyskyconditions_SCT	0.000887	16	hourlyskyconditions_CLR	0.001635
12	hourlyprecip	0.000513	17	hourlystationpressure	0.001215
9	hourlyskyconditions_OVC	0.000224	15	hourlywindspeed	0.000921
1	hourlyskyconditions_BKN	0.000177	4	hourlyskyconditions_SCT	0.000769
7	hourlyskyconditions_FEW	0.000127	0	hourlyaltimetersetting	0.000756
3	hourlyvisibility	0.000094	5	hourlysealevelpressure	0.000031

Figure 4. r^2 values for both LA (left) and Seattle (right).

In our data set, we have three features for pressure (hourly sea level, station pressure, and hourly altimeter setting) and three for temperature (hourly dew point, wet, and dry bulb temperature). Having multiple features for essentially the same quantity raises concerns over collinearity. **Figure 5** shows a scatter matrix for the different pressure features for both LA and Seattle. As predicted, these features show high collinearity and as a result we keep the feature with the highest r^2 as referenced in **Figure 4**. For LA it's altimeter setting, whereas for Seattle it's station pressure. Since the all the pressure features have similar values in LA, we choose the highest for Seattle, station pressure, and drop the rest of the pressure columns.

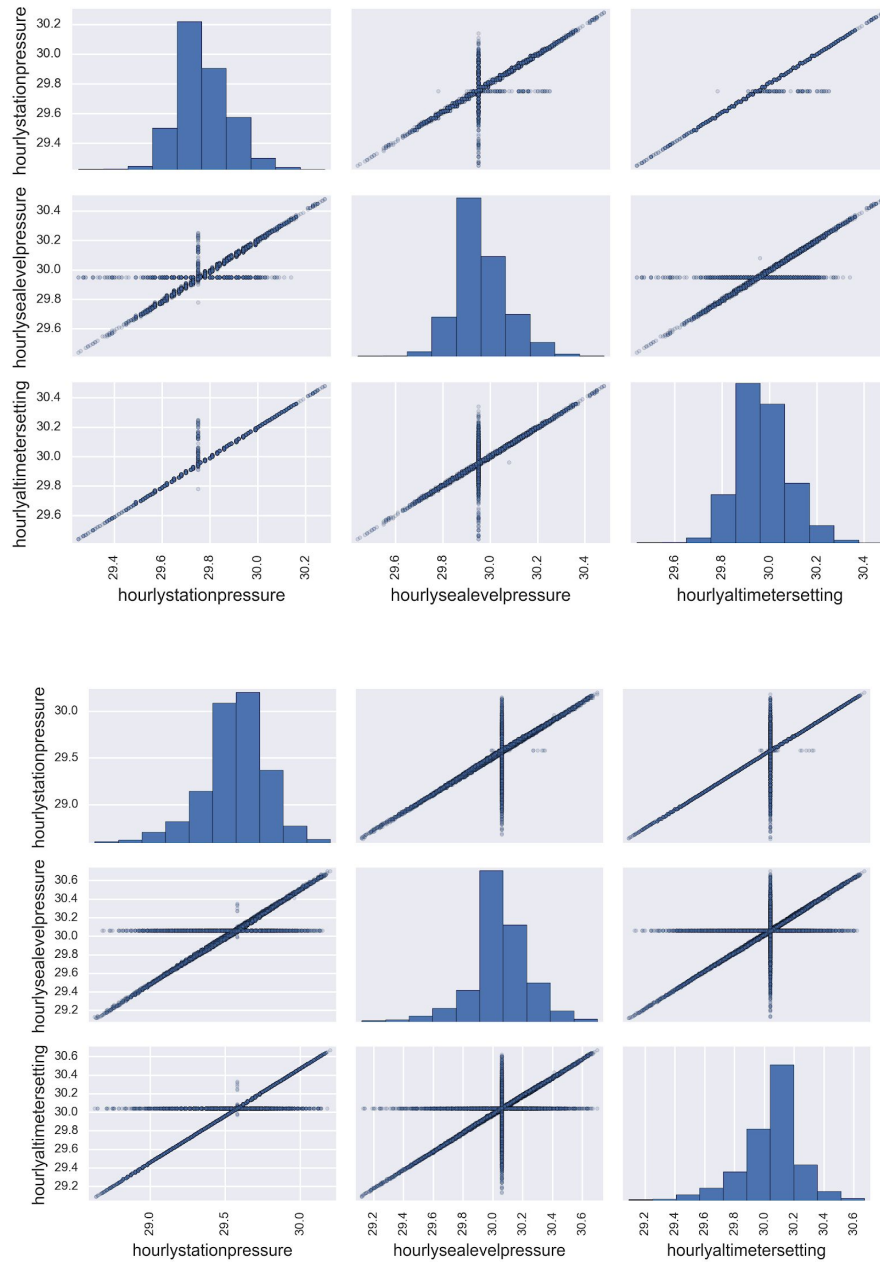


Figure 5. Scatter matrices for pressure features in both LA (top) and Seattle (bottom).

Collinearity is obvious in the scatter plots and the histograms also show very similar values.

Figure 6 repeats the above analysis but with the three temperature features. Collinearity is not as obvious but still strong. Since we derive hourly CDD and HDD from wet bulb

temperature, we drop that column. Dry bulb temp has a low r^2 value for LA, so we also drop that column, leaving us with dew point temperature as the main temperature feature.

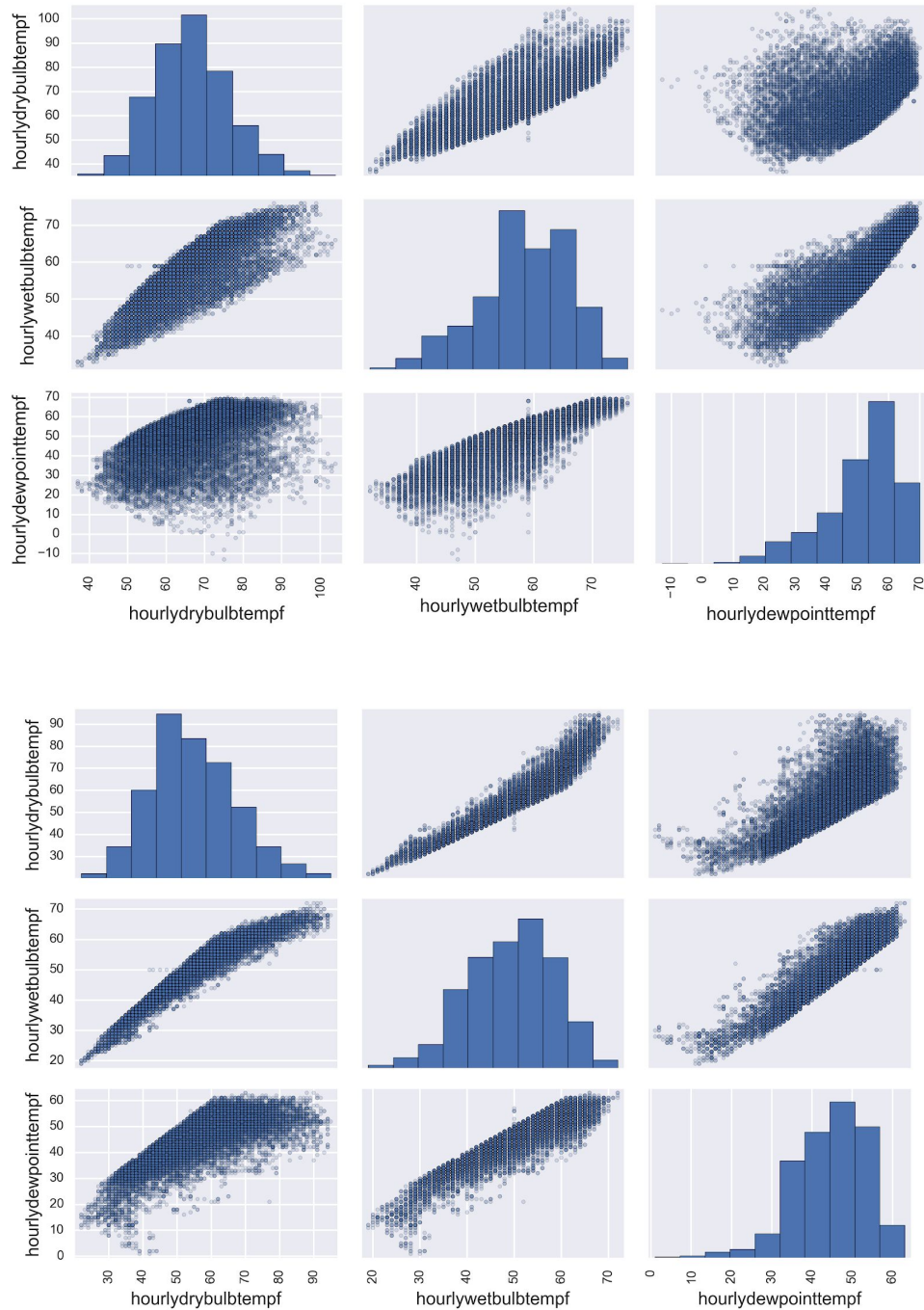


Figure 6. Scatter matrices for temperature features in both LA (top) and Seattle (bottom).

Collinearity is obvious in the scatter plots and the histograms also show very similar values.

Since people behave different in the daytime versus the nighttime regardless of how hot or cold it is that day, an 'hourlytimeofday' column was added, representing if the current time is day or night (zero between 6AM and 6PM, one otherwise). The temperature data is important for identifying heating and cooling peaks, but the regression can start leaning on the temperature as a proxy for daytime. This feature increased our multivariate regression r^2 considerably (from 0.686 to 0.701 for LA and from 0.419 to 0.587 for Seattle), signifying its importance.

Finally we perform a multiple OLS regression on all the features versus electricity demand. **Figure 6** shows the results for both Seattle and LA. High p-value features confirm our intuitions--that heating/cooling is not important for LA/Seattle respectively--LA doesn't use much heating and Seattle much cooling. Sky condition, i.e., the cloud coverage, and wind speed are also not important features for predicting electricity demand. These less-useful features are indicated by high p-values and any feature with a p-value greater than 0.1 was dropped from the data set.

-----LOS ANGELES-----

OLS Regression Results

=====						
Dep. Variable:	demand	R-squared:	0.701			
Model:	OLS	Adj. R-squared:	0.701			
Method:	Least Squares	F-statistic:	3970.			
Date:	Thu, 15 Nov 2018	Prob (F-statistic):	0.00			
Time:	12:14:49	Log-Likelihood:	-2.0240e+05			
No. Observations:	27055	AIC:	4.048e+05			
Df Residuals:	27038	BIC:	4.050e+05			
Df Model:	16					
Covariance Type:	nonrobust					
=====						
	coef	std err	t	P> t	[0.025	0.975]

const	4205.7364	914.386	4.600	0.000	2413.493	5997.980
hourlyvisibility	29.4799	1.741	16.935	0.000	26.068	32.892
hourlydewpointtempf	-22.0628	1.148	-19.217	0.000	-24.313	-19.812
hourlyrelativehumidity	20.3704	0.421	48.439	0.000	19.546	21.195
hourlywindspeed	-1.8849	1.196	-1.576	0.115	-4.228	0.459
hourlystationpressure	-73.6075	30.451	-2.417	0.016	-133.293	-13.922
hourlyprecip	-1034.1409	367.083	-2.817	0.005	-1753.643	-314.638
dailyheatingdegreedays	5.4324	1.098	4.949	0.000	3.281	7.584
dailycoolingdegreedays	113.6195	0.857	132.630	0.000	111.940	115.299
hourlycoolingdegrees	-32.0139	2.668	-12.001	0.000	-37.243	-26.785
hourlyheatingdegrees	-0.1662	1.452	-0.114	0.909	-3.013	2.680
hourlytimeofday	514.3887	7.579	67.872	0.000	499.534	529.244
hourlyskyconditions_BKN	73.7468	62.313	1.183	0.237	-48.389	195.883
hourlyskyconditions_CLR	127.3497	61.472	2.072	0.038	6.861	247.838
hourlyskyconditions_FEW	85.4083	63.257	1.350	0.177	-38.579	209.396
hourlyskyconditions_OVC	82.5619	61.228	1.348	0.178	-37.448	202.572
hourlyskyconditions_SCT	56.9317	62.880	0.905	0.365	-66.316	180.179

-----SEATTLE-----						
OLS Regression Results						
Dep. Variable:	demand	R-squared:		0.587		
Model:	OLS	Adj. R-squared:		0.587		
Method:	Least Squares	F-statistic:		2457.		
Date:	Thu, 15 Nov 2018	Prob (F-statistic):		0.00		
Time:	12:14:49	Log-Likelihood:		-1.7364e+05		
No. Observations:	27622	AIC:		3.473e+05		
Df Residuals:	27605	BIC:		3.475e+05		
Df Model:	16					
Covariance Type:	nonrobust					
	coef	std err	t	P> t	[0.025	0.975]
const	2305.1359	128.237	17.976	0.000	2053.785	2556.487
hourlyvisibility	-0.2699	0.510	-0.529	0.597	-1.270	0.731
hourlydewpointtempf	-7.4293	0.852	-8.719	0.000	-9.099	-5.759
hourlyrelativehumidity	0.8624	0.199	4.328	0.000	0.472	1.253
hourlywindspeed	-0.1924	0.186	-1.035	0.301	-0.557	0.172
hourlystationpressure	-35.3585	4.116	-8.590	0.000	-43.427	-27.290
hourlyprecip	110.8255	63.505	1.745	0.081	-13.647	235.298
dailyheatingdegreedays	14.5143	0.252	57.497	0.000	14.019	15.009
dailycoolingdegreedays	11.8944	0.353	33.734	0.000	11.203	12.586
hourlycoolingdegrees	-2.9932	2.807	-1.066	0.286	-8.495	2.509
hourlyheatingdegrees	-7.9634	0.923	-8.624	0.000	-9.773	-6.154
hourlytimeofday	196.9046	1.884	104.498	0.000	193.211	200.598
hourlyskyconditions_BKN	-23.8228	14.893	-1.600	0.110	-53.014	5.369
hourlyskyconditions_CLR	-9.0748	15.075	-0.602	0.547	-38.622	20.473
hourlyskyconditions_FEW	-16.2205	15.092	-1.075	0.282	-45.801	13.360
hourlyskyconditions_OVC	-18.8454	14.798	-1.273	0.203	-47.851	10.160
hourlyskyconditions_SCT	-5.7701	15.046	-0.384	0.701	-35.260	23.720

Figure 7. Multivariate OLS regression for all the features + constant. Shown are a list of coefficients with errors, t-statistics, confidence intervals.