

Energy Consumption Data Set

Agenda

1. Visualize Energy Consumption:
 - a. Daily, Weekly, Select Time Periods, Aggregate Submeter Data
2. Time Series Visualizations and Forecasts
 - a. Mondays at 8:00 PM Visualizations
 - b. Weekdays Visualizations
3. Decomposing Season and Trend
 - a. Mornings
4. Holt Winters Forecasting
 - a. Mondays at 8:00 PM
5. Summary of Goals
6. Business Recommendations
7. Lessons Learned

Daily, Weekly, and Holiday Visualizations

We can visualize data by day, week, and even by user-inputted time periods.

Daily

A homeowner can choose any particular day and see energy use throughout that day by many intervals, like per minute, per hour, every few hours, etc.

We will look at January 9, 2009. This was during Winter in Paris.

Visualize Energy Consumption Daily: January 9, 2008 Example



Kitchen: The family used the kitchen at 18:00 or 6:00PM.

Laundry Room: The interval orange spikes represent energy consumption by the fridge. The absence of higher spikes mean that the family did not do laundry on this day.

Water Heater & AC: Consumption for these appliances do not peak with that of the laundry room or kitchen. This means that no hot water was used for either laundry or dishwashing and the family took hot showers and or ran the AC.

Weekly

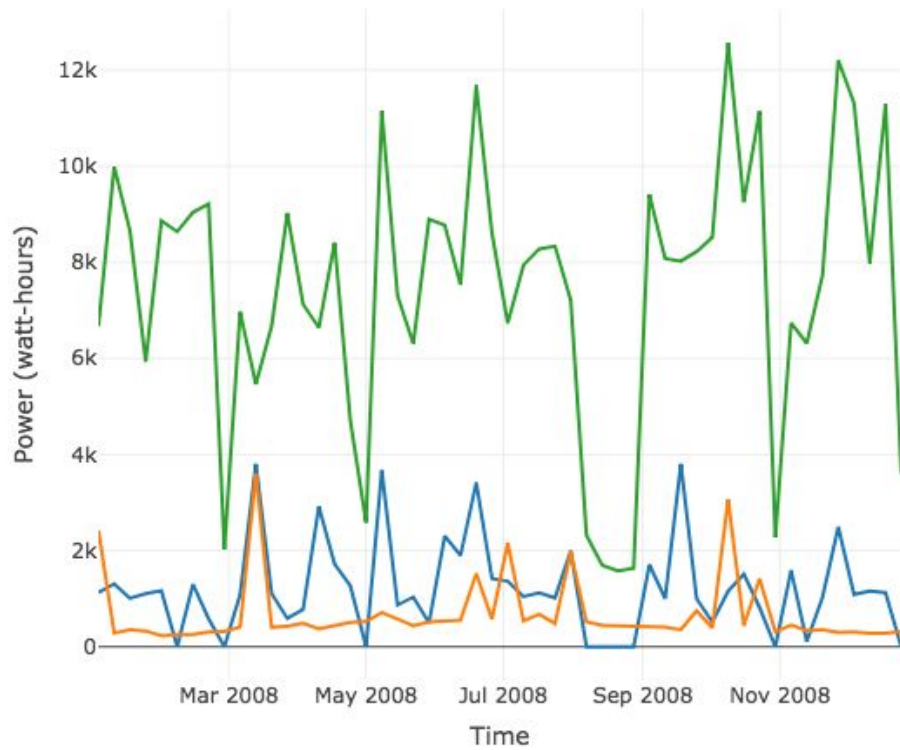
From weekly visualizations, we can answer questions like:

- Which days of the week do the family use the most energy?
- Which days of the week do the family use energy from a particular submeter the most?
- **Which days are usually laundry days?**
 - In the following visualization, we can see that energy consumption in the laundry room (in orange) is much higher on Sundays than Thursdays

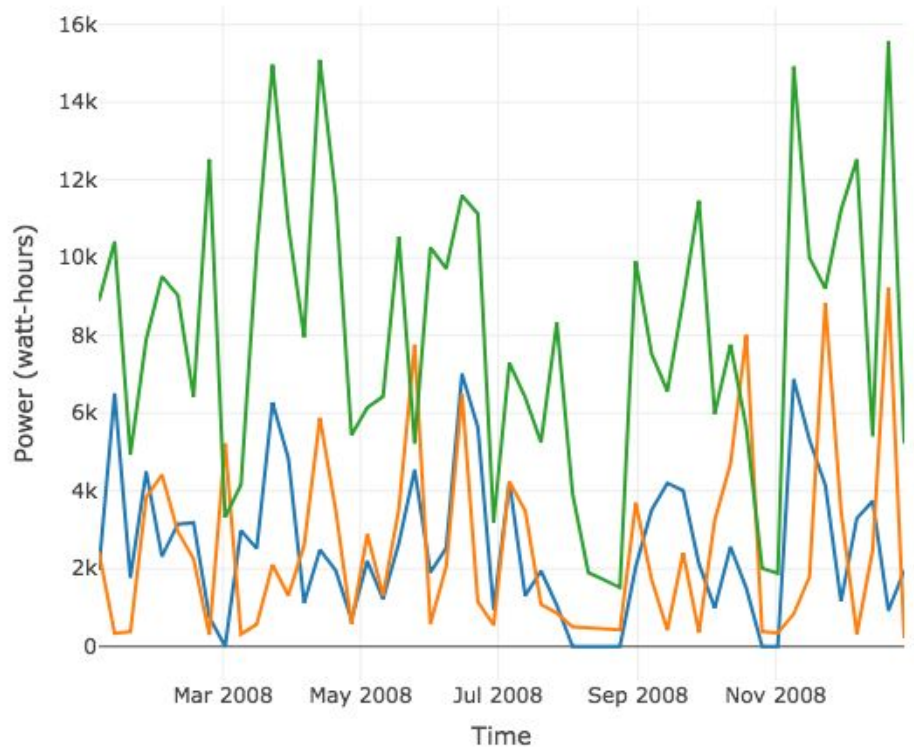
Which day is more likely to be laundry day? Thursday or Sunday?

— Kitchen
— Laundry Room
— Water Heater & AC

Every Thursday in 2008



Every Sunday in 2008

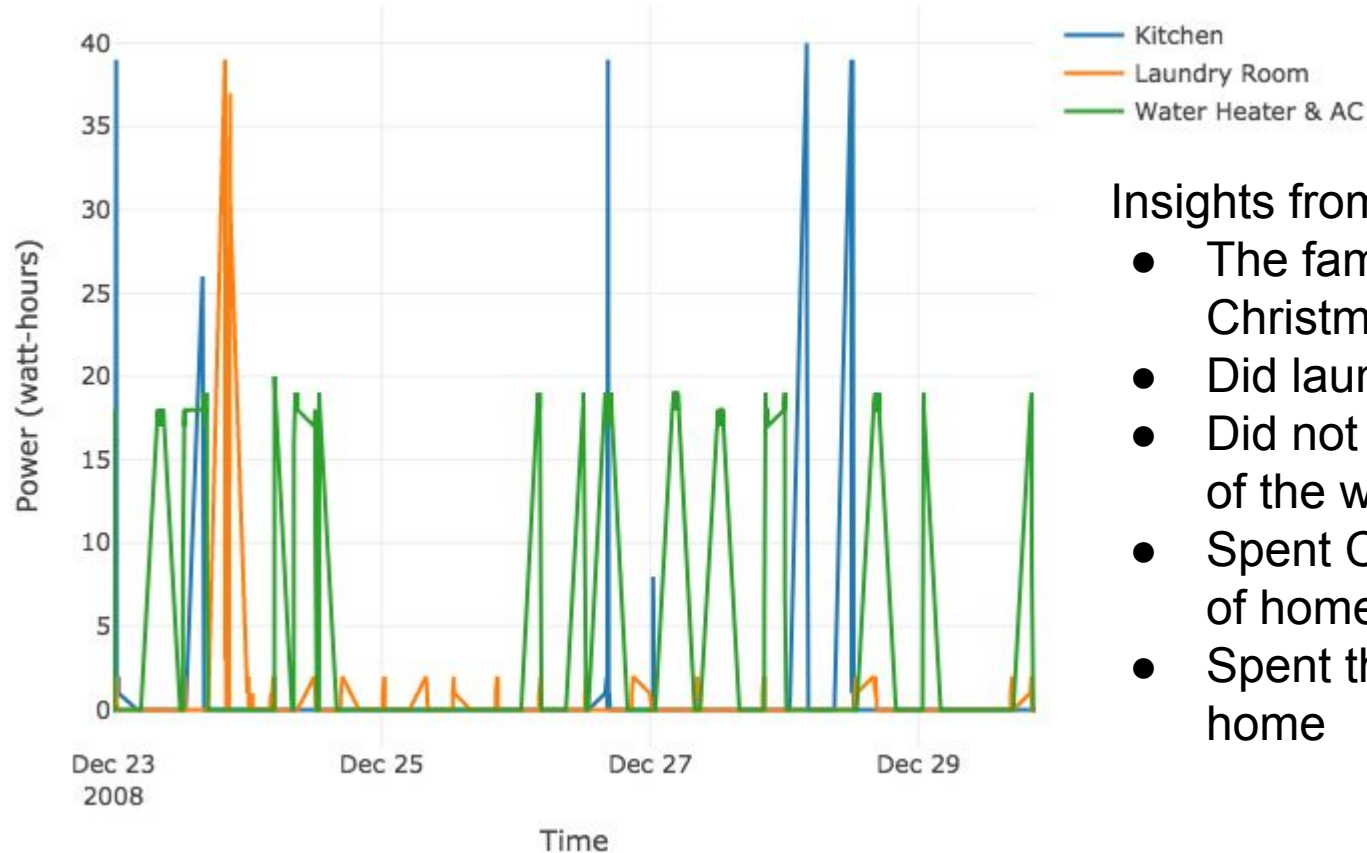


Select Time Periods

We are not limited to just days, or weeks. Submeter data can offer insights for special occasions, like weddings and holidays, as well as user-inputted aggregate time periods.

In the following figures, we examine Christmas time in 2008, total energy consumption broken down by time of day and from each submeter, over the years.

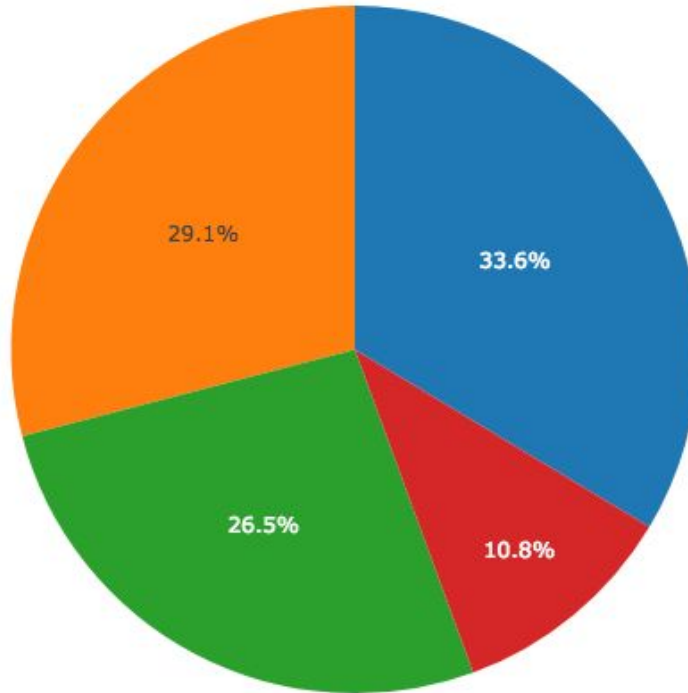
Visualize Energy Consumption by Select Time Periods: Christmas Week 2008, Every 4 Hours



Insights from the data:

- The family baked before Christmas
- Did laundry on Christmas Eve
- Did not do laundry for the rest of the week
- Spent Christmas day outside of home
- Spent the rest of the week at home

Power Consumption by Time of Day



■ evening
■ afternoon
■ morning
■ night

Morning: 6:00 AM - 11:59 AM

Afternoon: 12:00 PM - 4:45 PM

Evening: 5:00 PM - 11:59 PM

Night: 12:00 AM - 5:59 AM

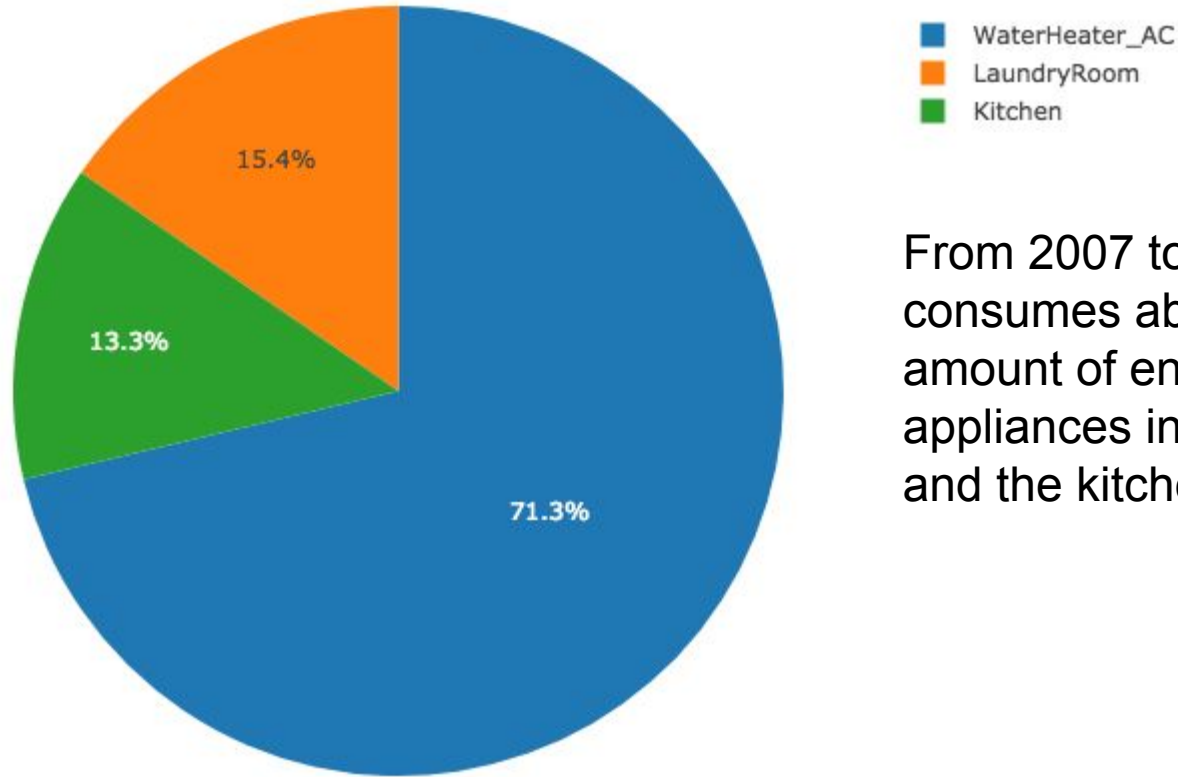
Submeters

We explore power consumption broken down by submeters.

This analysis could be more useful if energy consumption could be visualized from individual appliances (by using more submeters) or with more technical advancements.

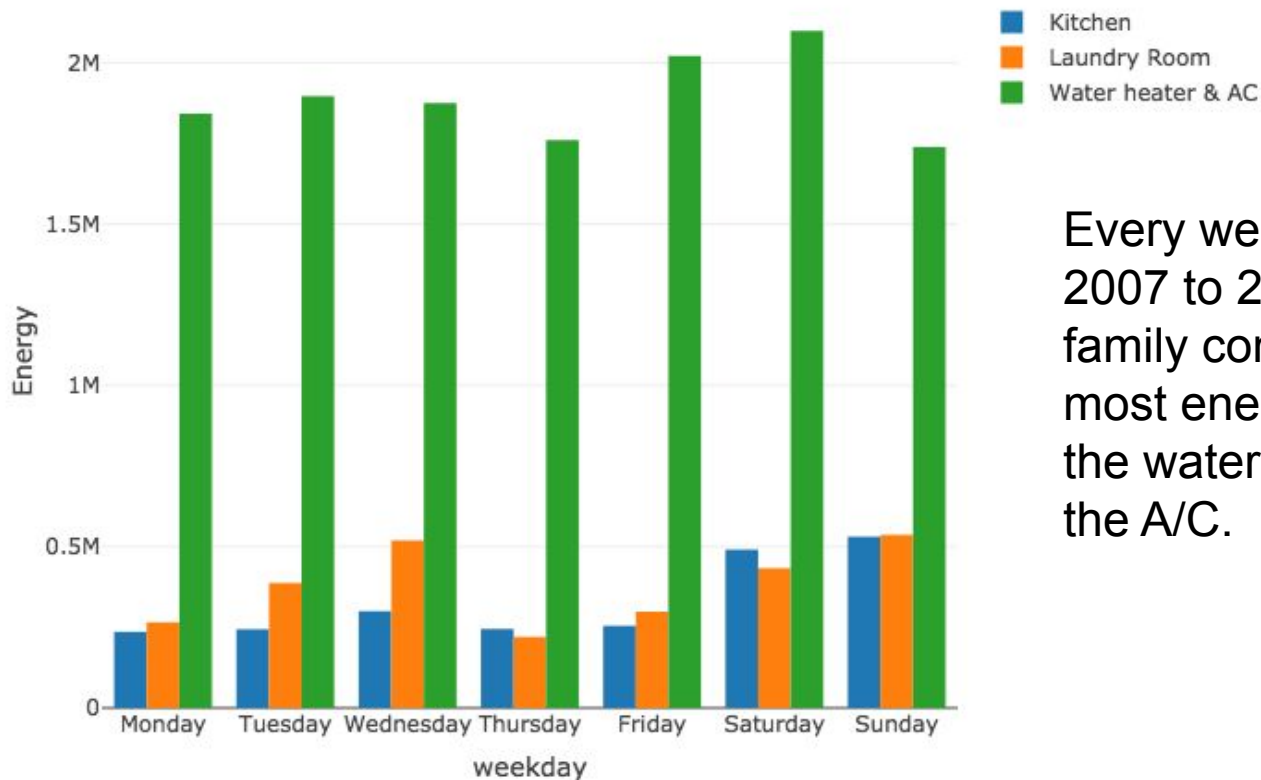
For example, can you get a submeter that can track energy consumption of the water heater separate from the AC, and even further, break down hot water for the laundry vs for showers.

Power Consumption by Submeters



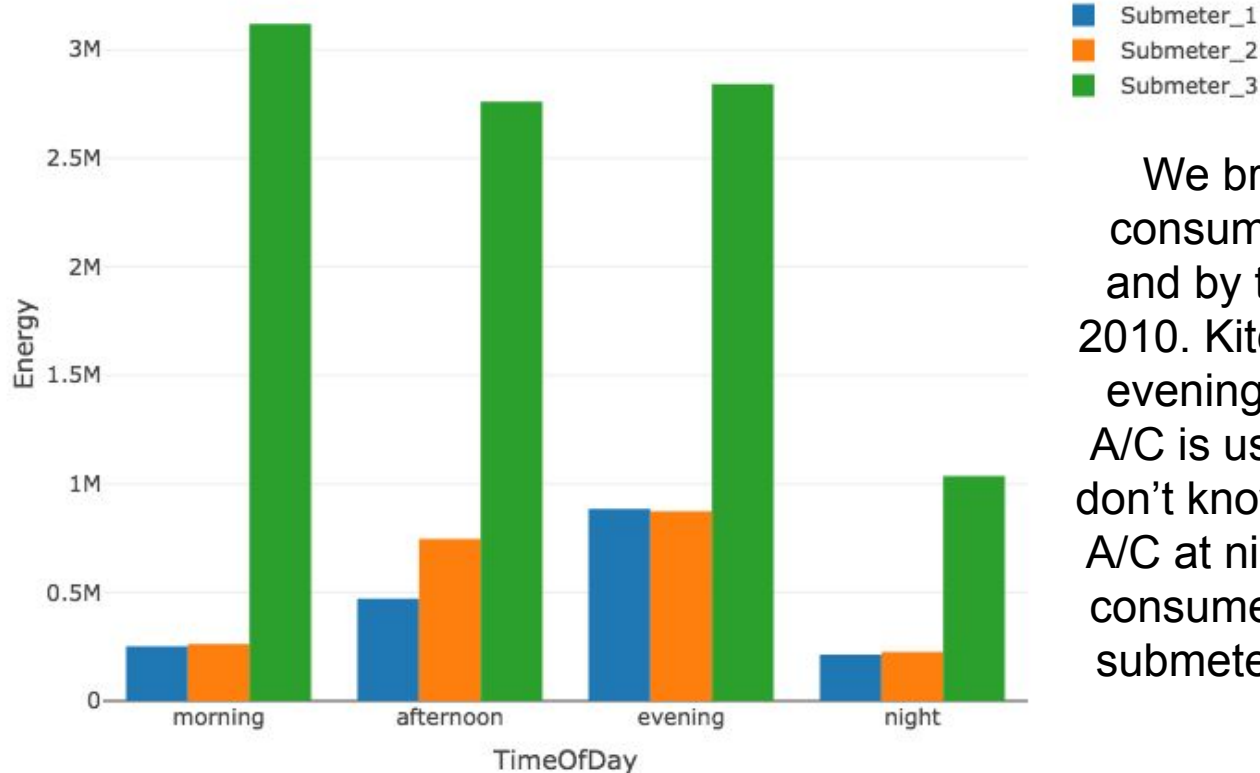
From 2007 to 2010, the family consumes about the same amount of energy through appliances in the laundry room and the kitchen.

Total Power Consumption by Weekday and Submeters



Every weekday from 2007 to 2010, the family consumes the most energy through the water heater and the A/C.

Total Power Consumption by Time of Day and Submeters



We broke down total energy consumption by each submeter and by time of day from 2007 to 2010. Kitchen use is the highest at evenings. The water heater and A/C is used the least at night. We don't know if the family turns off the A/C at night, or if the water heater consumes most of the energy the submeter records throughout the day.

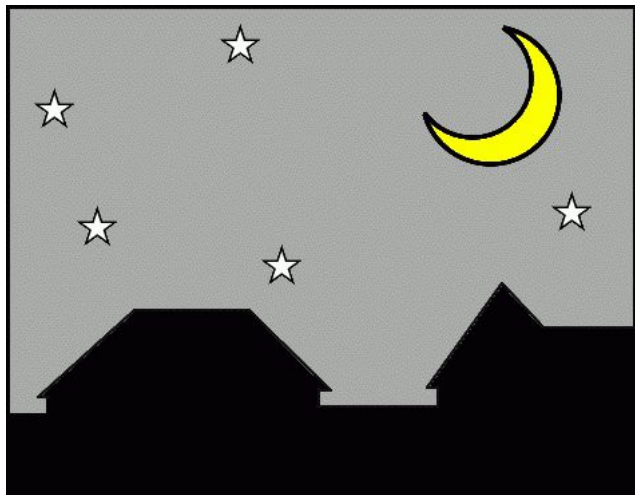
Time Series Visualizations:

How is energy consumed over time?

Plotting data over time allows homeowners to see how they consume energy over the days, weeks, and years. We explore energy use on Mondays at 8:00 PM.

By looking at submeter use over time, we can apply techniques like decomposing to see trends and seasonal patterns as well as forecasting to predict future energy consumption.

Mondays at 8:00 PM



Submeters allow homeowners to learn about energy consumption trends at a particular period of time.

From this kind of data, a homeowner can learn:

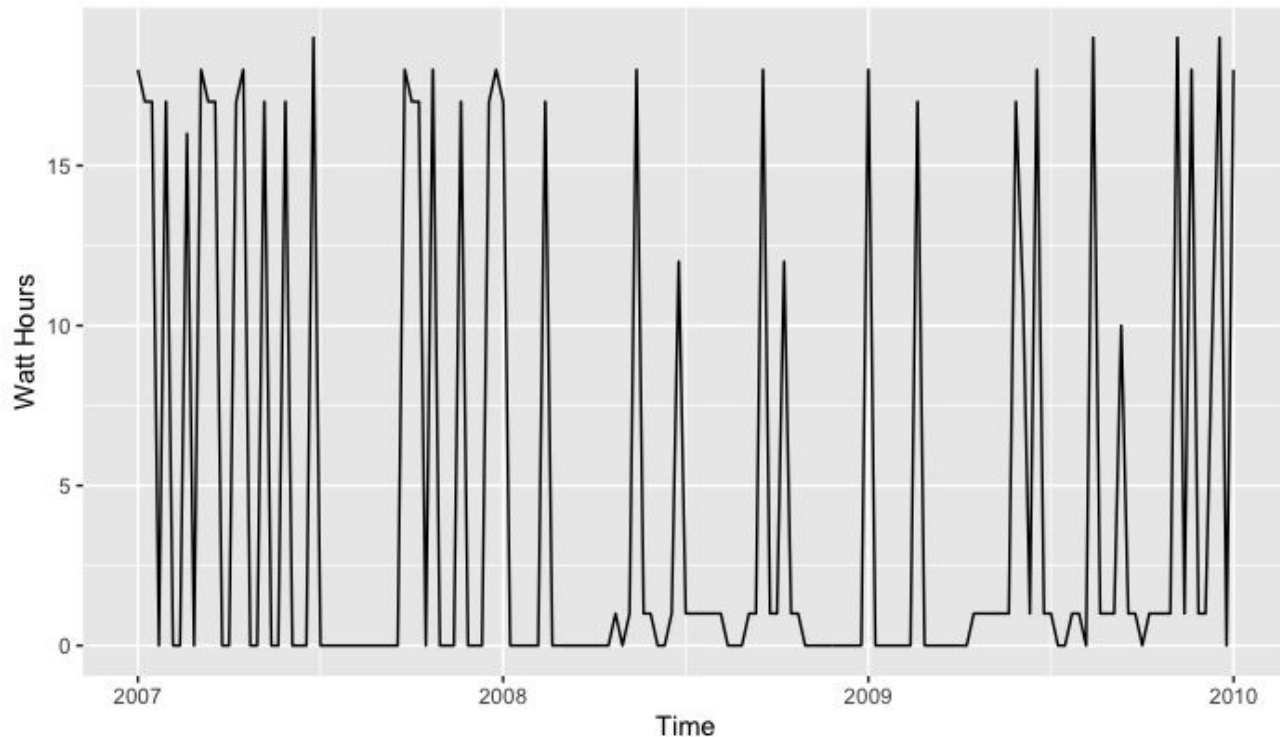
- Typical amount of energy residents require at particular time periods
- Trends in energy use over time
- How energy use changes with seasons

They can infer:

- What time the most energy is used
- When energy is used when it shouldn't be

We examine energy use on Mondays at 8:00 pm by the water heater and A/C.

Water Heater and AC Energy Consumption (2007-2010), Mondays at 8:00pm

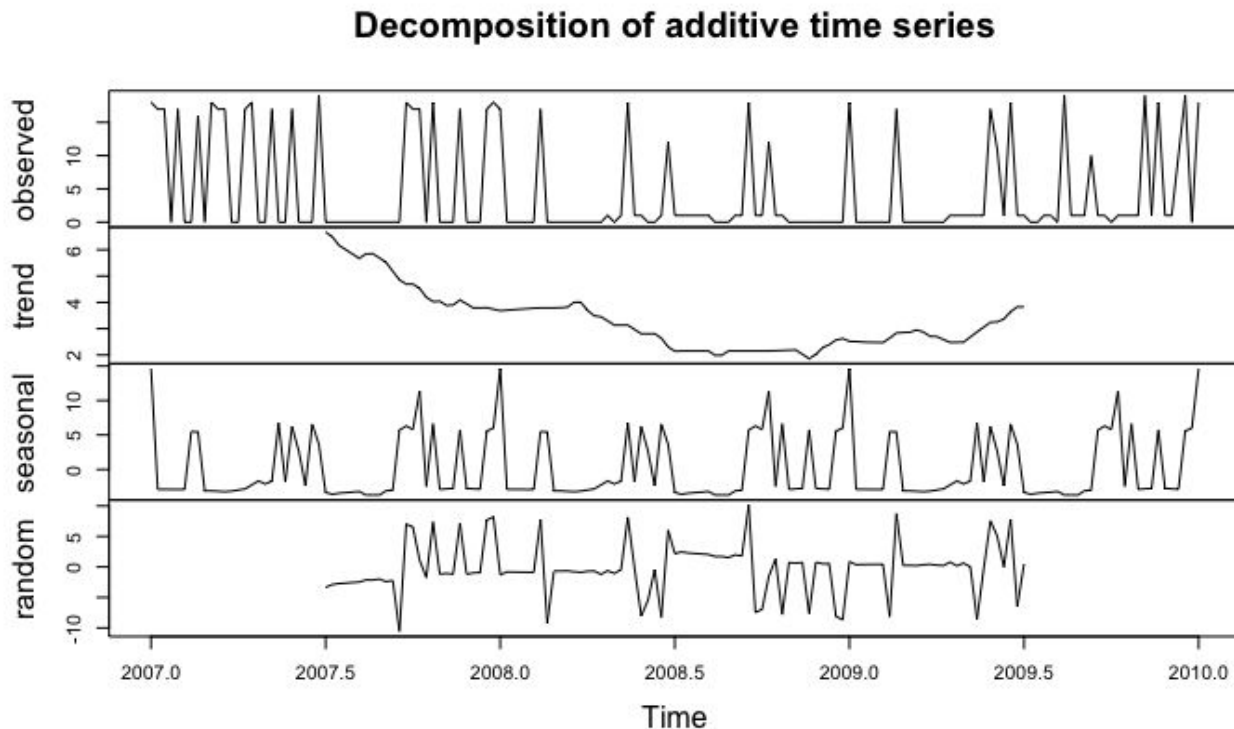


On most Mondays at 8:00 PM, the family consumes about 17.5 wH of energy from their water heater and A/C. This kind of data is useful for utility companies. It allows them to plan more accurately how much energy to produce, resulting in cost savings by preventing production of energy that is not needed. **Brokering the right kind of relationships with utility companies can ultimately pass on these cost savings to homeowners.**

Water Heater and AC Energy Consumption (2007-2010), Mondays at 8:00pm

Time series decomposition allows us to visualize trends and seasonality in data. In this example, we learn:

1. From 2007-2010, the family's overall use of the water heater and AC on Mondays at 8:00PM has declined.
2. In the middle and end of the year, they usually consume more and then start using less at the end of Winter throughout Spring. Summer means more consumption with peak consumption towards the end of Fall throughout Winter.

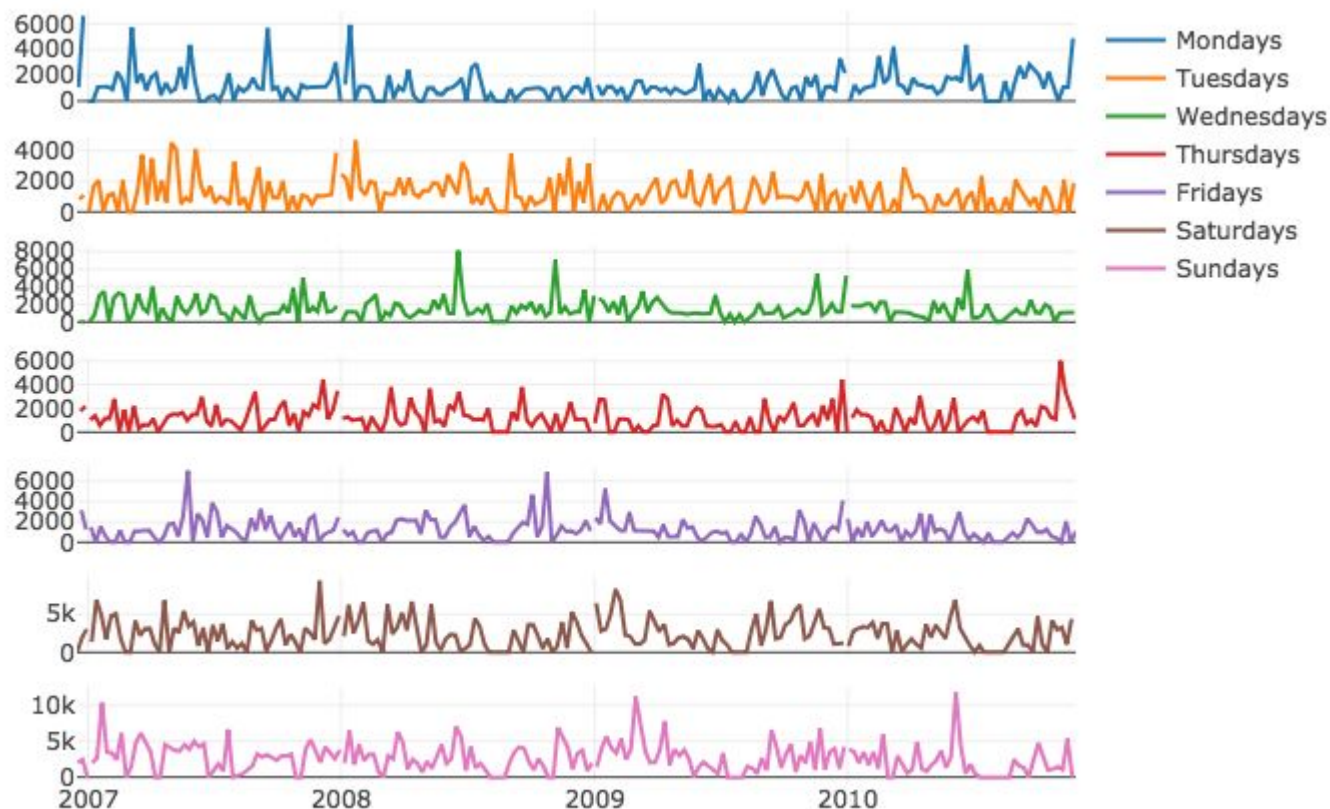


Weekdays over the Years

In another example of time series data, we explore how much energy is consumed each weekday over the years. We break this down by each submeter.

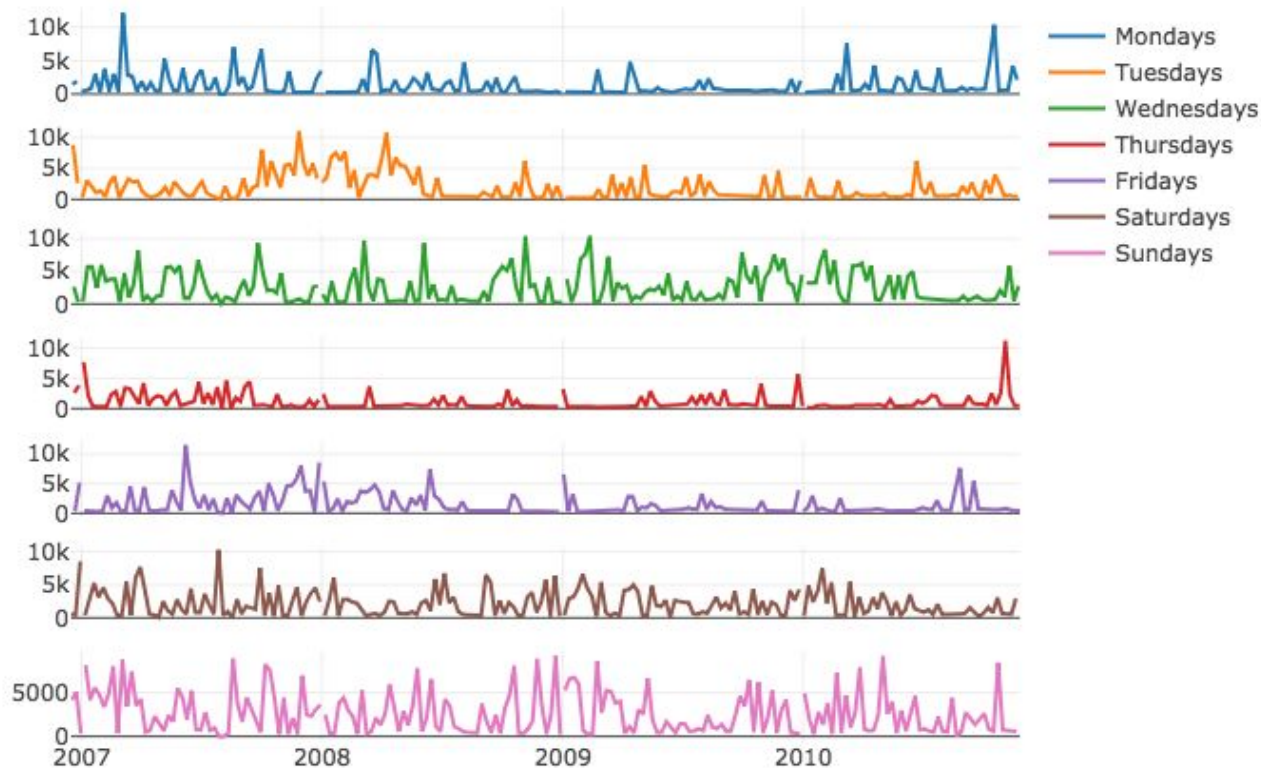
Kitchen Aggregate Energy Consumption (2007-2010), Weekdays

The family used the kitchen less on Wednesdays, Thursdays, and Fridays.



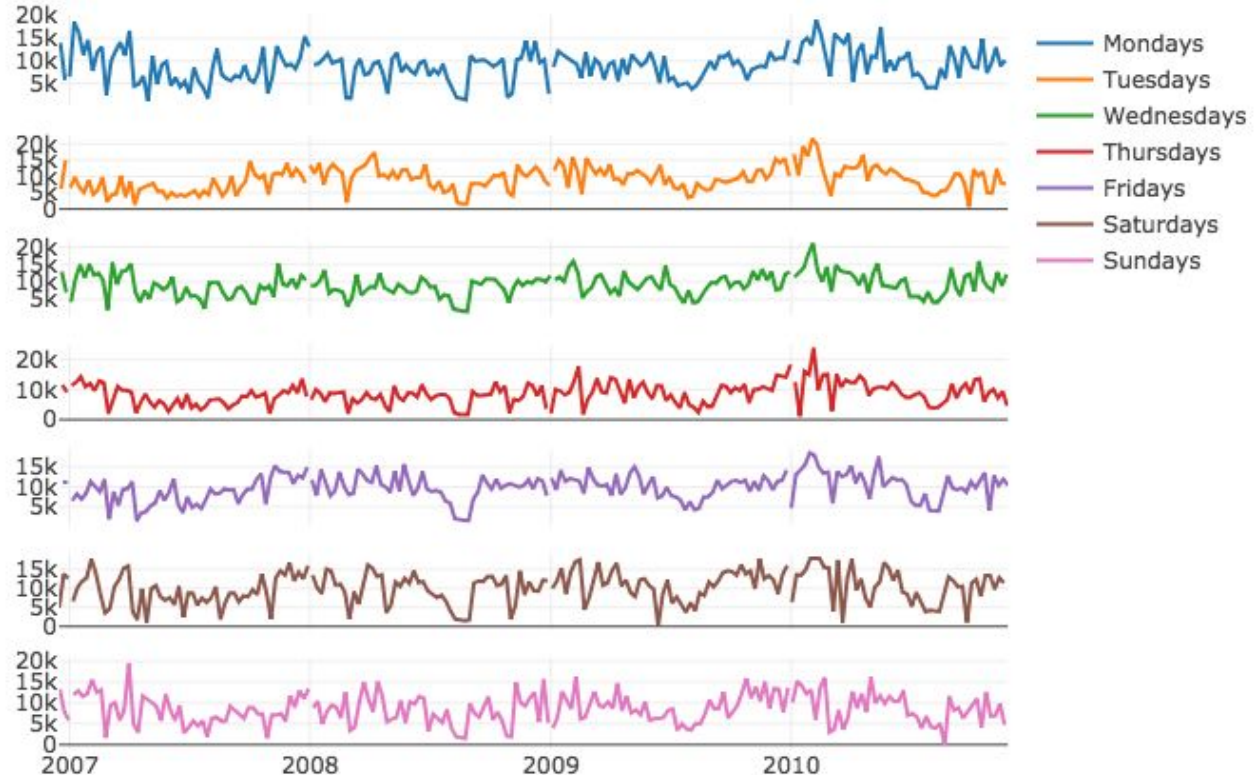
Laundry Room Aggregate Energy Consumption (2007-2010), Weekdays

Wednesdays and Sundays seem to consistently be laundry days. Thursdays are the days that the family typically does not do laundry.



Water Heater and AC Aggregate Energy Consumption (2007-2010), Weekdays

The family used the water heater and AC a lot through most days of the week. Still, they used it slightly less on Fridays and Saturdays compared to other weekdays.



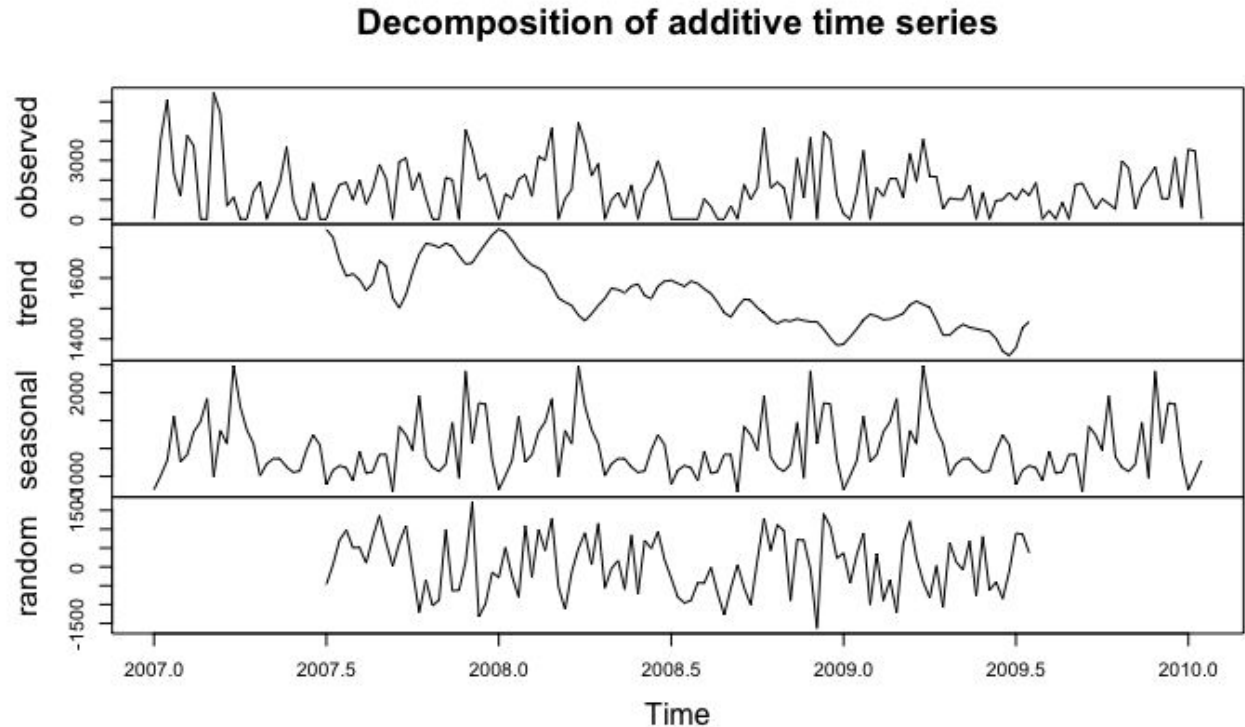
Visualizing Energy Consumption in Mornings Over Time

In this example, we explore decomposing time series in more detail. This type of information shows homeowners their energy consumption trends and seasonal patterns.

Morning is defined as 6:00 AM - 11:59 AM.

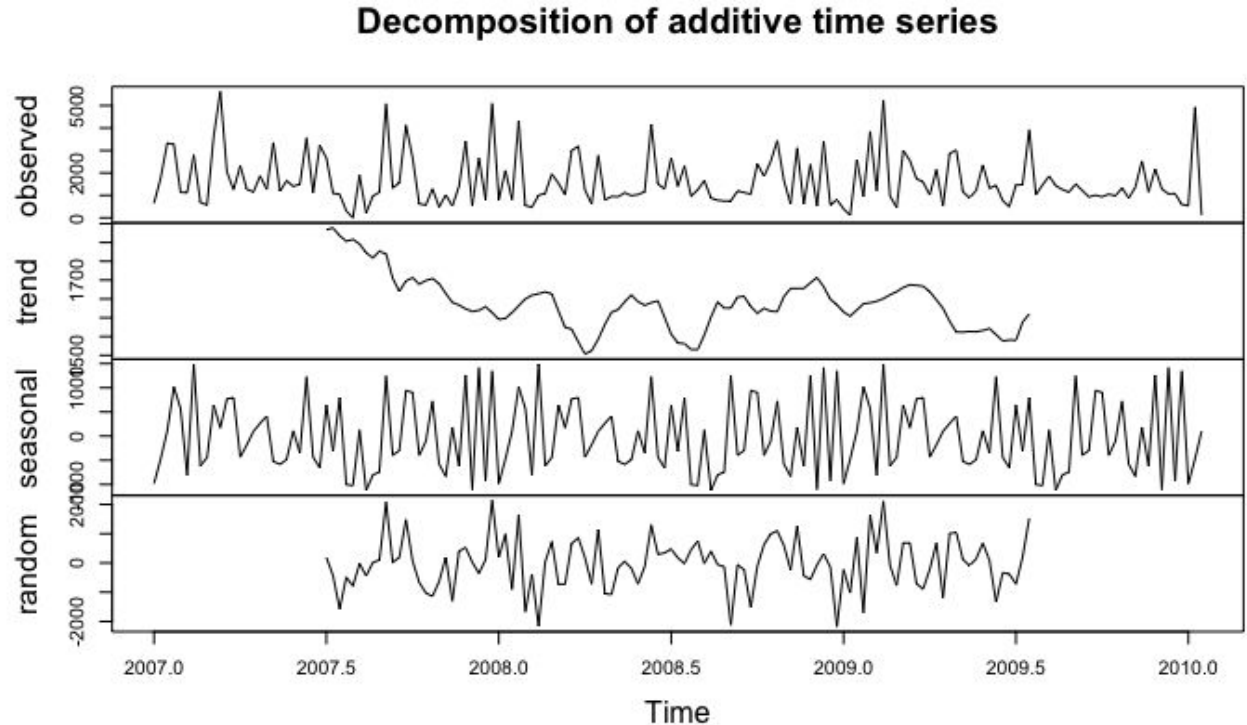
Kitchen Energy Consumption (2007-2010), Mornings

The family used less and less energy in the kitchen over time. When they did use more energy than usual, it was often in Autumn and Winter. During warmer weather, they used the kitchen less. **This is useful to homeowners because they can anticipate when they will need to spend more on their utility bills.**



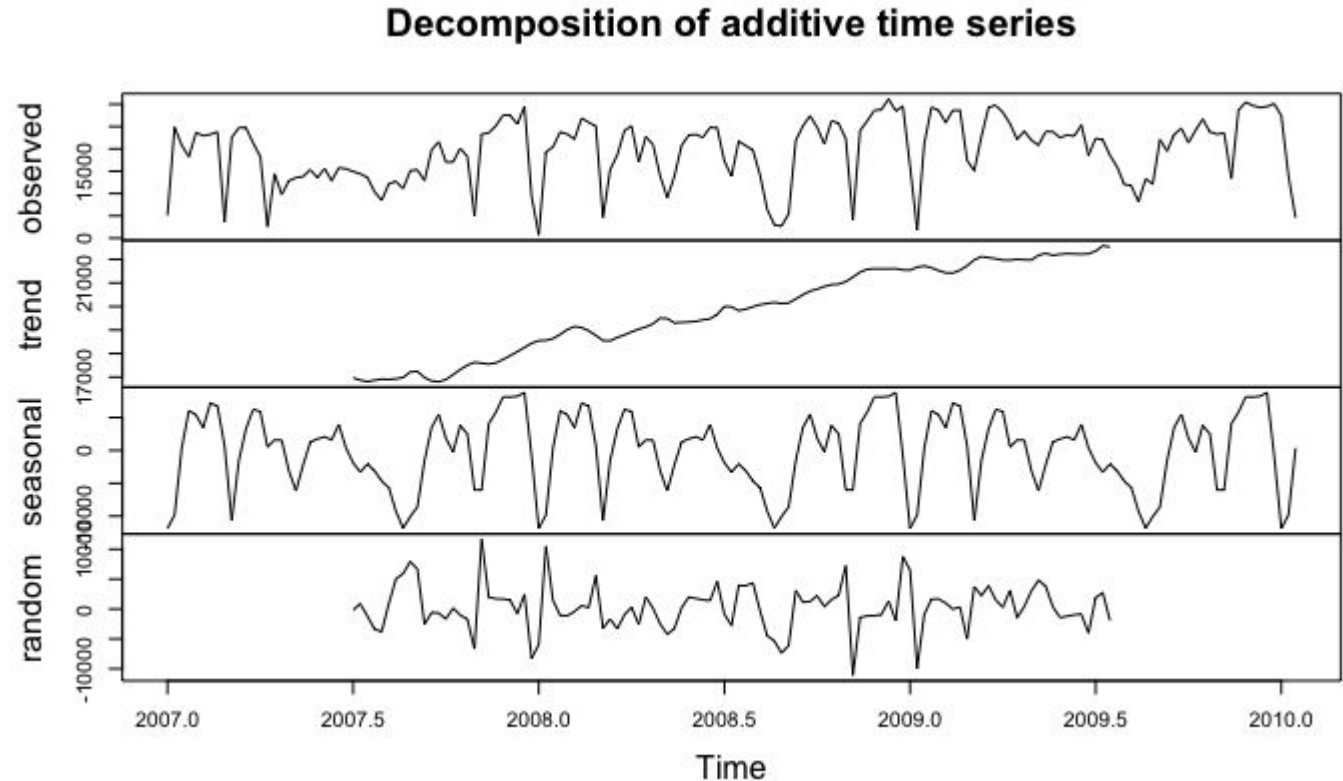
Laundry Room Energy Consumption (2007-2010), Mornings

In the middle of 2007, the family started reducing the amount of energy consumed for laundry, but this trend leveled out throughout the rest of the years. There is also a seasonal trend that repeats every year, showing that the family did the same amount of laundry at particular periods consistently.



Water Heater and AC Energy Consumption (2007-2010), Mornings

The family used the water heater and AC more and more, with definite seasonality. This is more intuitive since weather is seasonal and it affects how often the AC is used. Interestingly, the family consumed the least energy around the start of every year.



Summary Statistics for Time Series Decomposition

Submeter 1

	Length	Class	Mode
x	159	ts	numeric
seasonal	159	ts	numeric
trend	159	ts	numeric
random	159	ts	numeric
figure	52	-none-	numeric
type	1	-none-	
character			

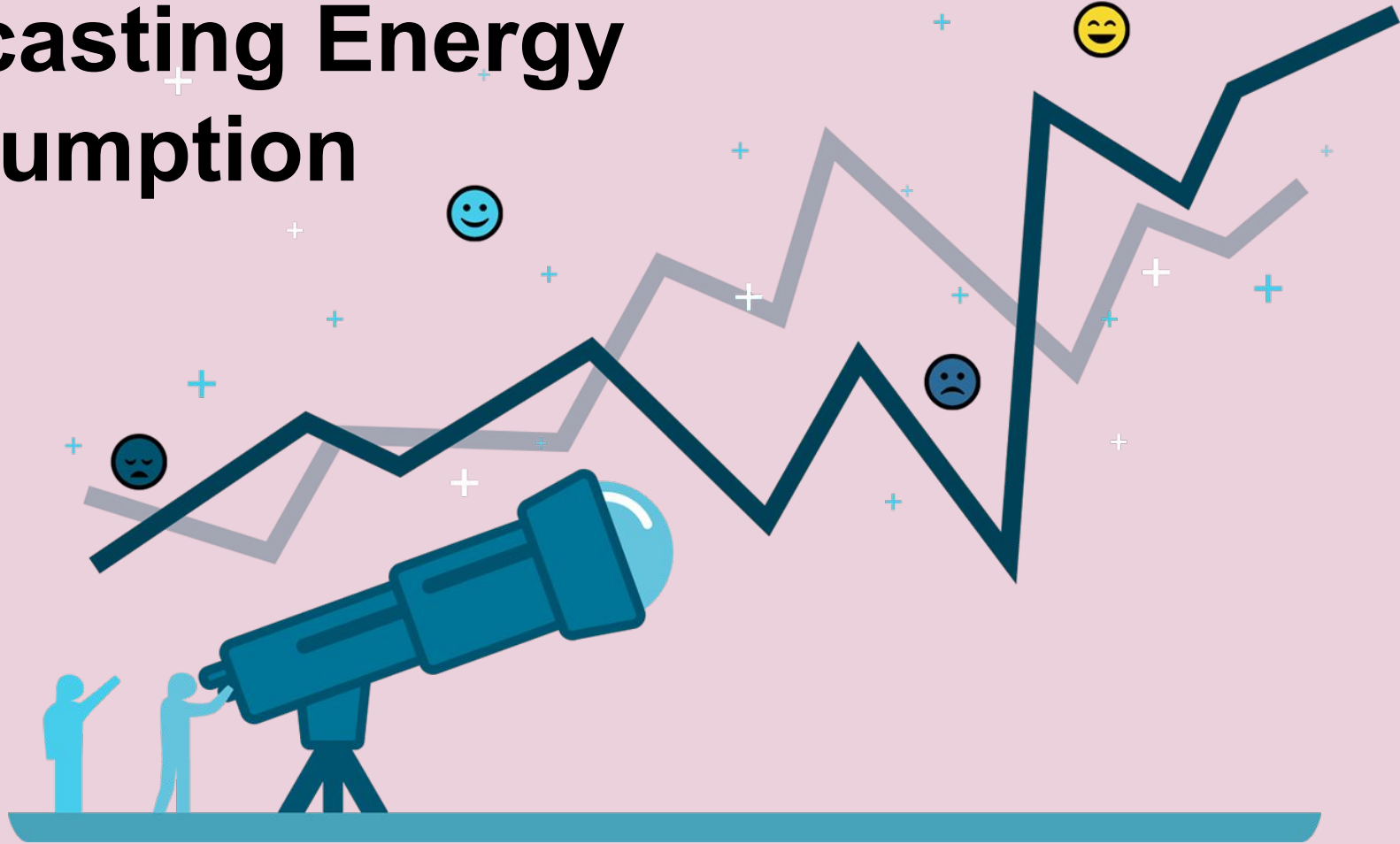
Submeter 2

	Length	Class	Mode
x	159	ts	numeric
seasonal	159	ts	numeric
trend	159	ts	numeric
random	159	ts	numeric
figure	52	-none-	numeric
type	1	-none-	character

Submeter 3

	Length	Class	Mode
x	159	ts	numeric
seasonal	159	ts	numeric
trend	159	ts	numeric
random	159	ts	numeric
figure	52	-none-	numeric
type	1	-none-	character

Forecasting Energy Consumption

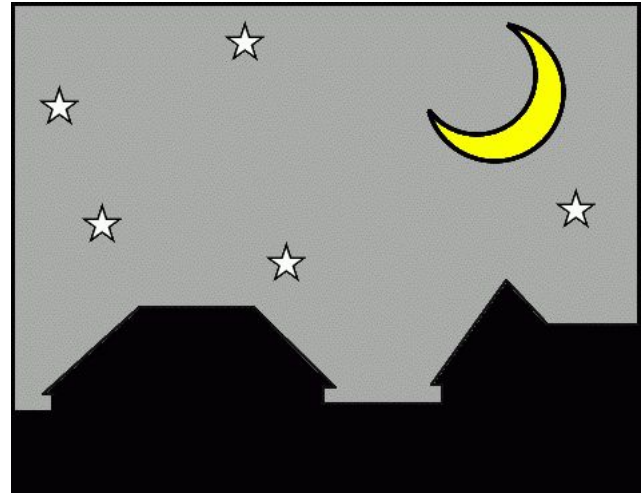


Forecasting Energy Consumption

The use of submeters over time provides homeowners with enough data to start predicting how much energy they will consume. This is beneficial because it **allows homeowners to budget** and can result in **cost savings** for utility companies (which can be passed on to homeowners). If actual energy consumption is different than what was forecasted, this **can alert homeowners** that there may be something wrong, like a broken appliance.

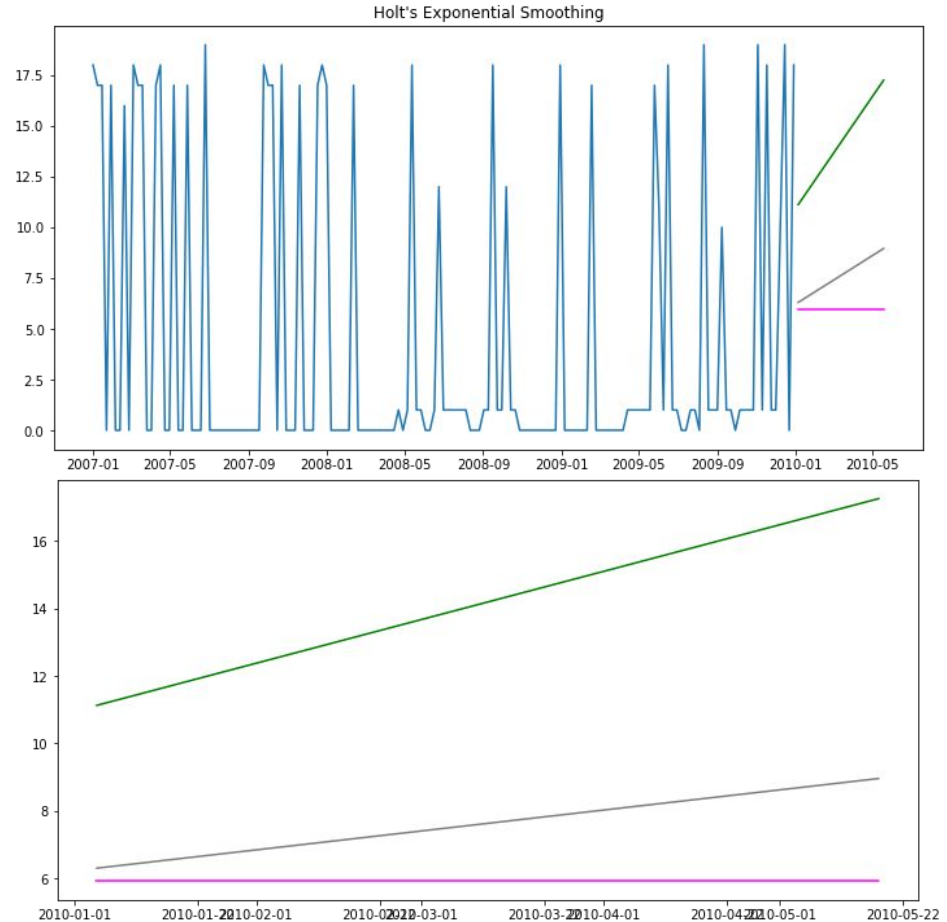
We use two models to predict energy consumption for Mondays at 8:00 PM.

Water Heater & AC Forecasts



Forecasting Water Heater and AC Energy Consumption in 2010: Model 1

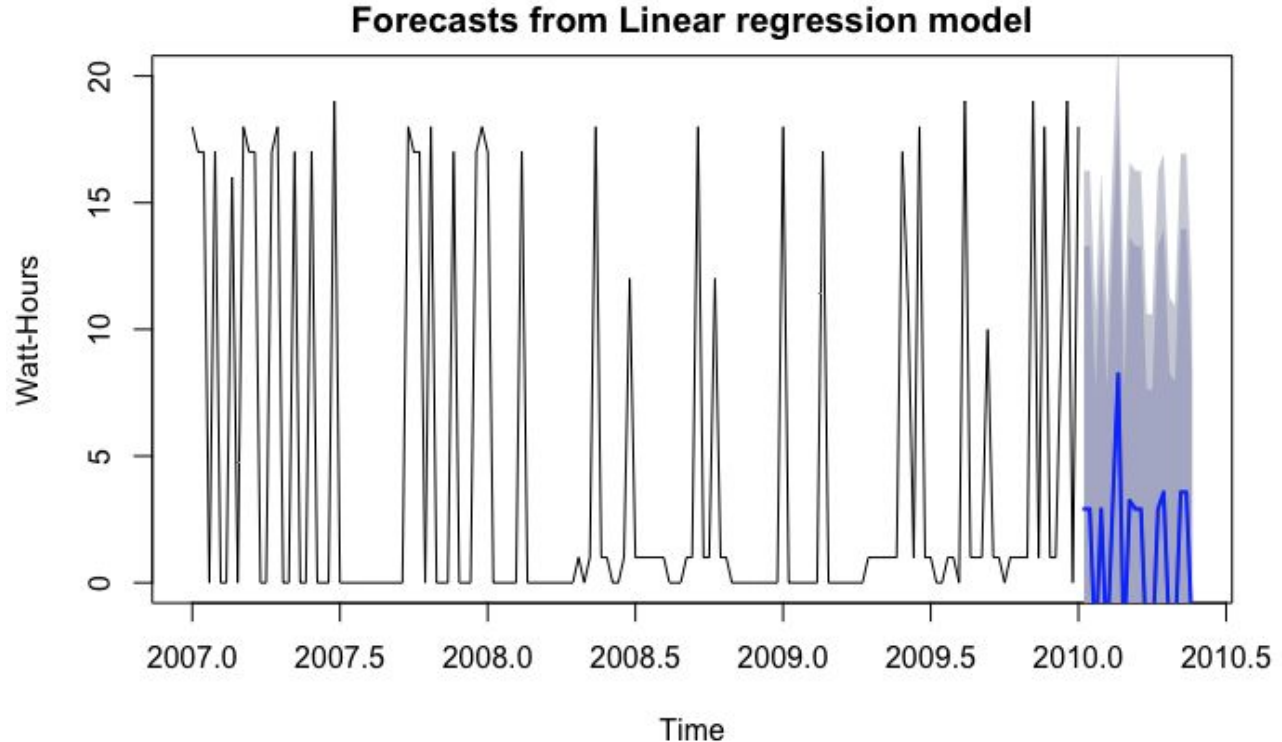
The following diagram shows our overall predictions for the first 20 weeks in 2010. On the low end, we expect the family to use approximately 6 wH on Mondays at 8:00 PM. On the high end, we expect the family to use from 11 wH to 18 wH.



Forecasting Water Heater and AC Energy Consumption in 2010: Model 2

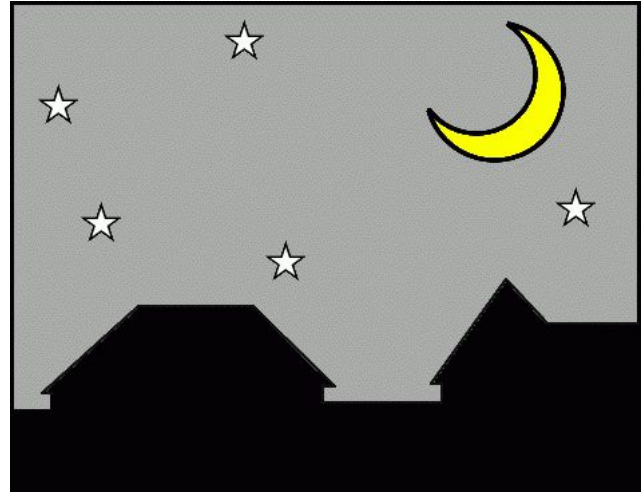
Our second model also plots energy consumption from Submeter 3 on Mondays at 8:00 pm.

Similar to the previous model, we can see the forecast in ranges with the blue line representing what the model predicts, the dark grey line representing 80 % confidence intervals, and the light grey representing 95% confidence intervals.



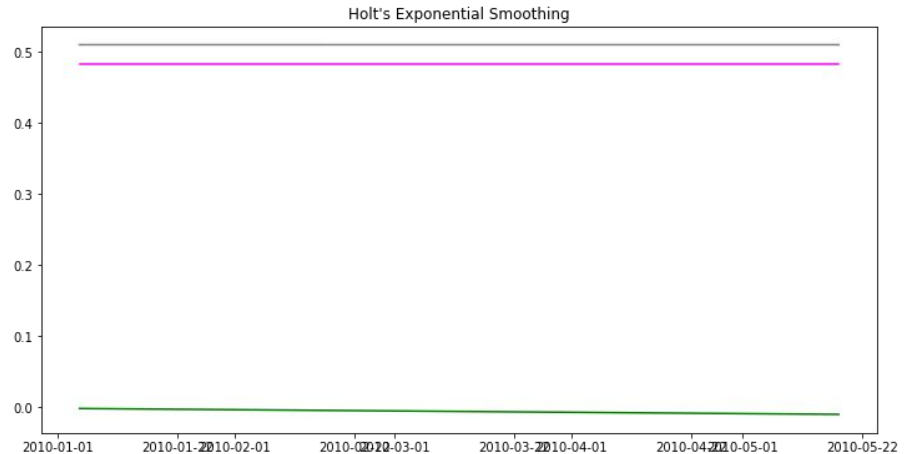
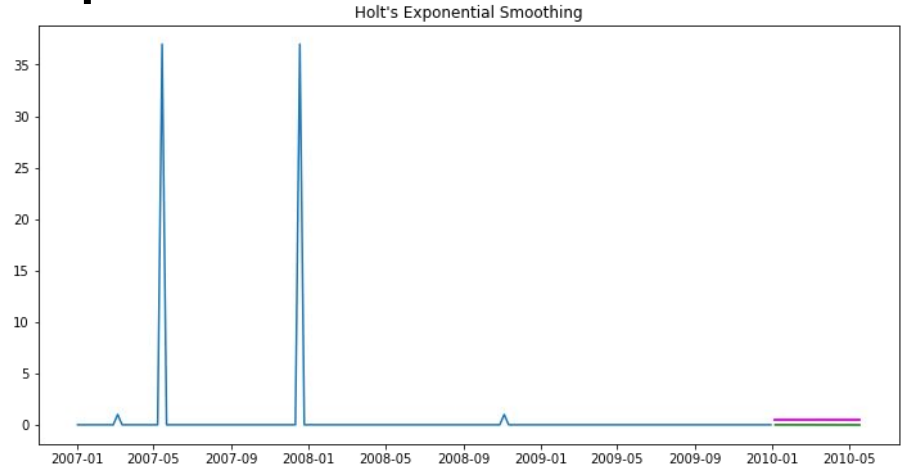
Kitchen

- Time Series Visualizations
- Decomposition
- Forecasts



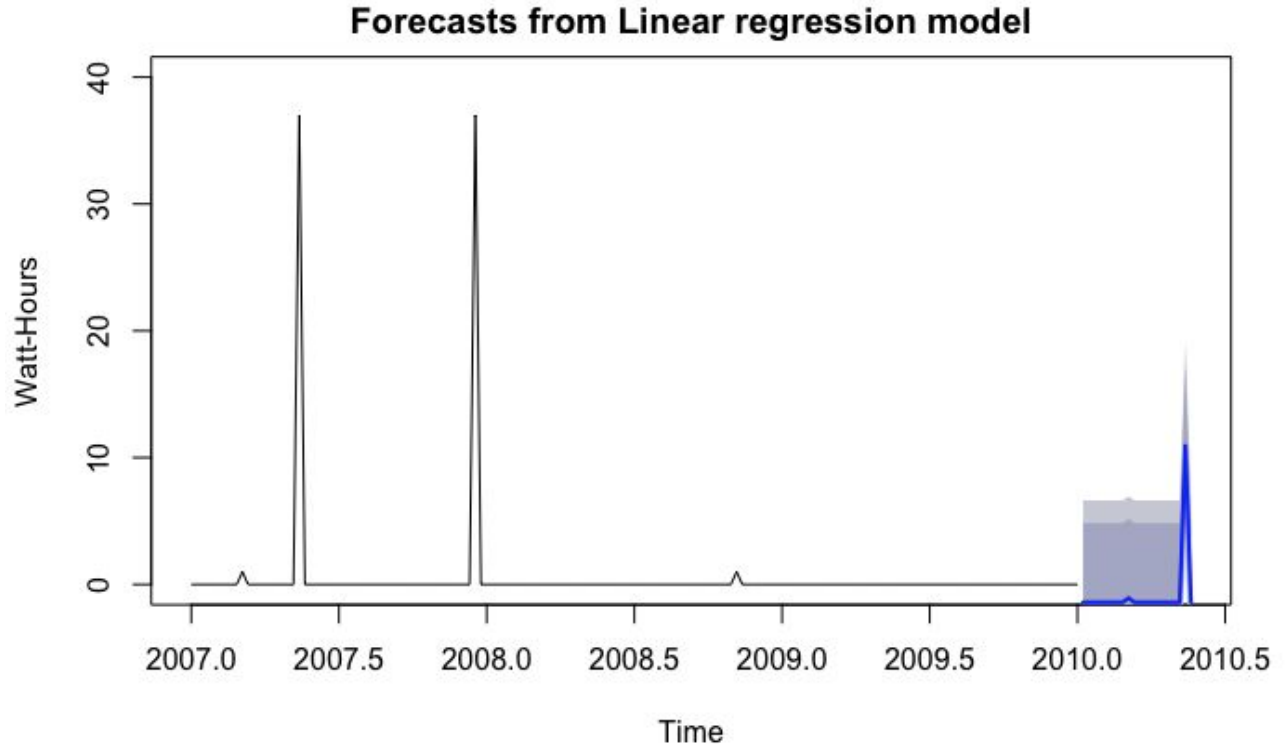
Forecasting Kitchen Energy Consumption in 2010: Model 1

The following diagram shows our overall predictions for the first 20 weeks in 2010. On the low end, we expect the family to consume no energy on Mondays at 8:00 PM. On the high end, they may use at most about 0.5 wH.

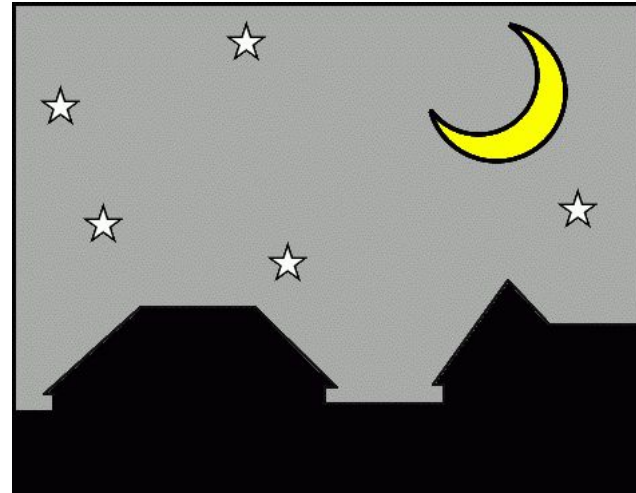


Forecasting Kitchen Energy Consumption in 2010: Model 2

Our second model also plots energy consumption from Submeter 1 on Mondays at 8:00 pm, with 80% and 85% confidence intervals. It's difficult to predict occasional peaks. On most Mondays at 8:00 PM, the family did not use the kitchen, except really for two days. Our model predicts that for the most part, the family will continue to not use the kitchen at this particular time.

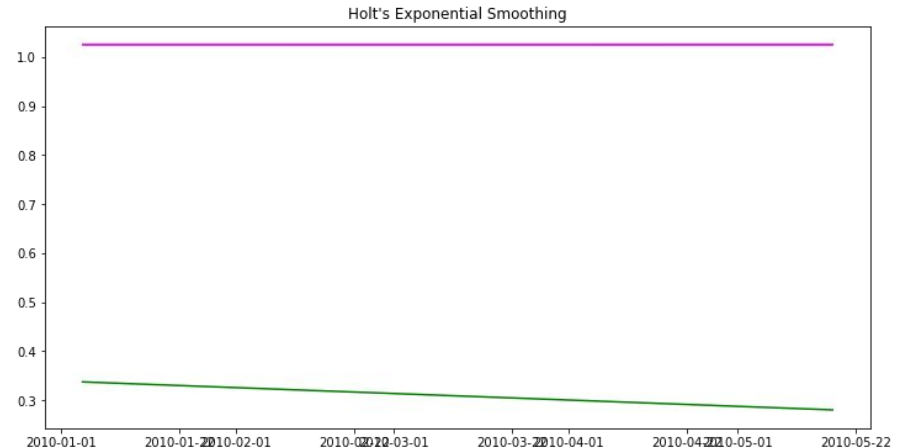
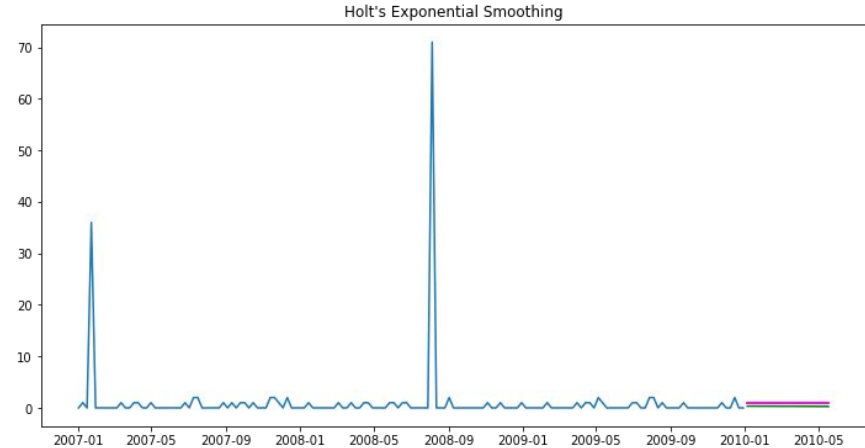


Laundry Room Forecasts



Forecasting Laundry Room Energy Consumption in 2010: Model 1

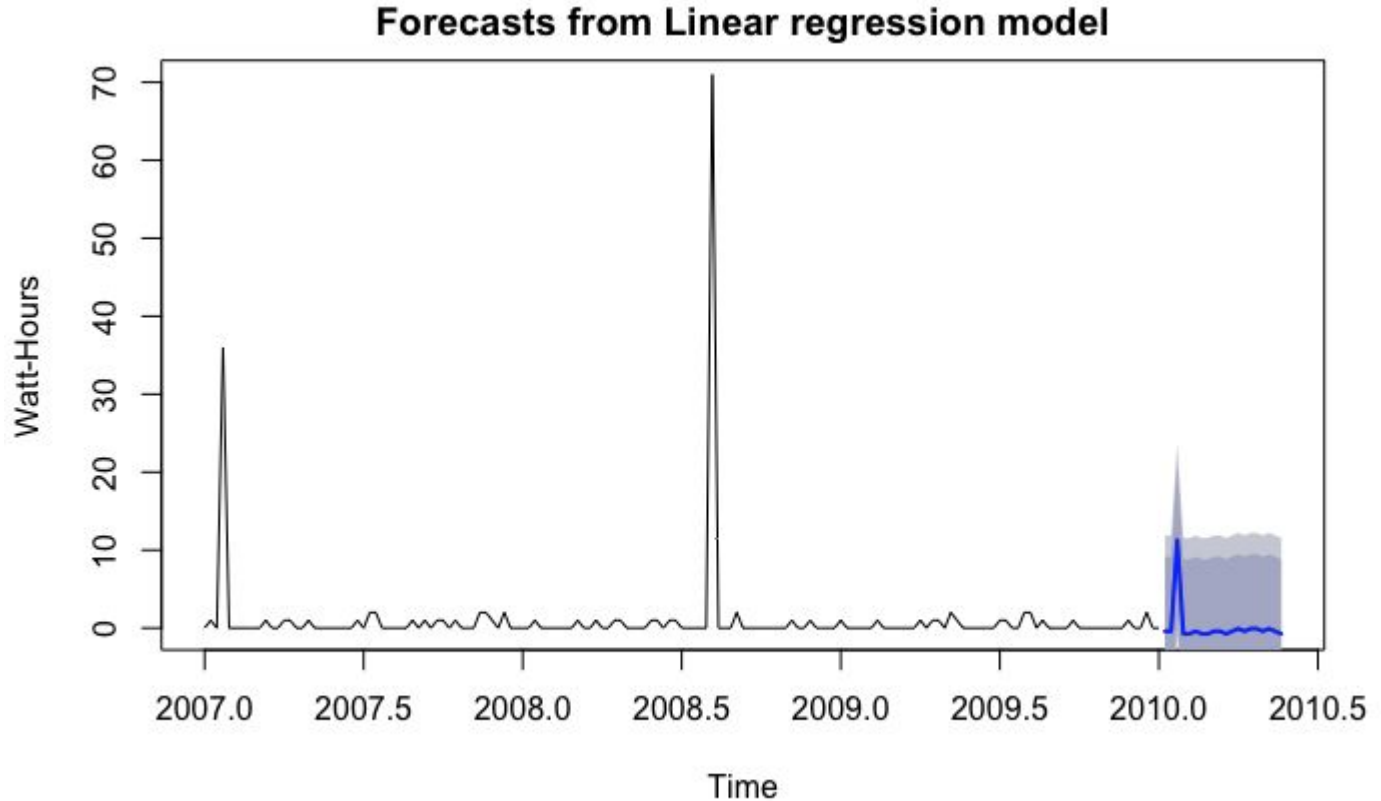
The following diagram shows our overall predictions for the first 20 weeks in 2010. On the high end, the family may use 1 wH (through the fridge) while on the low end, we expect the fridge to not take more than 0.35 wH on Mondays at 8:00 PM. The peaks represent when the family used the washer or dryer, which they only did twice in two years.



Forecasting Laundry Room Energy Consumption in 2010: Model 2

Our second model also plots energy consumption from Submeter 2 on Mondays at 8:00 pm.

Similar to the previous model, we can see the forecast in ranges with the blue line representing what the model predicts, the dark grey line representing 80 % confidence intervals, and the light grey representing 95% confidence intervals.



Additional Statistics for Model 2: Regression

	RMSE	R ²
Submeter 1	4.13	0.3437
Submeter 2	6.323	0.3343
Submeter 3	6.871	0.3831

Objective: Find insights from data collected from submeters that are beneficial to homeowners.

From our analysis, we were able to see:

- Energy use per submeter over:
 - one day (January 9, 2008)
 - one week (Christmas Week 2008)
 - every weekday (Every Thursday in 2008, Every Sunday in 2008)
- Energy use per:
 - Submeter (Pie graph of total usage)
 - Submeter & Time of Day (Pie graph of *total* energy use by time of day)
 - Submeter & Time of Day (Bar graph of energy used)
 - Submeter & Weekday (Bar graph of energy used, grouped by submeters and weekday)
 - Submeter & Minute (Mondays at 8:00 PM plots)
- Forecast energy use at a particular minute (Mondays at 8AM forecasts)
- See trends and seasonal patterns per submeter (seasonal graphs by mornings)

Business Recommendations

1. Submeters are definitely useful. First, they provide more data than regular utility bills. All homeowners can benefit from more insights on their energy consumption patterns.
2. However, the submeters should be adjusted to provide more intuitive readings:. Kitchen appliances should be read on one submeter instead of on multiple, or
 - a. This can be done by using more submeters, so that the use of kitchen appliances like the fridge are not mixed submeter readings for the washing machine and dryer.
3. Provide household behavioral reports with recommendations on how to reduce usage by providing homeowners with peak usage time patterns
4. Build relationships with utility companies to incentivize use of submeters
5. Use submeters on appliances to identify when appliances start breaking down
6. Provide budgeting assistant based on submeter data

Lessons Learned

- What are submitters
- How to visualize time series data with ggplot and plotly
- Find seasonality and trends in time series
- Forecast time series data using linear regression and exponential smoothing (through HoltWinters)