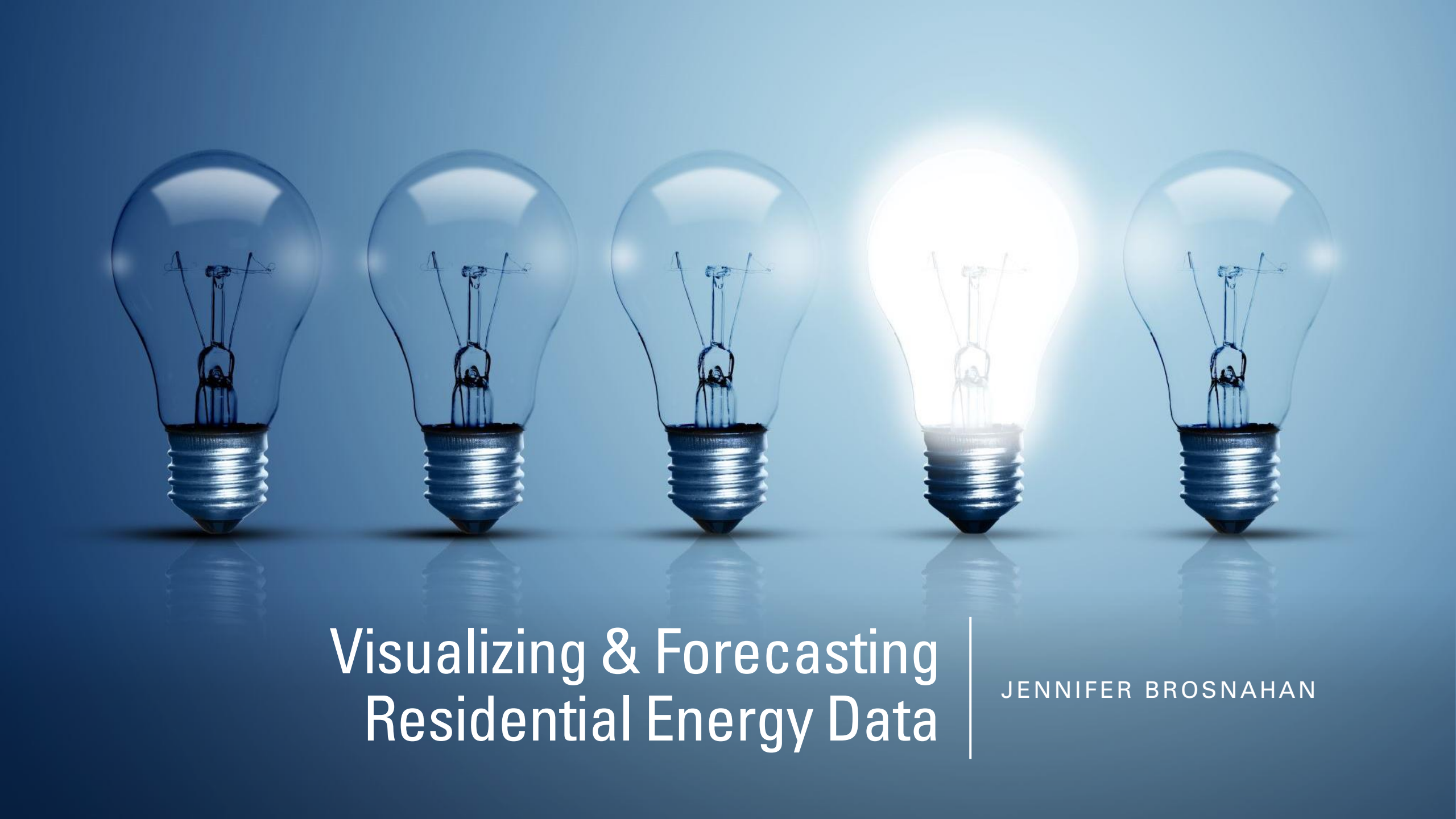


Visualizing & Forecasting Residential Energy Data

JENNIFER BROSNAHAN

Background

- IOT Analytics has been asked by a law firm to conduct an in-depth analysis of power consumption data for a client's residential home.
- The law firm's client claims to have not been occupying a specific residence at the time of an undisclosed event during Summer of 2008.
- Energy use records will be used to provide evidence on whether or not residence was occupied from July-September, 2008.

Business Objectives

- Analyze energy use records for client residence to answer the primary question:
  - Was client residence occupied during the Summer of 2008 (July-September)?
- Conduct in-depth analysis of power use by sub-meter from 2007 to 2010 to identify overall patterns.
- Visualize energy use patterns on high level (3-years) and precise-level (Summer of 2008).
- Use electrical power data from 2007-2009 to forecast energy use by sub-meter into 2010.

Data Description

Data consists of energy consumed per minute for 3 different sub-meters in residential home from 2007 through 2009

- 1,569,894 total minute observations
- Energy amount used each minute for each of 3 sub-meters:
  - Sub-meter 1: Kitchen (dishwasher, oven, microwave)
  - Sub-meter 2: Laundry (washing machine, drier, fridge, light)
  - Sub-meter 3: Electric Water Heater and AC

Data Description (Missing Data)

Missing Data (minutes from 2007 to 2010):

- 57 days with missing minutes (<1440 minutes per day)
- 7086 total missing minutes
- Range was 1 to 1380 minutes missing/day
- 25 days missing 1 minute
- 15 days missing 2-4 minutes
- **4 total minutes missing on 3 different dates during time period in question (July-Sept 2008)**

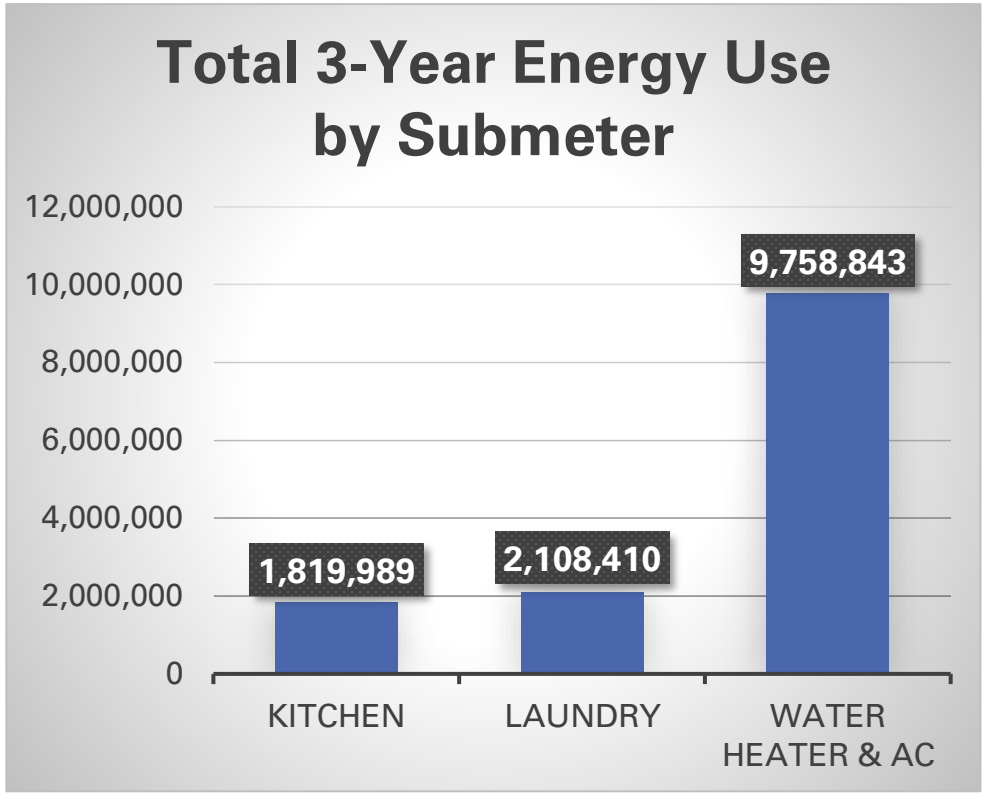
Due to relatively insignificant number of missing minutes during primary time focus, missing values were not adjusted in data set.

Summary of Energy Use by Sub-Meter (2007 to 2010)

Sub-meter 1: Kitchen
- Least total energy used (1,819,989 Watts)
- Average 1.16 Watts per minute
- Largest energy range (0-82 Watts)

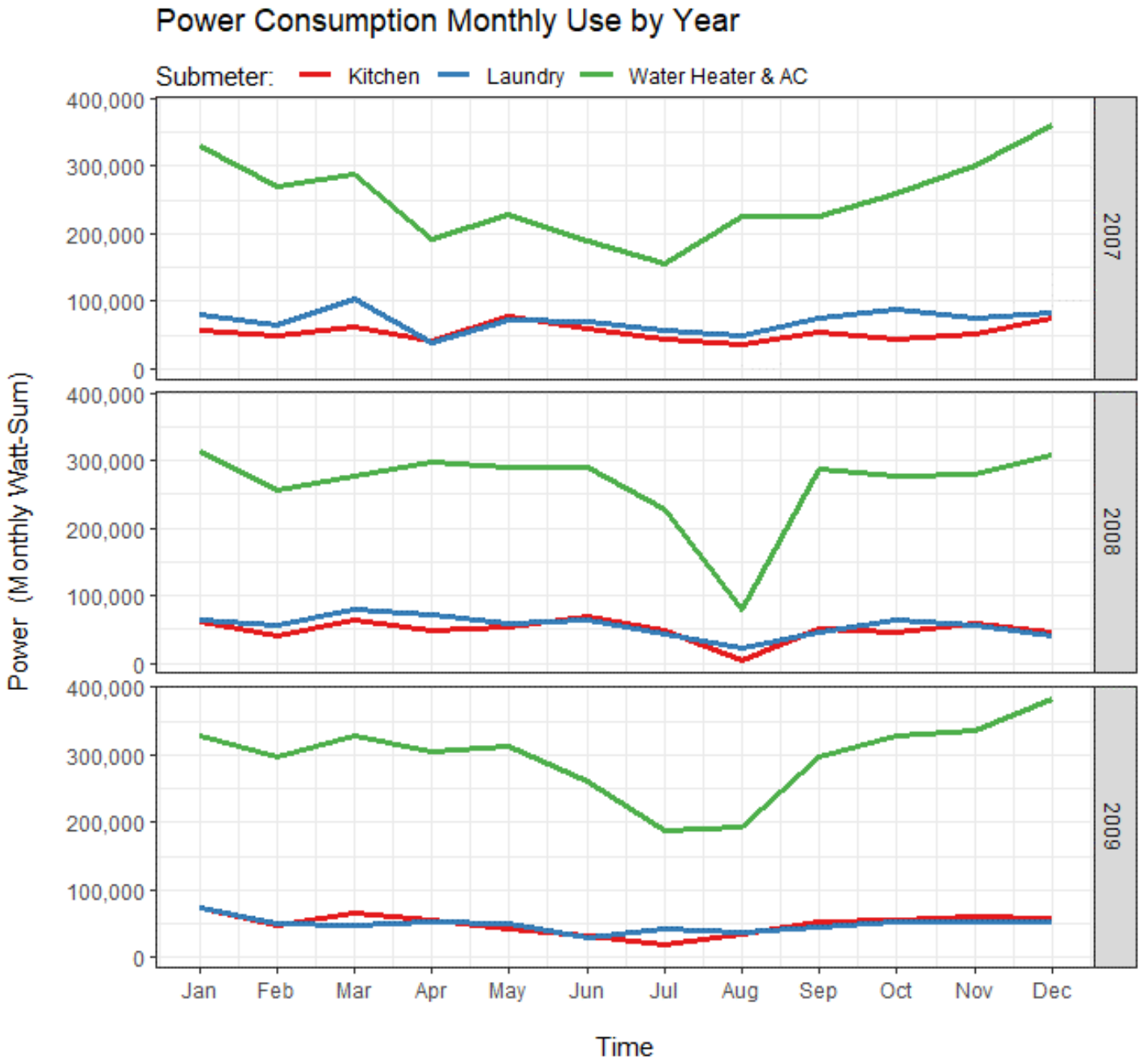
Sub-meter 2: Laundry
- Total energy used (2,108,410 Watts)
- Average 1.34 Watts per minute
- Energy range (0-78 Watts)

Sub-meter 3: Water Heater & AC
- Most total energy used (9,758,843 Watts)
- Average 6.21 Watts per minute
- Smallest energy range (0-32 Watts)



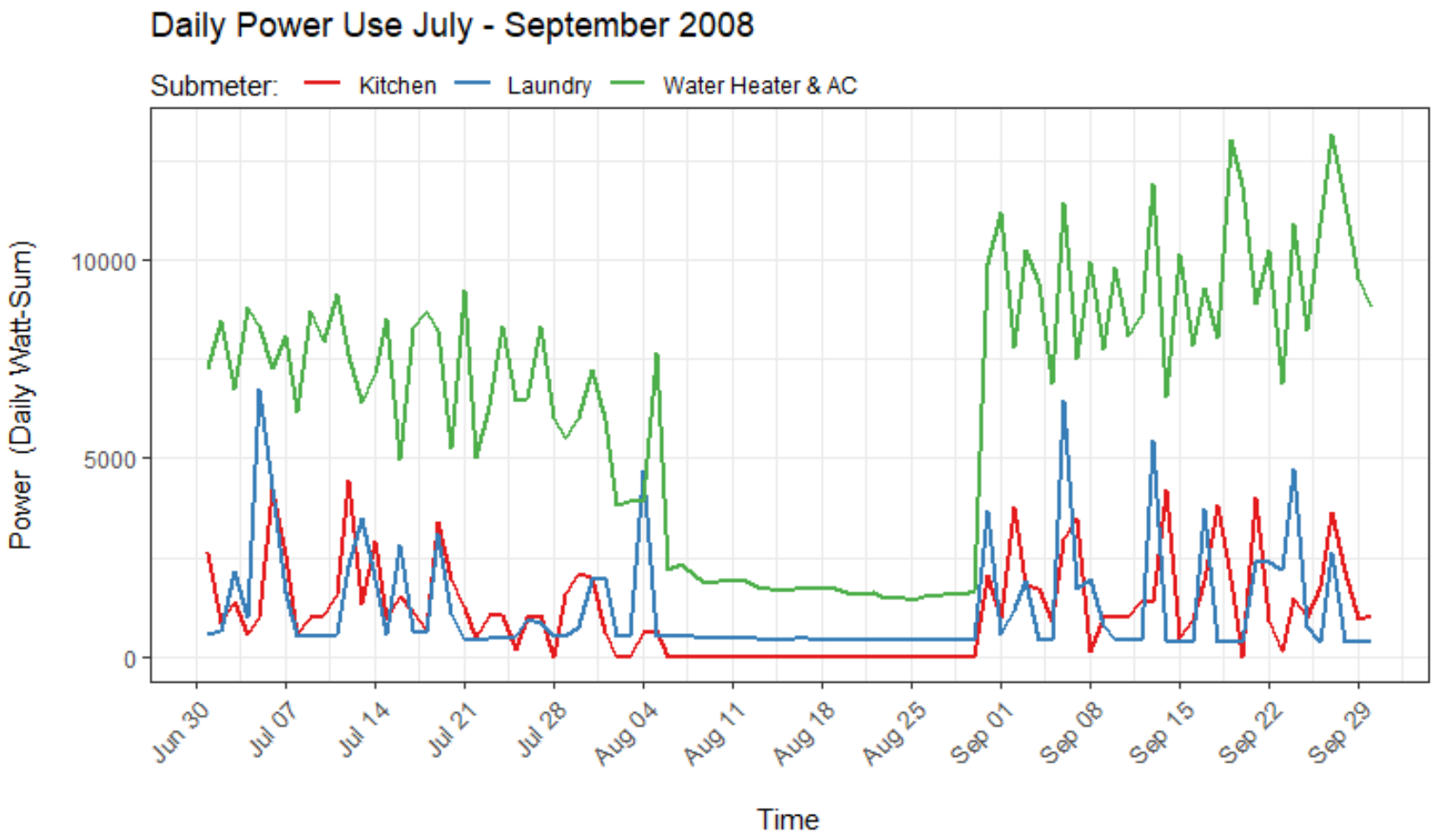
Seasonal Patterns: Monthly Energy Use Across 3 Years

- Water Heater & AC consistently use more energy than other sub-meters across years
- Seasonal patterns show peak energy use for Water Heater & AC in winter months, with steady decline reaching lows in summer months
- Sharp decline for all sub-meters seen in August 2008
- **Recommendation:** Explore Summer 2008 dip



Summer 2008: Daily Energy Use from Jul-Sept 2008

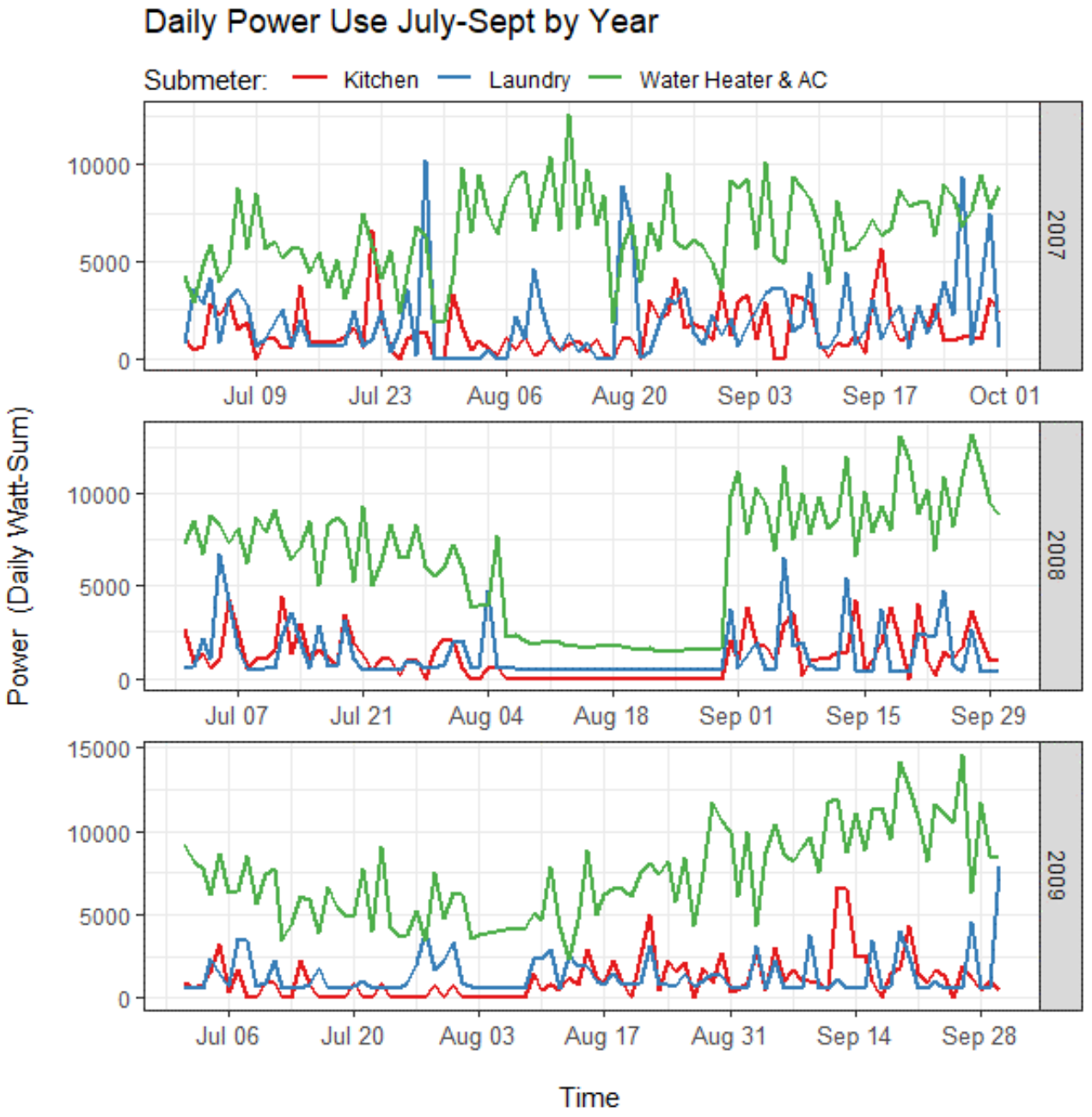
- Notice steep drop in energy use in all sub-meters from Aug 5-Aug 29, 2008
- Water Heater & AC consistently use more energy than other sub-meters, even during August time period
- **Recommendation:** Compare Summer months across years to see if 2008 is pattern or anomaly



Summer Comparison: Daily Energy Use Jul-Sept by Year

- Steep, extended drop in energy use is seen in Aug 2008 only
- Water Heater & AC consistently uses more energy than other sub-meters across years
- Less steep drop is seen for short duration beginning of Aug 2009

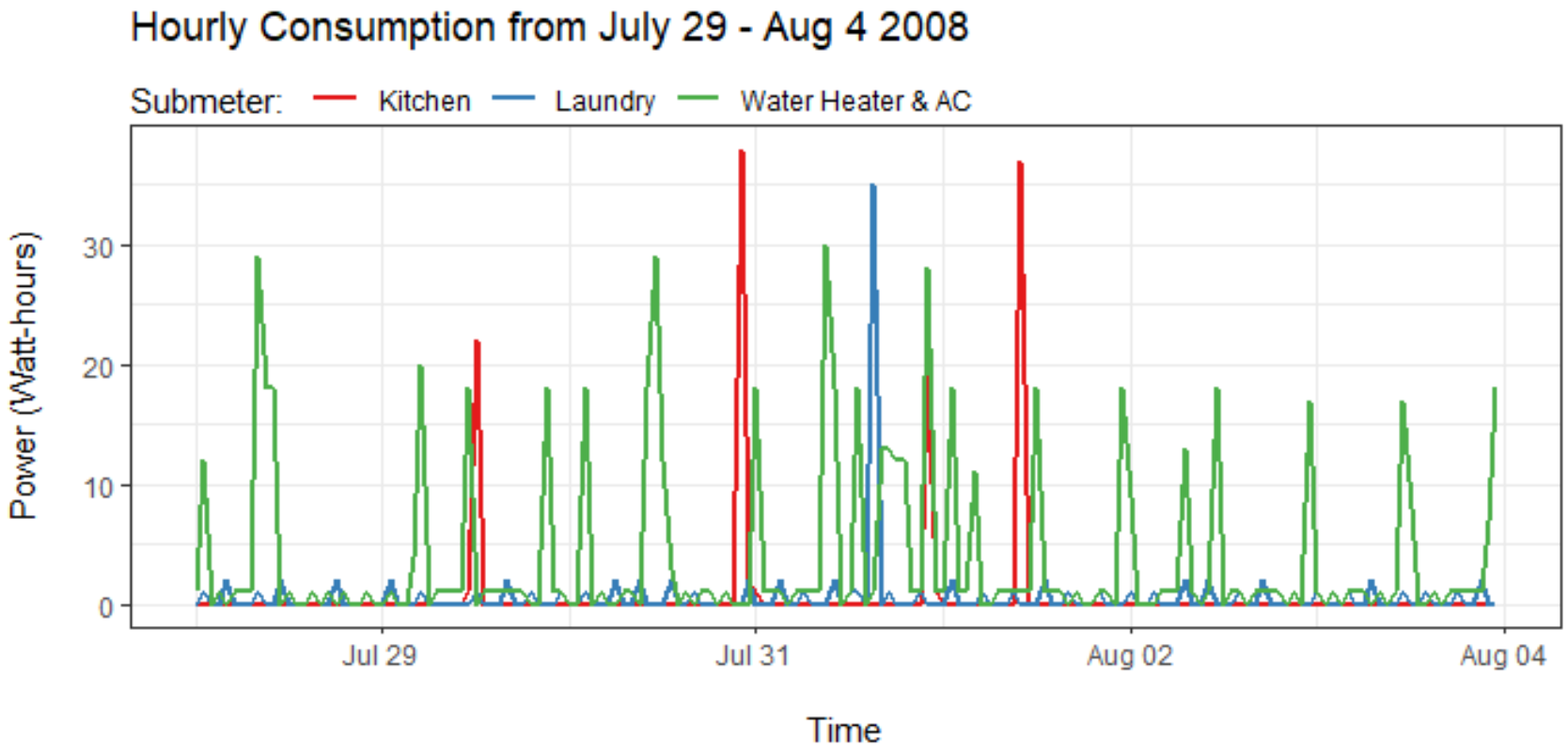
- **Recommendation:** Explore on microscopic level weeks and days within August 2008



Hourly Energy Use for 1 week Jul 29-Aug 4 2008

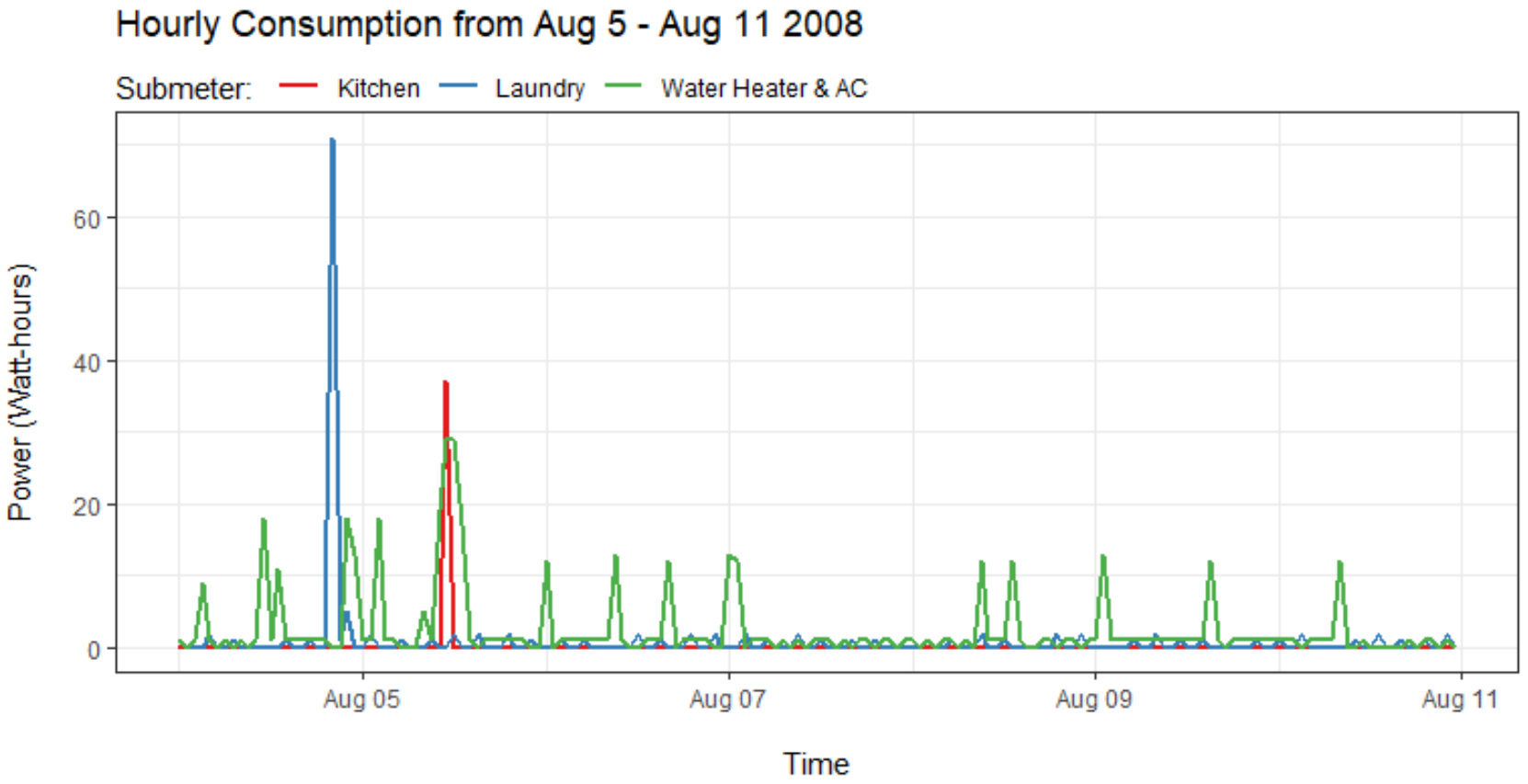
- Kitchen: used 4 times in 1 week period, 19-37 Watts/time
- Laundry: 1 higher use of 35 Watts, otherwise 2-3 Watts regular intervals
- Water Heater/AC: Range of 2-30 Watts used more frequently throughout the week

- **Recommendation:** Explore hourly use the following week



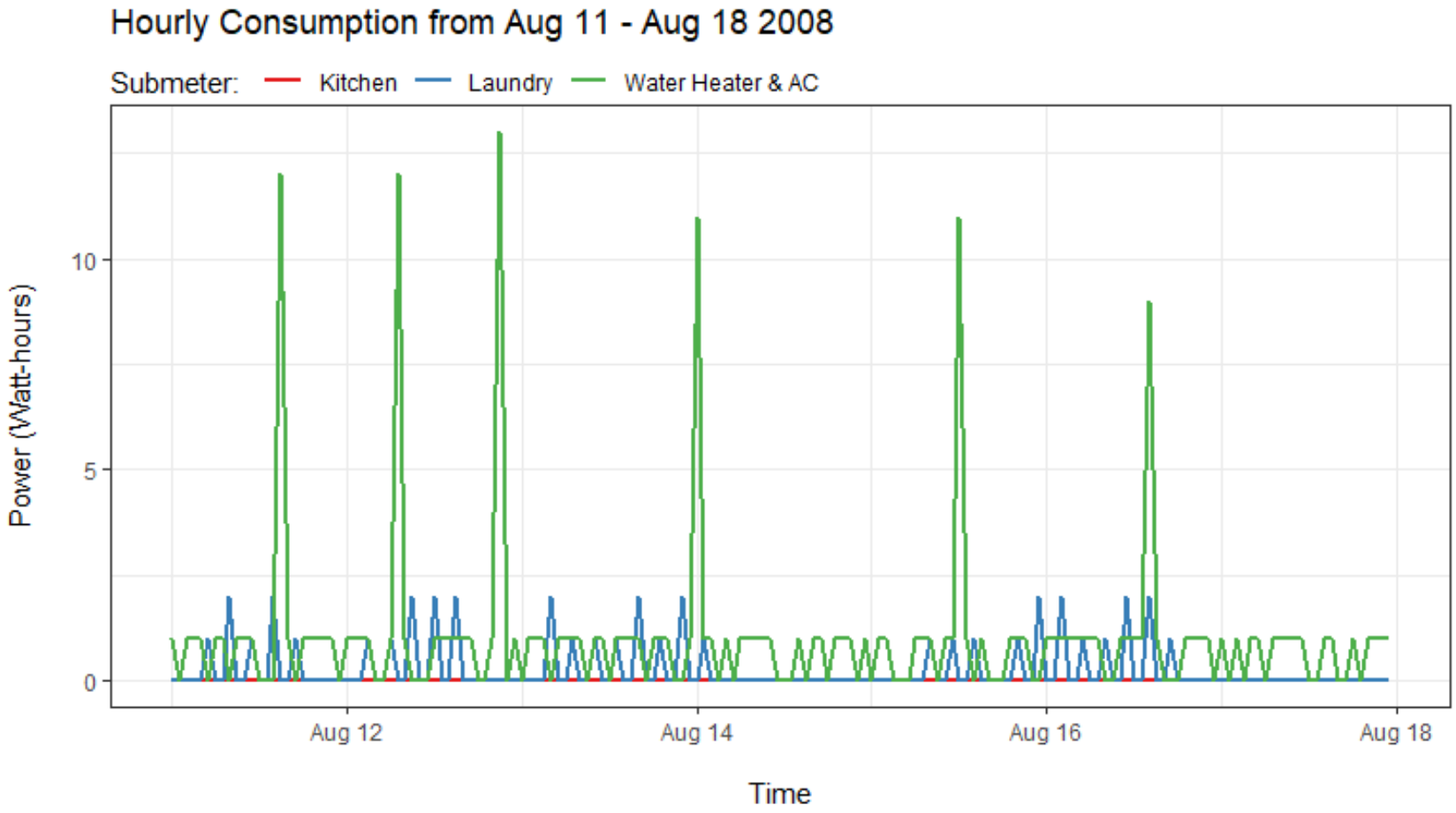
Hourly Energy Use for 1 Week: Aug 4-11 2008

- Noticeable difference in energy use Aug 5 on.
- Kitchen: reveals 1 spike of 39 Watts on Aug 5, with no more use
- Laundry: 1 spike of 71 Watts late Aug 4. Can see 2-3 Watts intervals rest of week.
- Water Heater/AC: High of 30 Watts occurred on Aug 5, followed by 1-2 Watt regular intervals with 12-Watt spikes about once/day
- **Recommendation:** Explore hourly use the following week



Hourly Energy Use for 1 Week: Aug 11-18 2008

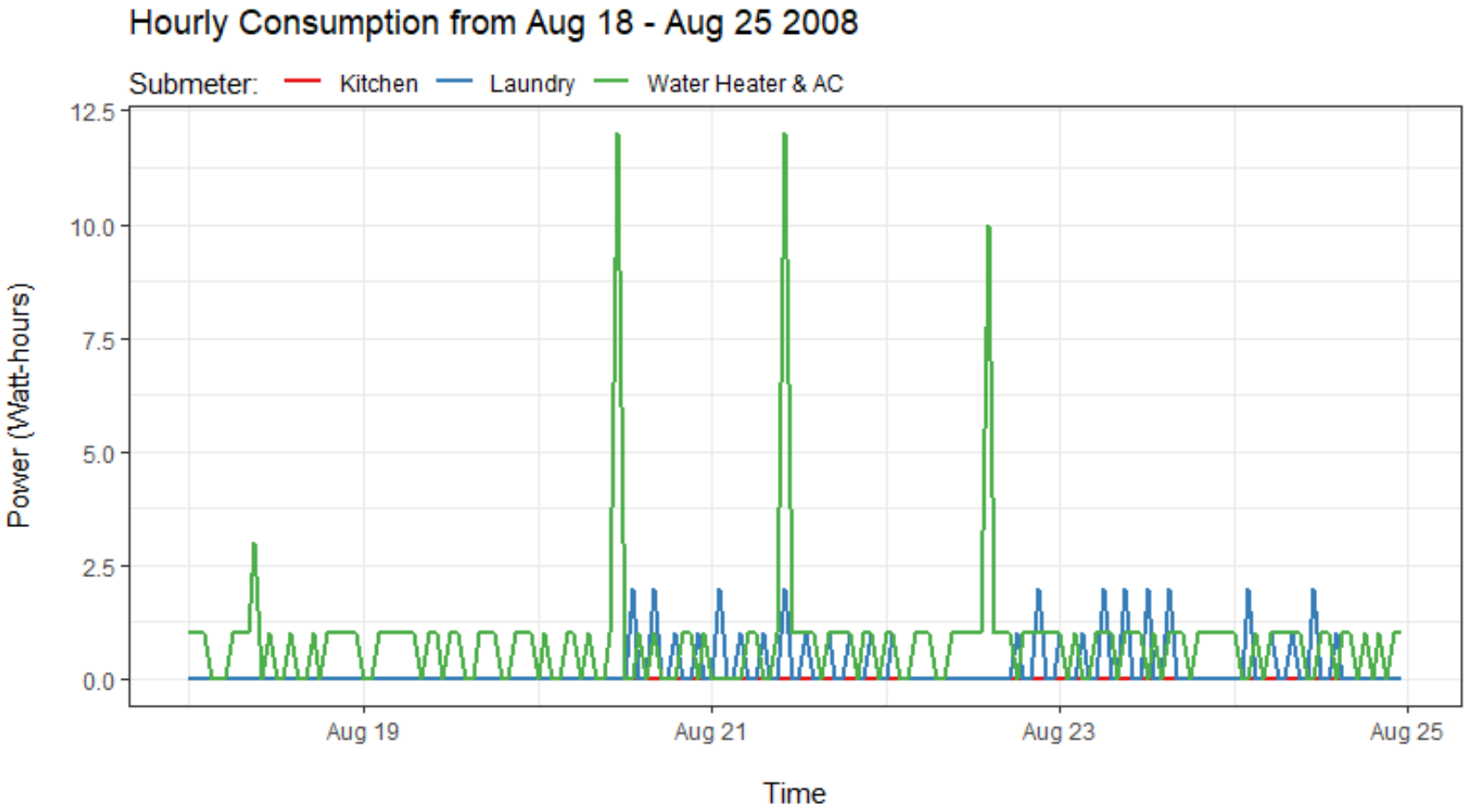
- Kitchen: Appears to be no energy use
- Laundry: 1-2 Watts daily intervals, however, also notice time periods of no energy use
- Water Heater/AC: 1-Watt regular intervals with 12-Watt spikes about once/day
- **Recommendation:** Explore hourly use the following week



Hourly Energy Use for 1 Week: Aug 18-25 2008

- Kitchen: Appears to be no energy use
- Laundry: Appears no energy used Aug 18-19, but used other days
- Water Heater/AC: 1 Watt regular daily intervals, with some spikes

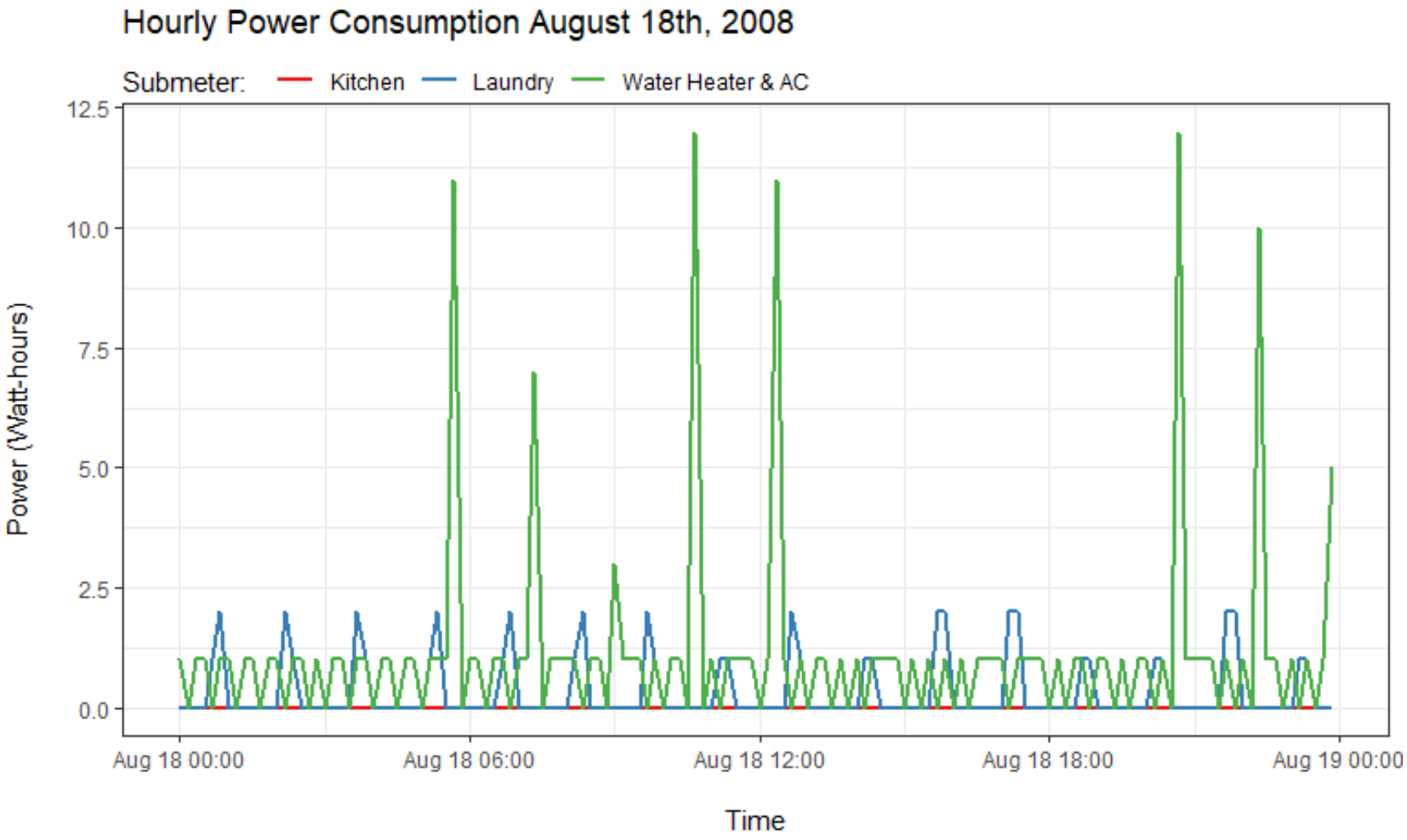
- **Recommendation:** Explore hourly use Aug 18 to see if Laundry room sub-meter is used or not



Hourly Energy Use for 1 Day: Aug 18, 2008

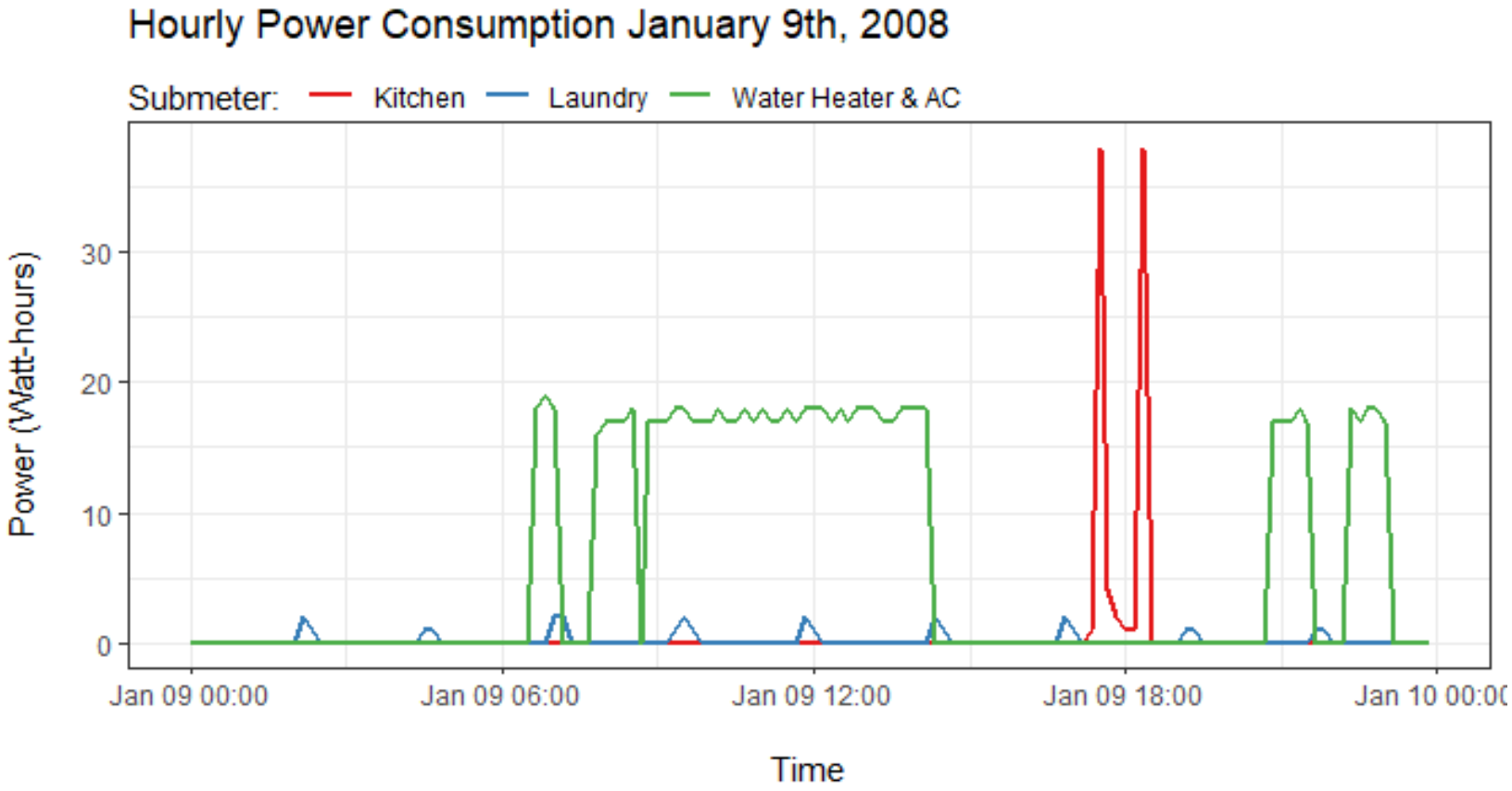
- Kitchen: No energy used
- Laundry: Reveals energy is being used at 1-2 Watt regular intervals
- Water Heater/AC: 1-Watt hourly intervals with spikes throughout the day

Recommendation: Compare sub-meter energy use to another day in different time period



Hourly Energy Use for 1 Day: Jan 9, 2008

- Energy use in kitchen indicates residence was occupied.
- Laundry has same 1-2 Watt pattern as Aug 18, 2008.
- Water Heater & AC consistently run during the day on this day in January



Top Insights from Energy Visualizations

- Water Heater & AC sub-meter consistently use more energy than other sub-meters all year, with peak in winter and low in summer months
- Sharp extended decline for all sub-meters seen from Aug 5th-31st 2008
  - This decline is atypical of all other time periods
  - No energy was used from kitchen sub-meter from Aug 6th-31st
  - Lower energy use than typically seen in summer from Laundry and Water Heater/AC sub-meters
- Energy use analysis recommendation is that residence was not occupied from Aug 6th-31st, 2008 and was occupied all other days within July-September 2008 time frame.

Forecasting Energy Use into 2010

Utilize various forecasting techniques on each sub-meter to predict energy use into 2010:

- Time Series Visualizations
- Seasonal Forecasting Visuals
- A Deeper Look at Seasonality, Trends, and Randomness in Energy Use
- Non-Seasonal Forecasting

Time-Series Observation Frequency

Sub-meter 1 Kitchen: Collected 1 observation daily at 6:00pm

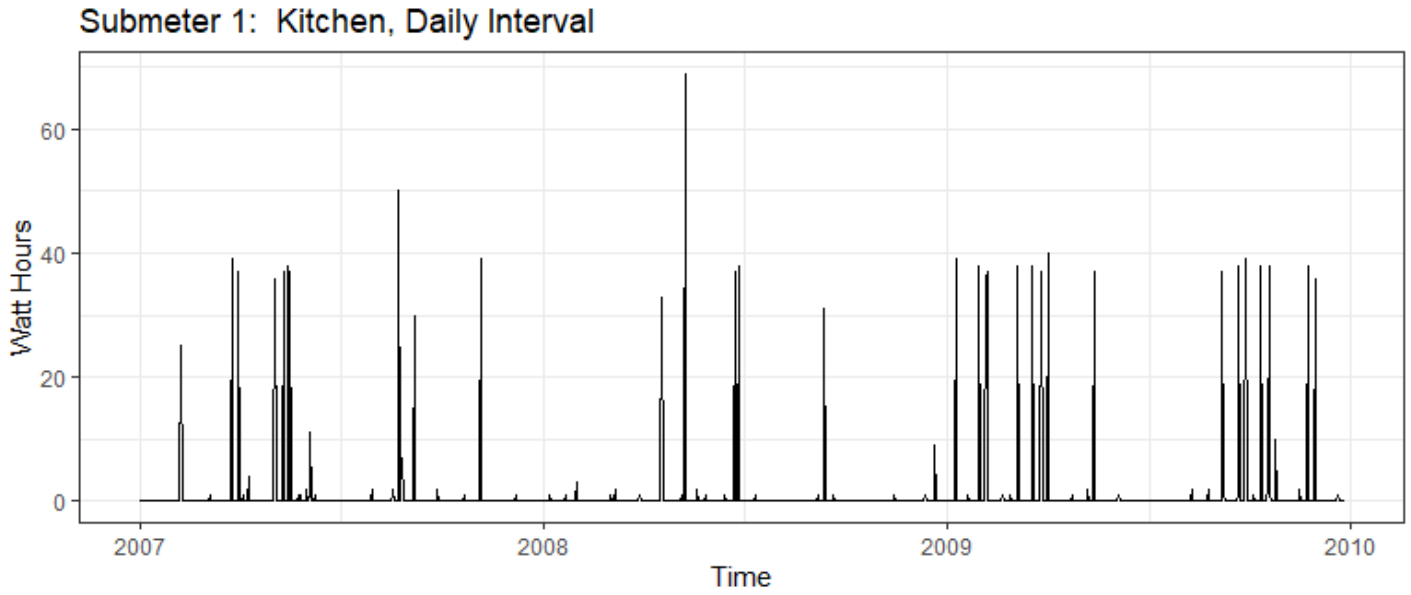
Sub-meter 2 Laundry: Collected 1 observation daily at 7:00pm

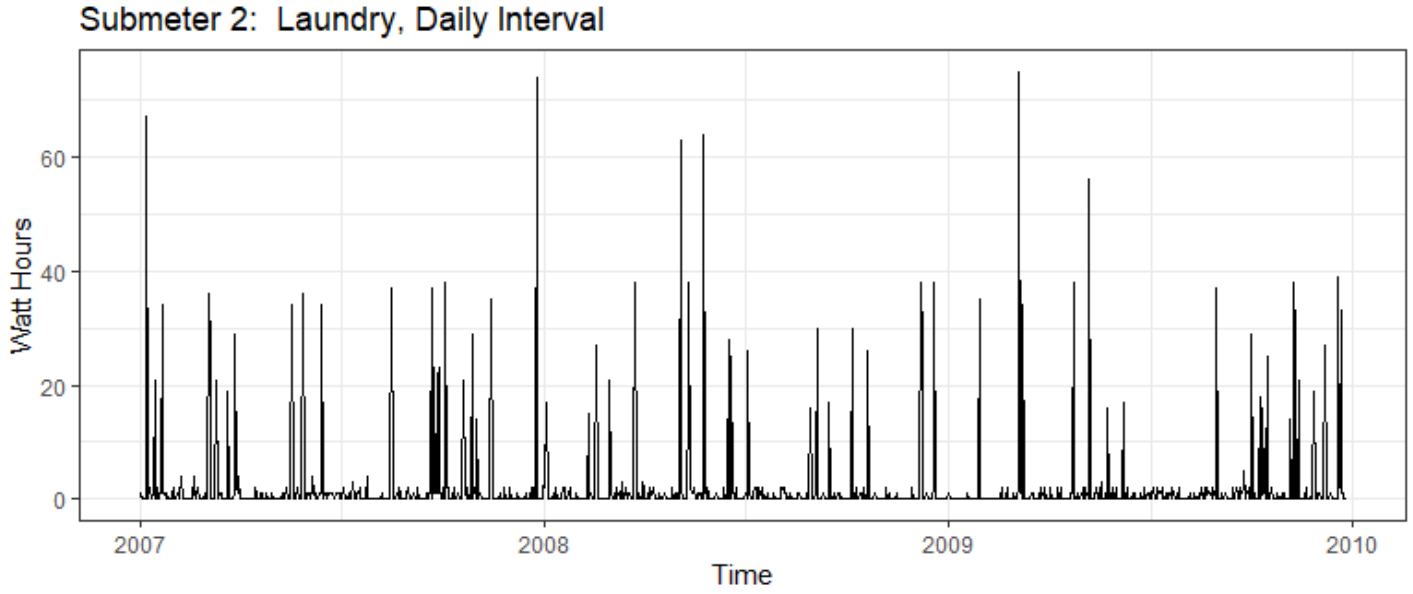
Sub-meter 3 Water Heater & AC: Collected 1 observation weekly on Monday at 8:00pm

Sub-meters 1 and 2 were collected more frequently since total use was significantly lower than Sub-meter 3

Time Series Visualizations 3-Year Period

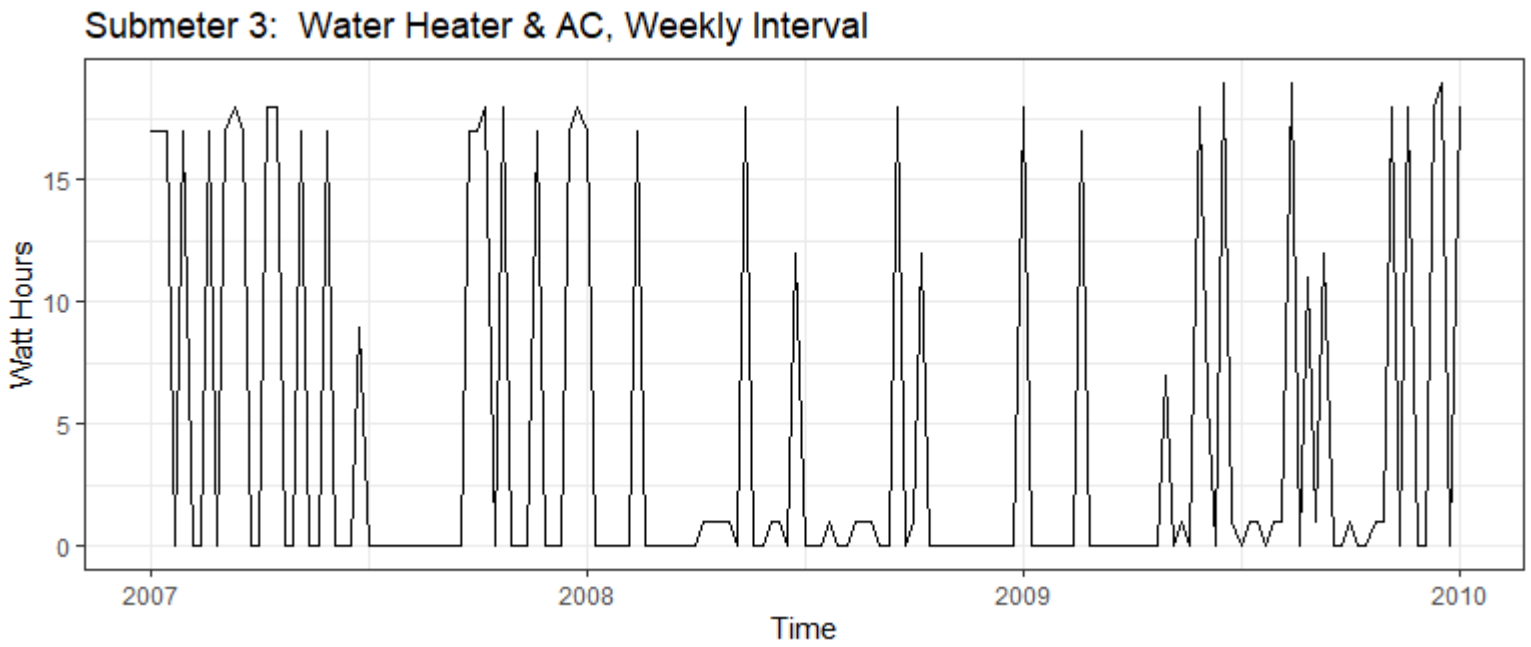
- Kitchen sub-meter
  - Less frequent spikes
  - Yields lowest total energy use (1,819,989 Watts)
- Laundry sub-meter
  - More frequent spikes than kitchen
  - Yields slightly more total energy than kitchen (2,108,410 Watts)





Time Series Visualizations 3-Year Period

- Water Heater & AC
  - Collected on Weekly basis vs. Daily
  - Shows relatively consistent energy use over time
  - Some lulls in 2008

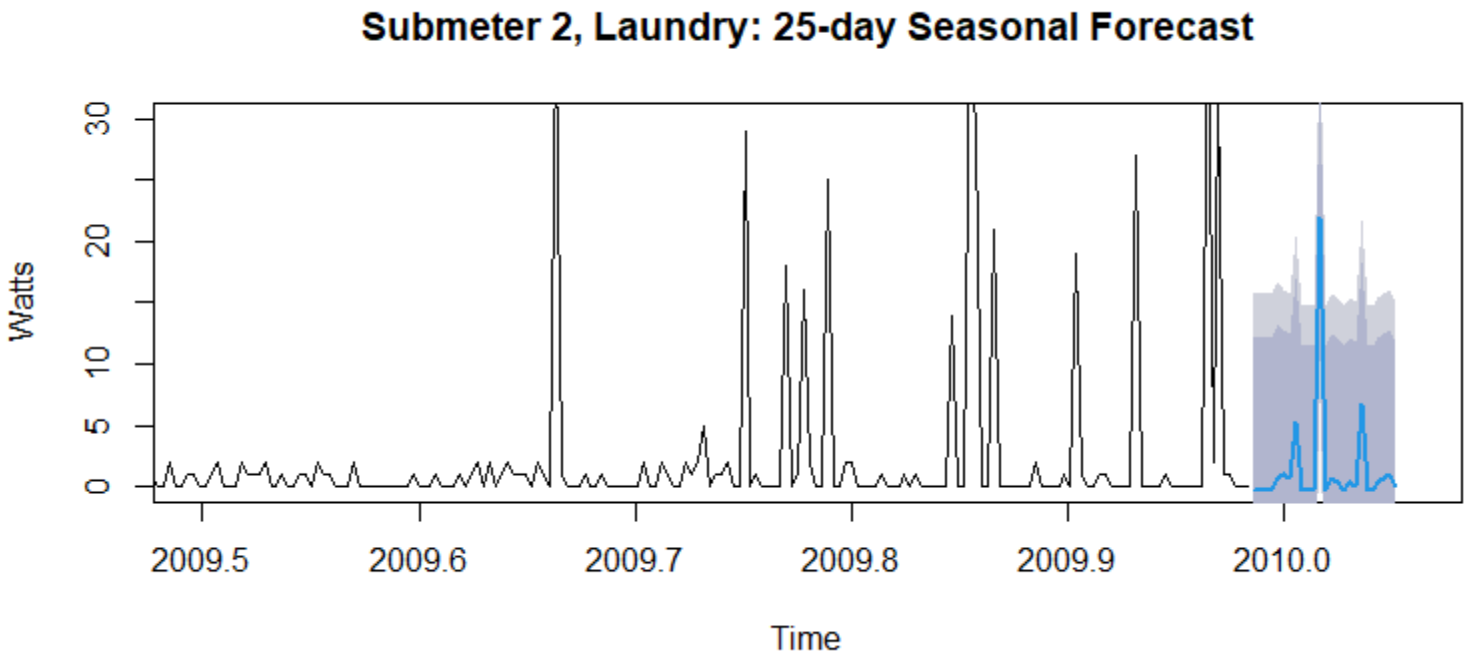


25-Day Linear Regression Forecast

- Sub-meter 1: Kitchen
  - Daily observation frequency at 6:00pm over 3-year time period
  - Forecasted energy use ranges from 0.47 to 0.95, with sharp peak to 13.6 on day 14
  - R2 (confidence): .313
  - RMSE (error): 6.56

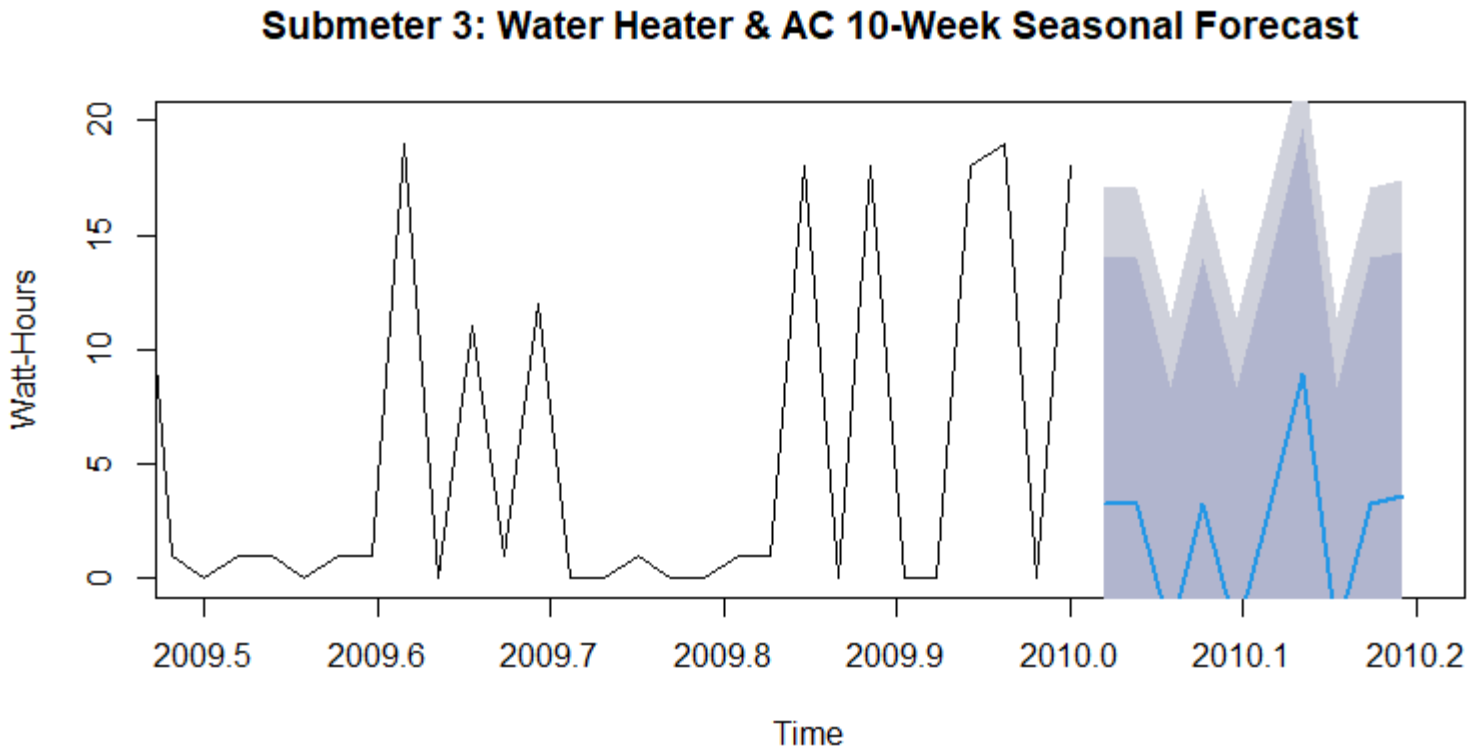
25-Day Linear Regression Forecast

- Sub-meter 2: Laundry
  - Daily observation frequency at 7:00pm over 3-year time period
  - Forecasted energy use line has negative values, ranges from -0.32 to a peak of 22
  - R2 (confidence): .334
  - RMSE (error): 7.91



10-Week Linear Regression Forecast

- Sub-meter 3: Water Heater & AC
  - Weekly observation frequency, Mondays at 8:00pm over 3-year time period
  - Forecasted energy use line has negative values, ranges from -2.37 to 8.95
  - R2 (confidence): .358
  - RMSE (error): 7.08



25-Day Seasonal Forecast: R2 & RMSE

- R2 (confidence): the closer to 1.0, the better
- RMSE (error): the lower it is to 0, the better
- Overall, the forecast for sub-meter 3 is most accurate
- All predicted negative values

	R2	RMSE	80% low	80% high
Kitchen	.313	6.56	-9.8	10.7
Laundry	.334	7.91	-12.7	33.7
Water Heater/AC	.358	7.08	-13.1	20

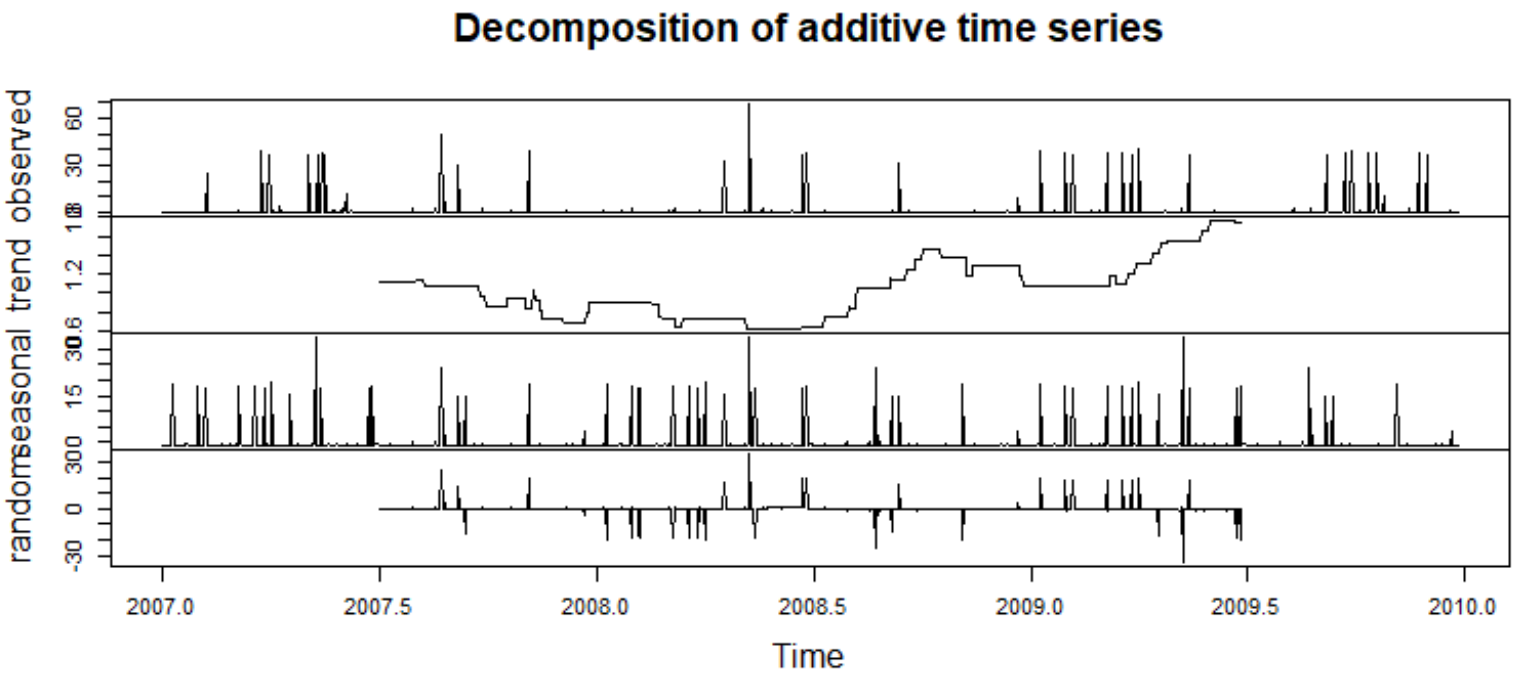
Trend, Seasonality, and Randomness Breakdown

Kitchen Sub-meter 1

Trend reveals steady decline from 1.1 mid-2007 to low of 0.6 mid-2008 then rise to 1.8 mid-2009

Reveals seasonality

Reveals some randomness



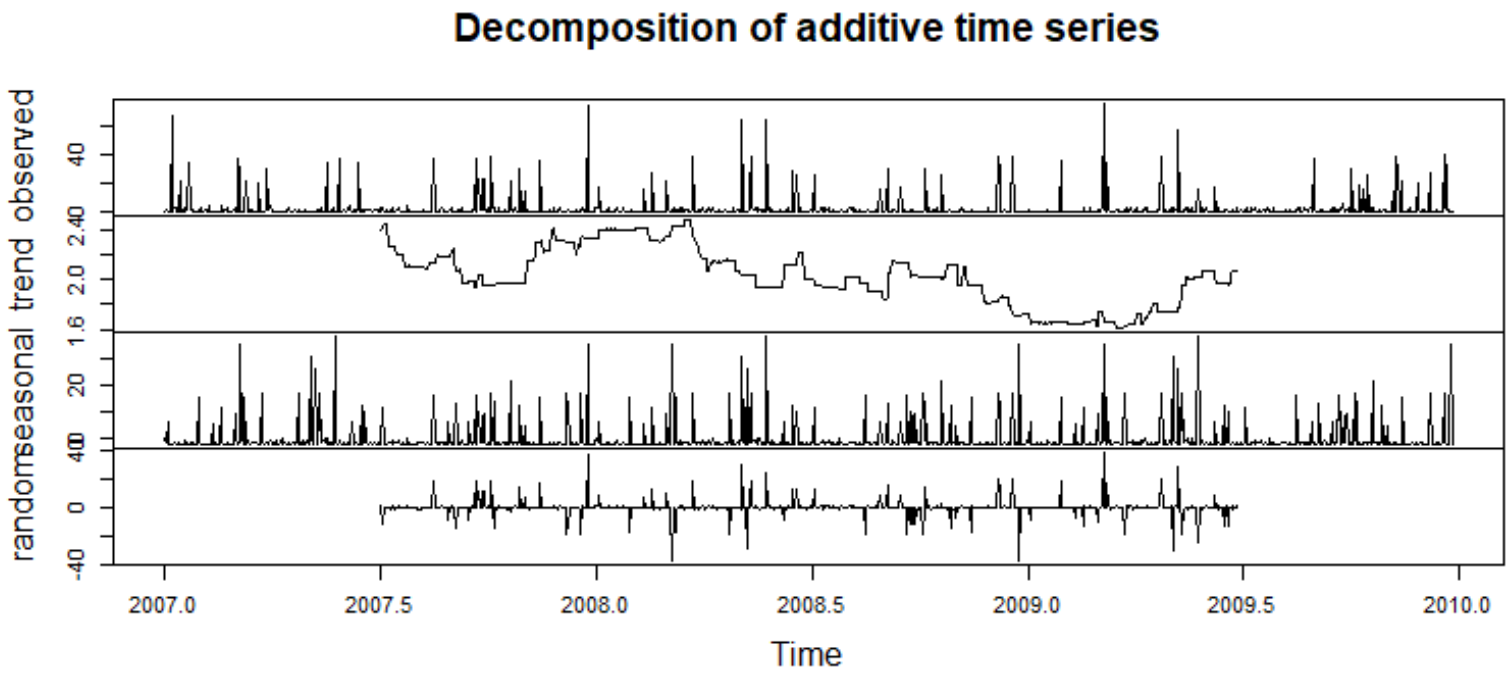
Trend, Seasonality, and Randomness Breakdown

Laundry Sub-meter 2

Trend reveals decline from high of 2.4 March 2008 to low of 1.6 in March 2009, then rise to 2.1 mid-2009

Reveals significant seasonality

Reveals some randomness



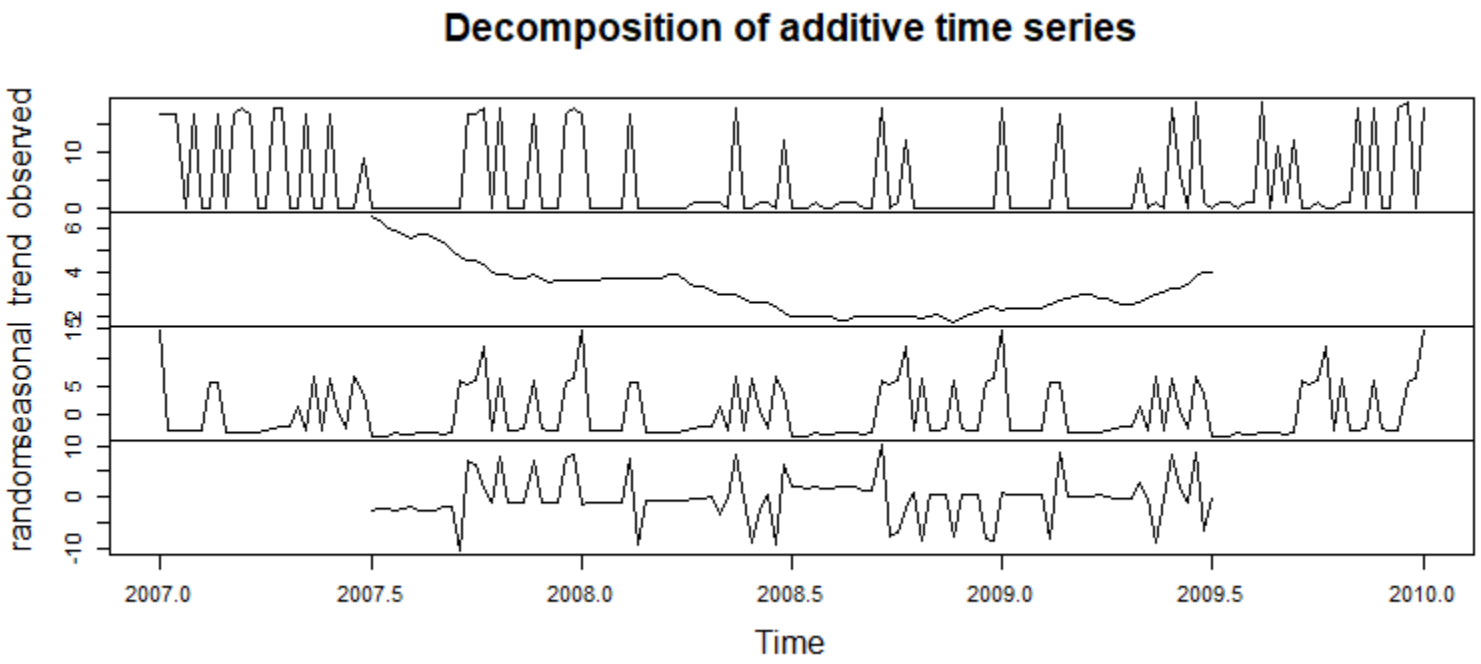
Trend, Seasonality, and Randomness Breakdown

Water Heater & AC Sub-meter 3

Trend reveals steady decline from high of 6 mid-2007 to low of 1 late-2008, then increase to 4 mid-2009

Seasonal effects show decreased use Q3s and peak use Q1s

Reveals some randomness



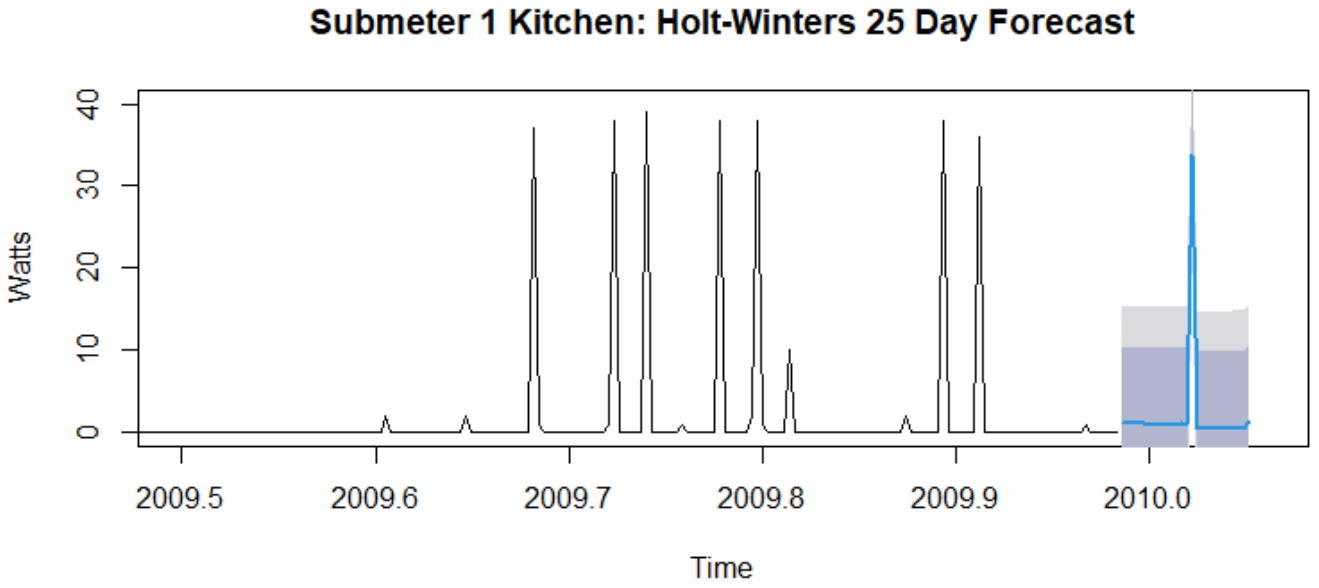
Trend, Seasonality, and Randomness

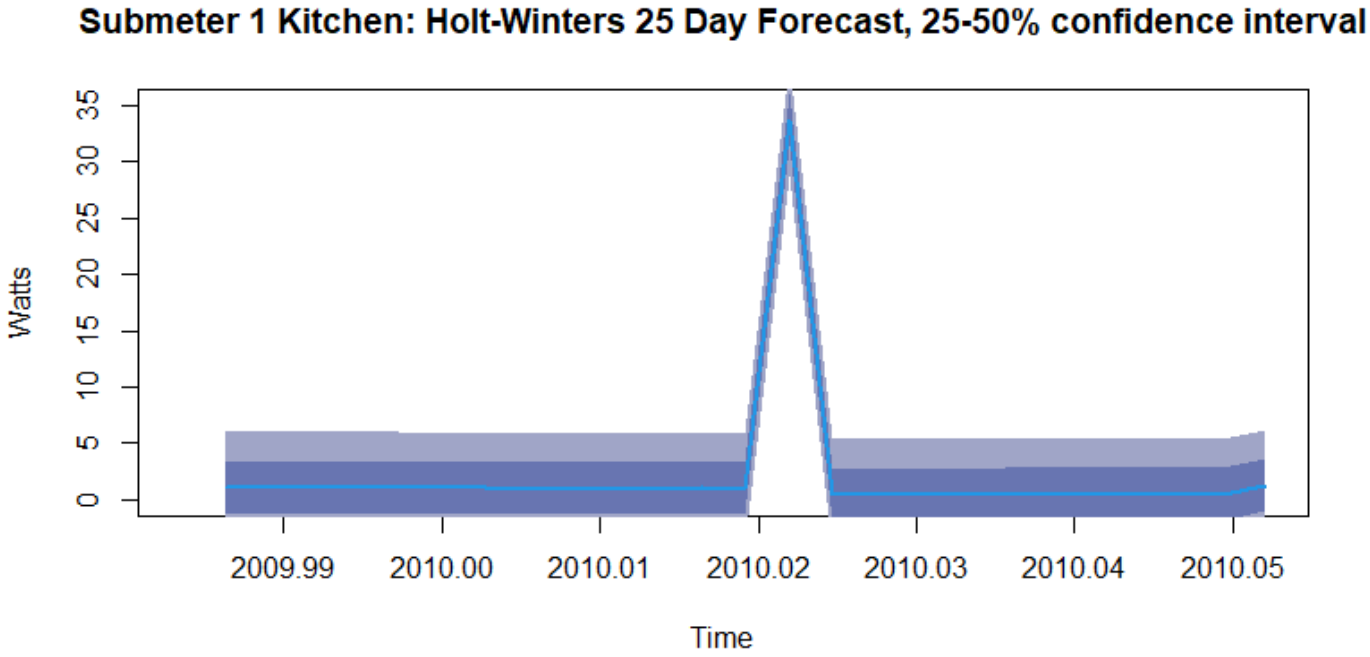
- Summary Statistics

	Seasonal	Trend	Random	Observations
Kitchen	1090	1090	1090	365
Laundry	1090	1090	1090	365
Water Heater/ AC	157	157	157	52

Holt-Winters 25-Day Forecast: Sub 1 Kitchen

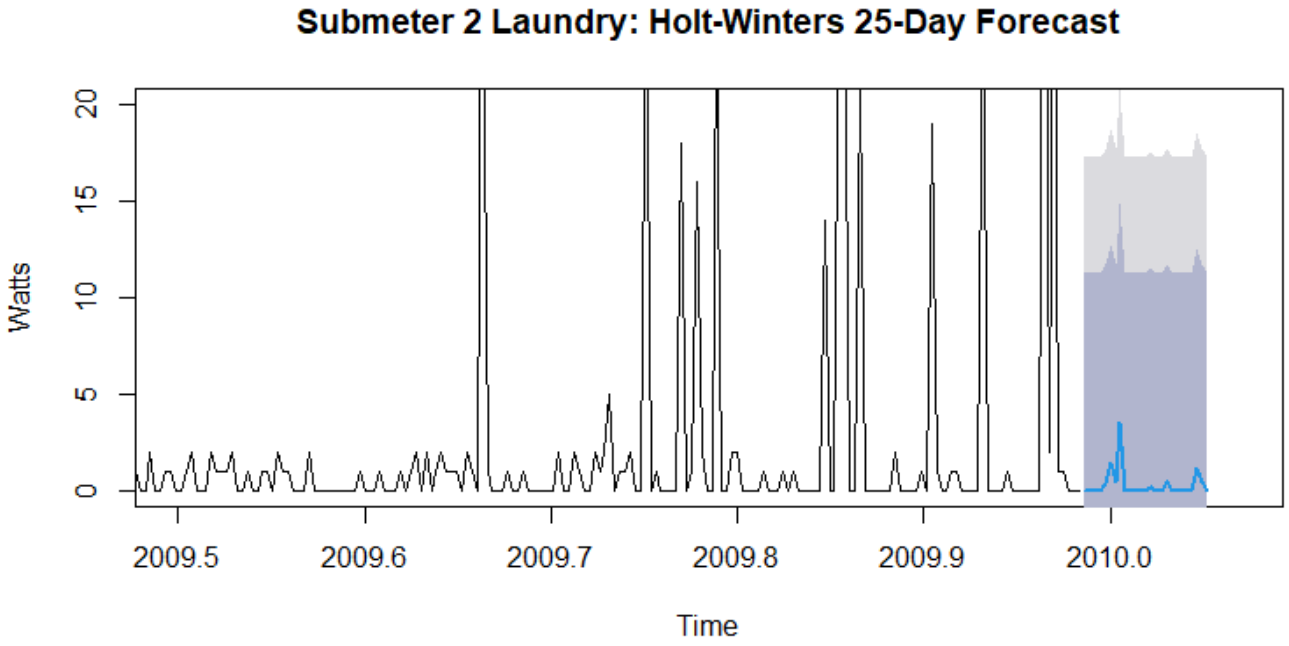
- Includes seasonality
- Daily observation frequency at 6:00pm for 3-year time period
- Forecasted energy use hovers around 0.5 to 1.28 watts per hour
- One sharp peak up to 33.7 watts on day 13, then back down to 0.5
- Overall, predictions similar to average energy use in kitchen from 2007-2009

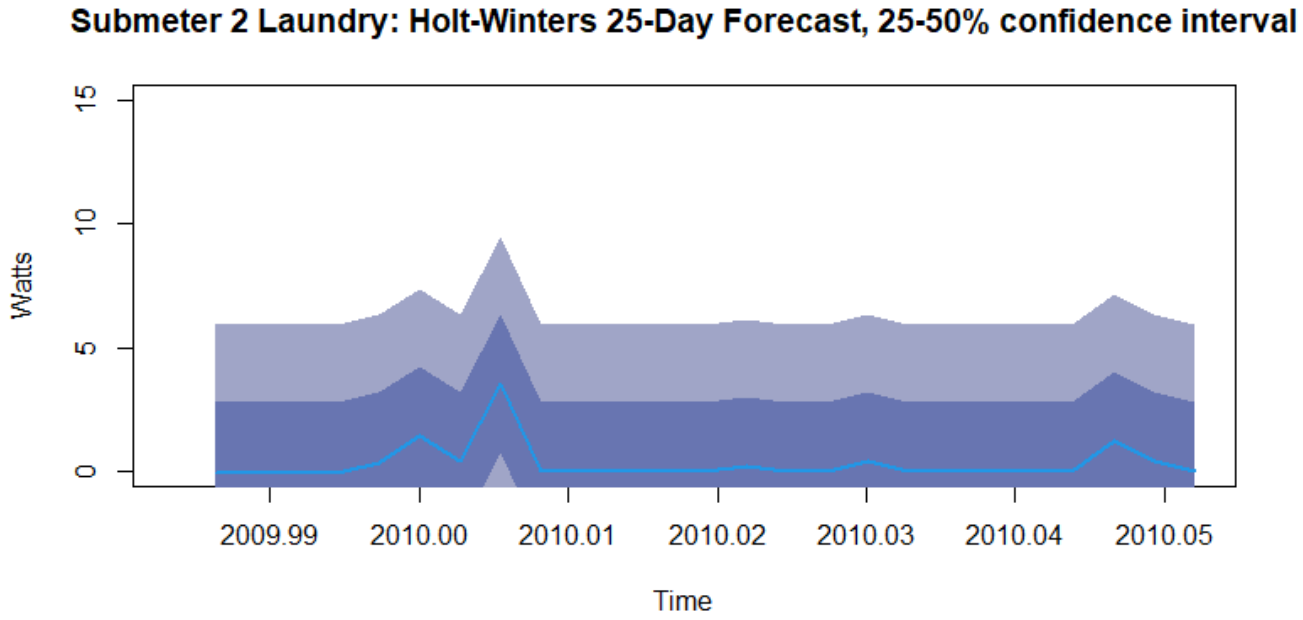




Holt-Winters 25-Day Forecast: Sub 2 Laundry

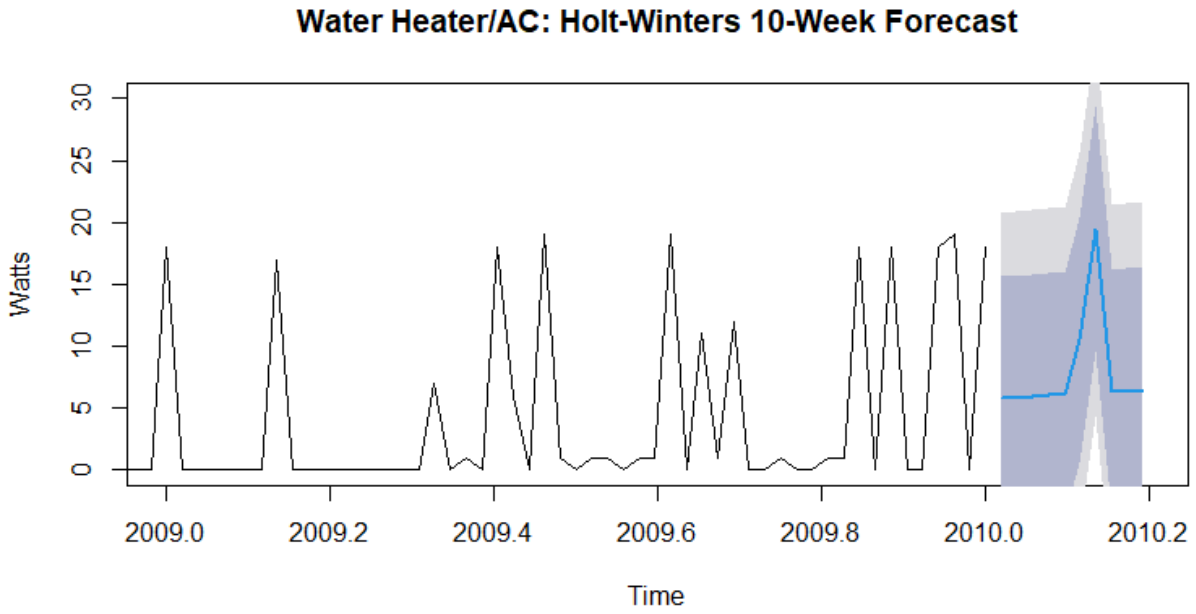
- Includes seasonality
- Daily observation frequency at 7:00pm for 3-year time period
- Forecasted energy use for submeter 2 includes negative values, and ranges from -0.06 to 3.54 (day 8), not as useful

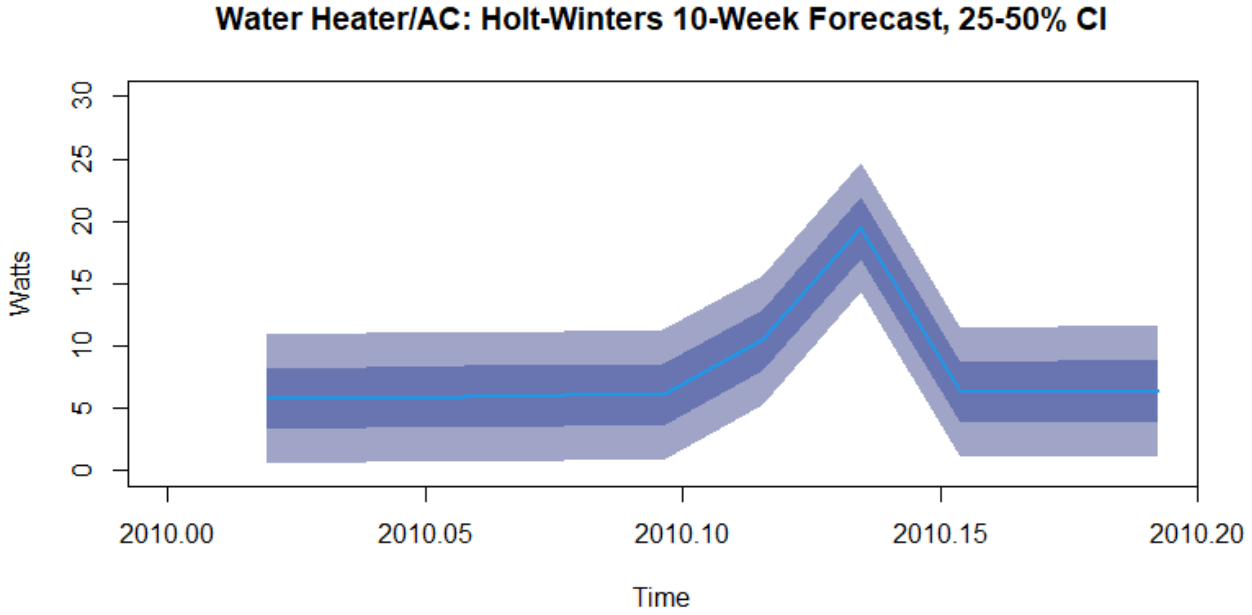




Holt-Winters 10-Week Forecast: Water-Heater/AC

- Includes seasonality
- Weekly observation frequency at 8:00pm for 3-year time period
- Forecasted energy use between 5.6 to 6.6 watts per hour primarily
- Increases to 10.5 week 6, peaks at 19.5 week 7, then back to 6 watts week 8
- Overall, predictions similar to average Water Heater/AC use from 2007-2009



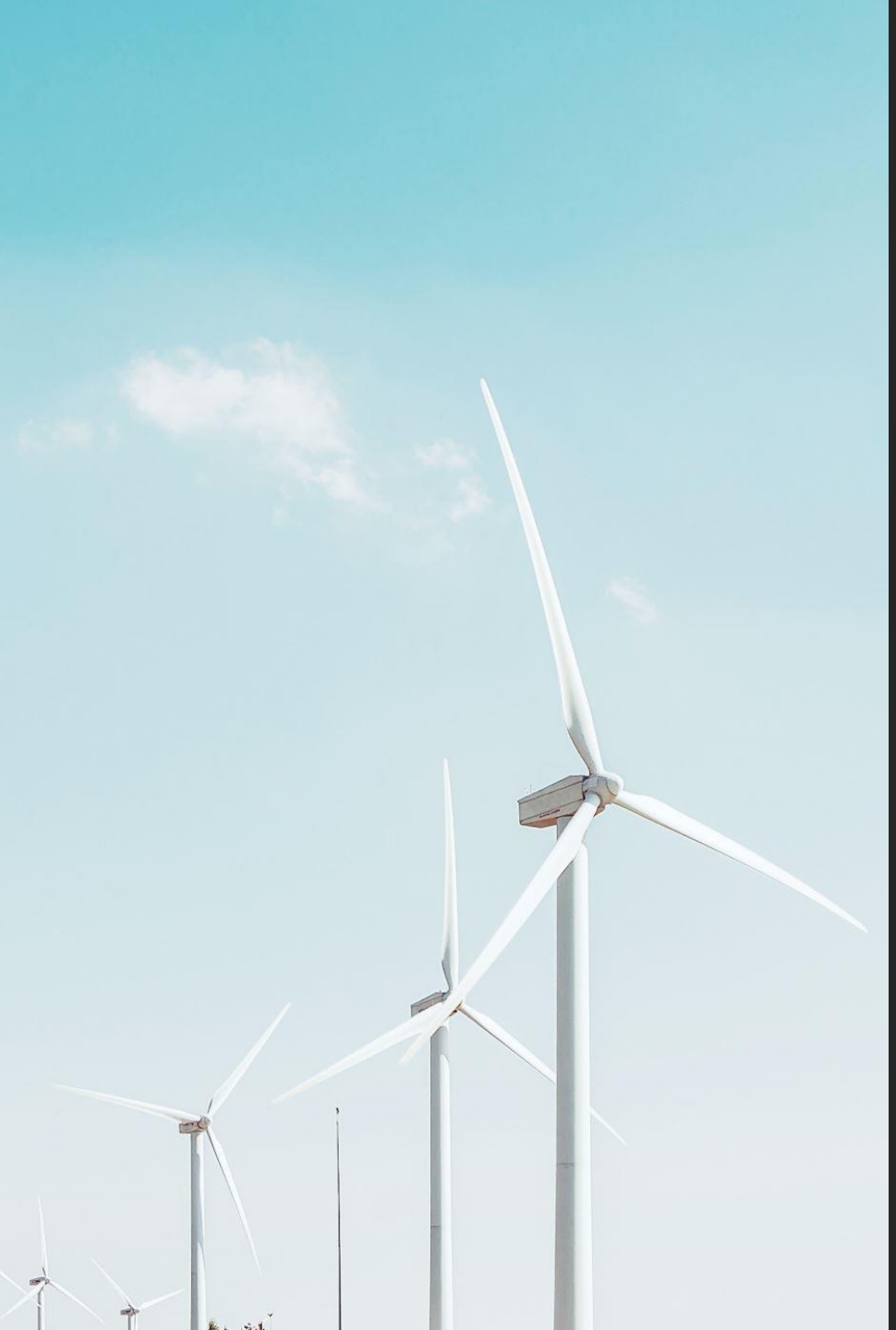


Insights from Energy Forecasting

- Holt-winters forecast for Submeter 1 (Kitchen) and Submeter 3 (Water Heater/AC):
  - provided positive forecast line while accounting for seasonality in the data
  - forecast line is similar to average use in both submeters acress 2007-2009
- Both methods forecasted negative energy use for Submeter 2 (Laundry)
  - Other time subsets may be needed to forecast positive values for energy use in Submeter 2

Summary

- Conducted in-depth analysis of power use by sub-meter for residential home from 2007 to 2010.
- Visualized energy use patterns on high level (3-year time period) and precise-level (during Summer of 2008).
- Used electrical power data from 2007 through 2009 to forecast energy use by sub-meter into 2010.
- Gained insights from visualizations and forecasts.



Energy Saving Recommendations

- Reset HVAC controls to reduce daily Water Heater & AC spikes noted throughout the year to save energy
- Reduce the length of time AC and/or Water Heater is programmed to turn on during the day
- Reset AC thermometer in winter months to higher temperature setting to reduce energy use during peak season
- Minimize sharp peaks in demand, as observed in July 2008, to cut energy costs

Lessons Learned

- DateTime is extremely difficult to pull apart, subset, and analyze.
- Tidyr gather() and Dplyr filter(), summarise(), group_by(), and the pipe %>% were lifesavers once I figured out how to use.
- Although plan of attack encouraged plotly, I quickly learned that I prefer ggplot2, code seemed more efficient.
- Just when I was about to give up, I finally discovered the code to label DateTime, which meant a lot to me: P <- scale_x_date(labels = date_format('%b %d'), breaks = date_breaks('1 day')) +

  theme(axis.text.x = element_text(angle = 45, hjust = 1, vjust = 1, size = 8)) +

I learned the hard way that we should keep seasonality within Holt-Winters forecast to allow an element of seasonality applied to our data.