AN EXAMPLE OF WHAT WE DO

For the sake of clarity, annotations and comments for context and direction will be provided to you in this format, which maps to the "annotation and comment" style in this document's style sheet.

1 Site A

HOME CHARACTERISTICS EXAMPLE[1]

This home is a single level, 2-bedroom, 2-bath bungalow with a conditioned attached garage in a new subdivision in the outskirts of Site A, MT. The main living spaces are in a great room format. The occupants are a retired couple. Part of the garage is used as an office and there is a sauna in the master bathroom. This home uses both gas and electric systems.

KEY METRICS FOR SITE B

Colourless Green worked with our client to create a reference table for each site in order to allow for quick and easy access to the numbers provided in the analysis. These allow for the sites to be easily compared against one another.

Metric	Values
Period of analysis	2013-06-01 to 2014-05-31
Net conditioned floor area	1,969 ft^2
Design space-heating load	18,347 BTU/hr
Total UA	262 BTU/hr-°F
Energy Performance Rating	27.3M BTU/yr
Energy Use	
Electric energy use	14,772 kWh
Natural gas use	None
BTU-equivalent energy use	50.41 M BTU
Space conditioning energy use	3,906 kWh
Domestic water heating energy use	3,157 kWh
Plug loads and lighting energy use	7,708 kWh

[1] As this is an example, the report has 10 sites; we will not be able to add up or find consistency in these numbers as the author has cut-and-pasted several sections together to give the reader a sample picture; in order to be brief, this cohesion is lost

Energy Use per square foot	BTU/ft²	kWh/ft²
House	25,602	7.50
Space conditioning systems[2]	6,771	1.98
Domestic water heating system	5,473	1.60
Plug loads and lighting	13,362	3.91

Figure 1.1 Summary table for Site B

Total Energy Use

1.1.1 Electric Energy

Bolded items are used throughout the report to allow someone to skim for relevant facts and figures. This makes the report easier to digest for a casual reader.

Site A used a total of **4,972 kWh** (16.97M BTU) of electric energy for the analysis period. It displays the characteristics of a home employing both heating and cooling equipment in that the shoulder seasons (spring and autumn) tend to have slightly lower energy use than the summer and winter seasons. The data suggests that more electric heating is done on site than cooling, primarily with the duct heater and the water pumps used for the hydronic loops. This is consistent with the heating-degree days versus cooling-degree days of this site (HDD_{65}=7110; CDD_{65}=840).

The **dominant technologies** are the **duct heater** (9.9% of site power; 494 kWh), **freezer** (10.2%; 508 kWh), **refrigerator** (14.2%; 707 kWh), and **water heater and pumps** (15.9%; 790 kWh). Unmonitored channels account for approximately 29%—1425 kWh— of the energy used in the home.

Site energy is strongly impacted by weather and the space conditioning systems shape site energy, which is not a surprising finding. Figure 1.1 displays the average monthly site energy readings versus outdoor air temperature readings to provide context and to illustrate the seasonality of these energy figures.

[2] Space conditioning systems include the following monitored electrical systems: both DHPs, the fireplace, and the HRV.

Period	Site energy (Σ kWh)	Airport Temperature (μ °F)	Outdoor Temperature sensor (μ °F)
May 2013	362	59.9	58.4
Jun 2013	318	69.0	66.9
Jul 2013	445	76.8	74.9
Aug 2013	444	75.0	74.2
Sep 2013	322	63.6	63.8
Oct 2013	402	44.7	44.8
Nov 2013	442	35.5	36.6
Dec 2013	543	23.3	23.8
Jan 2014	440	30.8	31.4
Feb 2014	519	20.7	20.9
Mar 2014	419	35.1	35.5
Apr 2014	314	48.3	44.8
Analysis Period total	**4,972**	**48.5**	**48.3**

Figure 1.2 Total energy use versus outdoor temperatures

The above figure shows the combined energy in both gas and electric and compares it with outdoor temperatures for reference. The primary items are in black whereas the reference items are greyed out allowing the reader to more easily get at the salient details quickly.

Not all the technologies are monitored, such as interior lighting and plug loads, but Figure 1.3 shows the composition of the monitored (and interpolated unmonitored) technologies compared to the total site energy, denoted as a grey area graph. The red area behind the space conditioning technologies shows the proportion of the space used for space heating.

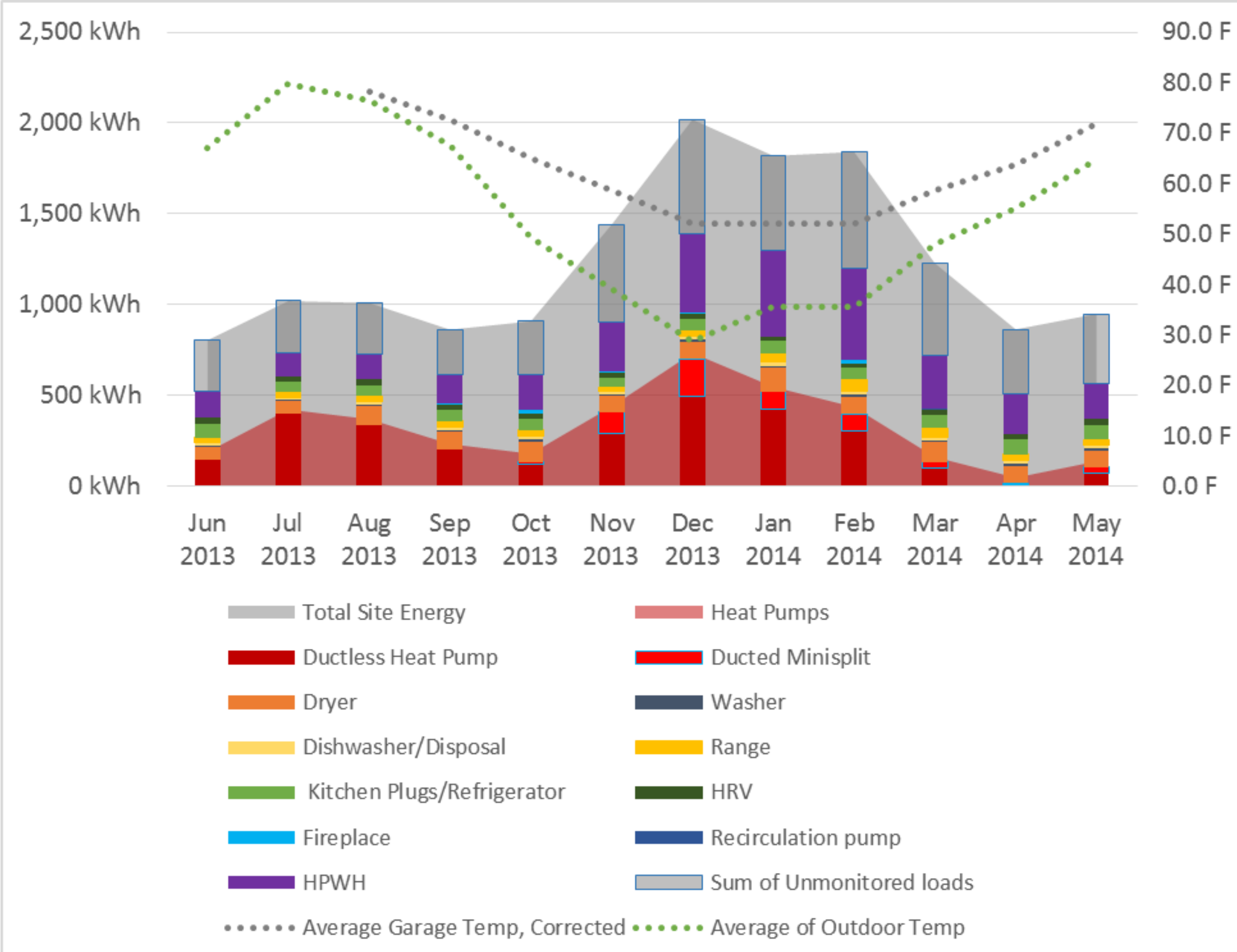

Figure 1.3 Total site energy composition by month

The above graph shows the energy composition of the house compared with the outdoor air temperature readings. This is an extremely dense chart, but allows us to quickly see the patterns and individual components that make up the total site energy. We can see that the heat-pump water heater seems to have a problem starting in November. More on that later…

1.1 Space Conditioning Scatter Plots

1.1.1 DHP defrost cycle energy use

I included these graphics to show the sheer power that Tableau allows us to see. This is minute-level data for 5 months plotting wattage against outdoor air temperatures. This allows us to see at a glance the emerging trends derived from over 500,000 data points. I used this to focus my analysis on the "cloud" in the top right in blue to see why the unit was running at such a high wattage at relatively warm outdoor temperatures. Individual snapshots showed us when the cloud activity was most active.

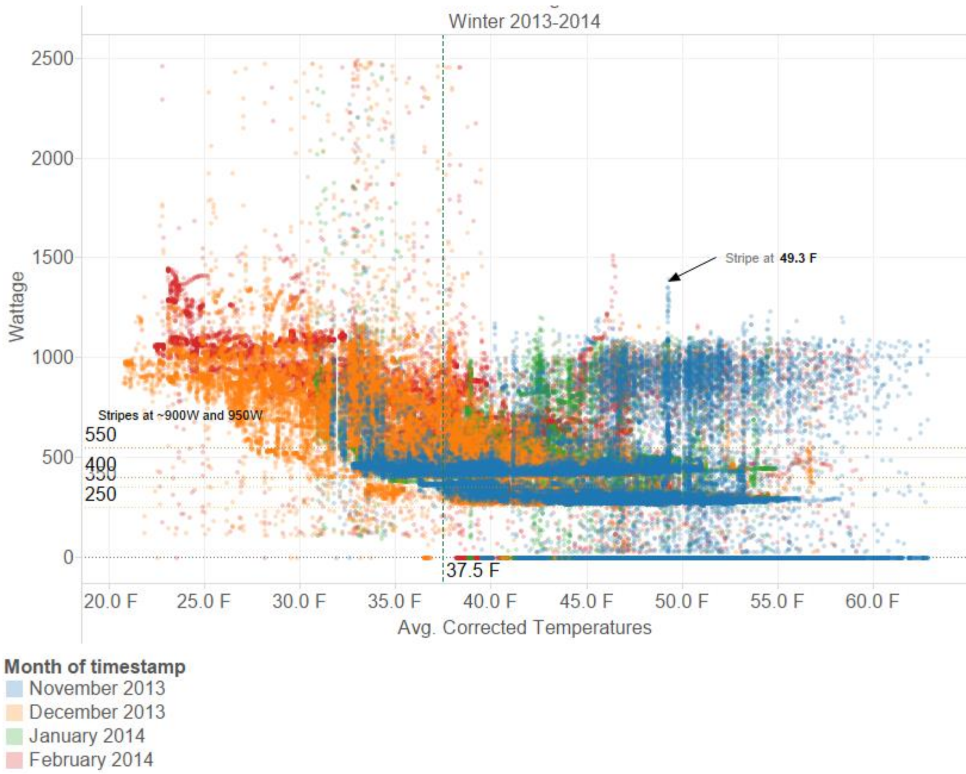

Figure 1.4 Winter 2013-14 DHP vs outdoor air scatter plot, colored by month

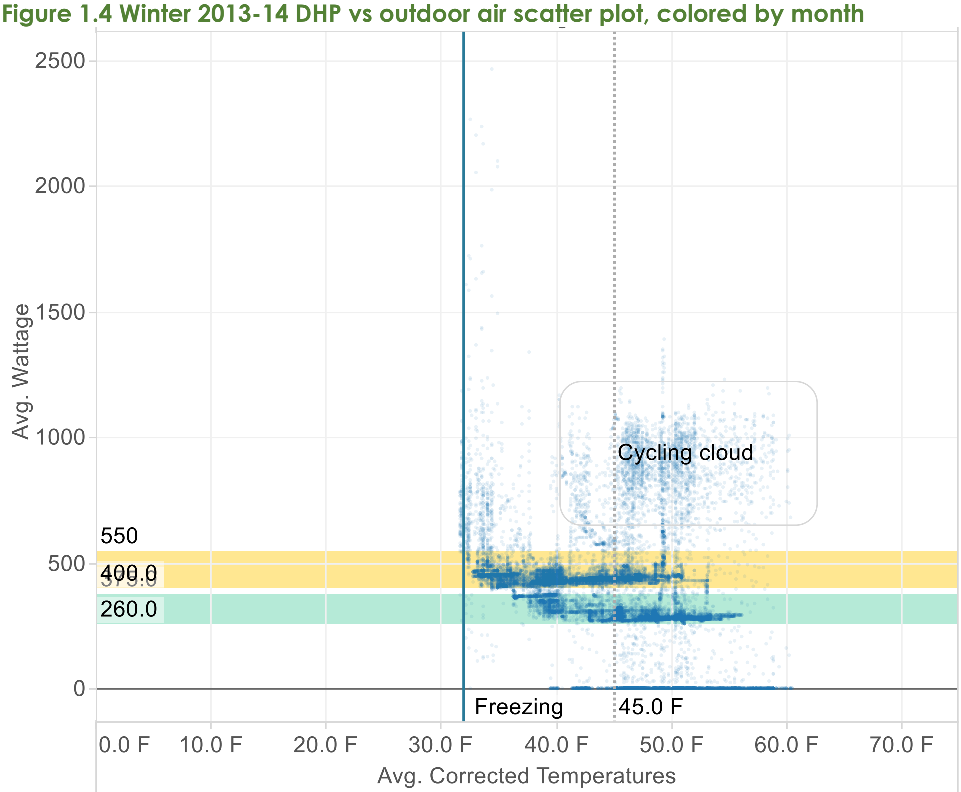

Figure 1.5 DHP vs Outdoor Air temperature, November 2013 (minute-level readings)

Another site shows us ideal activity: simply put, as it gets colder, the unit should use more energy. What is also notable about this is that I changed the palette of colors to indicate winter by using colder colors in blues, greens, and purples.

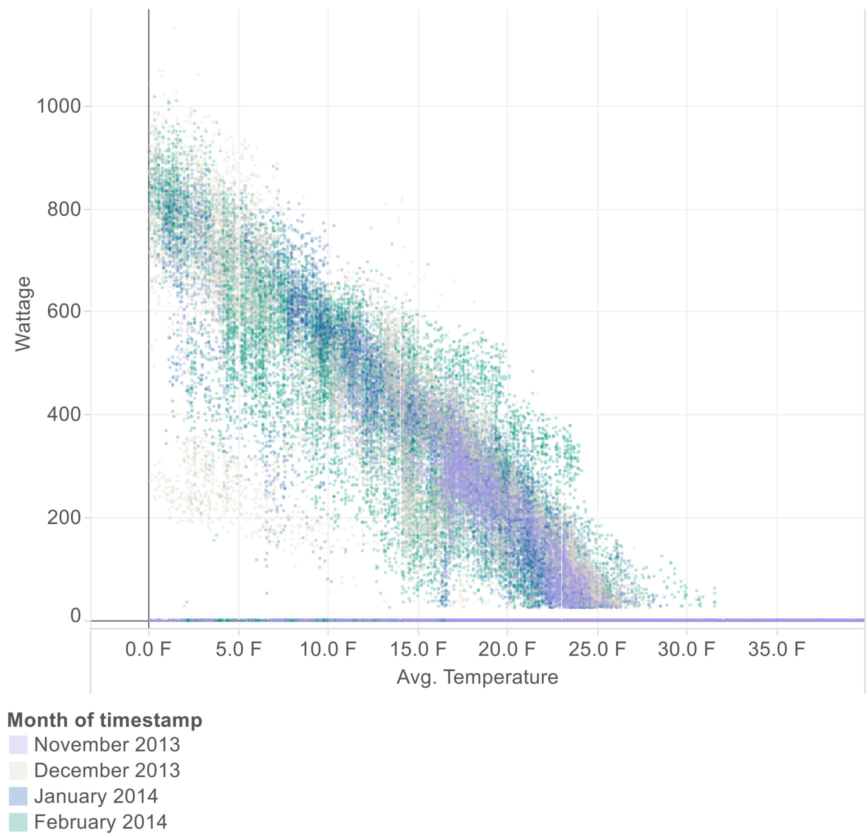

Figure 1.6 Duct heater wattage versus outdoor temperatures

1.2 Water Heating

1.2.1 Energy Use

I included a section with a special analysis to show the reader how I handled this particular issue with the heat-pump water heater.

Water heating accounts for approximately **18%** of all energy used on site. The heat-pump water heater used **1,888 kWh** over the analysis period. It is notable that there seems to be a mechanical issue with this particular unit, which artificially elevates this figure. Due to this malfunction, we would estimate on an annualized basis that, under normal operating circumstances, water heating at this site would use approximately 560 kWh fewer, resulting in an **adjusted annual estimate** of **1,314 kWh, or 12.3%** of the site. Section 1.3.1.1 below explains the methodology used to arrive at these figures.

Distinct from electric-resistance water heaters, its standard deviation is σ=81.3 kWh, roughly twice as wide as Site E. Water heating is strongly correlated with site energy use (ρ=0.96) and negatively correlated with outdoor temperatures (ρ=-0.86). This means that water heating is considered weather-sensitive in this environment, and more energy is used when it is colder. Heat-pump water heaters depend on the differences in temperatures between the outside and inside of the tank, so this finding makes sense.

Figure 1.7 displays the energy readings in comparison to weather and site energy.

Actual Month	Gross site energy (Σ kWh)	Outdoor On-site Temperature (μ °F)	HPWH, original (Σ kWh)	HPWH% of site	HPWH, estimated (Σ kWh)
Apr 2013	717	50.6	84	11.7%	84
May 2013	583	58.4	74	12.7%	74
Jun 2013	566	64.3	87	15.3%	87
Jul 2013	657	67.5	92	14.1%	92
Aug 2013	550	67.5	65	11.8%	65
Sep 2013	742	61.8	119	16.1%	119
Oct 2013	869	51.6	113	13.0%	147
Nov 2013	1,100	46.0	218	19.8%	156
Dec 2013	1,451	39.5	282	19.4%	147
Jan 2014	1,190	43.4	246	20.7%	125
Feb 2014	1,202	40.7	258	21.5%	106
Mar 2014	1,031	48.1	251	24.3%	147
Total	**10,656**	**53.4**	**1,888**	**17.7%**	**1,314**

Figure 1.7 Water heating versus site energy and outdoor air temperature

1.2.1.1 HPWH counterfactual reconstruction

Colourless Green used regression analysis to estimate the water heater use up to December. The regression resulted in values no further than 26 kWh from the actual readings and resulted in the curved upward line one would expect as temperatures grow colder. We mirrored it after December due to the third-order equation's propensity to 'hockey stick' upward, much like a logarithm. We altered a few of the later x-values to mimic the sinusoidal nature of the weather patterns more closely. When we finished, the March 2014 projection was 3 kWh over March 2013's figures, satisfying what we would consider reasonable. Figure 1.6 displays the regression curve visually by following the orange line.

Figure 1.5 displays a reconstructed, averaged based computation of what the heat-pump water heater would use, based on the regression created. This results in an estimated annual use **of 1,314 kWh**, rather than 1,888 kWh, **an adjustment of -561 kWh**. Figure 1.6 is a visual representation of these data. The purple line highlights the reconstruction path.

Period	Outdoor On-site Temperature (μ °F)	Original HWPH Readings (Σ kWh)	Extrapolated values based on original (Σ kWh)	Difference (original-extrapolated) (Δ kWh)	Reconstruc-ted Values (Σ kWh)
Apr 2013	50.6	84	87	-3	84
May 2013	58.4	74	79	-5	74
Jun 2013	64.3	87	78	+8	87
Jul 2013	67.5	92	82	+10	92
Aug 2013	67.5	65	90	-26	65
Sep 2013	61.8	119	106	+13	119
Oct 2013	51.6	113	125	-12	113
Nov 2013	46.0	218	147	+71	147
Dec 2013	39.5	282	156	+126	156
Jan 2014	43.4	246	147	+99	147
Feb 2014	40.7	258	125	+133	125
Mar 2014	48.1	251	106	+145	106
Total	**52.9**	**1,888**	**1,327**	**+561**	**1,314**

Figure 1.8 Heat-pump water heater reconstruction values

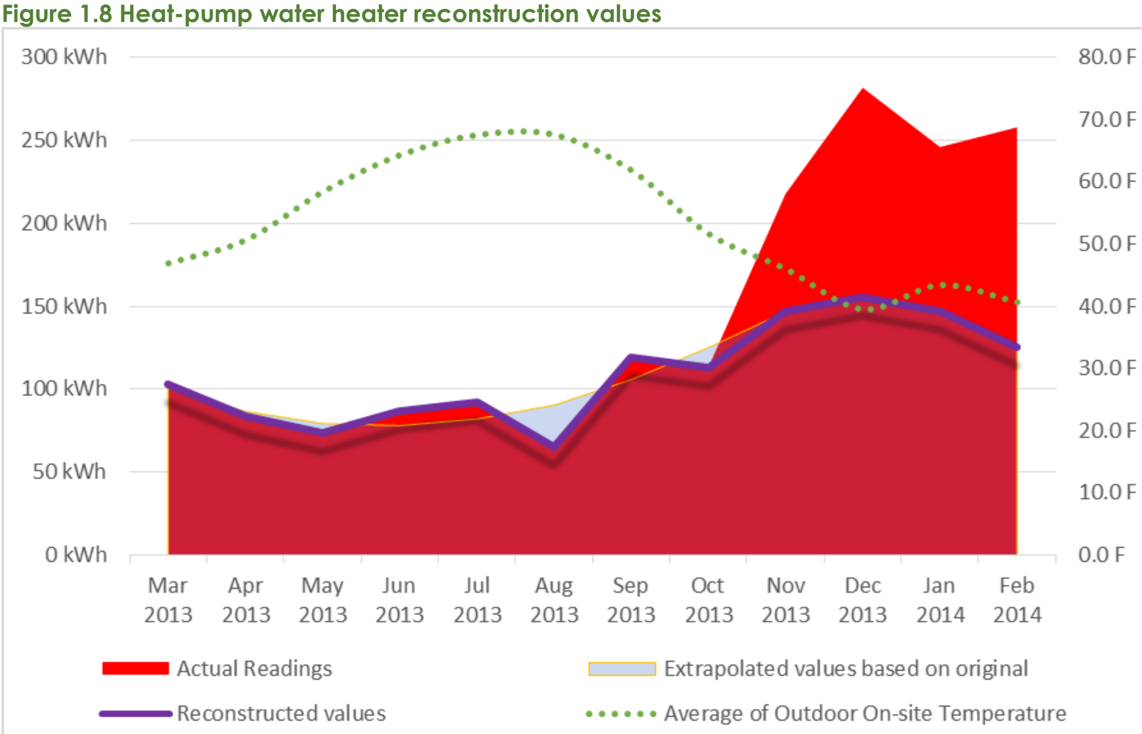

Figure 1.9 Reconstruction visualization

1.2.2 Setpoint

The **setpoint** for this heat-pump water heater is estimated at **125°F** based on observations of the *DHW out* temperature information. While the overall maximum was 126°, we took the whole year's values into consideration; the higher values also happened in summer months, and since this technology is weather-dependent, it seems more logical to consider the overall annual use (which is the right-most column in Figure 1.11).

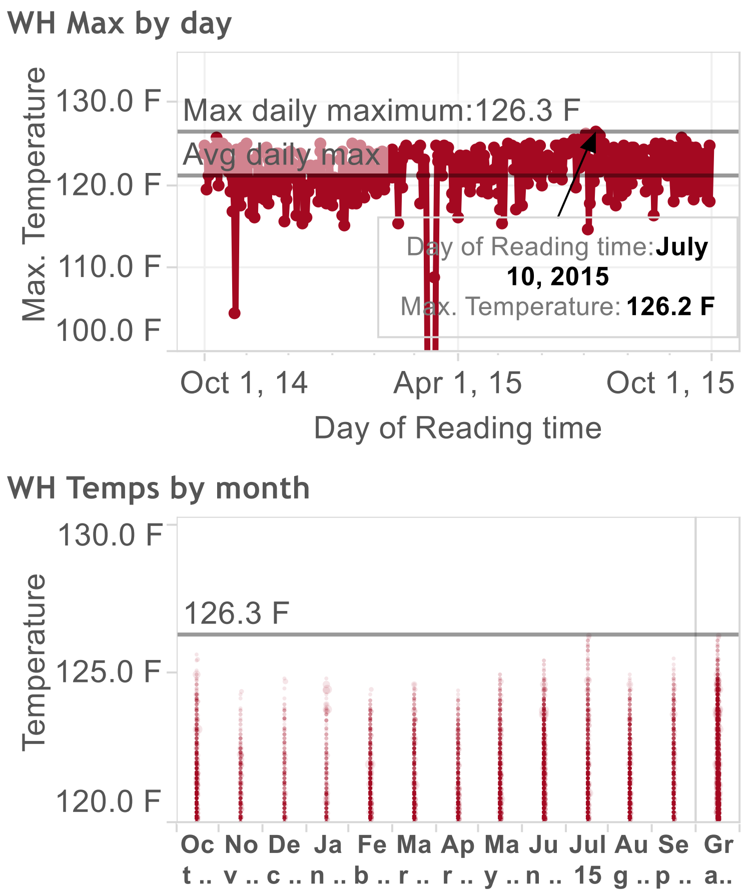

Figure 1.11 DHW-out readings versus maximum observed temperatures

1.2.3 Water heating time-of-use

The water-heater use by hour highly mimics the relative-humidity analysis: the waterheating occurs most frequenly in the mid-morning and late-evening hours (9–11 AM and PM). The correlations with the humidity analyses give us added confidence in these figures.

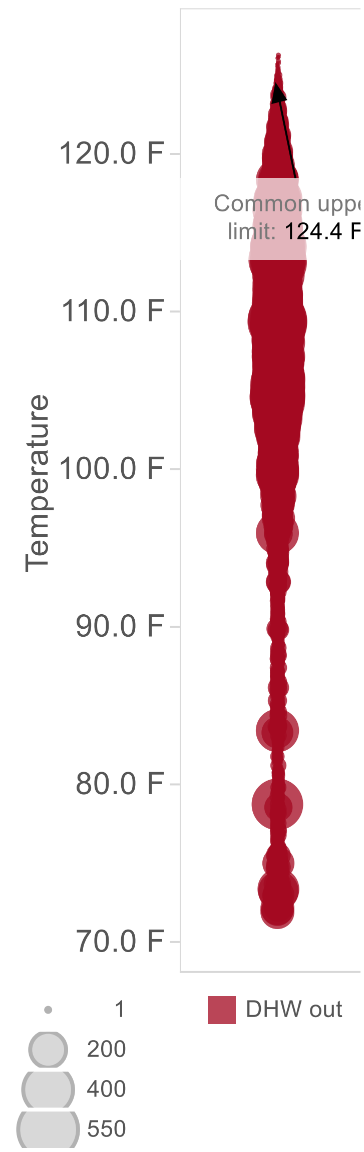

Figure 1.10 Water heating temperatures sized by count

Figure 1.12 shows us the average wattage by hour; it also shows us the sum of the kWh by time-of-day; the summation of those values under the curve totals to the total annual kWh.

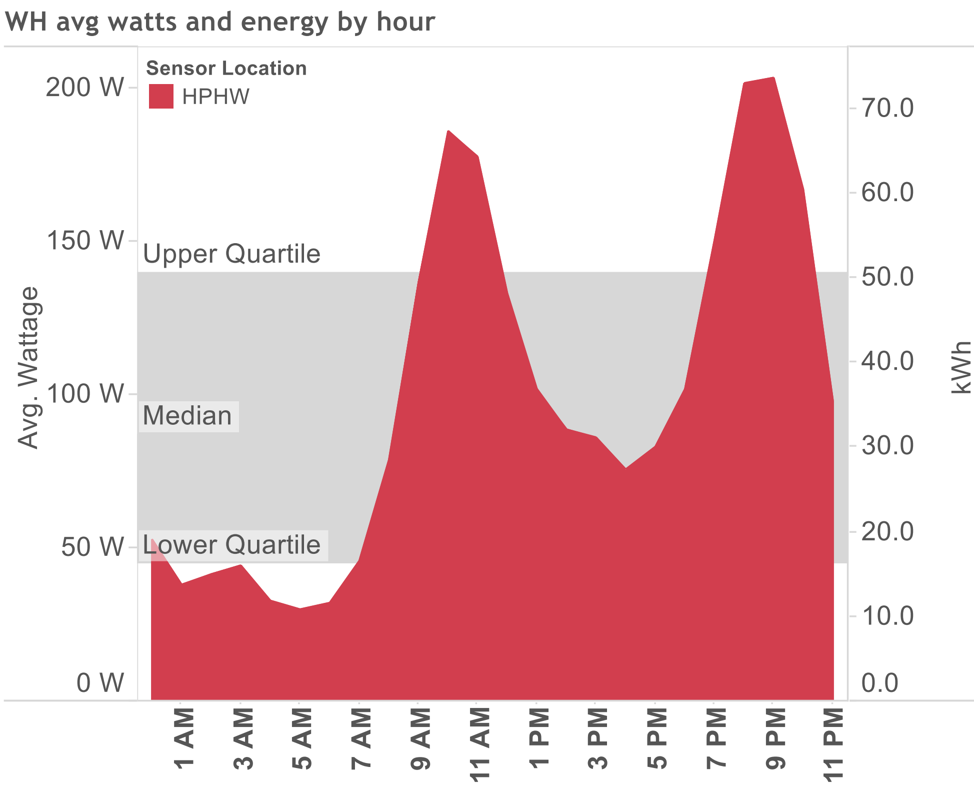

Figure 1.12 Water heater attributes by hour: average wattage and kWh summation

Figure 1.13 is a whisker-box plot of the wattages observed (minute-level). It shows the extremes and the average hourly wattages via the whisker-box. For clarity, we removed the dots behind the whisker-box; outliers still show up below. We can see from this that the unit runs at approximatly 1000 W when at max.

Figure 1.14 is a histogram of the count of readings by hour: this essentially shows us the same things as Figure 1.12, but gives us color coding by month. We can see from this that the unit runs more often at certain times of day fairly regularly, maning the pattern is consistent. Had there been longer bars in certain months than others, we would be seeing a change in (likely occupant) behaviors and patterns.

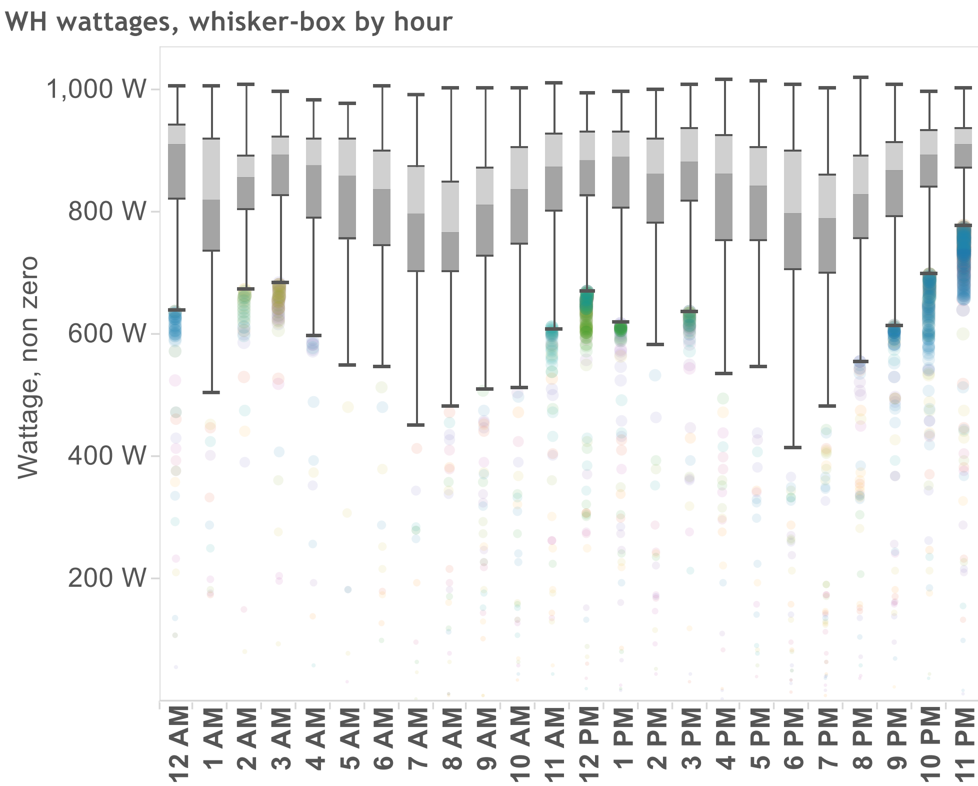

Figure 1.13 Water heater hourly whisker-box plots of non-zero wattages

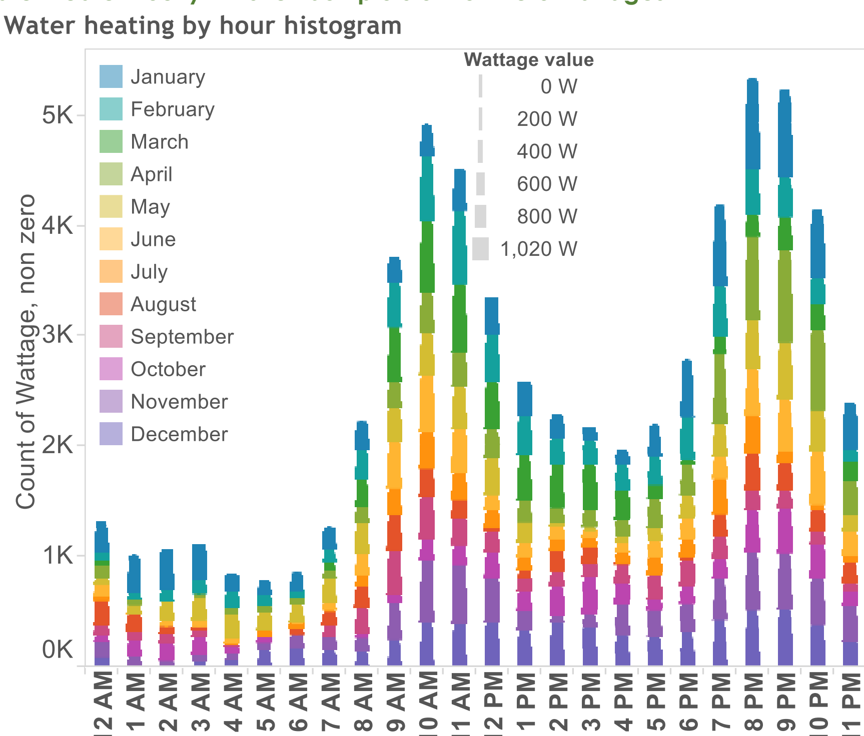

Figure 1.14 Hourly water-heater histogram, colored by month

1.3 Interior temperature

Monthly average temperatures in Site E range from 65.0 °F to 76.2 °F, an Δ=11.2 °F band. These temperatures are fairly consistent, displaying monthly standard deviations between σ=1.86 °F and 2.65 °F. The bathroom has the lowest temperature deviation, while the master bedroom has the highest deviation. Outdoor readings, for comparison, display a range of 23 °F–74 °F, a Δ=52 °F band and a standard deviation of σ=17.3 °F.

From detailed analysis of the indoor temperatures, Colourless Green estimates that the set-point is **72 °F**.

Figure 1.15 shows the variance in seasonal temperature by room. This figure displays hourly average temperature readings arranged by room. The size of the readings is solely to allow the reader to see readings that would normally be stacked or covered up by other readings.

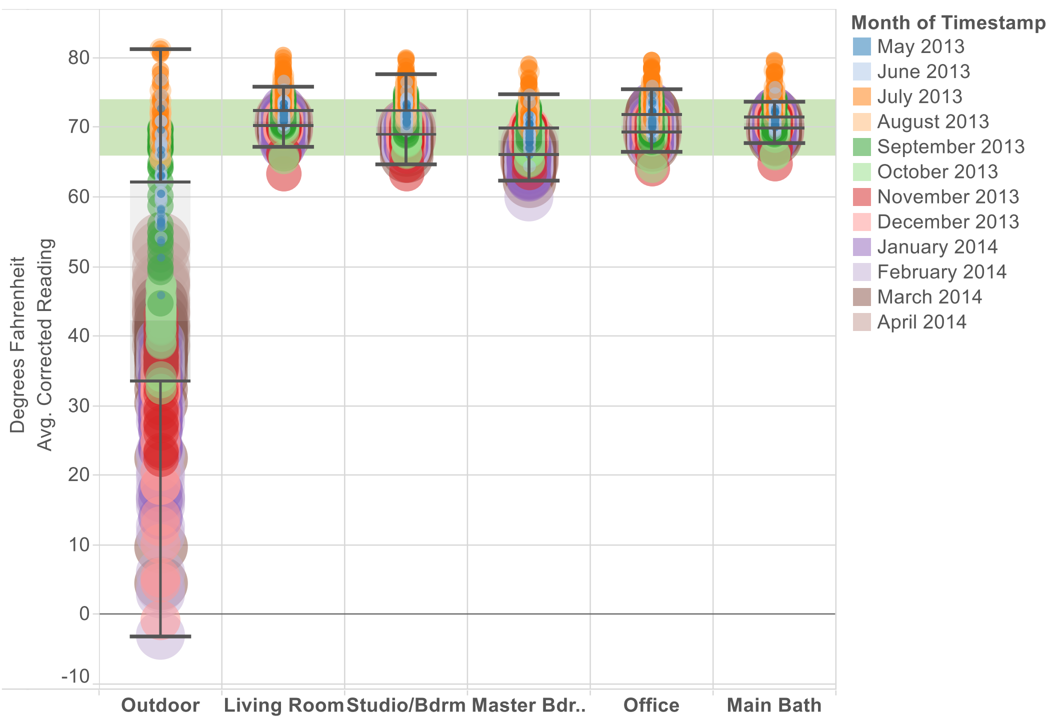

Figure 1.15 Whisker plots by room

The above whisker-box plot was a big hit with my client. He was able to quickly see the multiple dimensions of what was happening: the seasonality of the readings as well as the median and general range of the home's temperatures. Once I showed him this, he requested this throughout the report for a variety of items.

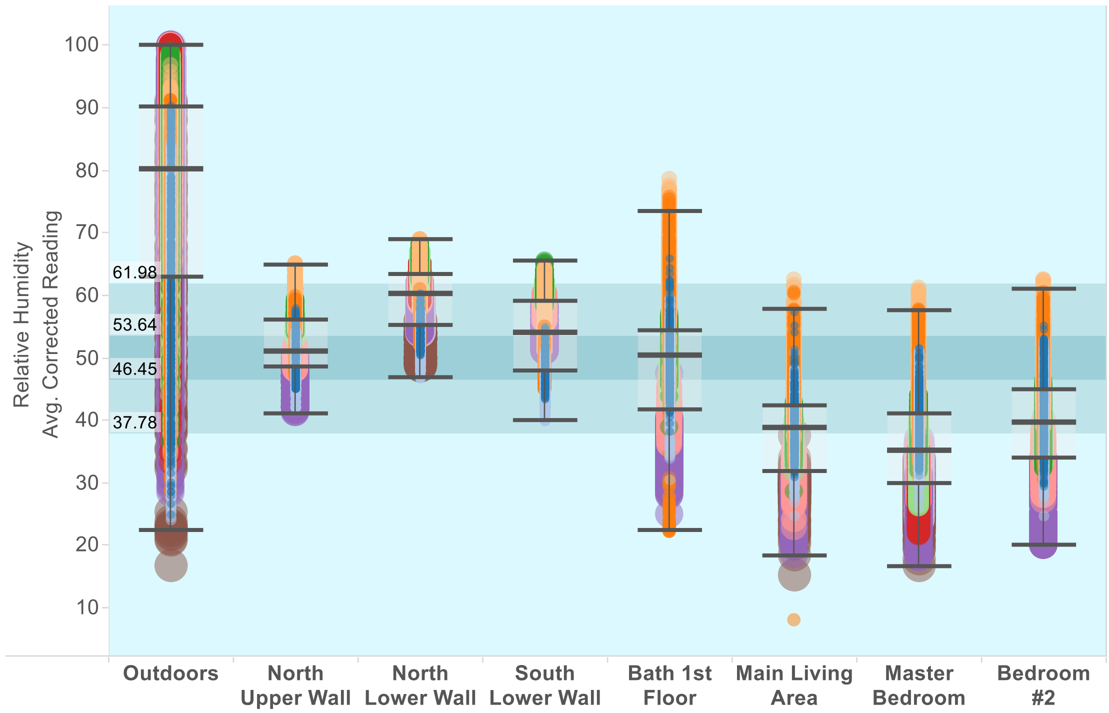

Figure 1.16 Site D RH whisker-box plot by room broken out by quintile

This is a second example of a whisker-box plot, but adds the additional dimension of the overall average for the entire set of values by using the color coding in the background.

1.4 Special Analyses

1.4.1 PV versus Dryer disambiguation

This is an example of where the information provided did not match the visualization. This section explains the context and the conclusion: that the PV monitoring channel now used to be the dryer channel. It shows how Tableau can stack and layer information in an intuitive way as well.

We can tell from the analysis of the dryer that when the PV was installed and properly monitored, the engineer repurposed and relabeled channels. Before Channel 4 was repurposed for the PV system, it was coupled with channel 5. For the purposes of this analysis, Channel 4 is labelled as "Photovoltaic Array" and Channel 5 as "Dryer."

Figure 1.17, shows us the "PV" channel in dryer mode. After the PV was assigned to channel 4, the dryer channel (Channel 4) values double and Channel 4 changes from a load to a generation signal. Figure 1.18 displays the transition.

To correct for this in the visualizations, we included the PV and Dryer channels stacked on top of one another when appropriate. It is notable that the PV channel had the motor signature on it.

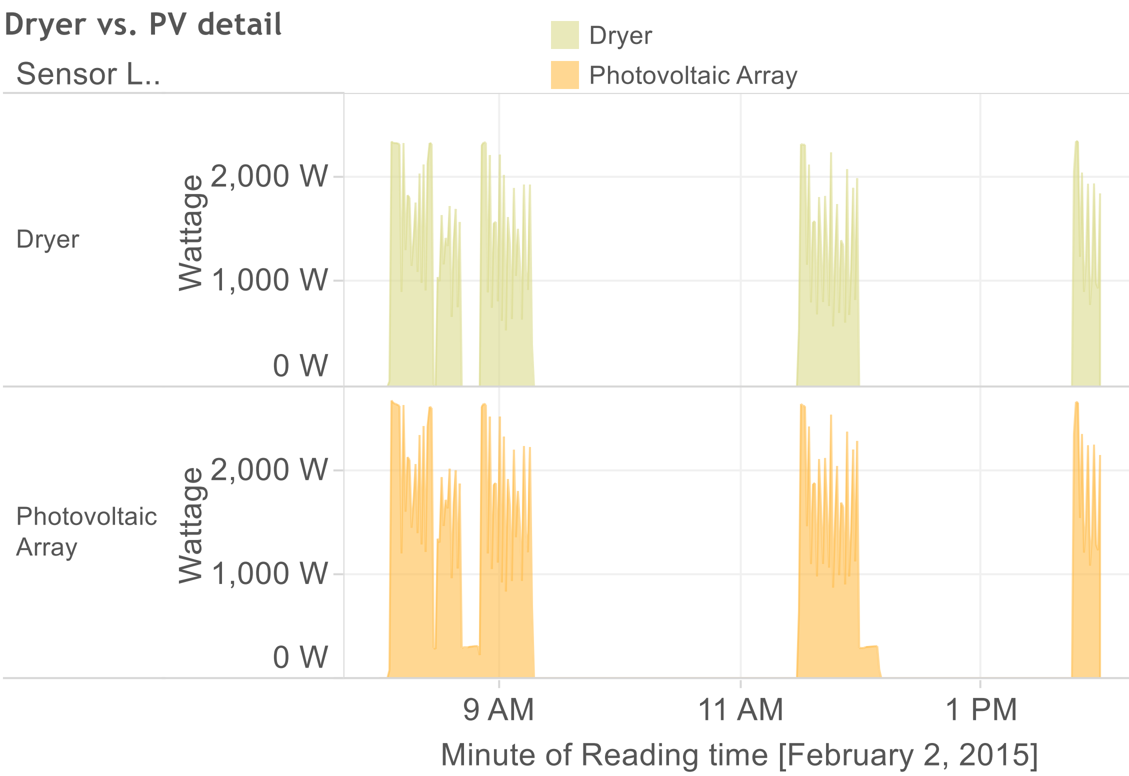

Figure 1.17 Dryer versus PV detail, pre-PV installation

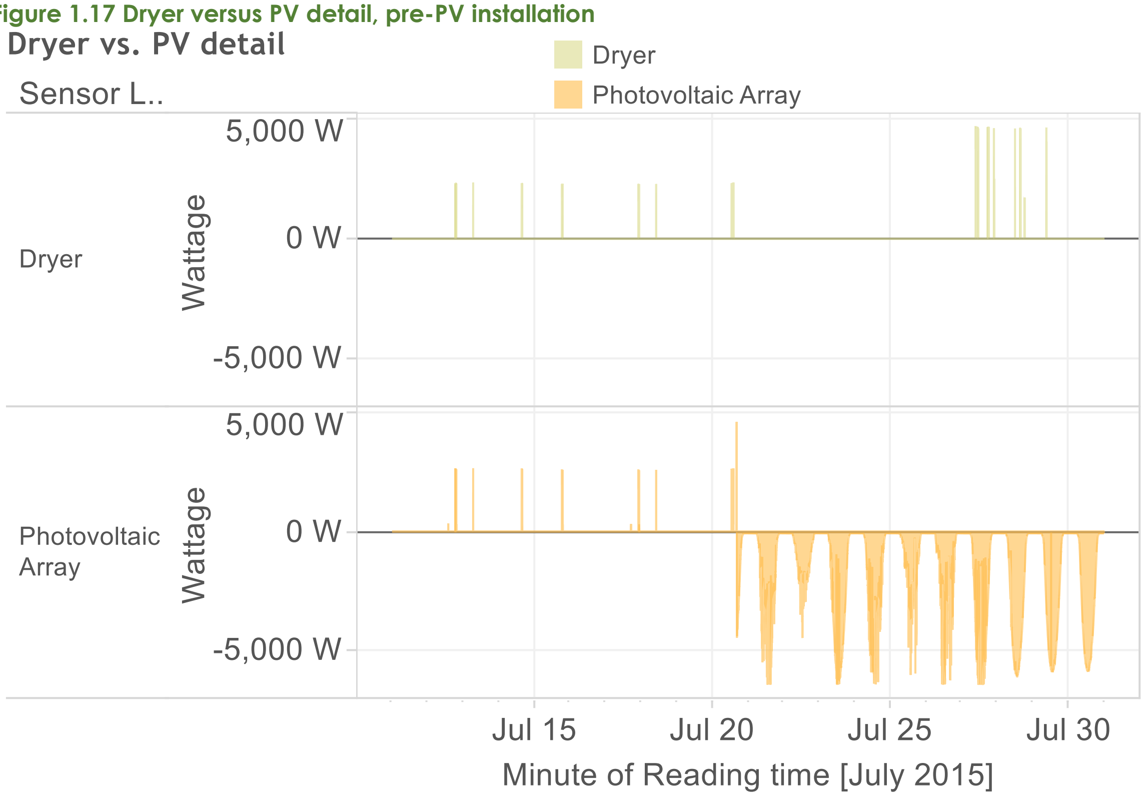

Figure 1.18 Dryer versus PV either side of calibration

1.4.1.1 Signature #1

Signature #1 runs approximately **30–60 minutes**; This cycle **uses 1.8 kWh–2.5 kWh**. It is characterized by running at **approximately 4.9 kW** until it cycles on and off as the load gets drier. At times, there were up to 1-hour versions of this cycle observed. At the end of the cycle, there is a **10-minute tail** that runs at ~300 W. This is likely the motor signature tumbling the load at the end to prevent wrinkling.

Figure 1.19 shows us this signature visually. Figure 1.20 shows us this cycle when the load did not fully dry: you can see that the dryer was on full power the entirety of the 30 minute load cycle and a 15-minute follow-up cycle (with a 5-minute tail) follows.

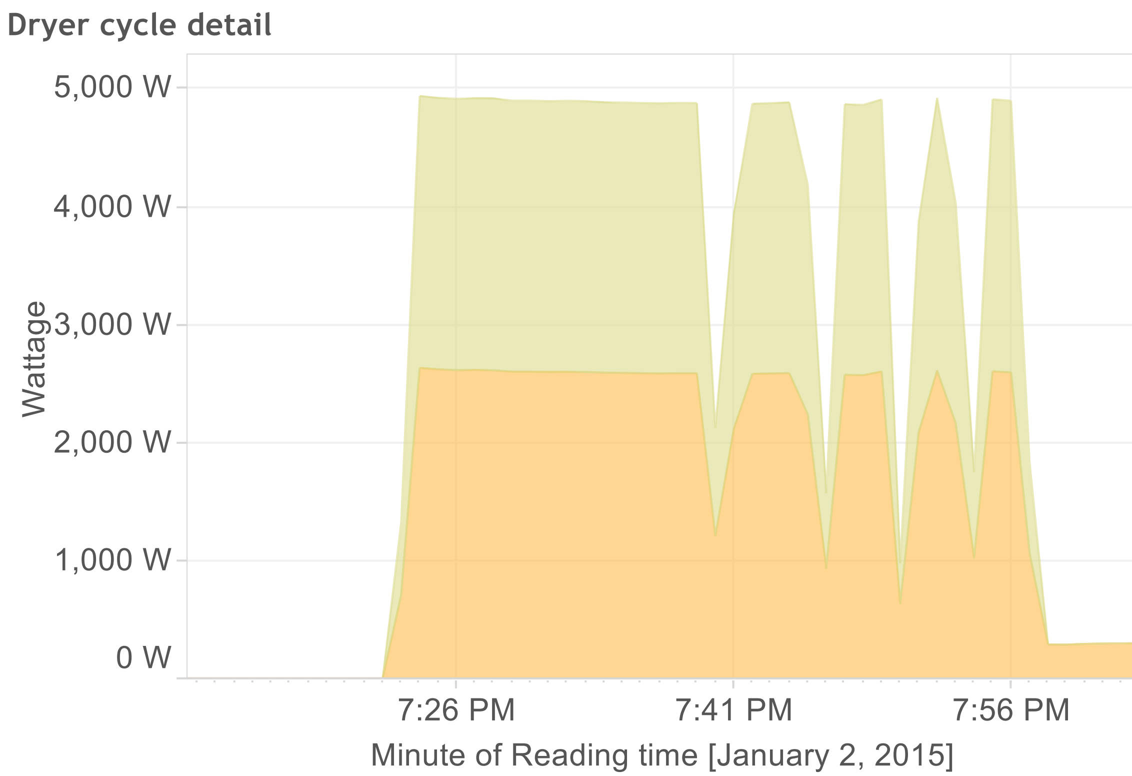

Figure 1.19 Example of Signature #1

Figure 1.20 Example of Signature #1 with follow-up cycle

1.4.1.2 Signature #2

Signature #2 has a more erratic, **sawtooth signal**; we estimate that due to its length, and attempt at a lower setting this is a gentle or low-temperature cycle. This uses approximately **5.2 kWh per load**. It has a 10-minute tumbler tail and the duration of the cycle before that spanned **1h:40m.**

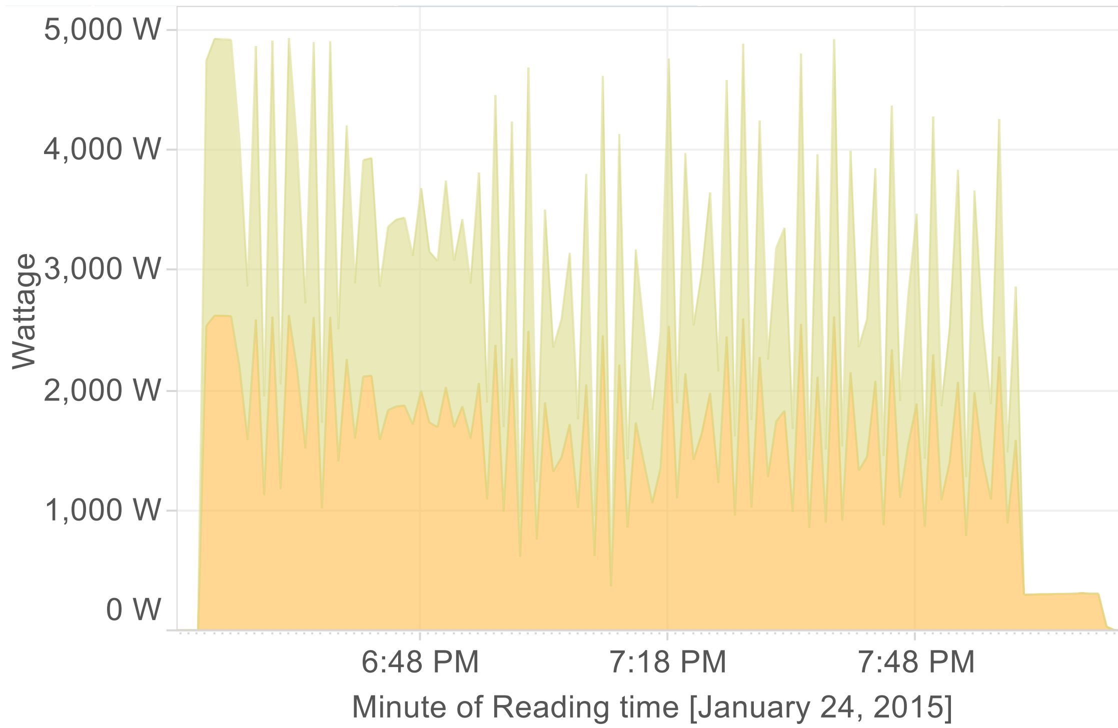

Figure 1.21 Signature #2 example

1.4.2 HPWH impact on garage temperatures

A HPWH is a heat-pump water heater. This is essentially the same technology as a refrigerator or air conditioner. This newer technology puts this heat pump on top of a typical tanked water heater. One of the concerns was if this had a meaningful impact on environmental temperatures, which this analysis addresses. In this case, the unit had a fluid leak, so I performed the analysis in two segments to address whether the unit performed differently under those two scenarios.

In August, a clear pattern emerges showing the impacts on garage temperatures. We then took similar samples throughout the time period to estimate an average impact on garage temperatures due to HPWH activities, which is summarized in Figure 1.22.

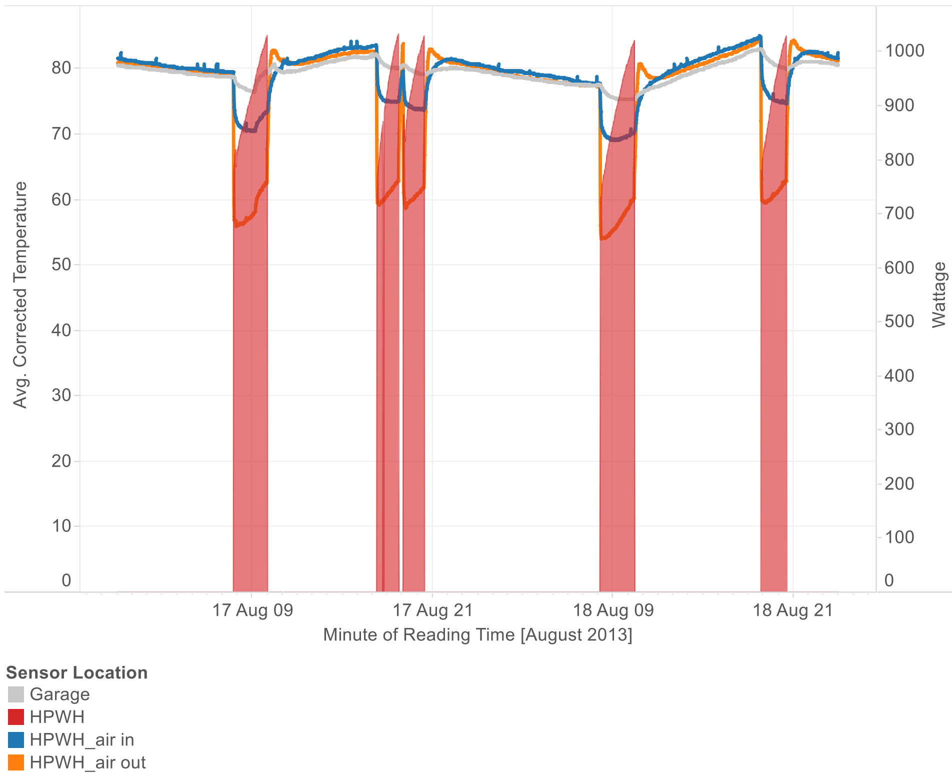

Figure 1.22 HPWH impact on garage temperatures, August sample

This graph clearly shows the ability for the tools I employ to chart temperature and wattage on the same graph.

After the fluid leakage, we see the HPWH working in sharp spikes which have a greater impact on garage temperatures for a short period. Figure 1.43 illustrates this trend.

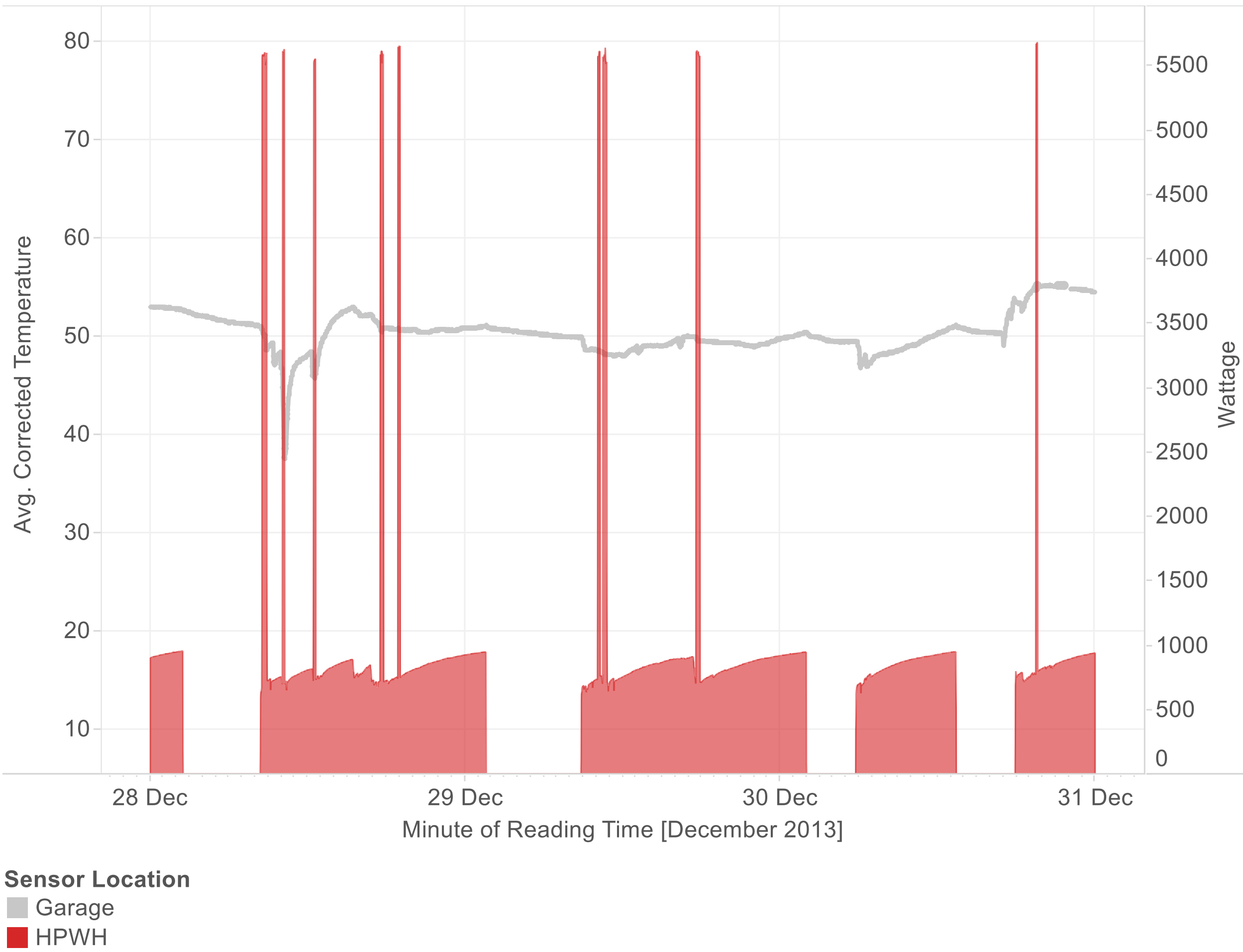

Figure 1.23 Sample time, post-fluid leak

1.4.2.1 Conclusion

From this analysis we have concluded that in the aggregate, the **heat-pump water heater impacts garage temperatures** on average **about μ=-2.8 °F**; this takes approximately an hour and a half to go from the initial start of the HWPH cycling to the lowest temperature reading.

Before the HPWH **compressor-fluid leak**, the temperature differential was slightly lower at **μ=-2.35 °F**, taking **approximately μ=2:00** to reach minimum temperatures in the garage. The standard deviation for this sample was σ=0.59°, meaning that there was some, but not a very wide, variation in the sample.

After the leak, the standard deviation was much greater (σ=3.69°) due to two readings that showed a very quick and sharp change in temperature. During this period, the average temperature change was **μ=-3.25°**, which is 0.9° different from the period before the leak. The change in temperature happened more rapidly, though, than before the leak, averaging **μ=1:03**, nearly half the time as before. This implies that the temperature changes would be more noticeable than before.

The implication here is that **a malfunction in the HPWH leads to a more extreme and rapid impact on environmental temperatures**. While the overall impact is less than one degree Fahrenheit, the sample revealed cases where extremely chilling air had a more significant impact on the garage temperature. Anomalies are highlighted in Figure 1.24 Sample of temperature drift by leak status.

Time of sample	Temperature Difference	Time elapse
Pre leak		
08/17/2013	-2.13	01:19
08/17/2013	-2.48	03:16
08/18/2013	-1.57	01:20
08/18/2013	-2.82	01:44
09/02/2013	-2.93	02:52
09/03/2013	-2.02	02:05
09/04/2013	-3.15	01:34
09/17/2013	-2.58	02:11
09/18/2013	-1.47	01:44
Pre leak average	-2.35	02:00
Post leak		
12/05/2013	**-4.39**	00:22
12/07/2013	-0.45	00:21
12/28/2013	**-13.05**	01:41
12/29/2013	-1.91	02:36
12/30/2013	-2.02	00:07
01/14/2014	-2.58	02:05
01/14/2014	**0.34**	00:35
01/15/2014	-2.59	01:31
01/16/2014	-2.93	01:14
01/16/2014	-2.92	00:06
Post leak average	**-3.25**	**01:03**
Total	-2.82	01:30

Figure 1.24 Sample of temperature drift by leak status

Table of figures

Lastly, since we follow a style sheet, things like tables of contents and tables of figures can easily be generated and regenerated, making it easy for users to find relevant information.