Chuck E Cheese

Grapevine, TX

OVERVIEW

Testing Overview

- Compare R-22 to alltemp®
- R-22 observed from 4/20/16 through 5/20/16
- alltemp® observed from 7/6/16 through 9/12/16
- Pre/Post testing methodology (not side-by-side)
- Measurements taken every minute during test period
  - Consumption(kWh)
  - Temperature (supply and return)
- Other data utilized
  - Daily sales
  - Daily high temperatures for the Grapevine TX area

Pre/Post analysis considerations

Pre-alltemp®

- Spring
- Lower ambient temperatures
- Lower M-F consumer traffic in location*
- Mother's Day
- Within a week of April 15th Tax Day
- Cinco de Mayo
- During school year

Post-alltemp®

- Summer
- Higher ambient temperatures
- Increased M-F consumer traffic in location* (higher return temperatures)
- Mixture of no-school and start of new school year

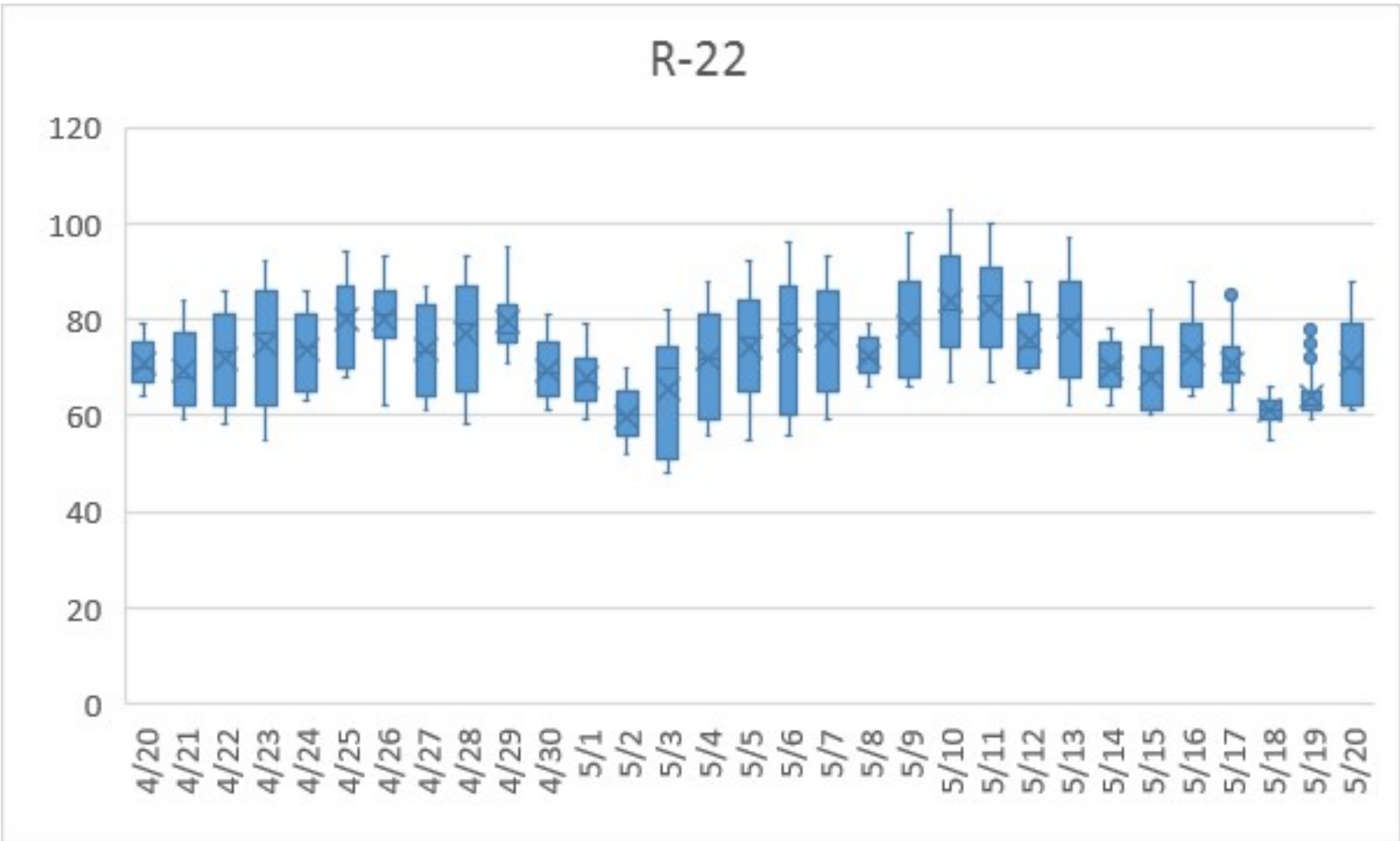
Summary

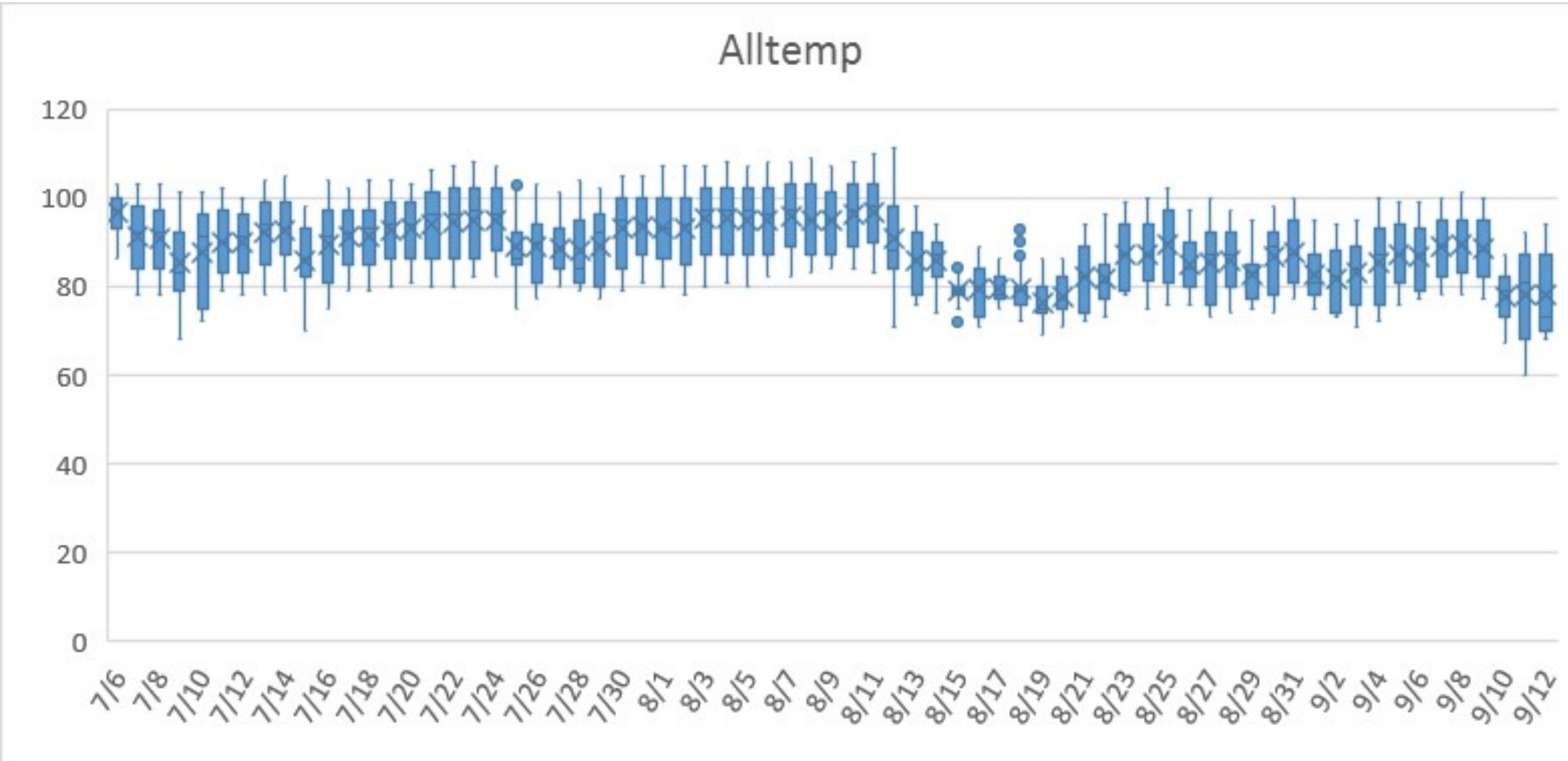
- Despite higher ambient temperatures and increased return temperatures, there was a **<u>33% energy savings</u>** using alltemp®
  - Though observed energy usage was higher for alltemp®, that increase was minor compared to what would have been experienced had R-22 remained in the unit, under similar conditions
  - Significant increases in the energy drivers of higher ambient temperatures and increased visitorship at the location caused power demand to increase substantially
  - Forecasted daily usage during the summer would have been 130kW for R-22 but instead was 98kW using alltemp® – a difference of about 32kW/day

Data Discovery

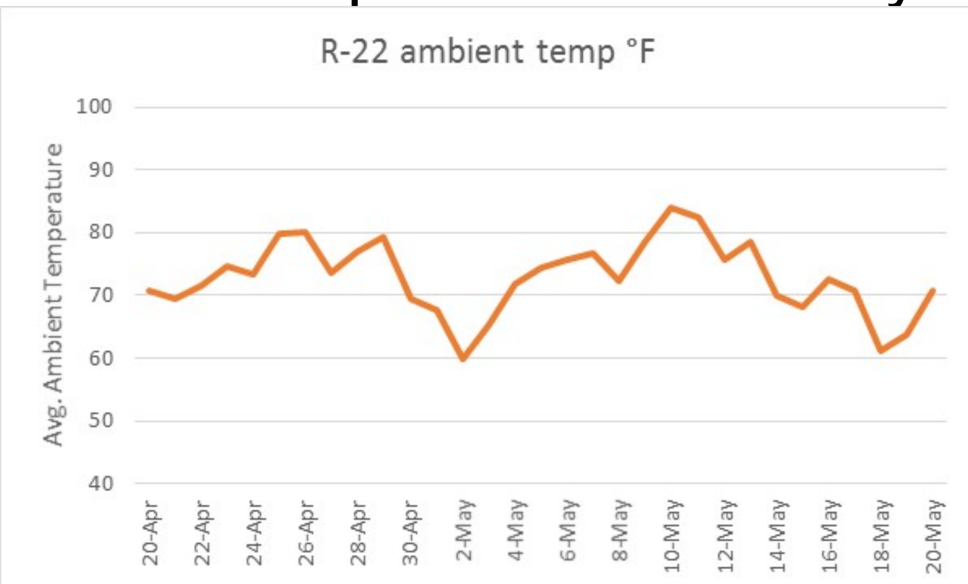
AMBIENT TEMPERATURE

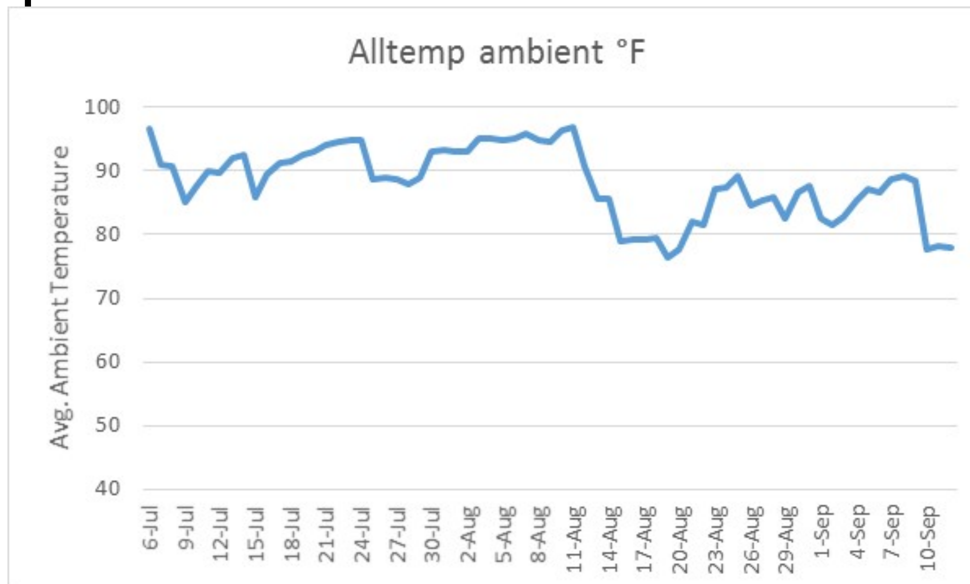
- Box and whiskers plot of ambient temperature by day for R22
- Most test days, the 25th-75th percentiles of observations ranged between 60º and 90º with means falling between 60º and 80º

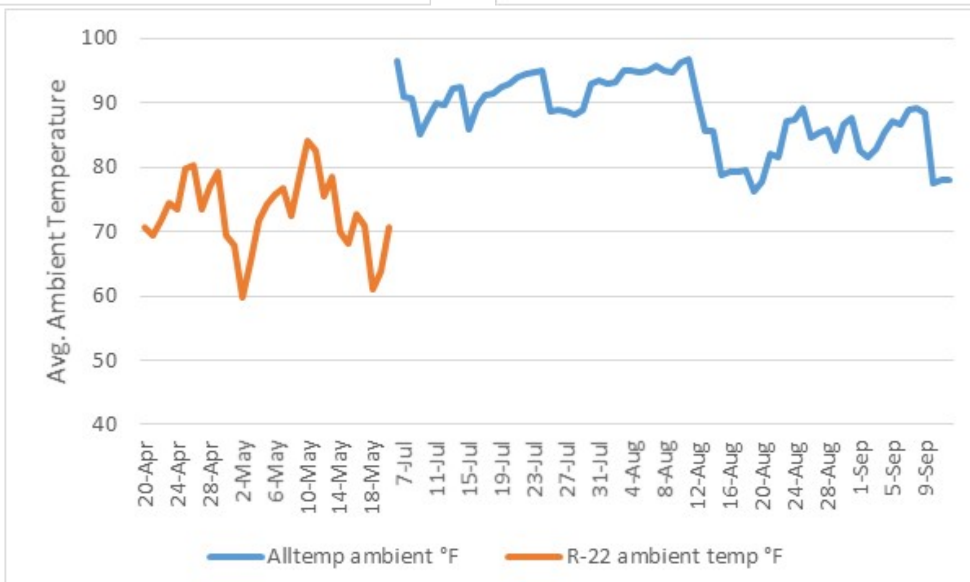


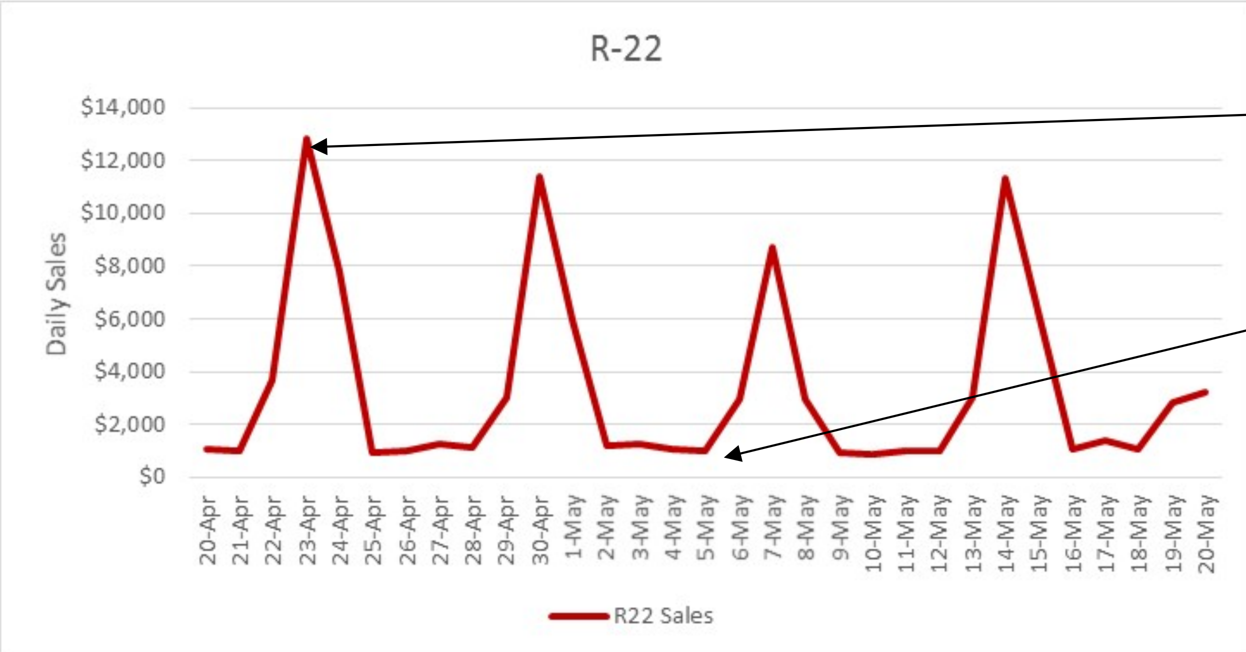
- Box and whiskers plot of average ambient temperature by day for alltemp®
- Most test days, the 25th-75th percentiles of observations ranged between 80º and 100º with means falling between 80º and 90º
- 

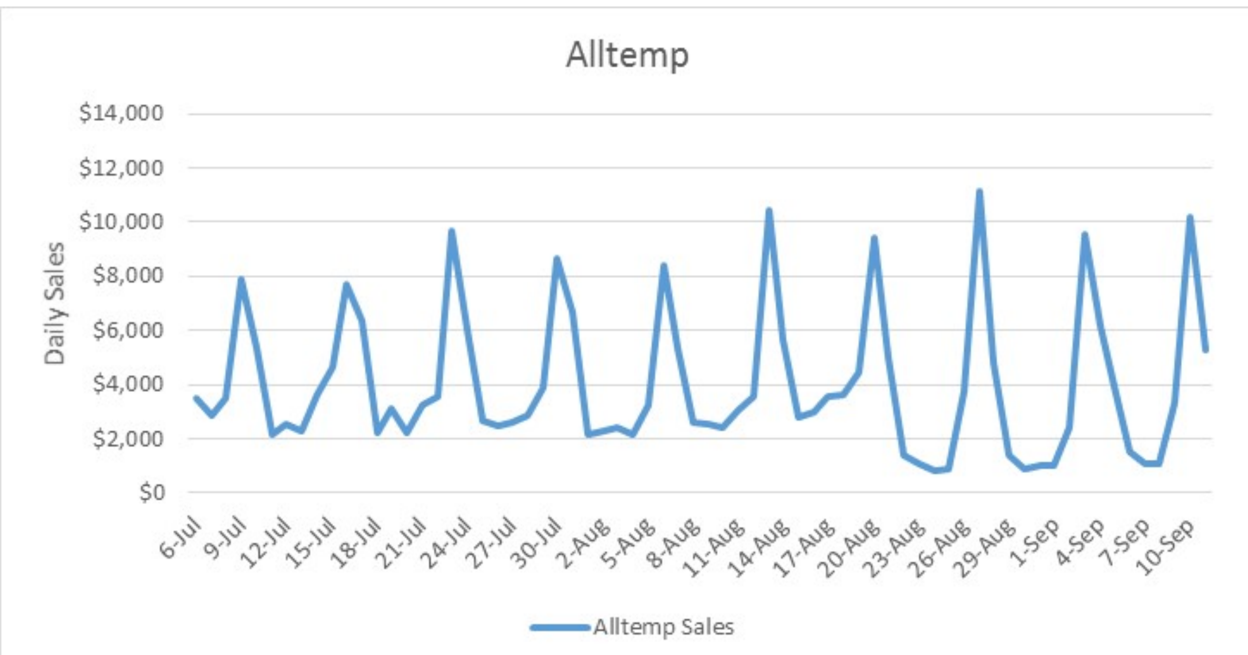
- Ambient temperatures were significantly higher during alltemp's® study time frame as compared to R-22's due to the expected seasonality temperatures of summer





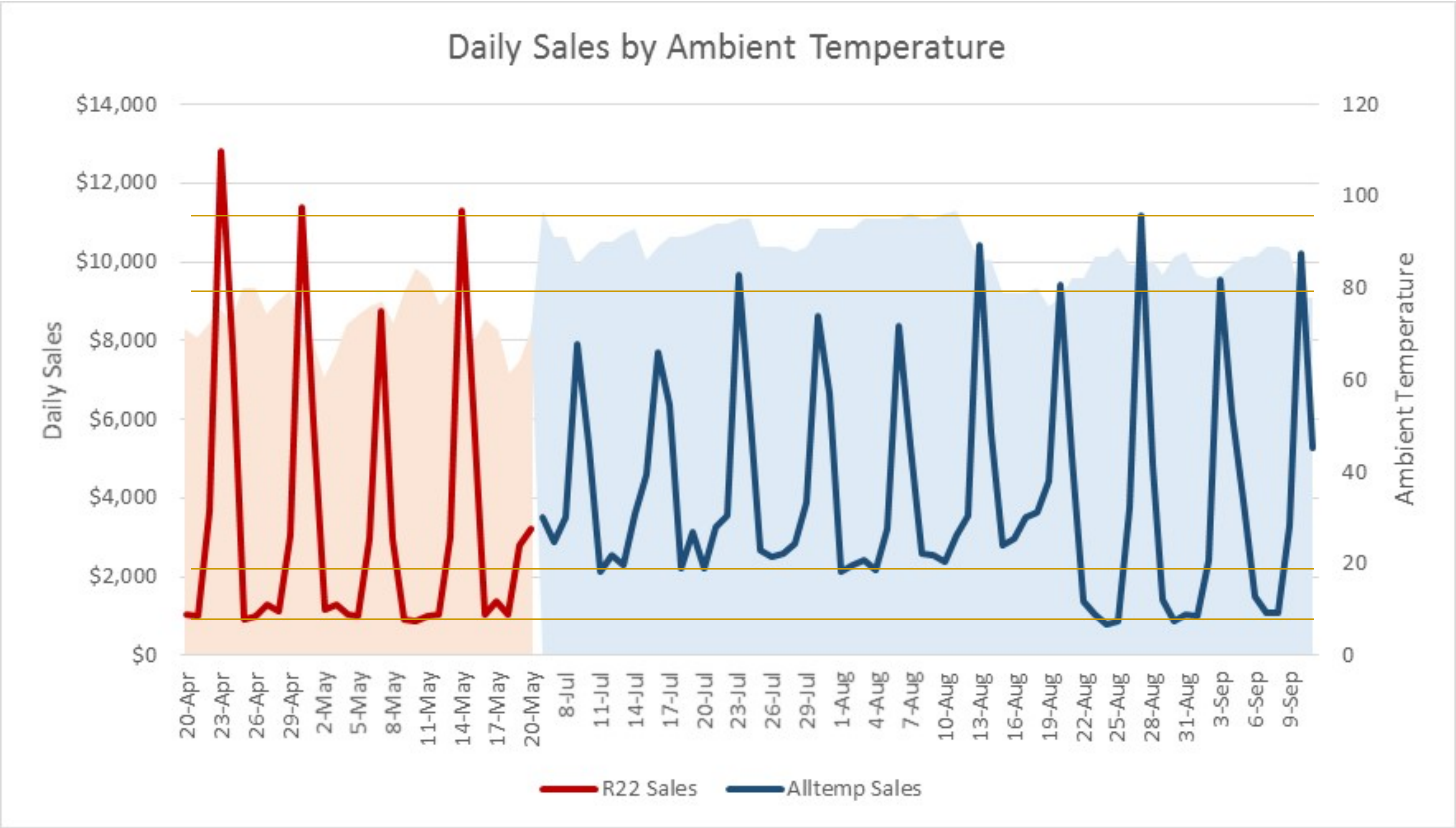






- R-22's sales were more "peaky" and had deeper "troughs" than that of alltemp®
- Important to note that seasonal milestones occurred during the R-22 time frame that most likely contributed to peaks and troughs observed: Mother's Day and post Tax Day

- “Troughs” increased from the $1k level to $2k level as average ambient temperatures moved from 70’s to 90’s



Data Discovery

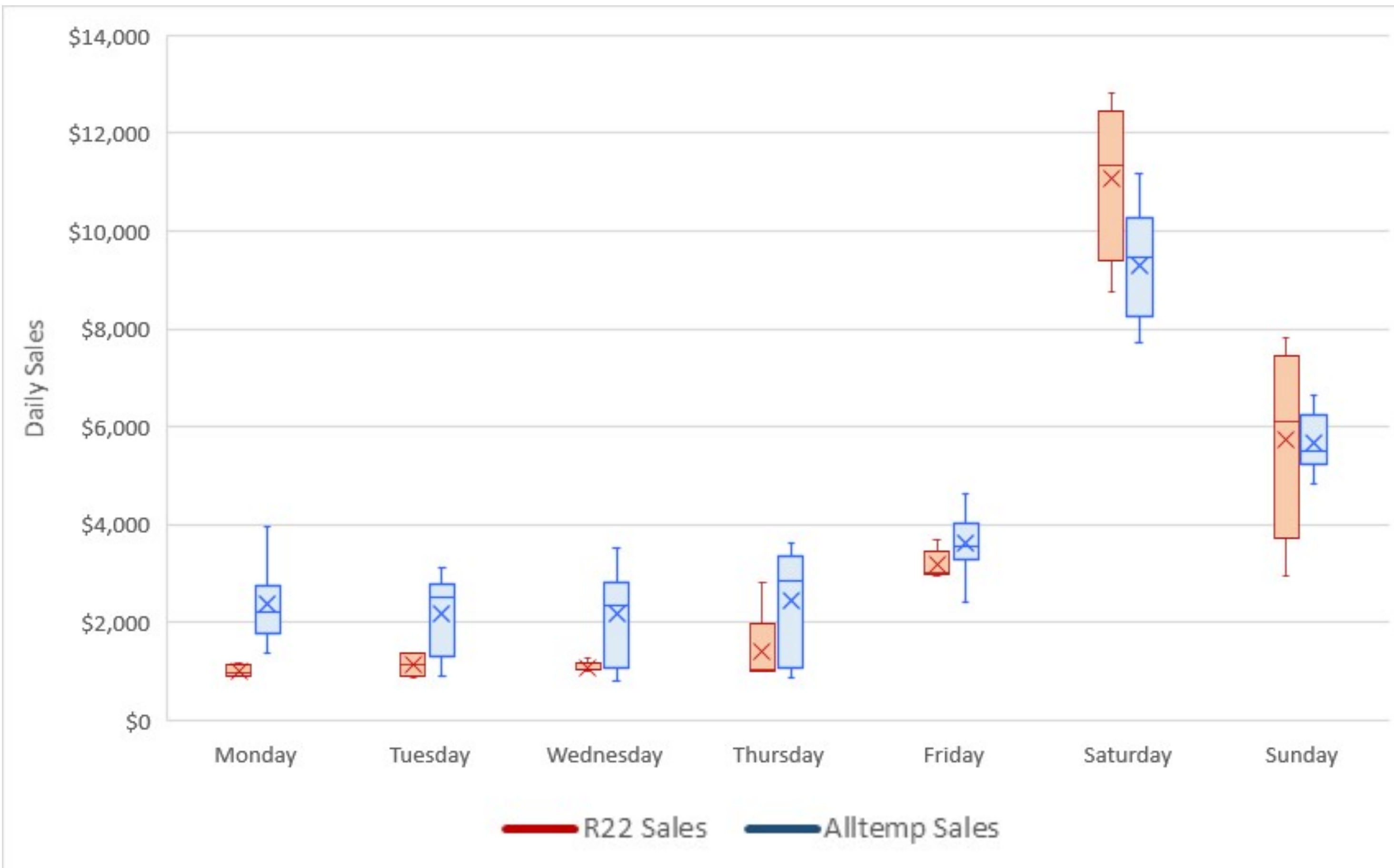
SALES

- Consumer demand for services **increased** substantially during test time frame
  - **Weekdays** were most affected as a result of no school (summer)
  - With higher temperatures and no school, parents sought activities in cooler locations such as malls, libraries and Chuck-E-Cheese’s

	Sales Avg. (Pre alltemp®)	Sales Avg (Post alltemp®)	% Difference
Monday	$1,013	$2,373	134%
Tuesday	$1,133	$2,168	91%
Wednesday	$1,087	$2,190	101%
Thursday	$1,400	$2,440	74%
Mon-Thur	**$1,168**	**$2,294**	**96%**

	Sales Avg. (Pre alltemp®)	Sales Avg (Post alltemp®)	% Difference
Friday	$3,180	$3,631	14%
Saturday	$11,061	$9,306	-16%
Sunday	$5,752	$5,674	-1%
Fri-Sun	**$6,396**	**$6,204**	**-3%**

- Box and whisker plots of daily sales by day of week clearly show a consumer visitorship bias between alltemp's® test time frame and R-22's
  - Weekends for the pre-test period appear to be outliers most likely as a result of Mother's Day and possibly after Tax Day activity (increase in disposable income as a result of tax returns)



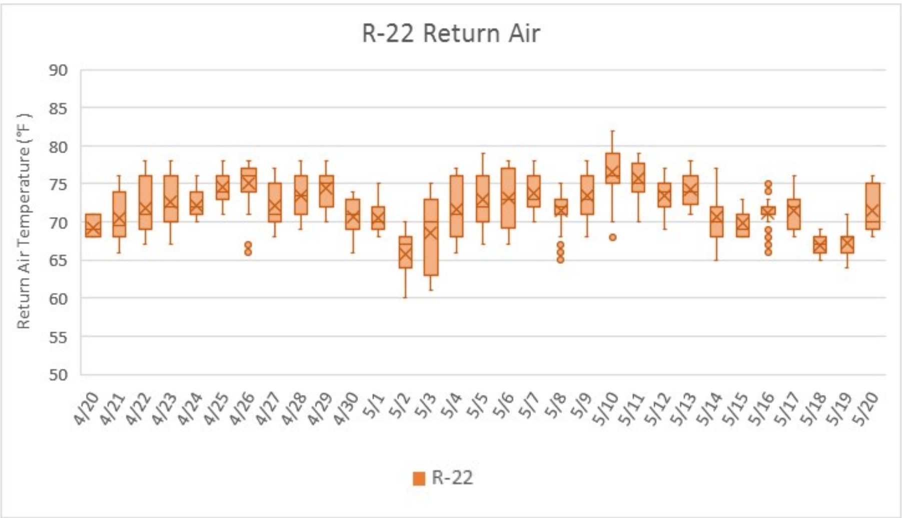
- Daily kW increases as BOTH ambient temperature and sales increase
  - Assuming sales is a proxy for number of visitors to the location, increased visitorship places a heavier “load” on system
  - As more people visit the location, the warmer the facility becomes internally and the harder the system must work to “cool” the inside temperature
  - Though ambient temperature had the strongest correlation to Daily kW, Sales had a positive correlation as well

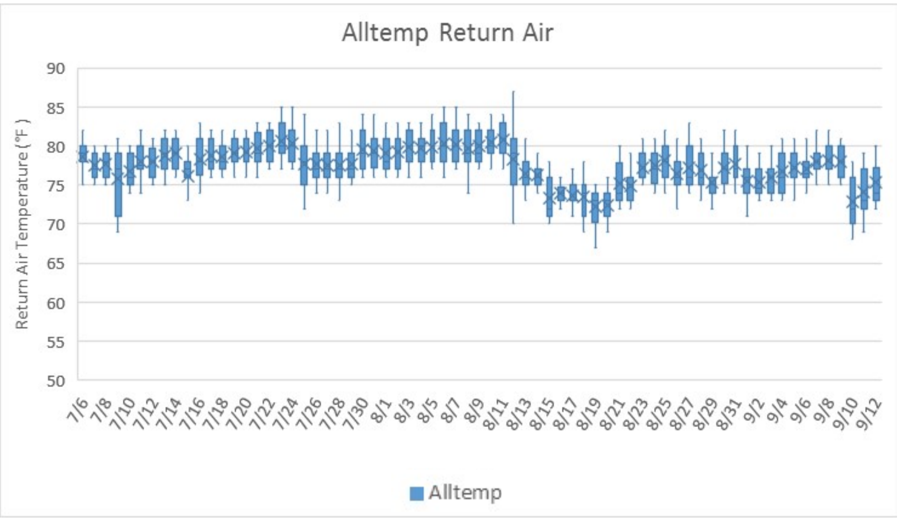
Variables	R22 - Daily kW (Pearson's rho)	P Value
R22 - Daily kW	**1**	**0**
Ambient Temp	**0.795**	**< 0.0001**
Sales (pre alltemp)	**0.239**	**0.195**

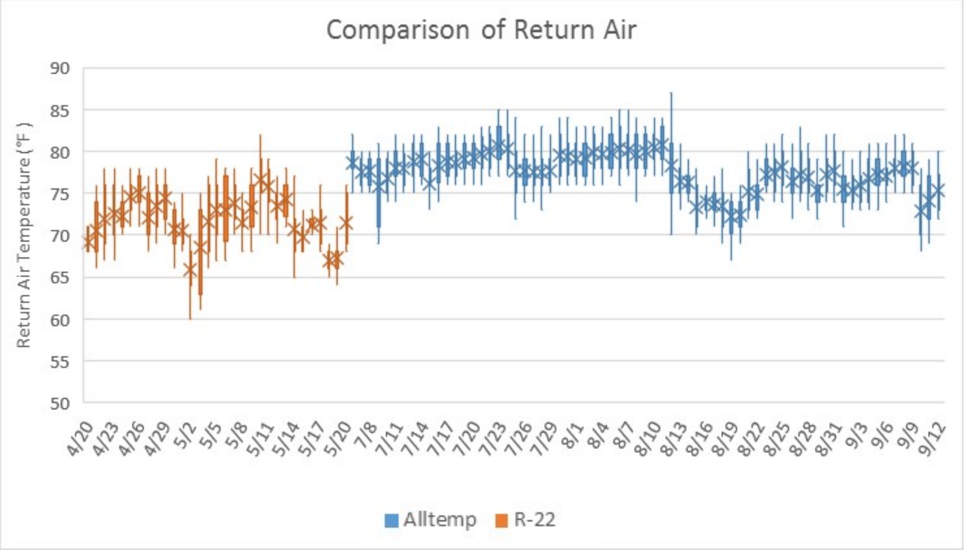
Data Discovery

RETURN AIR

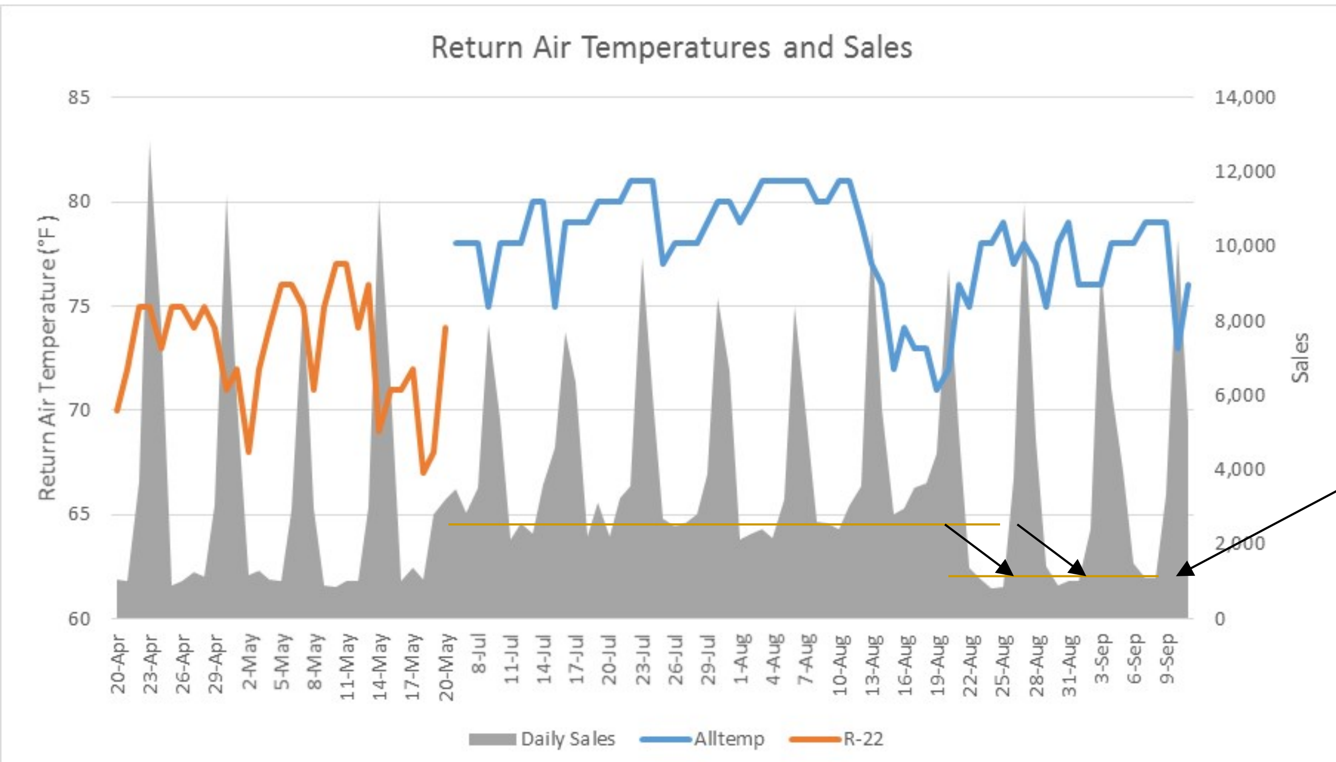
- Box and whiskers plots of Return Air show alltemp® handled higher Return Air temperatures as compared to R-22







- Higher Return Air temperatures appear to be the result of increased visitorship at the location
  - More visitors, people inside the location, increase the internal temperature of the location. That is, each individual person acts as a "heater" thus the more people that visit the location at a single time, the more heat that is "people generated" occurs and leads to higher Return Air temperatures
  - By-product heat creation also occurs as a result of ovens running more, games operating more, etc. and create additional heat above "normal" and expected temperatures

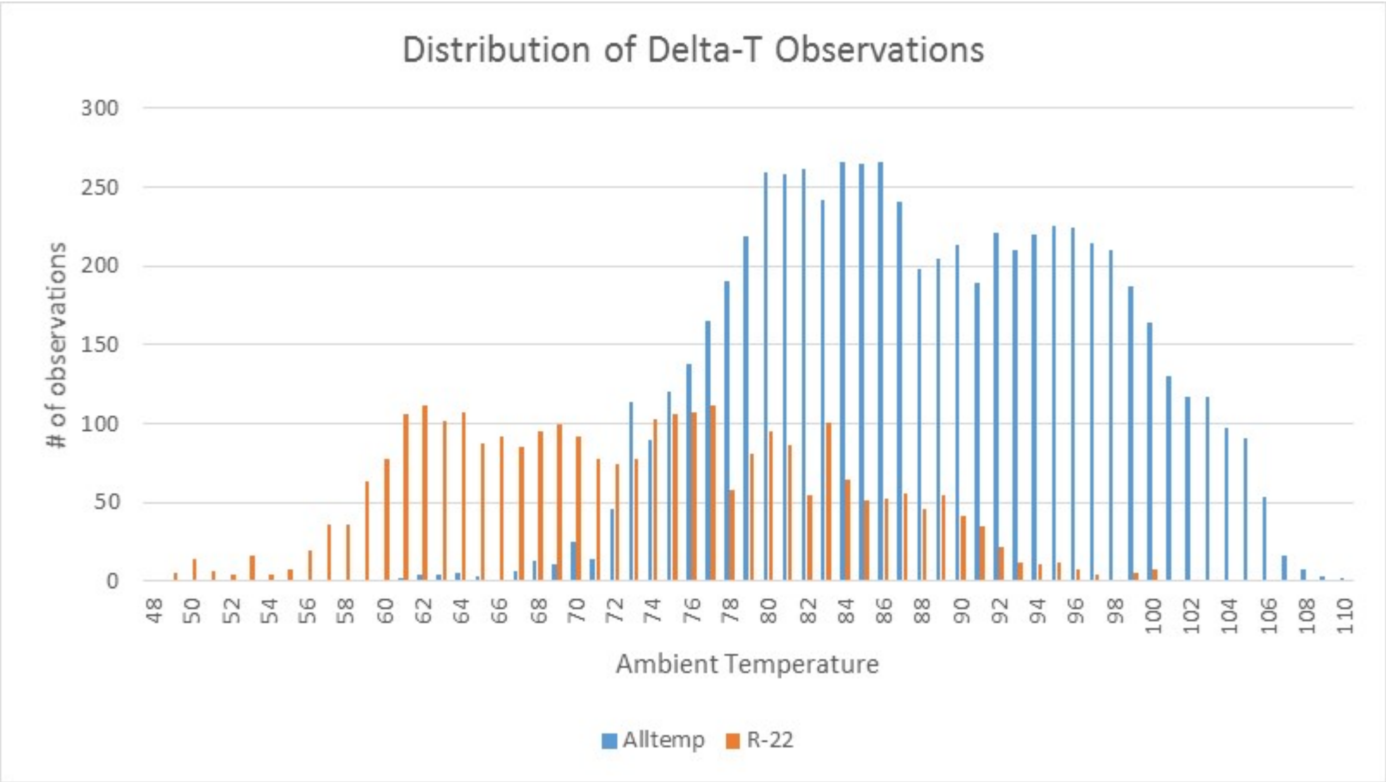


School began Aug 22nd and noticeable shift occurred in sales

Data Discovery

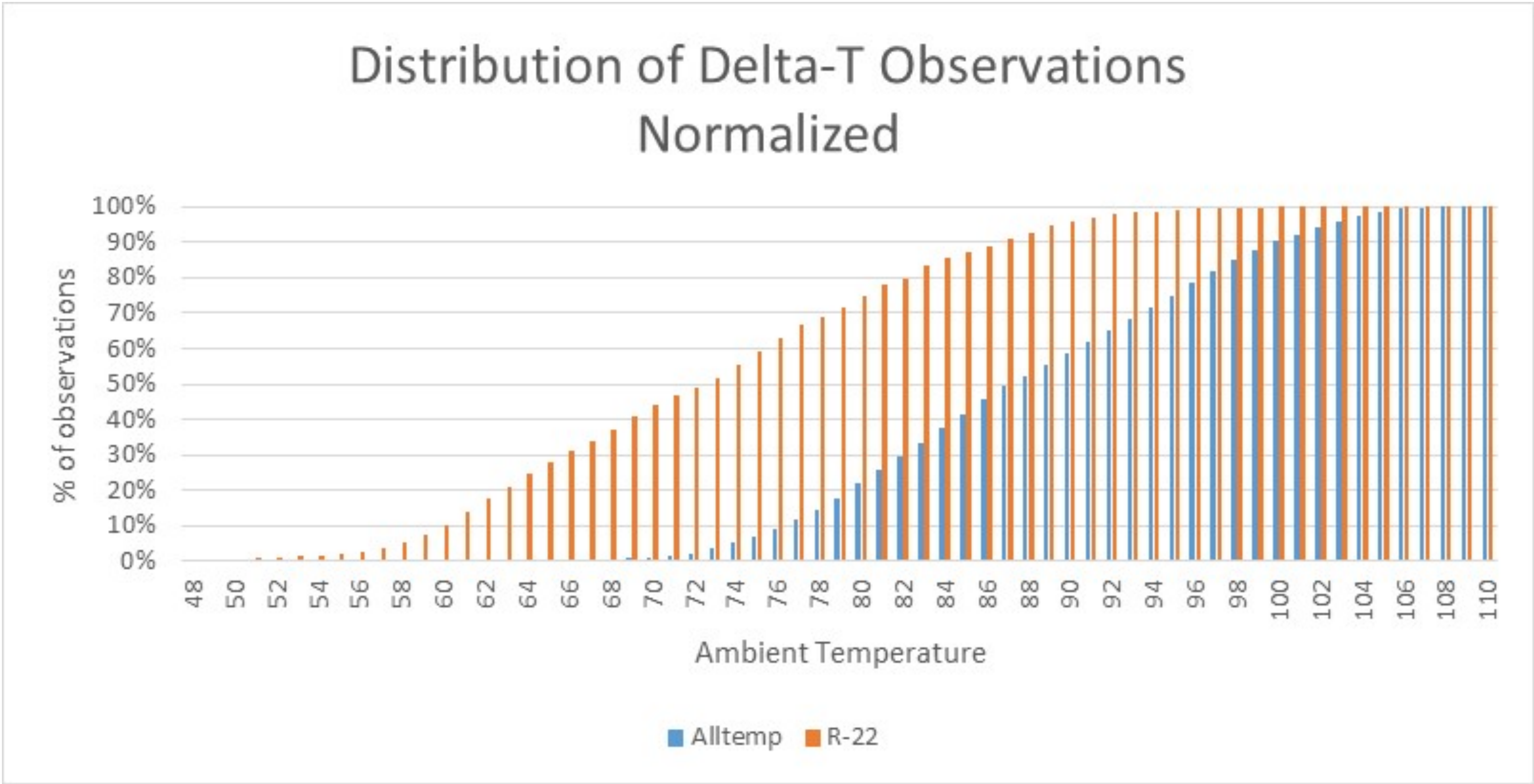
DELTA-T

- Remembering that alltemp® was run when ambient temperatures were much higher than those when R-22 was run, the distribution of observations by ambient temperature was very different
- Additionally, rooftop-supply air measures were not available prior to 8/9 though alltemp® was loaded on 7/6

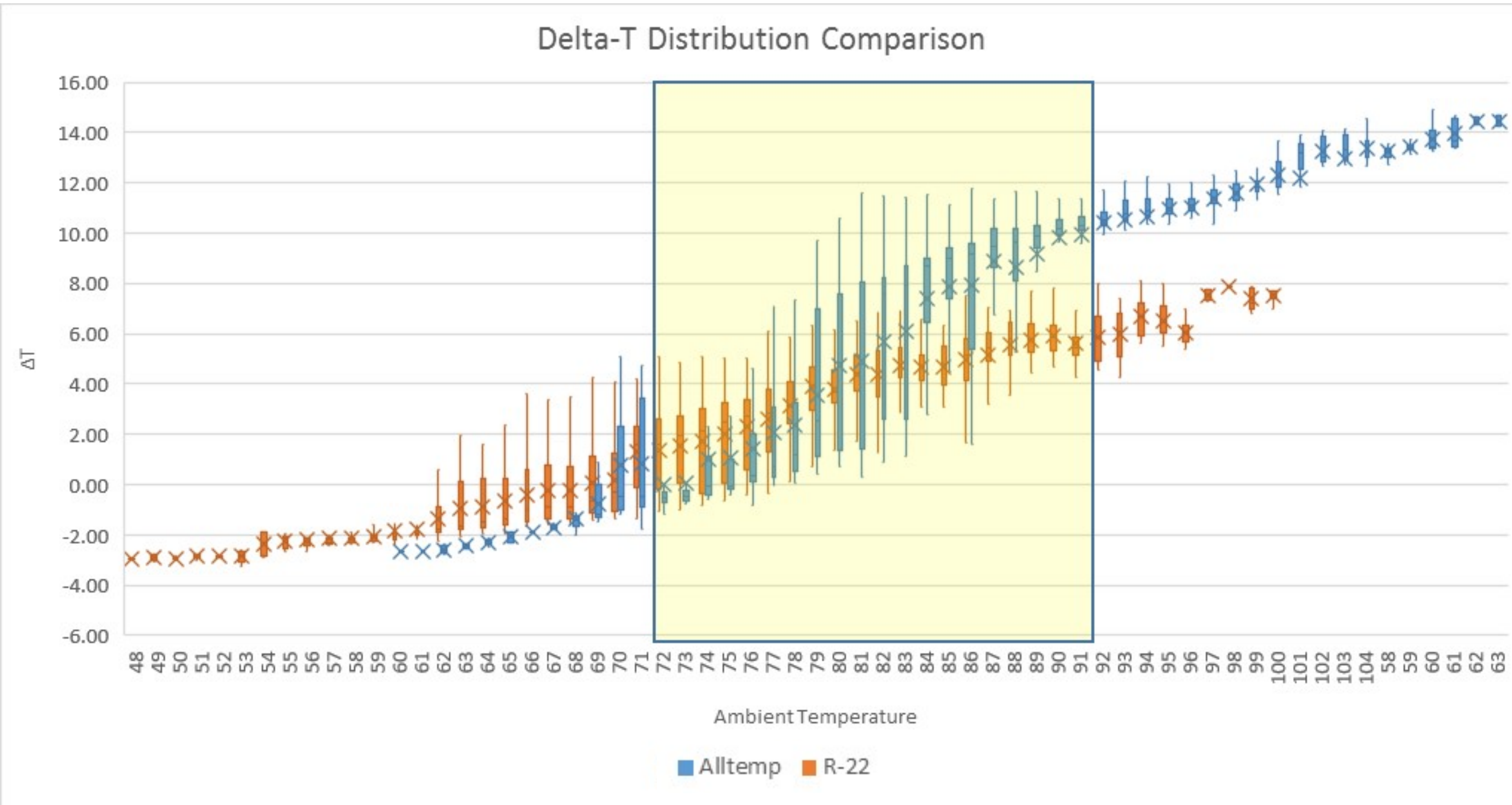


Ignoring the "height" of the bars in the chart because the alltemp® test ran for a longer period than the R-22 comparison period, alltemp's® distribution (the blue bars) is noticeably "shifted" to the right of R-22's (the red bars) meaning only that more of of it's measures occurred at higher temperatures

- Normalizing the number of observations as a percentage of records observed at each degree of temperature, about 80% of the R-22 ΔT records were observed by 82º as compared to alltemp® which climb to about 97º to achieve the same 80^{th}- percentile
- Clearly, a larger percentage of alltemp's® ΔT's were observed and measured at higher ambient temperatures



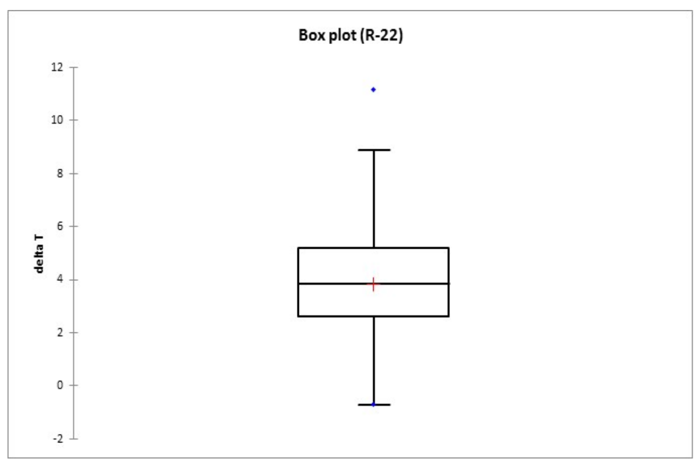
- A comparable ambient temperature range is 72º-91º due to small sample size (less than 30 measures for a given ambient temperature)

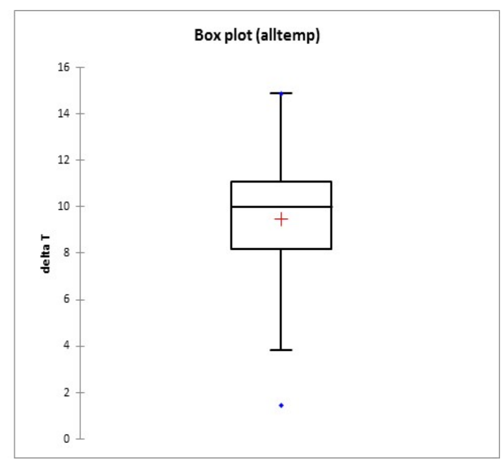


- “untrimmed” comparison, uncontrolled by comparable ambient temperature measurements, alltemp® delivered substantially larger ΔT’s than R-22

- Data must be “trimmed” to control for ambient temperature
- That is, if ambient temperatures were not similar and R-22 experienced lower ambient temperatures than alltemp®, than R-22 did not have the opportunity to “achieve” better ΔT’s
- As seen in prior slides, ambient temperatures were very different for R-22 vs. alltemp®

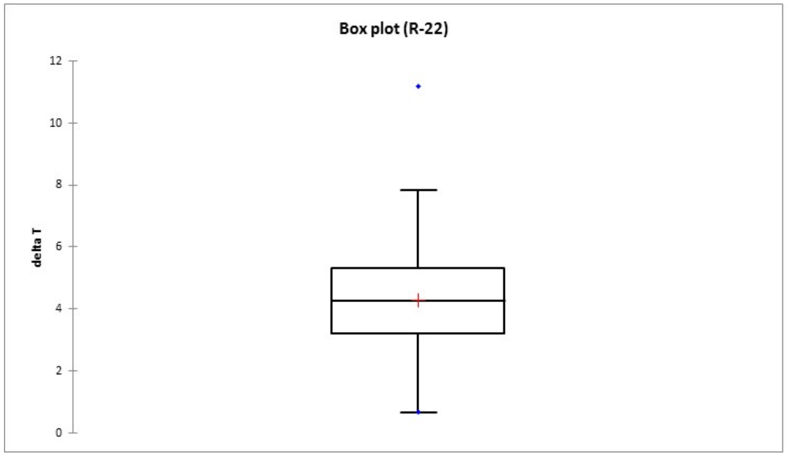
All obs. (5+min)	Average ΔT	25^{th} %ile	50^{th} %ile	75^{th} %ile
R-22	3.8	2.6	3.9	5.2
alltemp®	9.5	8.2	10.0	11.1
% Diff	147%	214%	159%	113%

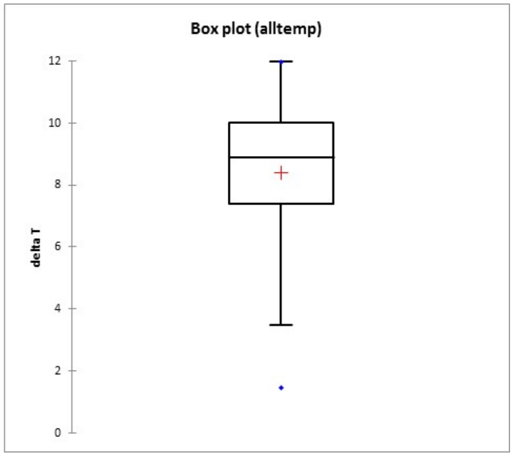




Controlling for ambient temperature, alltemp® delivered nearly **double** the ΔT's of R-22 when looking at compressor "on" times of 5 minutes or more

72º-91º (5+ min)	Average ΔT	25th %ile	50th %ile	75th %ile
R-22	4.3	3.2	4.3	5.3
alltemp®	8.4	7.4	8.9	10.0
% Diff	97%	130%	109%	88%





- **alltemp® delivered a 97% higher average ΔT than R-22**
- Data included for selected ambient temperatures (N>=30) only when compressor was on at least 5 minutes during a 15 minute interval

Data Discovery

DAILY KW

Recall the Pre/Post analysis considerations

Pre-alltemp®

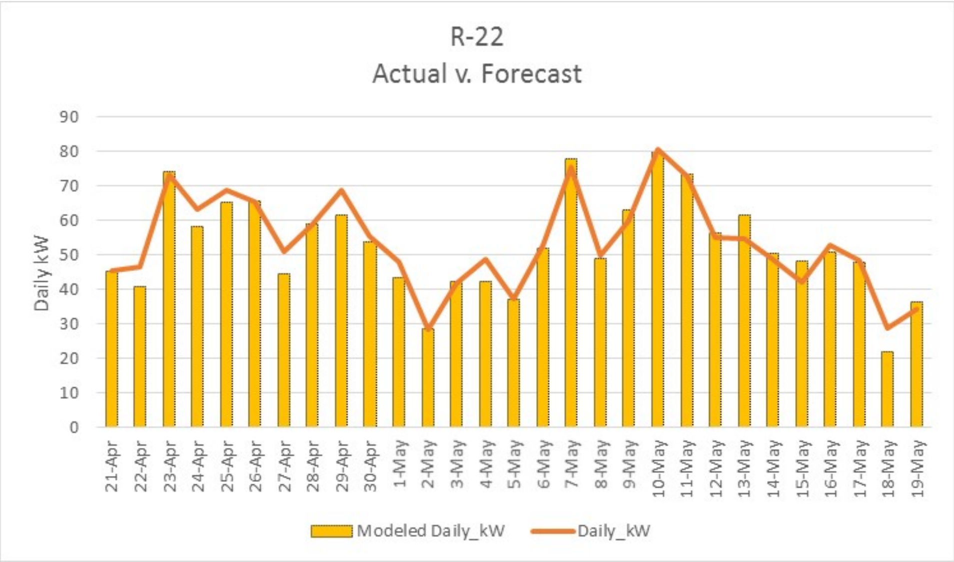
- Spring
- Lower ambient temperatures
- Lower M-F consumer traffic in location*
- Mother's Day
- Within a week of April 15th Tax Day
- Cinco de Mayo
- During school year

Post-alltemp®

- Summer
- Higher ambient temperatures
- Increased M-F consumer traffic in location* (higher return temperatures)
- Mixture of no-school and start of new school year

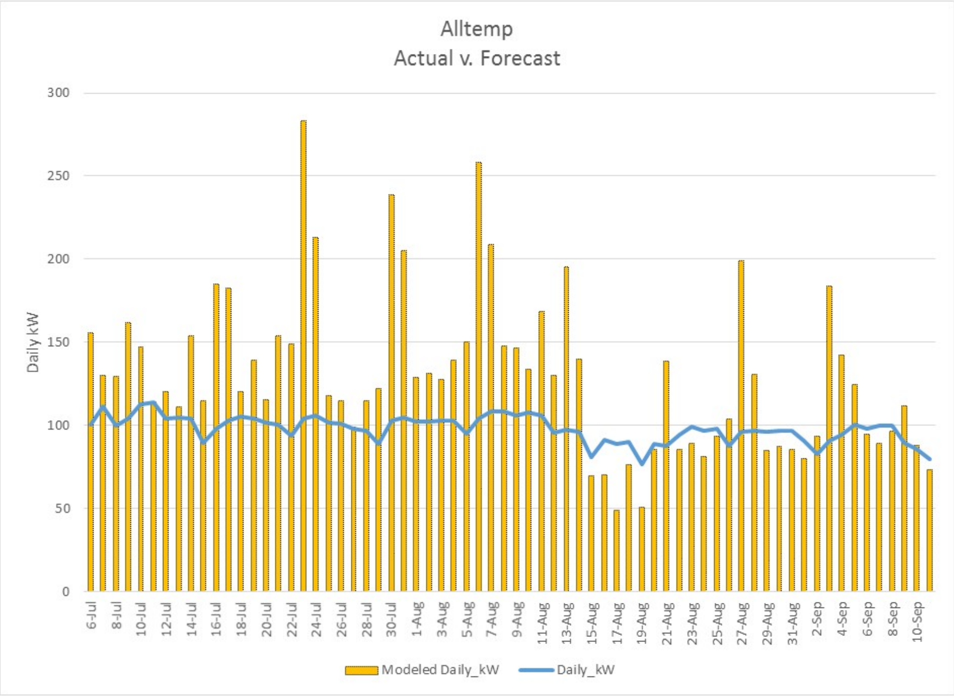
- alltemp® did technically use more kW during the summer test timeframe than R-22 in the spring baseline timeframe because of higher ambient temperatures and more consumer traffic in the location
- Given the test conditions of pre/post versus side-by-side, a statistical model was created and fitted to the R-22 data during the spring to forecast daily kW usage based on selected inputs
- That statistical model was then used to forecast the expected R-22 usage during the summer timeframe
- When the forecasted and actual Daily kW usage were compared, alltemp® presented a **33% Daily kW savings over R-22**

- alltemp® delivered an estimated **33% Daily kW savings over R-22**



- Between 4/21 and 5/19, approximately 1,558 kW's were used. The model fit to this yielded a forecast of 1,530kW (1.8% of actual)

Note: end points of 4/20 and 5/20 were removed because of partial data



- Between 7/7 and 9/11, approximately 6,566 kW's were used. Using the fitted model, a forecast of 8,699 resulted (32.3% above actual)
- Thus, had alltemp® not replaced R-22, Daily kW's would have been expected to be approx. 33% higher than what was actually experienced

Note: end points of 7/6 and 9/12 were removed because of partial data

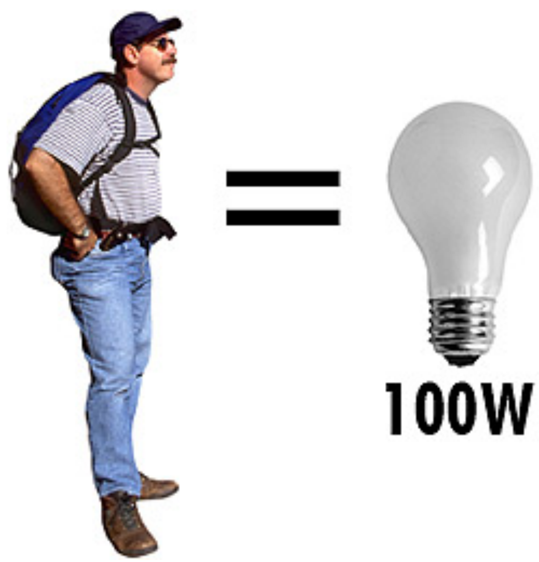
- Identified factors* that impacted daily kW usage in model
  1) Ambient Temperature (OSAT)
  2) Daily Sales (acts as proxy for visitorship)
  3) Wednesday
  4) Friday
  5) Cinco de Mayo
  6) Number of degrees temperature exceeds 80º

- Other factors* were offered in the model but either could not reach or maintain significance to stay in the model
  1) Other weekdays
  2) Minimum temperatures
  3) Sq. root, log, ln, power transformations of variables
  4) Mother's day, day before mother's day
  5) 15th and 30th (pay days)
  6) Pay weekends (payable weekend based on a 15th/30th payday)

*the factors, variables, have been transformed in some instances to dummy variables or are multiplied by another listed variable because of an interaction

APPENDIX

- Single person creates about 100W
  - The average human (according to my Coke® can's Nutrition Facts label) consumes approximately 2000 Calories per day (it's actually usually somewhere between 2200 and 4000, but 2000 is a nice number). Using a simple conversion (1000 calories = 1 Calorie, 1 calorie = 4.1868 J), this amounts to 8.37×10^6 joules ingested per day.
  - This means that the average person expends ~8.37×10^6 joules of energy per day, since most of us are in some sort of equilibrium with our surroundings. Assuming most of this energy leaves us in the form of heat, I calculate that on average we radiate ~350,000 J of energy per hour. Since Watt is just Joules per second, this is roughly equal to energy given off by a 100 Watt light bulb!



Statistical Interaction

The simplest situation is when the effect of each independent variable is completely separate from the other independent variables. Whatever the effects of the different independent variables are, they just add up or accumulate in a simple way. We call this additive effects, i.e. no interaction.

The more complicated situation is when the effect of one independent variable depends on another independent variable(s). We are familiar with examples in the area of drugs. A drug X might be desirable for treating a certain condition, but not if you are taking drug Y, because if you do take drugs X and Y together there is a bad consequence from their combination, a bad drug "interaction".

"Statistical interaction means the effect of one independent variable(s) on the dependent variable depends on the value of another independent variable(s)." Conversely, "Additivity means that the effect of one independent variable(s) on the dependent variable does NOT depend on the value of another independent variable(s)."

Interaction and Association

Easy to confuse the concepts of association (a.k.a. correlation) and interaction. Or to assume if two variables interact, they must be associated. But it's not actually true.

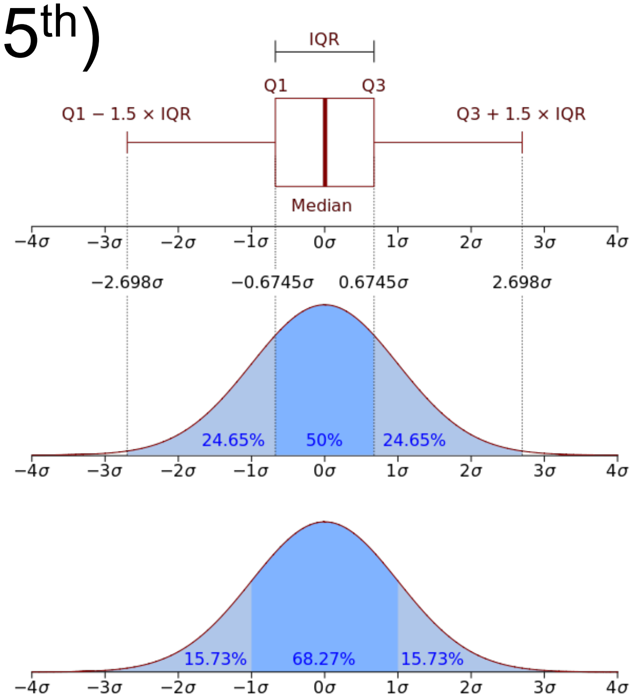
Association between two variables means the values of one variable relate in some way to the values of the other. Essentially, association means the values of one variable generally co-occur with certain values of the other.

Interaction is different. Whether two variables are associated says nothing about whether they interact *in their effect on a third variable*. Likewise, if two variables interact, they may or may not be associated.
An interaction between two variables means the effect of one of those variables on a third variable is not constant—the effect differs at different values of the other.

Lastly, correlation is not causality. Just because correlation exists, it does not mean that one "caused" the other. It merely means that 2 things appear to occur together.

Box and Whiskers Plot

- a box plot is a convenient way of graphically depicting groups of numerical data through their quartiles (25^{th}, 50^{th} and 75^{th} percentiles
- “whiskers” are lines extending from the boxes indicating variability outside the upper (Q3 or 75^{th}) and lower quartiles(Q1 or 25^{th})



- Model Methodology
  1) Data discovery
  2) Descriptive & univariate analysis
     - Additional variable of visitorship identified as a possible dependent variable
     - Used Sales as a proxy for visitorship
  3) Pearson's Rho's assessed
  4) Interaction variables created
  5) Regression model built to predict Daily kW usage
     - Built using only spring data (R-22 data)
     - different methods considered: stepwise, Mallow's CP, Adjusted R
  6) Model applied to summer data (alltemp® data)

Research

- http://www.greenbuildingadvisor.com/blogs/dept/musings/calculating-cooling-loads
- http://www.physlink.com/education/askexperts/ae420.cfm
- http://ergo.human.cornell.edu/studentdownloads/DEA3500notes/Thermal/thcondnotes.html
- http://www.usclimatedata.com/climate/grapevine/texas/united-states/ustx0548
- http://www.gcisd-k12.org/Page/2959
- https://commons.wikimedia.org/wiki/File:Boxplot_vs_PDF.svg#/media/File:Boxplot_vs_PDF.svg