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Puget Sound Energy Temperature Trend Study

Submitted to:

Puget Sound Energy

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Puget Sound Temperature Trend Study

1. Overview

Over the last twenty years, there has been a growing concern about the impact of climate change on the environment, the economy, and long-term human health. It has been well-documented that the air mass and oceans are warming, contributing to more extreme weather events, and by extension, potentially catastrophic weather events in the future. In the Northwest, the Bonneville Power Authority (BPA), the Army Corps of Engineers, and the Bureau of Reclamation (*River Management Joint Operating Committee – RMJOC*) have been studying climate impact on the Columbia River Basin since 2009. The RMJOC studies, like climate-model-based studies across the country, project increasing temperatures. The Northwest Power and Conservation Council (NWPCC) has been building on this work as part of the 2021 Power Plan; updated climate scenarios based on the RMJOC analysis will be incorporated into long-term energy and demand forecasts.

Itron was contracted by Puget Sound Energy (PSE) to evaluate temperature trends in the PSE service area. Rather than basing analysis and projections on Global General Circulation Models (sometimes referred to as Global Climate Models - GCM), we have taken a data-driven approach based on historical temperature trends. Trend-based projections provide a comparison against the wide-range of temperature outcomes derived from GCM models and provide a basis for developing weather inputs for sales, energy, and peak forecast models. Itron has performed similar analyses for NVEnergy and NYISO (New York Independent System Operator). The focus on temperature trends, rather than complex interactions in climate, provides a simple, data-driven approach for analyzing and evaluating the impacts on electricity and natural gas consumption.

The primary objectives include:

- Evaluating historical temperature trends observed in PSE's service area
- Developing estimates of future temperature trends based on results of the historical temperature analysis
- Translating temperature projections into long-term Heating Degree Days (HDD) and Cooling Degree Days (CDD) used for PSE's load forecasting models
- Comparing PSE's observed temperature trends to recent regional and other climate impact studies

The focus of this work is on temperature trends. It is not a climate study. The analysis does not address other components of weather and climate, such as precipitation, snowpack, extreme weather events, or El Niño/La Niña events.

2. Summary

Our analysis shows that there is a strong and statistically significant increase in average temperature in the PSE service area. Temperatures at the Seattle-Tacoma International Airport (SEA-TAC) have been steadily increasing over the last fifty years. Itron's analysis of long-term temperature trends shows temperature increasing approximately 0.04 degrees per year or 0.4 degrees per decade. This trend is consistent with other analyses of historical temperature trends and recent Colombia River Basin climate impact study. Forecasts based on the average of past temperatures are likely to underestimate future cooling requirements and overestimate heating requirements.

While PSE average daily temperatures are increasing, peak-day temperature trends are statistically weak, but still positive. We are still likely to experience extreme cold-days consistent with the past and summer peak days that are not significantly warmer than they are today.

3. Climate Impact Studies

Increasing global temperatures have been well-documented. The majority of climatologist attribute temperature increases to a rise in anthropogenic (i.e., caused by humans) greenhouse gas concentrations.

The Intergovernmental Panel on Climate Change (IPCC), the world's leading organization on climate change, in their most recent temperature projections show that by 2100, global average temperatures increase 1.1 to 2.6 degrees Celsius for RCP 4.5 and 2.6 to 4.8 degrees Celsius for RCP 8.5 over the base-year period (1986 – 2005); this translates into roughly 0.5 to 0.9 degree (Fahrenheit) increase per decade (*Appendix A*, *Reference 1*).

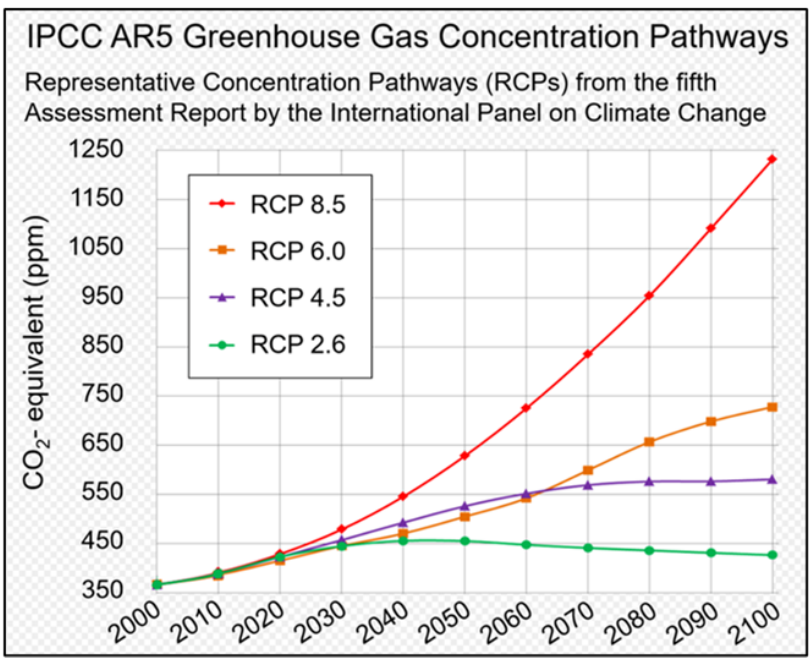
The River Management Joint Operating Committee (RMJOC) began studying the impact of climate change on the Columbia River Basin in 2009. The RMJOC includes Bonneville Power Administration, United States Army Corps of Engineers, and United States Bureau of Reclamation. The 2009 – 2011 analysis indicated that there was a strong likelihood of increasing temperatures due to anthropogenic causes. In 2013, RMJOC began work to update the study. The updated analysis and associated water flow data set was published in June 2018 (*Appendix A*, *Reference 2*). The focus of the study was on the potential impact of climate change on the Federal Columbia River Basin Power System. RMJOC concluded increasing greenhouse gases will result in increasing temperatures that in turn will contribute to declining snowpack, more of the winter runoff in the form of rain, earlier spring runoffs, lower water levels in the summer months, and greater difficulty managing the river system. The study further concluded there will be a decrease in regional heating requirements (3% to 4% in December) and an increase in cooling loads (1% to 3% in July). Depending on future greenhouse gas paths, temperatures are expected to increase 0.3 to 1.0 degrees per decade between 2010 and 2040 (*Appendix A reference 1*).

NWPCC, which is responsible for regional power planning in the Pacific Northwest, is currently working on the 2021 Power Plan. Updated climate scenarios based on the RMJOC climate modeling work were presented in April 2020. Results indicate fewer heating degree-days (HDD) and more cooling degree-days (CDD), both of which are consistent with increasing temperatures.

The basis for climate projections in the RMJOC, the NWPCC, and other climate projections are derived from Global Climate Models (GCM). There are over fifty GCMs that model the interaction between greenhouse gas, the physical environment, and solar radiation. Over the last ten years, there have been significant improvements in understanding the complex relationship between increasing greenhouse gases, air circulation, oceans and ocean currents, land and its topography, vegetation, and human activity, as a result of increased computing power, advances in data collection, and improvements in modeling. This has allowed climatologists to develop more confidence around localized climate impact results.

GCM model outputs are based on one of four greenhouse gas paths established by the IPCC. The paths reflect the greenhouse gas accumulation to reach specific Radiative Forcing (RF) levels by the year 2100. Figure 1 shows these paths.

Figure 1: GCM Greenhouse Gas Paths



RF is a measure of the difference between insolation (the amount of heat the earth absorbs from the sun) and the amount of heat released back to space. In 1750, the RF value was 0. Estimated 2018 RF value is 3.1. Most climate impact studies focus on the RF 4.5 and RF 8.5 paths. Many climatologist and studies (including the RMJOC) believe we are on the 8.5 path. Other climatologists believe that the 4.5 path is the more likely outcome. Currently, there is little divergence in these paths. Very few expect the 2.6 path, as that would imply an aggressive worldwide greenhouse gas mitigation effort. There should be a better idea as to which path we are on over the next ten years.

Each model and selected greenhouse gas path generates a different temperature path based on the underlying model structure and model inputs. Given differences in models, model inputs, and greenhouse gas path assumptions, there is a large range of possible temperature outcomes. In developing temperature and other climate variable projections, climate studies will weigh the regional output from multiple models; for the NWPCC this involved utilizing an ensemble approach across 19 GCM. References to recent climate impact studies and projected temperature trends are provided in Appendix A.

Rather than basing temperature and degree-day projections on GCM results, this study bases CDD and HDD projections on historical temperature trends. The advantage of a data-driven approach is that we can calibrate into specific regional weather data and statistically measure both trend and variance. Regional global climate modeling work provides a framework to compare against trend-based temperature projects.

4. PSE Temperature Analysis

The primary objective of this study is to estimate temperature trends for the PSE service area and to develop normal heating degree-days (HDD) and cooling degree-days (CDD) that reflect estimated temperature trends. Temperatures in the PSE service area are increasing approximately 0.4 degrees per decade. With increasing temperatures, HDDs can be expected to decline and CDDs to increase.

Our approach was developed as part of the climate impact study conducted for the New York ISO. The study estimated temperature trends for over twenty-weather stations across the state with simple linear trend regression models. Temperature trend coefficients derived from the regression equations were used in calculating regional trended normal heating and cooling degree-days. Daily, monthly, and peak degrees were then used in estimating long-term end-use load models and developing long-term hourly load forecasts for each of the New York ISO planning zones (*Appendix A, Reference 3*).

Estimate Temperature Trends

The PSE temperature analysis is based on reported temperatures for the Seattle-Tacoma International Airport (SEA-TAC) for the period 1950 through 2019. Annual average, maximum, and minimum temperatures are calculated from the historical hourly temperature data. While we evaluated a number of temperature concepts, we ultimately focused on:

- Average annual temperature
- Minimum temperature during peak winter heating period
- Maximum temperature during peak summer cooling period

Average Annual Temperature. Temperature trends are estimated using simple linear regression models that relate temperature to time as measured by a linear trend variable.

Figure 2 shows the calculated average temperature trend and coefficient statistics. The light-blue line shows the 90% confidence interval. The model is estimated with annual average temperature starting in 1950.

Figure 2: Average Annual Temperature Trend

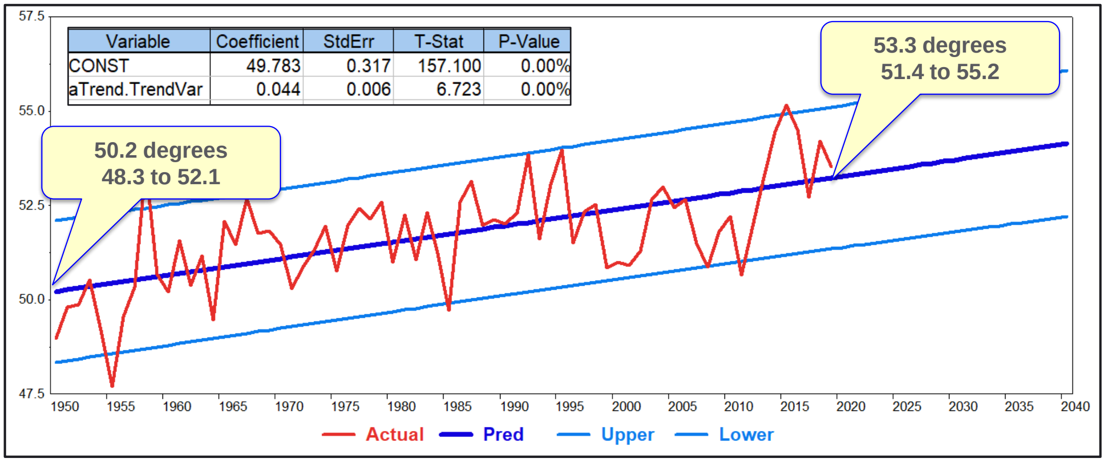


Figure 2 shows a positive and statistically significant temperature trend with a T-Statistic of 6.7 and a P-Value of 0.0%. The estimated trend coefficient is 0.044; this implies that over the estimation period, average temperatures have been increasing 0.044 degrees per year or 0.44 degrees per decade. Given the model standard error, at the 90% confidence level, temperatures have been increasing 0.34 to 0.54 degrees per decade. The expected temperature in 1950 was 50.2 degrees compared with 53.2 degrees in 2019. Expected average temperature increased 3 degrees over this period.

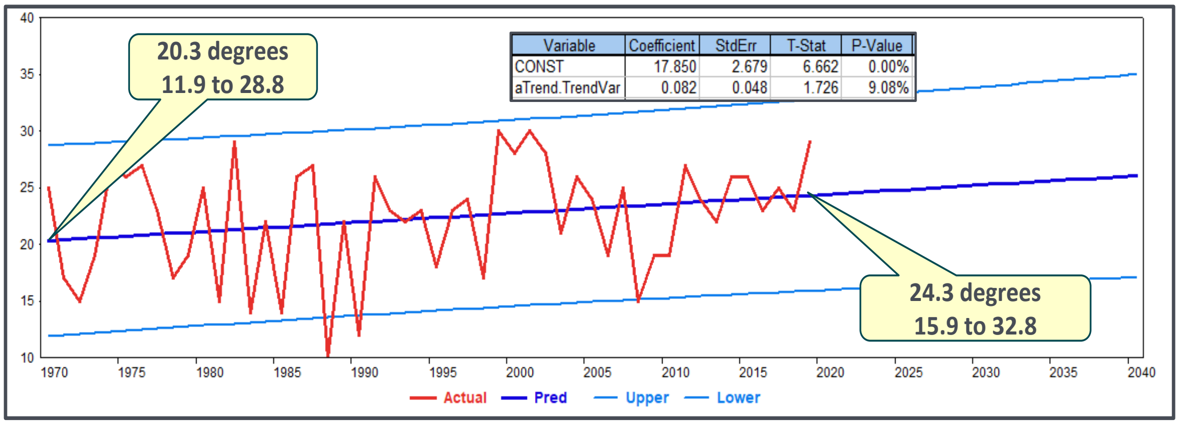
In the New York study, there was some discussion as to whether the temperature trend was linear or in-fact increasing at a faster rate over time. We evaluated a number of functional forms, but in the end, concluded that temperatures are best explained by a linear trend. This is also the case with PSE; there is no indication that changes in temperature are accelerating.

Over the last seventy years, temperature measurement has been impacted by changes in measurement location and measuring equipment (e.g., transitioning from analog to digital measurement). Shortening the estimation period to 1970 (i.e., 50 years) results in 0.037 degrees per year (0.37 degrees per decade). Depending on the start year, the estimated trend coefficients vary from 0.33 to 0.47; all within the 90% confidence interval. The average across the different estimation periods is approximately 0.4 degrees per decade.

The impact of increasing temperatures on energy demand largely depends on the sensitivity of electricity or natural gas use to changes in temperature. PSE is a winter-peaking utility with significant electric and natural gas heating load; winter energy requirements are strongly correlated with winter temperatures. The relationship of summer loads and temperatures are relatively weak given low cooling load requirements due to generally mild summer temperatures. Increasing temperatures will have a stronger impact on the heating side in the form of decreasing HDD while increasing CDD are likely to have only a small impact on cooling-related energy use. As a result of increasing temperatures, HDD can be expected to decline on average 0.5% per year; ultimate impact on sales will depend on customer-class size and usage-sensitivity to changes in HDD.

Winter Heating Peak Temperature. PSE is most concerned with minimum temperature trends as it is cold-day temperatures that drive heating requirements and system peak. PSE uses minimum temperatures for hours 8 to 21 for the heating season (November to February) to define the peak temperature. Figure 3 shows the minimum winter temperature trend for the hours when peaks can occur.

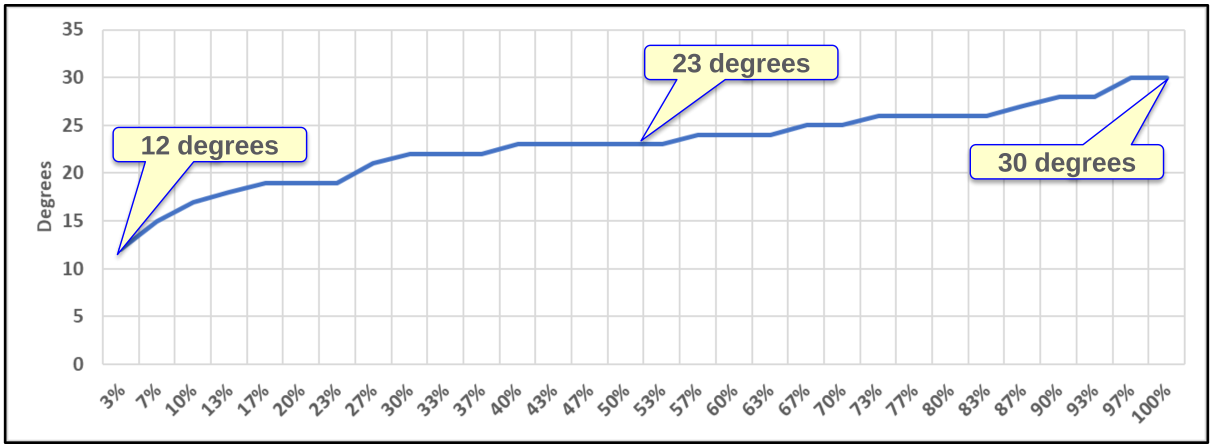
Figure 3: Winter Peak Temperature Trend



Starting estimation from 1970, the winter peak temperature is increasing 0.082 degrees per year or 0.82 degrees per decade. While this is faster than average temperature, the standard error is significantly larger, resulting in a relatively large 90% confidence interval around the minimum temperature trend. The expected minimum temperature in 1970 of 20.3 degrees is still within the 2020 90% confidence interval. This has implications when considering the appropriate assumptions for modeling peak-day weather impacts.

PSE electric system demand peaks in the winter period. The peak demand is largely driven by peak-day minimum temperatures. PSE currently plans for an expected peak-day temperature of 23 degrees. The 23-degree design day is based on the minimum winter temperature that occurred in each of the last 30-years. This is depicted in Figure 4 **Error! Reference source not found.**.

Figure 4: Winter Minimum Peak-Day Temperature (30-years, ranked low to high)

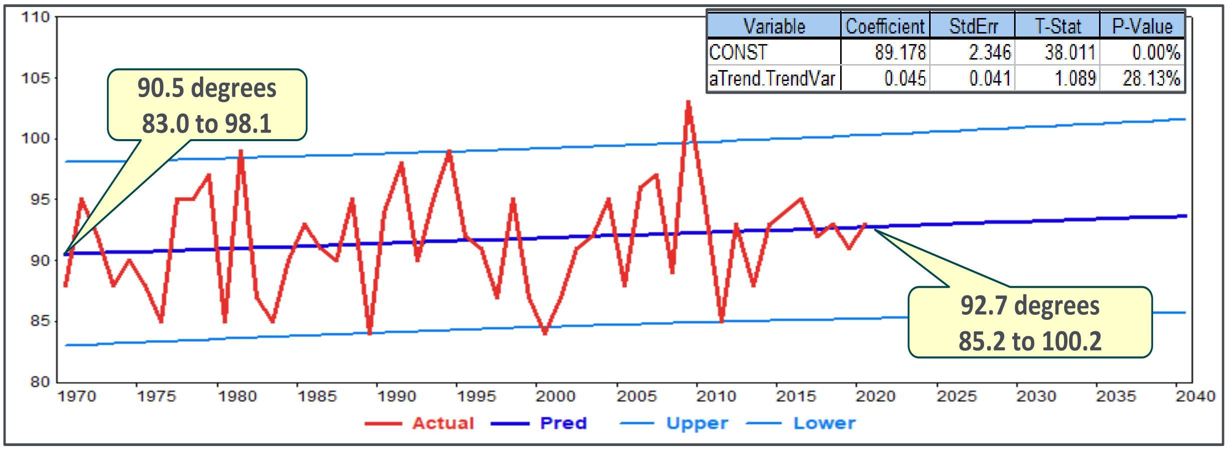


The coldest temperature in each year is ranked from the lowest temperature (12 degrees) to the highest minimum temperature (30 degrees). PSE plans system peak for the median of the data series -- 23 degrees, which is also the mean for this data series, as well as the mode, with 5 out of the last 30 years experiencing a day where minimum temperature fell to 23 degrees.

Based on the minimum temperature trend model, the expected minimum winter temperature in 2019 is 24.4 degrees with a 90% confidence interval of 16.4 degrees to 32.4 degrees. The current 23 degree-design temperature falls well within this range. Given the large number of occurrences where this temperature actually occurred, it is appropriate to plan for a 23 degree minimum temperature day even as minimum temperatures continue to rise. Calculating winter peak-day normal weather conditions based on the prior thirty years is a reasonable approach.

Summer Cooling Peak Temperature. The summer peak temperature is defined as the highest temperature over the summer cooling hours. This includes hours 8:00 to 20:00 for the months July and August. Figure 5 shows the summer maximum temperature trend starting in 1970 for the hours when peak occurs.

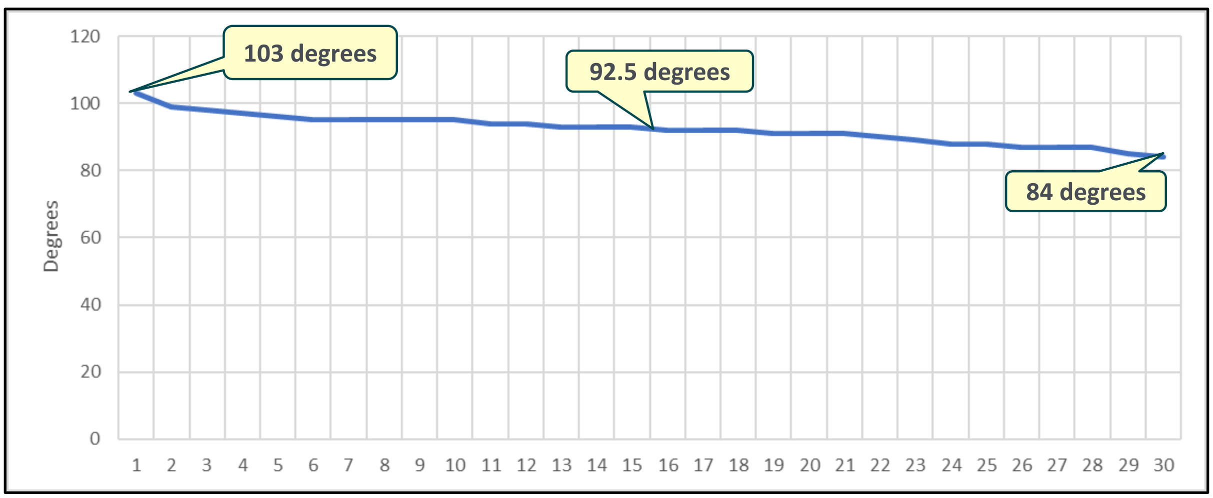
Figure 5: Summer Peak Temperature Trend



While the summer maximum temperature trend is positive at 0.45 degrees per decade, it is statistically significant only at the 70% level of confidence. For PSE, these translates into a wide expected summer peak temperature range with a 90% confidence bound of 85.2 to 100.2 degrees in 2020.

Figure 6 shows the peak-day temperature for the summer months (July through August). Temperatures are ranked from the highest peak-day temperature (103 degrees) to the lowest annual peak-day temperature (84 degrees).

Figure 6: Summer Peak-Day Temperature (30-years, ranked high to low)



The summer peak demand design temperature is defined as the median summer peak-day temperature (the midpoint of the temperature curve). The median temperature for the last 30 years is 92.5 degrees. As discussed above, the summer peak temperature trend is statistically weak and as a result there is a wide 90% confidence interval around the temperature trend line. The expected temperature based on the summer peak temperature trend line is 92.7 degrees with a minimum expected temperature of 85.2 degrees and a maximum expected temperature of 100.2 degrees. The 92.5 design temperature falls within the 90% confidence interval. Even as far out as 2040, the summer design temperature is well within the 90% confidence interval.

Temperature Trend Comparisons

In addition to New York, we have evaluated temperature trends for several utility service areas across the country, with estimated average temperature trends varying from 0.4 to 1.0 degrees per decade. In all cases, the average temperature trend is statistically significant. A recent study by the Penn Institute for Economic Research (PIER) found similar results (*Appendix A, Reference 4*). Table 1 shows average degree-day per decade derived from the PIER study.

Table 1: Estimated Temperature Trends

City	Station	TempChg	Per Decade
Atlanta	ATL	4.36	0.76
Boston	BOS	2.06	0.36
Baltimore	BWI	2.25	0.39
Cincinnati	CVG	2.53	0.44
Dallas-Fort Worth	DFW	3.44	0.60
Des Moines	DSM	3.93	0.69
Detroit	DTW	4.09	0.72
Las Vegas	LAS	6.05	1.06
New York (LGA)	LGA	4.03	0.71
Minneapolis	MSP	4.72	0.83
Chicago	ORD	2.86	0.50
Portland	PDX	2.55	0.45
Philadelphia	PHL	4.78	0.84
Salt Lake City	SLC	3.92	0.69
Tucson	TUS	4.89	0.86
Median		**3.93**	**0.69**

The median temperature trend across the 15 cities evaluated is 0.7 degrees per decade. Temperature trends varied from 0.36 degrees (Boston) to 1.06 degrees (Las Vegas). The highlighted cities show temperature trends close to what was estimated for the PSE service area. Like Seattle-Tacoma, these cities are in close proximity to the ocean, where temperature increases have tended to be lower.

While the PIER study measured average temperature trend, the primary focus was the diurnal temperature range (DTR); the DTR is the difference between the maximum and minimum temperature; the PIER study found a statistically significant decline in DTR across the sample cities. Other earlier work showed decline in DTR is largely the result of nighttime low temperatures increasing faster than daytime high temperatures.

Summary. The average temperature has been showing a strong statistical increase over the last fifty years in the PSE service area and across the country. PSE winter heating peak temperature is increasing faster than average PSE temperature, though there is a larger variance in expected minimum temperatures when evaluated for the 90% confidence interval.

While the summer cooling peak temperature is increasing, the trend is statistically weak. In other studies, we have found similar results where there has generally been a small positive maximum temperature trend, but the trend is statistically weak. Evidence from the PIER study and our analysis of other service areas indicate that it is largely increased in overnight minimum temperatures that are contributing to long-term overall temperature increase.

5. Translating Temperature Trends to Degree-Days

Electric and natural gas sales are significantly impacted by heating and cooling requirements. In electric and natural gas load modeling, the weather impact is generally captured by heating degree-days (HDD) and cooling degree-days (CDD). Actual HDD and CDD are key variables in usage models with expected HDD and CDD used in projecting future demand and isolating weather-related sales for variance analysis. HDD are designed to capture heating requirements and CDD cooling requirements. HDD and CDD are often referred to as spline variables as they only take on a positive value when a specified condition is met. For example, HDD with a 65 degree temperature base, only takes on a positive value when the average temperature is ***below*** 65 degrees. If the average daily temperature is 50, then HDD is 15 (i.e., 65 degrees – 50 degrees = 15); if the temperature is 65 or greater HDD equals 0. CDDs are the opposite; CDD have a positive value when temperatures ***exceed*** a defined reference temperature. For a CDD with a 65-degree reference point, a day with average temperature of 70 degrees results in a CDD of 5 (70 degrees – 65 degrees = 5); if the temperature is 65 degrees or lower CDD equals 0.

The following are the formulas for CDD and HDD, both with a base temperature of 65 degrees:

$$CDD65_d = Max(T_d - 65, 0)$$
$$HDD65_d = Max(65 - T_d, 0)$$

Where:

T = Average Daily Temperature
d = Date

Calculating Normal Degree Days. Normal HDD and CDD reflect our best expectation of future weather conditions and associated heating and cooling energy requirements. Normal degree-days also provide the basis for evaluating the weather impact on current electricity and natural gas sales. Normal HDD and CDD are calculated as an average of past weather conditions; we assume that the best estimate for future weather conditions is an average of past conditions. The industry standard has been to derive normal degree days using a 30-year historical period. Many utilities have moved to a 20-year and even 10-year normal period in recognition that temperatures are increasing; the shorter estimation period gives more weight to the current, warmer temperatures.

PSE calculates normal weather using the most current 30-year period. The current period is 1990 to 2019. PSE captures some of the increasing temperatures over time as the 30-year period is updated each year.

PSE uses a standard approach for calculating normal HDD and CDD for a range of temperature breakpoints. PSE first calculates daily HDD and CDD from historical daily average temperatures. The daily degree days are then averaged by date (i.e., average all the January 1st values, average all the January 2nd values, ..., average all the December 31st values) across the 30 years of historical weather data. The result is an average (or normal) daily degree-day series (366 values, including leap-year) for each temperature breakpoint concept. The normal daily degree-days are summed to derive calendar-month and annual normal HDD and CDD. Daily normal degree-days that reflect the billing period are derived by combining the meter read schedule and daily normal degree-days.

Table 2 shows calculated calendar-month and annual normal degree-days for different temperature breakpoints.

Table 2: PSE Normal Degree-Days (1990 -2019)

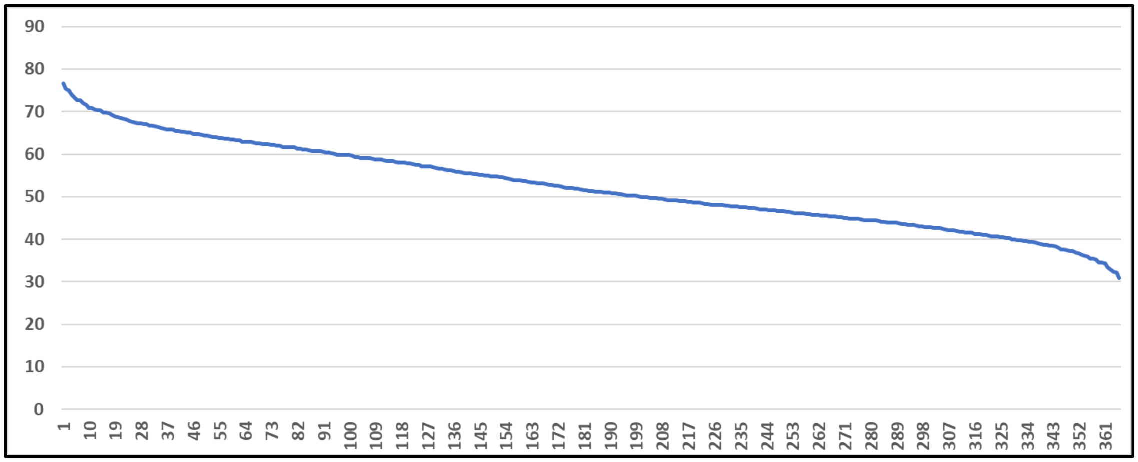
Month	HDD55	HDD60	HDD65	CDD60	CDD65
Jan	404.3	559.3	714.3	-	-
Feb	348.8	493.8	638.8	-	-
Mar	279.2	432.2	586.7	0.6	0.2
Apr	165.5	303.2	450.2	3.7	0.7
May	53.8	153.6	287.2	28.2	6.9
Jun	7.6	54.9	159.9	70.8	25.7
Jul	0.1	6.8	53.8	186.5	78.5
Aug	-	3.5	44.7	185.4	71.6
Sep	4.0	40.0	135.2	71.5	16.8
Oct	101.4	236.3	389.5	1.8	-
Nov	282.4	430.7	580.6	0.0	-
Dec	434.0	588.8	743.8	-	-
Total	**2,081.2**	**3,303.0**	**4,784.8**	**548.5**	**200.3**

Based-on the most recent 30 years, there are 2,081 normal HDD with a 55 degree-day base and 200 CDD with a 65 degree-day base. As summer weather conditions are mild in the PSE service territory, there are relatively few CDD.

Since temperatures have been increasing, the 30-year average is more representative of 2005 weather conditions (i.e., the mid-point of the 30-year normal estimation period) than 2019 weather conditions. By 2019, we would expect to see fewer HDD and more CDD than those derived from the 30-year average.

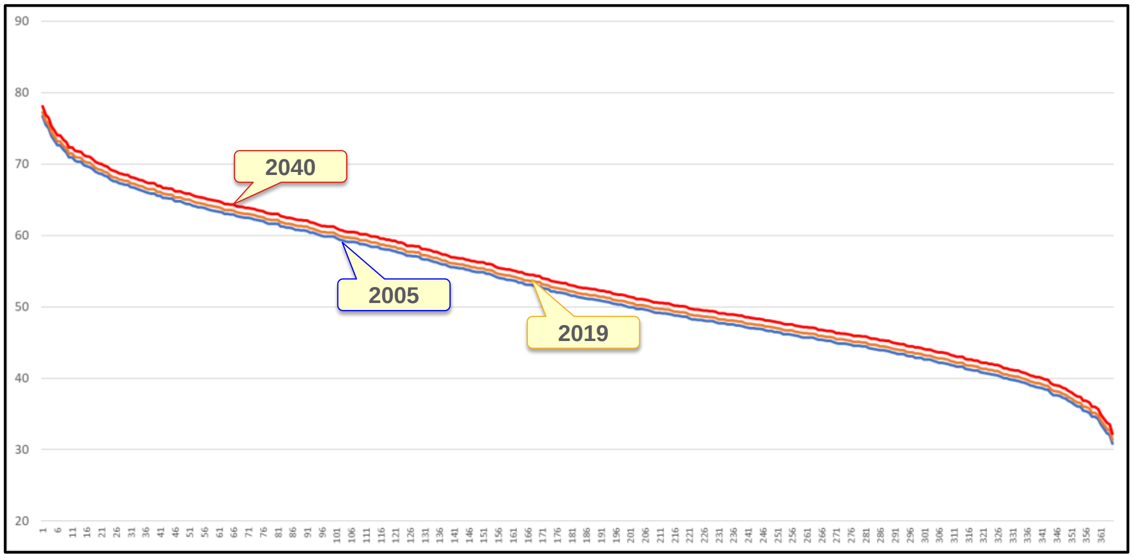
Calculating Trended-Normal Degree-Days. Trended normal HDD and CDD are derived for the PSE 0.4 degree/decade average temperature trend. The process starts with a 30-year average daily temperature series (366 observations) for the same 30-year period (1990 to 2019). Normal HDD and CDD are derived from average temperature (as opposed to daily degree-days) in order to calculate the impact of the temperature trend over time. The starting-year normal daily temperatures are derived using rank-and-average by month; in this process daily temperatures are ranked from the highest temperature to the lowest temperature within each month and then averaged across the monthly rankings. This results in an average temperature duration as depicted in Figure 7.

Figure 7: Average Daily Temperature (1990 - 2019)



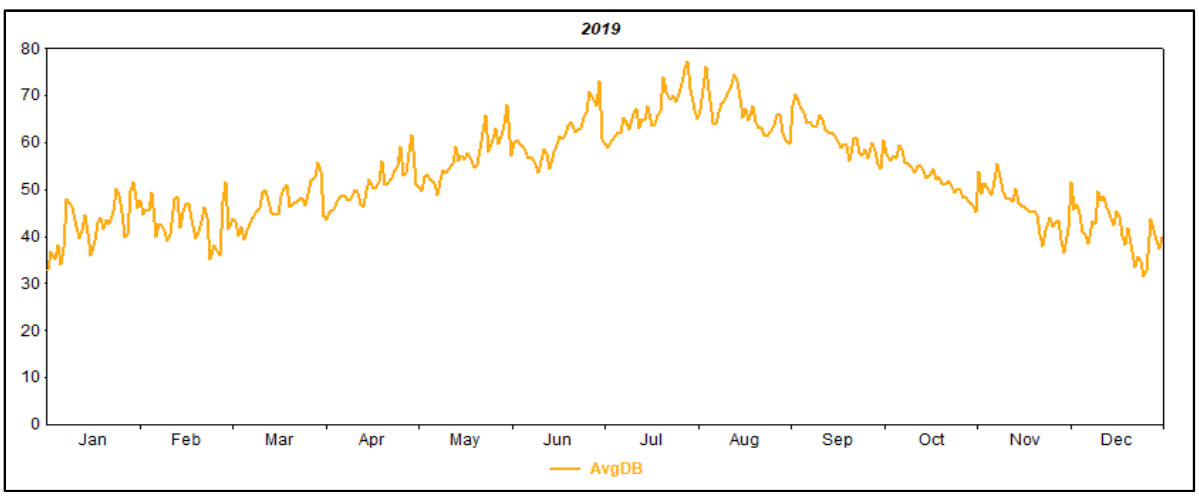
We assume that this curve best represents the average temperature in 2005 (the midpoint of the 30-year period). The normal daily temperature curve is then shifted out 0.04 degrees per year or 0.4 degrees per decade. Figure 8 shows the starting duration curve in 2005, the curve in 2019, and the curve in 2040.

Figure 8: Adjusted Temperature Duration Curves



The normal temperature curves are mapped to a typical calendar-year pattern as depicted in Figure 9.

Figure 9: Normal Daily Temperature Profile (2019)



The normal temperature profiles incorporate the expected temperature trend. The data set is used in generating daily normal degree days. Any aggregation bias (as a result of calculating normal degree-days from normal daily temperatures) is corrected by calibrating the start year (2005) to the PSE 30-year normal degree-days. Figure 10 and Figure 11 show resulting monthly HDD for a 55-degree base and CDD for 65-degree temperature base.

Figure 10: Trended Normal HDD (Base 55 Degrees)

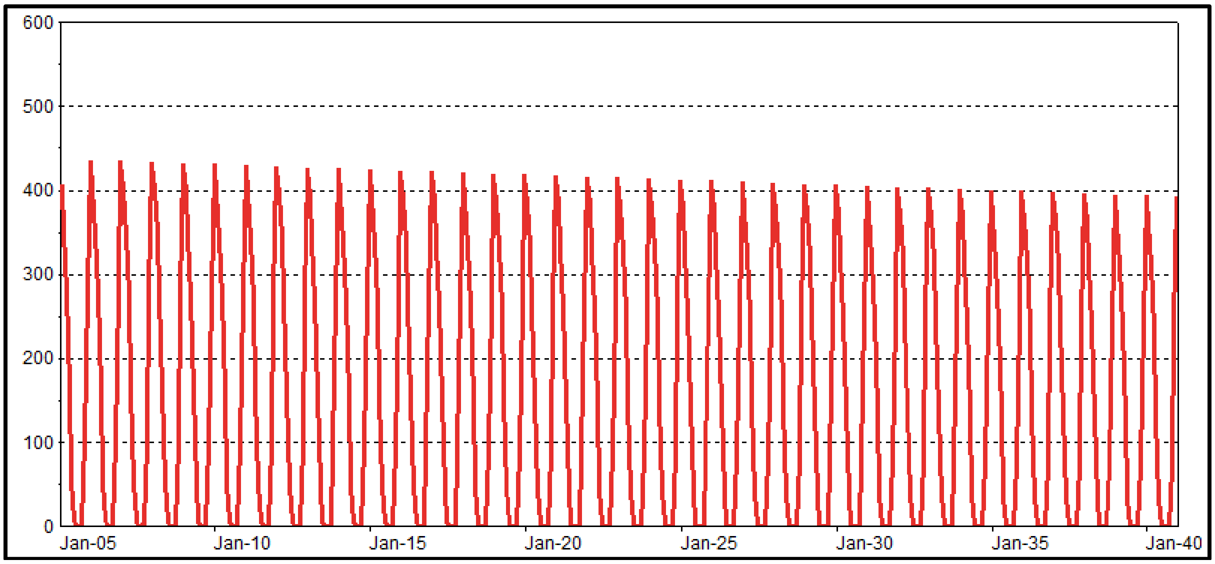


Figure 11: Trended Normal CDD (Base 65 Degrees)

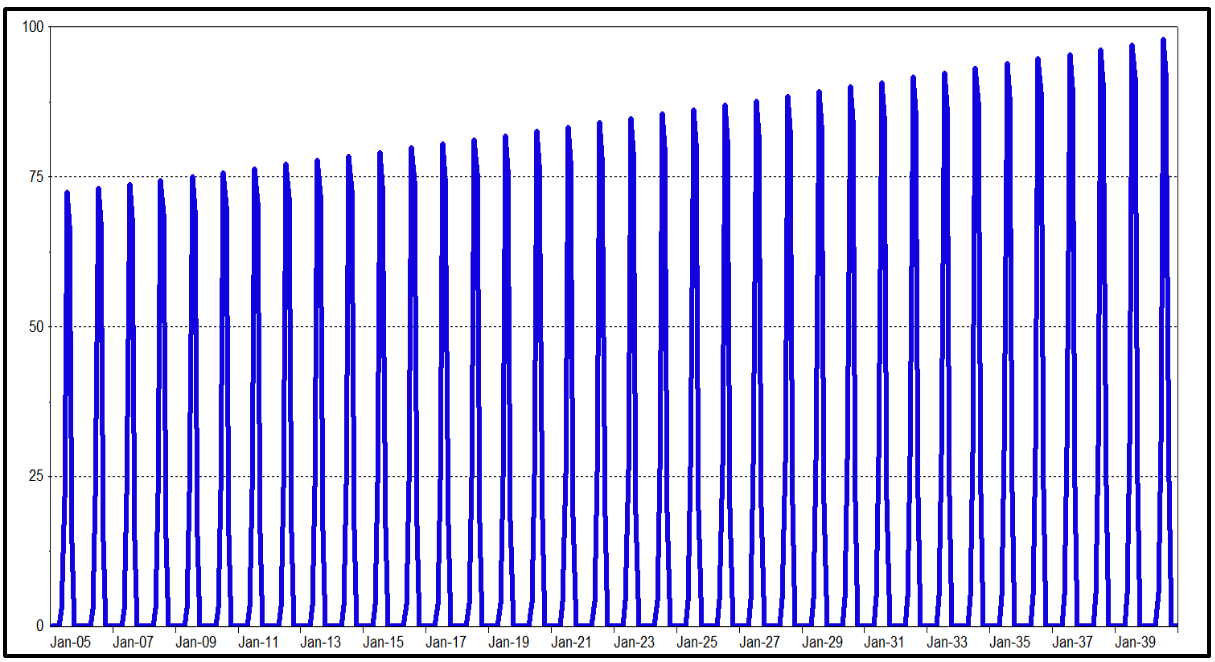


Table 3 shows a comparison of 2020 trended normal degree-days against the 30-year normal.

Table 3: 30-Year Normal and Trended Degree Days

	HDD 55 Degrees		CDD 65 Degrees	
Month	**30-Yr Nrm**	**Trended Nrm**	**30-Yr Nrm**	**Trended Nrm**
Jan	404.3	385.5	-	-
Feb	348.8	336.1	-	-
Mar	279.2	260.8	0.2	-
Apr	165.5	149.4	0.7	-
May	53.8	43.9	6.9	4.0
Jun	7.6	4.6	25.7	25.3
Jul	0.1	-	78.5	82.7
Aug	-	-	71.6	77.0
Sep	4.0	1.7	16.8	17.9
Oct	101.4	87.3	-	-
Nov	282.4	264.5	-	-
Dec	434.0	415.2	-	-
Total	**2,081.2**	**1,948.9**	**200.3**	**206.8**

By 2020 trended HDD with a 55-degree temperature base are 6.4% lower than the thirty-year normal. Assuming average temperatures continue to increase 0.4 degrees per decade, by 2030 the number of HDD are 10% below the 30-year normal and 15% below the 30-year normal by 2040.

While the July trended CDD 65 degree-day base are 5% higher than the 30-year normal and August is 7% higher, the total annual CDD increase is relatively small. May and June trended CDD are slightly lower than the 30-year normal as a result of the normal temperature mapping to the calendar year profile.

6. Conclusions

Electricity and natural gas sales are strongly impacted by weather conditions. Forecasts thus require assumptions of future weather conditions. The traditional approach is to assume that future temperatures will look like the recent past. Long-term energy and demand forecasts are generally based on HDD and CDD derived from averages of historical temperature data. In our most recent benchmark survey, 76 percent of the survey respondents based normal HDD and CDD on 20 to 30-years of historical temperature data. Twelve percent of the respondents based normal temperatures off of 15-years of historical temperature data and 10 percent used ten-years of historical temperature data. PSE currently uses the most recent thirty-year period for calculating normal HDD and CDD.

Utilities are just beginning to evaluate the impact of increasing temperatures on electric and natural gas loads. Our survey shows 12% or respondents are considering $C0_2$ emission targets and 16% are making climate change adjustments. The normal weather survey response is provided in Appendix B.

Data shows that temperatures have been increasing across the country. Average temperatures in the PSE service area have been increasing since at least the 1950s. On average, temperatures are increasing 0.4 degrees per decade. Compared with other regions, this is a relatively slow rate of increase; increases in temperatures are likely lower given PSE/Seattle's proximity to the Pacific Ocean. While average temperature is increasing, the maximum temperature has been relatively muted; as in other regions, it appears most of the average temperature gain is due to increasing minimum temperatures.

Nearly all climate models show temperatures are likely to increase through 2100. Our estimate for PSE service area is close to the RMJOC lower temperature projections based on the RCP4.5 greenhouse gas path. RMJOC, like many organizations, believes that the RCP8.5 path represents "business as usual" and as a result could see significantly higher temperatures that begin to increase at a faster rate than the historical trend. At this point, there is no evidence to support future temperatures will increase at a faster rate. For energy forecasting and weather normalization, it is reasonable to assume that expected HDD will be lower today than thirty-year average HDD, and CDD will be higher than the thirty-year average. Temperatures will likely continue to increase 0.4 degrees per decade; trended-normal HDD and CDD can be estimated to reflect this trend.

While minimum temperatures are increasing, PSE's current method for calculating winter peak-day weather is reasonable. Five of the last 30 years saw years in which the winter minimum temperature fell to 23 degrees. The 23-degree design day is also well within the expected peak-day temperature range. The summer peak-day design temperature is also within the 90% confidence interval. As the 90% summer confidence interval is quite wide, the summer design day temperature is within the 90% confidence interval as far out as 2040.

Appendix A: References

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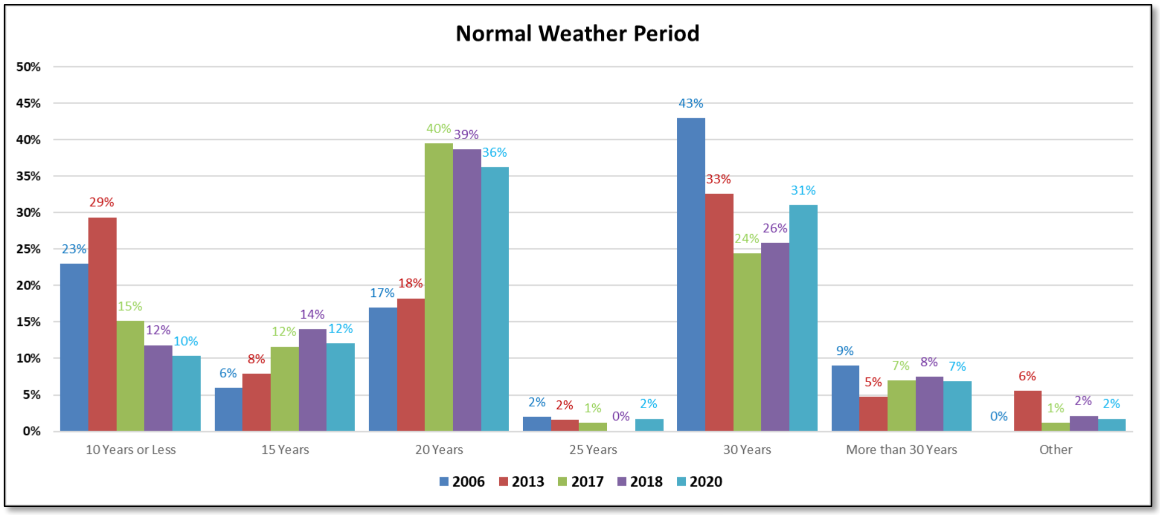
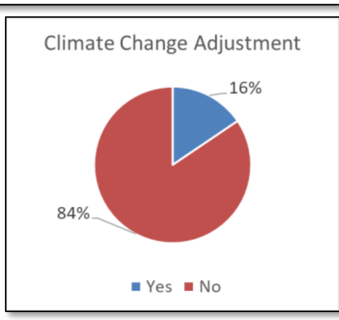
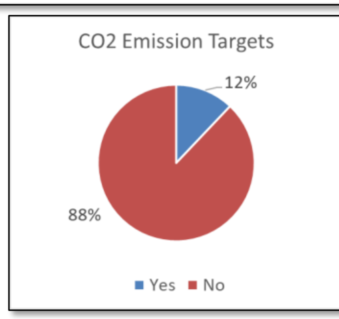
Appendix B: 2020 Itron Benchmark Survey







- 20- and 30-year normal weather are the dominate normal weather periods.
- Few companies recognize climate issues in their forecast.