

The Weather in the Details

Why have utilities lost millions of dollars on weather-normalization plans? Blame deprecated NOAA calculations.

BY JEFFREY A. DUBIN AND VILLAMOR GAMPONIA



A hypothetical Northwest utility with a revenue requirement of \$50/MWh to \$90/MWh and weather sensitivity on the order of 500 MWh to 800 MWh per degree-day would expect revenues to rise by roughly \$45,000 for each additional heating degree-day experienced per annum. Reliance on National Oceanic and Atmospheric Administration (NOAA) standard measurements results in approximately 77 additional heating degree-days of weather adjustment as compared with using hourly average heating degree-day measurements.

In other words, NOAA's measure of

heating degree-days between a normal 30-year period and a given test year is consequently too high by 77 degrees when compared with the more accurate hourly estimates for the 30-year period and for the test year. In this case, the hypothetical utility would see a revenue shortfall of between \$2 million and \$5 million.

Put another way, NOAA's measure of heating degree-days would yield extra weather normalization of roughly 25 percent, with rates being set too low by similar magnitudes. This shortfall is likely to be larger for gas utilities, where the weather sensitivities are greater, and

larger in temperate regions where this difference between NOAA and average hourly heating degree-day is magnified.

Empirical Results

In our study, we analyzed hourly temperature from 1971 through 2005, measured at Washington's Sea-Tac Airport.¹ There were 306,816 such hourly temperatures. We calculated the skewness for each day in this period (daily skewness), as well as the mean daily temperature and the mid-range temperature. All temperatures were recorded top-of-the-hour by NOAA. We then calculated daily heating degree-days comparing the D^a and D^m measures (average based and mid-range based). The temperature distribution was found to be positively skewed, with a greater likelihood of warmer extreme temperatures than colder extreme temperatures. Heating degree-days were lower by 100 to 140 degree-days per year (depending on the month) using the mid-range estimate as compared with the mean. Skewness in the temperature distribution, therefore, causes the average to be underestimated by 10 to 15 degrees. As the mid-range is larger than the true average temperature, the base temperature less the mid-range estimate typically is smaller than the difference between the base temperature and the true average temperature. For the period 1971 through 2000, the estimate of heating degree-days based on the mid-range (average of minimum and maximum top-of-the-hour temperatures) is 4,817 on an annual basis. This is 125 degree-days lower than the estimate based on the true average.

We examined actual hourly temperatures to compute the hourly degree-days and found that for the period 1971 through 2000, there were 5,093 heating degree-days on an annual basis (method D). Using the daily average of such hourly temperatures lowers the

estimate to 4,942 heating degree-days (method D^a). Using the mid-range estimate of the mean degree temperature published by NOAA further lowers the estimate to 4,817 heating degree-days (method D^m). There is a further difference of 20 degree-days to get to the published normal of 4,797 due to NOAA errors, spline adjustments, and rounding. Hence, heating degree-days

are underestimated by 0.4 percent due to miscellaneous adjustments, 2.6 percent due to the difference between mid-range and daily average temperature, and a further 3.1 percent due to the difference between daily average temperatures and hourly based estimates. The conclusion is that:

$$D \geq D^a \geq D^m.^2$$

The NOAA method relying on the

mid-range produces an estimate of heating degree-days that is significantly lower than actual hourly degree-days.

With respect to weather normalization and rate making, an important consequence of these results is that a smaller degree-day adjustment should be expected between normal periods and test-year periods when using actual hourly degree-days as compared »

THE MATHEMATICS OF HEATING DEGREE-DAYS

Empirical practice reveals a significant correlation between heating degree-days and thermal energy load. Our discussion begins with the concept of a degree-hour. Degree-hours are defined as:

$$Z_b = |b - U_b|_+ \equiv \max(b - U_b, 0) = \begin{cases} b - U_b & U_b < 0 \\ 0 & \text{otherwise} \end{cases}$$

where b = base temperature and U_b = temperature at hour b , Z_b = hourly degree-days for hour b . A degree-hour is, therefore, the number of degrees during a given hour when temperatures are lower than the base level.

Next, daily degree-days D are the sum of hourly degree-days so that:

$$D = \sum_b |b - U_b|_+$$

By contrast, the NOAA estimator of daily degree-days D^a :

$$D^a = n_b |b - \bar{U}_D|_+$$

where $\bar{U}_D = \frac{1}{n_b} \sum_b U_b$ and n_b is the number of hours in the day.

Under the assumption that daily average temperatures are drawn from a distribution with the same variability as hourly temperature, Guttman and Lehman (1992)¹ are able to show that the expected daily degree-days are lower using the average temperature as compared with the expected sum of hourly degree-days.² However, this relationship is more general, independent of the distribution of hourly temperature, and is a consequence of Jensen's inequality.³

Thus, hourly degree-days always are larger than expected daily degree-days. In practice, this difference is non-negligible, as has been noted by Guttman and Lehman (1992), Lehman (1987)⁴ and Huang *et. al.* (1987).⁵

As an example, for the period from 1975 through 2004, hourly degree-days, D^a , are calculated to be 5,053 from Sea-Tac hourly temperatures (measured at the top of each

hour). The degree-days based on the daily average temperature for the same period are 4,899. Hence, there is a 154 degree-day under-estimate based on average temperatures as compared with the sum of hourly degree-days.⁶ Other things being equal, we would expect the hourly degree-day measure to provide a more accurate indicator of daily energy load as it adds the energy load for each hour rather than relying on a calculation based on the daily average temperature. This difference is particularly acute in "shoulder" months where average temperature differs from base temperature to a lesser degree. Using average temperature may miss events in some hours where temperatures are cold enough to generate heating degree-days, even though these events are not counted when the average temperature for the day exceeds the base temperature.

The heating degree-day measure used most often in utility rate making relies on an estimate of average daily temperature, but one that differs from \bar{U}_D . Traditionally, the daily average temperature was estimated by the average of the minimum and maximum daily temperature. This is the procedure most commonly used by NOAA when calculating heating degree-days.⁷ We denote a daily heating degree-day measure based on this estimate by:

$$D^m = n_b |b - t^m|_+ \\ \text{where } t^m = (\min t + \max t) / 2.$$

Here $\min t$ and $\max t$ denote the minimum and maximum temperatures for each day. This procedure, while saving on data collection efforts, severely biases the estimate of the true average daily temperature in most cases.

The concept of taking the average between the minimum and maximum temperature is known as the "mid-range" estimate in statistics. The mid-range is known to be an unbiased estimate of the center of a symmetric distribution where the mean, median, and mode all coincide. For asymmetrical distributions, the sample mid-range does not correspond to any fixed parameter of the population. »

In sum, as a theoretical matter, the mid-range has very little to recommend it. It is neither efficient nor is it even robust when the underlying distribution is symmetric. In the asymmetric case, it is not clear what the mid-range estimates. It is clear, however, that skewness in the temperature distribution can have an effect on the mid-range estimate of average temperature and therefore a significant effect on estimated heating degree-days.

—JAD & VG

Endnotes

1. Guttman, Nathaniel B., Lehman, Richard L. 1992. Estimation of Daily Degree-Hours. *Journal of Applied Meteorology* 31: pp. 797-810.
2. When hourly temperatures are \bar{U}_h , randomly distributed, average daily temperature, \bar{U}_d , is also random with mean $\bar{\mu}_d$ and variance that depends on the hourly variances σ_h^2 and the diurnal correlation of hourly temperatures. This proposition is proved in Dubin and Gamponia (2006), *Mid-Range, Average, and Hourly Estimates of Heating Degree-Days*, mimeo.
3. This proposition is proved in Dubin and Gamponia (2006).
4. Lehman, Richard L. 1987. Probability Distributions of Monthly Degree-Day Variables at U.S. Stations. Part I: Estimating the Mean Value and Variance

from Temperature Data. *Journal of Climate and Applied Meteorology*: 26 (3): pp. 329-340.

5. Huang, J.; Ritschard, R.L.; Bull, J.C., and L. Chang. 1987. Climatic Indicators for Estimating Residential Heating and Cooling Loads. *American Society for Heating, Refrigerating, and Air-Conditioning Engineers*. 93 (1): pp.72-111.
6. The difference between the two methods for the period 1971-2000 is 151 degree-days.
7. Until recently, NOAA's method to calculate heating degree-day daily normals did not calculate daily values from daily data. Instead, NOAA's method first focused on monthly normal heating degree-days. Specifically, sequential monthly degree-days were derived using procedures developed by Thom (1954). This technique utilized the historical monthly average temperature and its corresponding standard deviation to compute monthly degree days. Then, NOAA daily normals were derived by statistically fitting smooth curves through monthly values; daily data were not used to compute daily normals. Apparently, NOAA has modified this procedure for the recent 1971-2000 normal period: "For first-order stations, where daily data sets are largely devoid of missing values, monthly degree day totals were derived directly from daily values." See, e.g., <http://wf.ncdc.noaa.gov/oa/climate/normal/usnormalsprods.html#CLIM85> and <http://www.ncdc.noaa.gov/oa/climate/normal/usnormals.html#Overview>.

with the difference between normal and test-year using the mid-range average (NOAA method). The reason for this is that the averaging that occurs in forming a normal (30-year average for each month of the normal year) is likely to narrow the difference between the mid-range and average temperature. For instance, using the period of 1971 through 2000 as the normal period and October 2004 through September 2005 as the test-year period, we found that the adjustment between the NOAA normal and the test year is 344 degree-days, but is only 275 degree-days using daily average temperatures. Using the more accurate hourly based estimate implies a

difference of 267 degree-days.

The data requirements for calculating degree-days by more precise techniques are minimal. We conclude that an accurate weather adjustment in the rate-making context requires accurate estimates of heating and cooling degree-days. Until NOAA adopts an alternative calculation methodology, our specific recommendation is that electric and natural-gas utilities adopt an hourly or average based measure of heating degree-days when comparing normal and test-year periods in rate-making proceedings. Rote reliance on NOAA calculations leads to excessively large weather adjustments in typical situations. ■

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The views and findings expressed herein are solely those of the authors and should not necessarily be attributed to PSE.

Endnotes:

1. Sea-Tac Airport is a "first-order" weather station with largely complete and accurate historical temperature information.
2. Our results apply to hourly-degree-days as well.



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