Recent Declines in Wisconsin Residential Gas Use — Reality or Artifact?

Scott Pigg, Energy Center of Wisconsin, Madison, WI
Richard Hasselman, Energy Center of Wisconsin, Madison, WI
Jim Mapp, Wisconsin Energy Bureau, Madison, WI

Abstract

This paper looks at trends in residential gas usage in Wisconsin, focusing on an apparent decline in average gas usage in the late 1990's. Aggregate monthly gas sales data from 1980 through early 1999 for eight Wisconsin gas utilities were analyzed using PRISM.

The results suggest that residential gas usage has been declining at an accelerated rate in Wisconsin since at least the early 1990's, but the precise extent and timing of this decline are lost in the inherent uncertainty of the weather normalization process and inconsistencies in weather data. Depending on the source of the weather data used in the analysis, the decline in gas usage appears as either a sudden unexplained decline starting in the 1995/96 heating season, or as a more gradual decline that could at least partially be explained by factors such as the high penetration of high efficiency furnaces in the state.

The analysis also reveals that weather-normalized estimates of gas usage are sensitive to inconsistencies in temperature data, with a 1F° bias in recorded temperature creating a 3-3.5% error in estimated gas usage. Moreover, inconsistent weather data may be more prevalent than previously thought, especially given the current large-scale effort on the part of the National Weather Service to upgrade and automate data collection from first-order weather stations around the country.

Introduction

In the spring of 1998, several Wisconsin gas utilities approached the Energy Center of Wisconsin seeking an explanation for an apparent drop in residential gas use in the previous several years.[1] Even after accounting for variation in the weather, the declines reportedly were in excess of forecasting models, and appear as a recent acceleration of a longer-term decline in usage. The utilities were interested in understanding the extent of the decline as well as its underlying causes. Discussions among the utilities and the Center led to agreement that the Center would undertake a preliminary investigation of this phenomenon using publicly available gas sales data reported to the Public Service Commission of Wisconsin by all of the state's gas utilities. The objectives of this investigation were: (1) to address whether the phenomenon was occurring throughout the state, (2) to better establish the extent and timing of the decline; and, (3) to begin to look at possible contributory factors to the decline.

In this paper, we review the results of this analysis. A more comprehensive report of this analysis is available from the Energy Center of Wisconsin.

---

[1] The sponsoring utilities were: Madison Gas & Electric Company, Wisconsin Gas Company, Wisconsin Electric Company, and Alliant Energy (formerly Wisconsin Power & Light Company).

Method

The analysis is based on utility aggregate gas usage data been reported to the Public Service Commission of Wisconsin on a monthly basis since 1980. For each calendar month, the utilities report total gas sales (in thousands of therms), revenues (in thousands of dollars) and average number of customers by customer class. The reports separate residential gas usage into two classes of customers : space-heating, and "general use" customers (i.e., no gas space-heat).[2] We focused on the space-heating class in this report, which make up about 96% of all residential customers, and analyzed the aggregate average gas usage per customer. In all, we analyzed aggregate gas usage data for the eight Wisconsin utilities listed in Table 1. During the 18-year period of our analysis, the total number of customers grew from about 800,000 to 1.35 million.

Table 1, Utilities and weather stations.

Utility	Weather station	Statewide Percent of Customers
Wisconsin Gas	Milwaukee (MKE)	36%
Wisconsin Electric	Milwaukee (MKE)	25%
Wisconsin Public Service	Green Bay (GRB)	14%
Alliant/WPL	Madison (MSN)	9%
Madison Gas and Electric	Madison (MSN)	7%
Northern States Power	Eau Claire (EAU)	5%
Wisconsin Fuel and Light	Green Bay (GRB)	3%
Superior Water Light and Power	Superior (SUP)	1%

Variation in the severity of Wisconsin winters can create swings in annual gas usage of ±15% or more. In particular, the last two heating seasons have been among the warmest on record. We therefore used the Princeton Scorekeeping Method (PRISM) to adjust actual aggregate average gas usage to average weather conditions (Fels, 1986). Given gas consumption data and daily average temperature data for a nearby weather station, PRISM develops a weather adjusted estimate of annual consumption, called the Normalized Annual Consumption (NAC), using a three-parameter model:

$$NAC = 365\alpha + \beta H_0 \tau$$

where

α is an estimate of base gas usage per day that is not weather related;
β is an estimate heating slope, or therms used per heating degree-day;
τ is an estimate of the "reference temperature" or the outdoor temperature at which gas heating is required; and,
$\mathbf{H_0}$ is the long-term average annual degree-days at reference temperature τ.

We used weather data from five Wisconsin stations for the analysis, as shown in Table 1. Several utilities (notably Wisconsin Gas and Alliant) have geographically dispersed service territories.

[2] One utility, Alliant (WP&L) stopped reporting space heating and general use separately in 1993. To maintain consistency, we combined the two classes for this utility throughout the 1980-1999 analysis period.

We chose the weather stations to best represent the customer-weighted center of the service territory. Long-term heating degree days were based on the 20-year period from 1978 through 1997.

We had initially planned to use a special aggregate implementation of PRISM, which weights heating degree days to account for the fact that utility meters are read in cycles that are staggered throughout the month (Fels and Goldberg, 1986). But we immediately discovered that the aggregate PRISM fits were much poorer than the standard PRISM model. This led us to discover that the Wisconsin utilities all attempt adjust the data that is reported to the Public Service Commission to calendar month gas sales. Though the methods they use to accomplish this vary somewhat, the utilities mostly follow a method that divides calendar month usage into billed and unbilled portions for usage that occurs before and after the month's meter read, respectively.

The key to the method is that the known usage between meter reads represents the sum of the accrued unbilled portion of the *previous* month and the billed portion of the current month. By subtracting the previous month's accrued unbilled estimate from the actual usage between meter reads, one gets an estimate of the billed portion of the current calendar month. In effect, each estimate of calendar month gas usage also contains a correction for any error in the previous month's estimate. In practice most of the utilities also reconcile these estimates to calendar month system-wide gas usage obtained from metering at the city gate (the point at which the utility receives gas from the pipeline company).

With a few exceptions, the data suggest that the methods used by the utilities to adjust billing cycle data to calendar month usage are largely successful; only about 10% of the PRISM fits had an R^2 values lower than 0.96, and the average was 0.98. This resulted in estimates of annual gas usage with a typical uncertainty of about ± 5% at a 90% confidence level. Two notable exceptions are Alliant and Superior Water Light & Power, which generally have wider confidence intervals. We also found that the data for one utility (Northern States Power) was unreliable prior to 1987; we discarded the 1980-1986 data for this utility.

To better analyze time trends in usage, we used a 12-month sliding PRISM analysis, which is analogous to a rolling average. The 229 months of data from January 1980 through April 1998 yield 218 one-year analysis periods, with the most recent being February 1998 through January 1999. We also slightly smoothed the resulting time trend, using three passes of running nine-period medians.

To aggregate the utility data to the state level, we weighted the results for each utility by its proportion of the total customers in the state for each analysis period. Although these weights change slightly over time, Table 1 shows the approximate importance of each utility to the statewide total. Note that the two utilities whose service territory covers the heavily populated southeast corner of the state, Wisconsin Gas and Wisconsin Electric, account for over 60% of the state's customers.

Results

Figure 1 shows the initial weather normalized usage estimates aggregated to the state level. These results seem to confirm that—after sharply declining usage in the early 1980's followed by relatively flat average usage per customer into the early 1990's—gas usage started to drop precipitously again in 1996. The results indicate an 11% decline in average weather adjusted gas use per customer since the1992/93 heating season, or about 3% per year. Although not included here, analysis of the individual PRISM parameters indicates that it is space-heating related usage that has declined rather than non-heating usage.

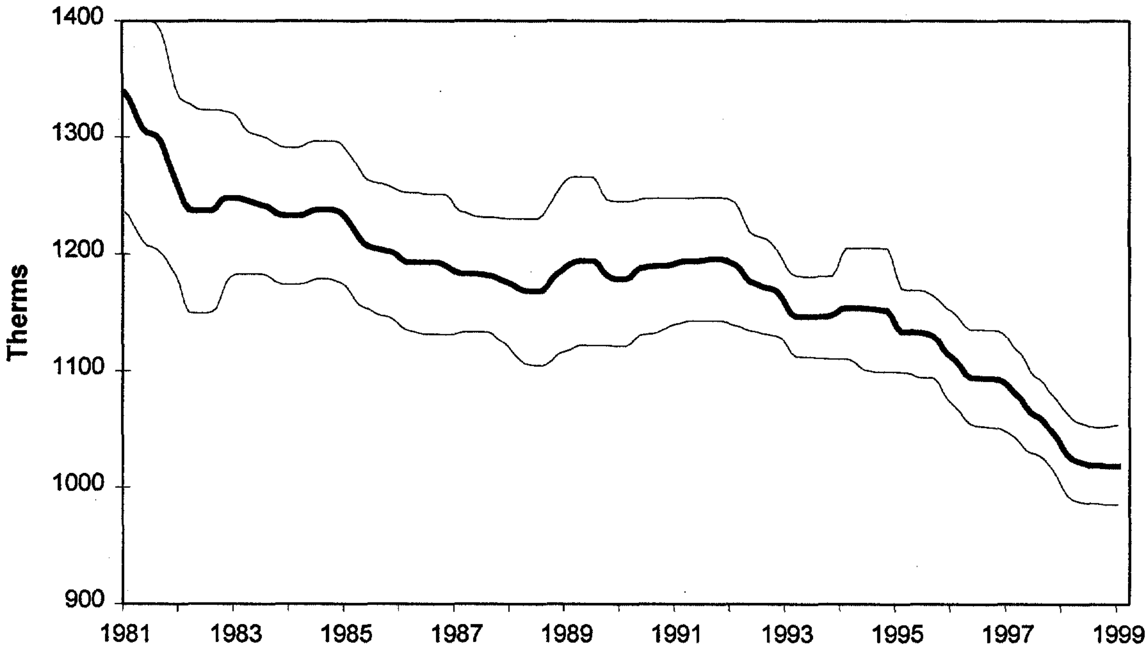


Figure 1, Statewide average annual gas use (therms) based on weather normalization with daily station-level data, with 90% confidence interval, 12-month rolling analysis ending on date shown.

We became concerned about the validity of these results when we learned that particularly steep apparent declines for some utilities in 1995 and 1996 coincided with equipment changes at several of the National Weather Service stations used in the analysis. These changes were part of a national project to automate data collection at first-order weather stations, and involved replacing the previous equipment with a new automated surface observation system (ASOS), as well as (at some sites) relocating the instrumentation (Biederman, 1998).[3] The Milwaukee, Madison, and Green Bay stations were all converted to ASOS in 1995 and 1996.

A recent study conducted by Colorado State University suggests that the ASOS equipment records slightly lower temperatures on average than the older equipment as a result of the interplay of three factors: (1) inherent instrument bias; (2) solar heating of the old instrument enclosure under certain conditions; and, (3) relocation effects (Schrumpf and McKee, 1996). The magnitude and direction of the discontinuity varies from station to station. By analyzing data obtained from parallel operation of the old and new equipment, the CSU study was able to separate and measure the three types of effects for a number of stations, including the three in Wisconsin. The results indicate that all three Wisconsin weather stations show differences between the old and new equipment that are at the extreme end of variation seen nationally, with a decrease in indicated temperature of 2-3 F°.

A few degrees might not seem like much, but when we simulated a sudden change in recorded temperatures (by simply adding or subtracting a fixed number of degrees to our weather data after a given date) we found that each degree F of bias in the temperature data changes the estimate of normalized gas usage by 3 to 3.5%. If the instrument reads slightly warmer, the estimated usage goes

---

[3] More information about the ASOS conversion program, including the implementation status at each of several hundred stations around the country can be found at: http://tgsv5.nws.noaa.gov/asos//

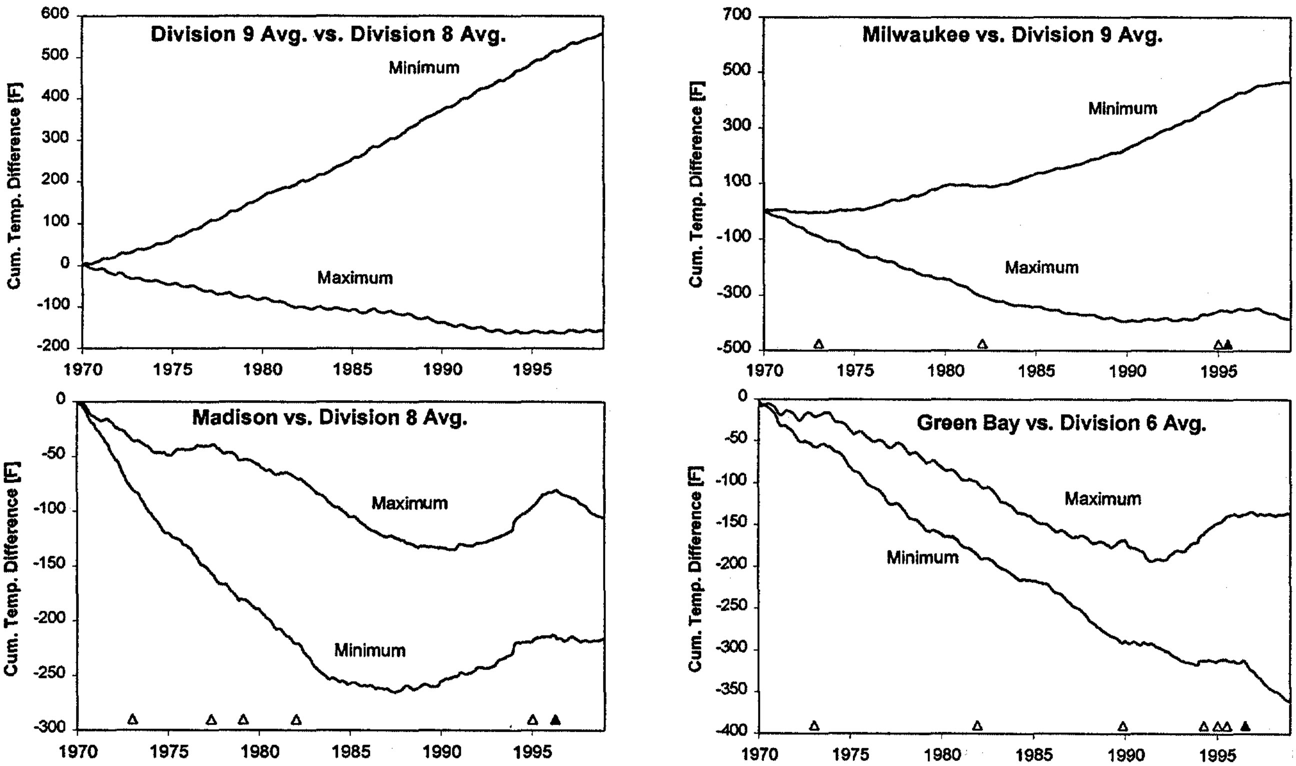


Figure 2, Cumulative deviation of monthly minimum and maximum temperatures for three stations versus division averages. Triangles denote dates listed in station history, including ASOS conversion (solid triangle). Division 9 versus Division 6 shown for comparison.

up. Conversely, when the instrument reads slightly cold, estimated gas usage goes down. Because we use a rolling analysis period to smooth out time trends, there is an 11-month transition period in the time trend as the new temperature data is incorporated into the analysis period. The utility time trends show a 4-5% decline in gas use for the utilities normalized to Milwaukee and Green Bay weather data coincident with the ASOS conversion, but no coincident decline is apparent for the two utilities normalized to Madison weather data.

We also looked for more direct evidence of abrupt temperature changes at the ASOS stations by examining the relationship between temperatures recorded by the ASOS stations and other nearby weather stations. We were able to obtain monthly average minimum and maximum temperatures back to 1970 for each of the nine climate divisions in the state.[4] These figures are derived by averaging daily data across the roughly 10 to 25 weather stations within each division. Our premise was that since the division averages represent the combined measurements of multiple sites, abrupt changes in the relationship between a station's recorded temperature and the division average could be attributed to a change at the station.

We therefore plotted the cumulative difference between the monthly average station maximums and minimums and the averages for the division in which the station resides (Figure 2). In these plots,

[4] Climate divisions and division level data for each state are found in Climatological Data Summary reports, published by the National Climatic Data Center.

an upward sloping line indicates that the station tends to record higher temperatures than the division average, and a downward line indicates that the station records lower temperatures. The important thing to look for in these plots are abrupt changes in the slope of the line, which would suggest a systematic change in the temperatures recorded by the station in question.

In contrast to the very smooth plot when we compare two division average against one another, all three individual stations show evidence of abrupt changes in recorded temperature. Moreover, all three appear to abruptly read cooler at the time of the ASOS conversion (though change on the Milwaukee plot is less noticeable due to the wider scale). These results are only partly consistent with a theory that the ASOS conversion creates an artificial decline in gas use estimates, since the Madison temperatures show some significant changes around the time of the ASOS conversion, even though the utility data show no coincident decline. [5] Overall, the plots in Figure 4 suggest that changes that affect the recorded temperature are frequent enough to creates concern about their effect on the PRISM estimates.

If division average temperature data are more reliable than that of any individual stations, then why not weather normalize the usage data to the division-level weather data? Traditionally, the answer is that these data are not easily available in the form of daily averages, which are required by PRISM. However, our aggregate data are reported by calendar month, as are the division average temperatures. Using the station-level data, we found that there is little difference in PRISM estimates based on daily temperature data, compared to those obtained by simply substituting the average monthly temperature for each day of the month. The resulting estimates are almost always within ±2% of the standard approach (though using monthly average temperatures does appear to create a small bias of about –0.2% and increases the uncertainty of the PRISM estimate by an average of 10%). We therefore re-normalized the utility data using monthly average temperatures for the appropriate climate division for each utility.

Figure 3 shows side-by-side comparisons of the usage trends for each utility using daily weather station data versus those obtained using monthly division average temperatures. Although differences between the two trends are mostly less than the uncertainty bands of the estimates themselves (which average ± 30-50 therms for most utilities), the estimates are significantly different for Wisconsin Gas from about 1990 to 1997. Less dramatic differences also emerge in the early 1990's for several other utilities. On the other hand, the two sets of estimates generally converge with the station-level data in the most recent estimates, suggesting that the declines that coincide with the ASOS conversion are not entirely artifacts of these changes.

When we aggregate the data up to the state level (Figure 4), the two sets of analysis tell somewhat different stories about what has been occurring with gas usage in the 1990's. The estimates from divisional weather data suggest only a modest acceleration in the gas usage decline from 1.0% to 1.7% per year that occurs in the early 1990's. The estimates from daily station data suggests a more abrupt decline that starts about two years later. The inherent statistical uncertainty in these estimates is enough that we cannot conclusively accept one scenario over the other, though some increase in the rate of decline appears likely.

---

[5] Interestingly, the Madison plot also shows evidence of a rather slow change in its relationship with the division averages from about 1984 to 1994—as evidenced by the gradual arc in the plots—suggesting that some local phenomenon (perhaps urban development) caused the station to gradually read higher temperatures.

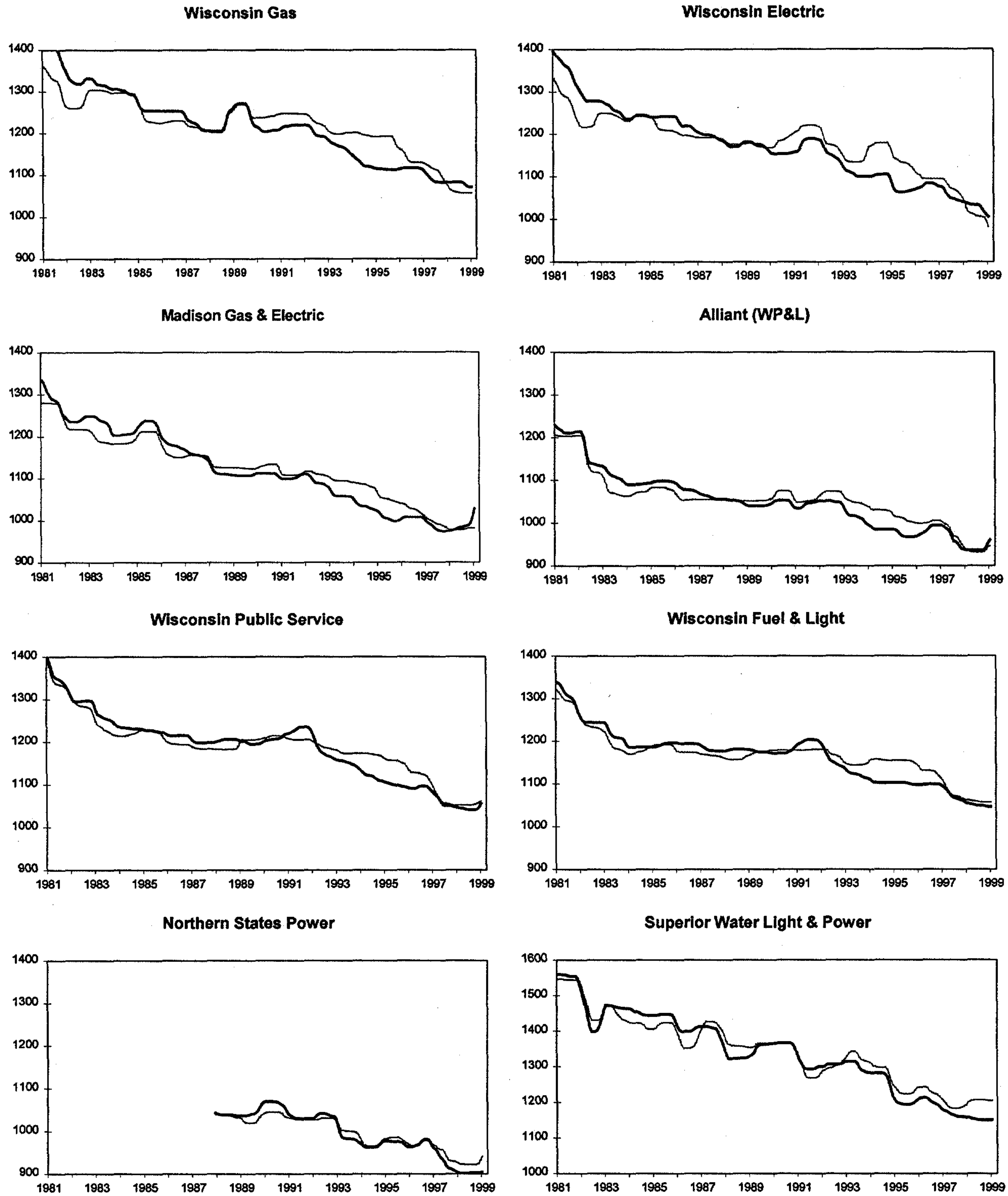
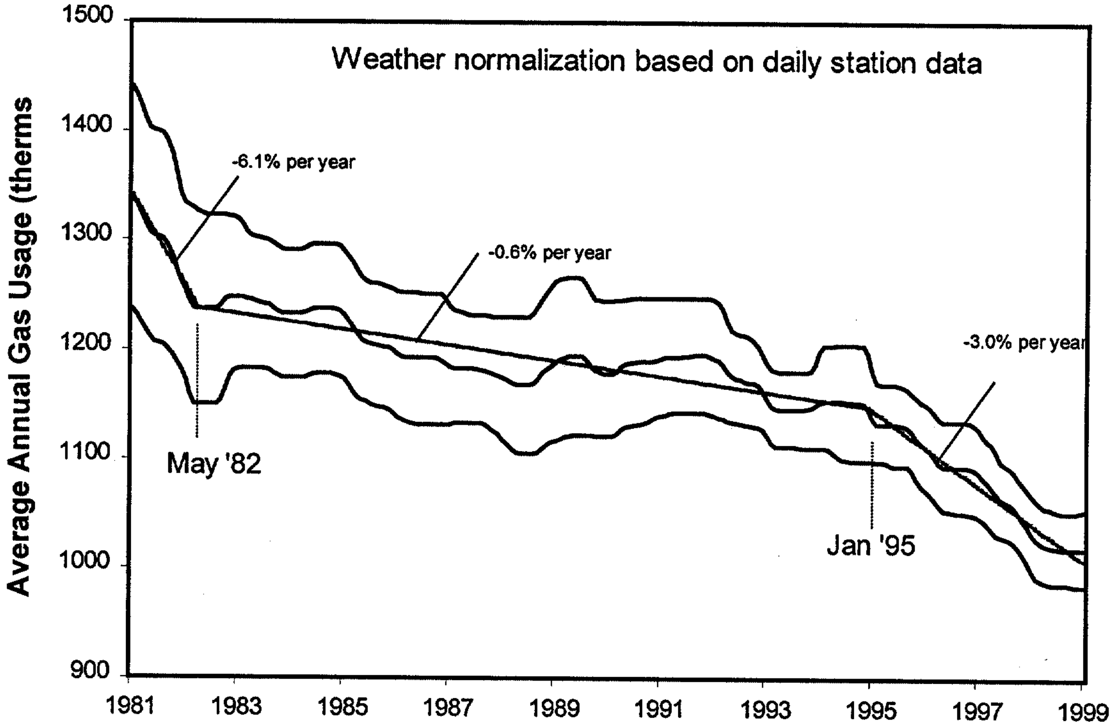


Figure 3, Average annual gas usage estimates (therms) derived from daily station level weather data (light lines) and monthly division average weather data (dark lines), by utility, 12-month rolling analysis ending on date shown.



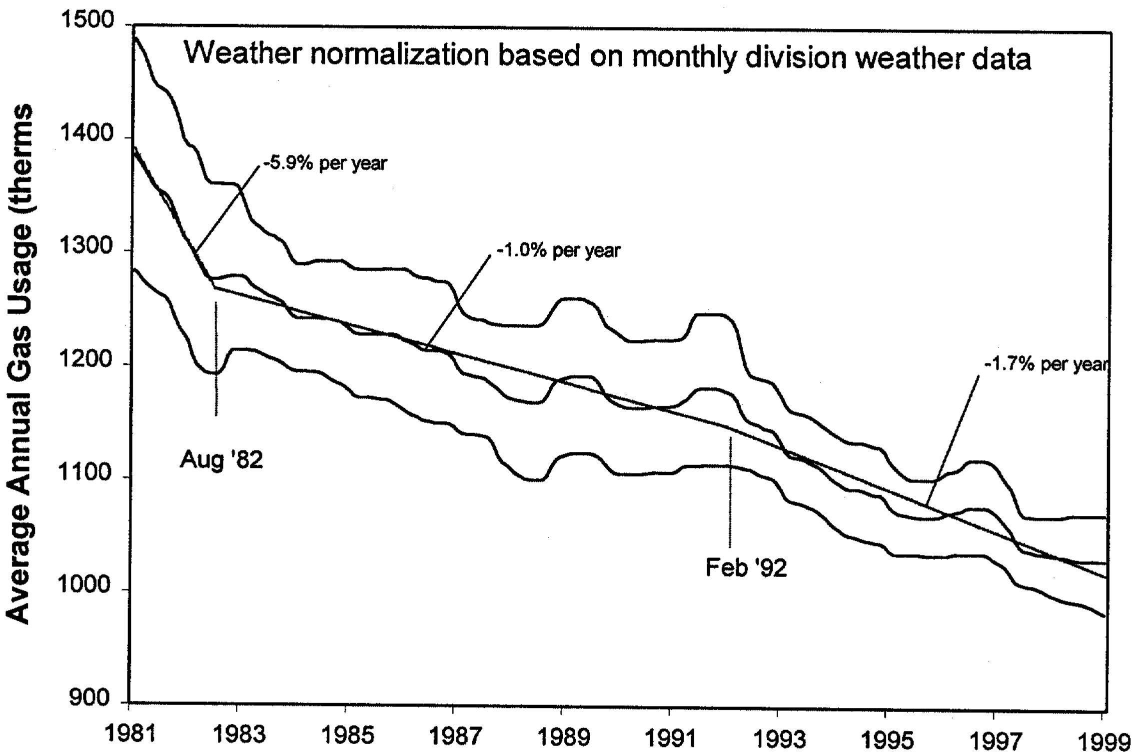


Figure 4, Statewide average gas use (therms) based on weather normalization using daily station data (top) and monthly division average data (bottom), with 90% confidence interval and fitted three-segment trend, 12-month rolling analysis ending on date shown.

Possible Causes of the Decline

Explanatory factors for a recent gas usage decline can be grouped into four broad categories:

1. Weather Normalization Errors
2. Changing Customer Mix
3. Heating System and Structural Changes
4. Behavioral Changes

Normalization Errors. We have already discussed the issues arising from inconsistent weather data. Additional possible sources of weather normalization error include:

- the tendency of the PRISM model to weather adjust some seasonally variable gas usage that is not related to space heating (Fels, Rachlin, and Socolow, 1986);
- not including other weather variables that might affect gas usage, such as sunshine and wind speeds;
- non-linear effects, such as degradation of insulation R-values at extremely cold temperatures and changing customer behavior in the face of unusual weather.

For various reasons, we tend to discount the importance of these factors in explaining the apparent gas usage decline. The gas decline is fairly stable through two cold winters and well as several that were warmer than average. This would not have been the case if the model were falsely weather adjusting seasonally variable non-heating gas usage in a serious manner. Research into using artificial neural networks to predict daily gas send-out has generally shown that factors such as wind speed and sunshine have a much weaker influence on gas usage than does outdoor temperature (Feng and Brown, 1994). As for non-linear effects, at the aggregate level, gas usage appears to be very linear in degree days; we found no evidence of non-linearities in the usage data that would affect the analysis, and few outliers or particularly influential data points.

Changing Customer Mix. It is important to remember that the gas usage estimates presented here are averages for a population of customers that has increased at an annual rate of roughly 1.5% to 3.5% over the period of analysis. If customers that are added to the system have different usage levels, the average use per customer will be affected over time. New customers can be added to the system by any of the following mechanisms:

- Expansion of a utility's service territory into additional towns and developments
- Conversion of non space-heating accounts to space heating (i.e., migration of "general use" customers to "space-heating")
- New construction

Housing abandonment could in theory also affect aggregate gas usage.

We have little data on service territory expansion, but suspect these tend to be into newer developments, which would affect aggregate average usage in a manner similar to new construction. Data on the number of customers who leave the "general use" class indicate that the maximum possible number of non space-heating customers who might be converting to space heat is too small in the 1990's to be a factor.

This leaves new construction. Growth from new housing could contribute to the decline in aggregate gas consumption if new houses are better insulated and have efficient heating systems. However, national data indicate that the size of the average new house has increased by about 25%

since the early 1980's (Wilson, 1999), so it is not a given that new houses uses fewer total therms than older houses. The impact depends on how much less gas new houses use, the growth rate in new housing, and the number of years of growth. For example, if houses that use 25% less gas than existing houses appeared on the market about nine years ago at an annual growth rate of 3% per year, aggregate average gas usage would have declined by 5.8% by now.

Unfortunately, we do not have much hard data on usage for new houses versus older housing stock (though the Center is engaged in a residential characterization project that will provide this information). However, Wisconsin Gas Company conducted an internal study (unpublished) of gas usage by over 1,000 homes constructed in 1992 which showed average weather normalized usage of that was within about 5% of our PRISM estimate of aggregate average residential usage for Wisconsin Gas customers at the time. This tends to support the theory that the larger size of new homes offsets the fact that they tend to be more energy efficient per square foot.

Heating System and Structural Changes. The impact of high efficiency heating systems is an important consideration for this analysis, because the Wisconsin furnace market has been held up as an early example of market transformation toward a more efficient product (Prahl and Pigg, 1997). In contrast to the furnace markets in other states, tracking data from furnace distributors indicate that since at least the early 1990's, the vast majority of furnaces sold in Wisconsin each year are high efficiency models—though the market share for high efficiency furnaces has slipped considerably in the southeastern corner of the state in recent years. Statewide, the most recent data show that over 80% of furnace replacements in Wisconsin are high efficiency models.

From appliance purchase surveys conducted by the Center in 1995 and 1997 (ECW, 1997, 1998), we know that 3.5% to 4% of heating systems are replaced each year in Wisconsin. Based on these figures, we estimate that the gradual penetration of high efficiency furnaces would result in at most a 0.5% drop each year in average residential gas consumption, or roughly 5% over a ten year period.[6] The data at hand suggest that market effects of utility programs to promote high efficiency furnaces would largely explain why gas usage might have started dropping slightly more rapidly beginning in the late 1980's to early 1990's, consistent with the PRISM estimates using the division-level weather data. It would be unlikely to explain a more precipitous drop that occurred later, however.

It is also possible that people have been adding insulation to their houses or sealing them more effectively against infiltration, but we do not have data to confirm or refute this hypothesis.

An increase in household electricity usage has been offered as a possible explanation for the gas decline, since most electricity used in a residence ends up as heat that offsets the need for gas heating. However, while summer electricity usage in the residential sector has been increasing dramatically as air conditioning penetrates the Wisconsin housing stock, analysis of statewide trends in electricity usage in the winter and shoulder seasons show much smaller increases that would not have a substantial impact on the amount of gas needed for space heating.

Behavioral Changes. It is possible that people have begun to set their thermostats lower or practice night setbacks with greater frequency in recent years, but there is little data to bring to bear on this. We do have some information on the prevalence of—and growth in—setback thermostats, which we

---

[6] for example, if 4% of households save 20% on heating usage (about what one would expect in going from an AFUE of 70% to 90%), which represents about 80% of total usage, the aggregate impact on gas usage would be 4% times 20% times 80%, or 0.6%. Note that some houses are actually heated with hydronic or steam boilers, which do not show as large of an efficiency gain on replacement, so the aggregate impact from heating system replacement would be less than the furnace data alone suggest.

collected as part of the Center's most recent Appliance Sales Tracking survey in 1997 (ECW, 1998). In this random-digit dial survey of three thousand Wisconsin households, 18% of respondents reported using a setback thermostat to regulate their heat. More illuminating is that about a quarter of these (23%) reported that they had installed the thermostat in the past year. This implies that 4.4% of households acquire a setback thermostat each year. If these thermostats save 10% on average, this would result in about a 0.4% reduction in average aggregate gas usage. Of course having a setback thermostat and using it are not necessarily the same thing (Cross and Judd, 1997), and it will take additional surveys to confirm whether setback thermostats are indeed gaining penetration into Wisconsin homes.

An econometrician would look first at whether gas price changes would explain the observed decline in gas usage. While there have been a few short-term increases in the price of gas in recent years, the real price of gas to residential customers has dropped by about 50 percent from the early 1980s, making the near term changes small relative to the long term trend. Given that residential gas demand is relatively inelastic, we do not feel that prices are a likely driving factor in the decline in gas usage in the state, though there remains the possibility that a short term price spike perhaps combined with an unusually cold winter month could result in high bills that spur people into reducing their gas use.

Conclusions

There are indications that residential gas use in Wisconsin is declining more rapidly in the 1990's than it did in the 1980's. However, inherent uncertainty in the weather normalization process—and the issue of inconsistent weather data—makes it difficult to draw conclusions about whether the decline is a more gradual one that began in the early 1990's or a more abrupt decline starting a few years ago. A more gradual decline in gas usage starting in the early 1990's would be more consistent with what is known about the penetration of high efficiency furnaces in the Wisconsin heating system market. Several factors simultaneously at work would probably be needed to explain the more abrupt decline suggested by the analysis based on station-level weather data. Of course, it is also possible that the decline is just a short-term behavioral phenomenon that will reverse itself over time; the most recent estimates suggest that it is at least flattening somewhat.

Our analysis also reveals a weakness in procedures that are commonly used to adjust energy usage data for variation in the weather. It appears that estimates of weather-normalized gas usage are sensitive to even slight inconsistencies in weather data. Moreover, events that create these inconsistencies appear to be common enough to be of concern. Because many accounts are typically weather corrected using data from a single weather station, the weather data becomes something of an Achilles heel if an equipment change such as conversion to ASOS results in inconsistent weather data: all weather normalized usage estimates will be subject to a bias that stems from the weather data.

The best defense against this problem, of course, is to employ a control group to remove any weather-data related bias from estimated pre/post changes in usage. If a control group is lacking—or is not feasible, as is the case in the analysis reported here—it might be prudent to average temperature data over a number of weather stations before applying it to a weather normalization procedure such as PRISM. These effects bear special consideration, given that the weather service is currently engaged in a large-scale effort to upgrade the first-order stations that are most often used in energy program evaluations to ASOS.

References

Biederman, N. 1998. "Effect of New Weather Sensing Equipment on the Natural Gas Distribution Industry," Gas Research Institute Topical Report GRI-98/0063.

Cross, D. and D. Judd. 1997. "Automatic Setback Thermostats: Measure Persistence and Customer Behavior," Proceedings of the 1997 International Energy Program Evaluation Conference. Pp. 441-445.

Energy Center of Wisconsin. (ECW) 1997. "Appliance Sales Tracking: 1995 Residential Survey," Energy Center of Wisconsin, Report 151-1.

Energy Center of Wisconsin. (ECW) 1998. "Appliance Sales Tracking: 1997 Residential Survey," Energy Center of Wisconsin, Report 171-1.

Fels, M. 1986. "PRISM: An Introduction," Energy and Buildings, Vol. 9, #1-2, pp. 5-18.

Fels, M. and M. Goldberg. 1986. "Using the Scorekeeping Approach to Monitor Aggregate Energy Consumption," Energy and Buildings, vol. 9, #1-2, pp. 162-168.

Fels, M., J. Rachlin, and R. Socolow. 1986. "Seasonality of Non-Heating Consumption and its Effect on PRISM Results," Energy and Buildings, vol. 9, #1-2, pp. 139-148.

Feng, X. and R. Brown. 1994. "Development of Models to Predict and Analyze Gas Consumption," Year 1 Final Report, Energy Center of Wisconsin.

Prahl, R. and S. Pigg. 1997. "Do the Market Effects of Utility Energy Efficiency Programs Last?" Proceedings of the 1997 International Energy Program Evaluation Conference. Pp. 523-531.

Schrumpf, A., and T. McKee. 1996. Temperature data continuity with the Automated Surface Observing System (ASOS). Climatology Report 96-2, Atmospheric Science Paper #616, Dept of Atmospheric Science, CSU, Fort Collins, CO, June. 242 pp.

Wilson, A. 1999. "Small is Beautiful: House Size, Resource Use, and the Environment," Environmental Building News, Volume 8, No. 1, January 1999.