CONSUMERS GAS

Heating Load Model Analysis

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1 Executive Summary

This paper explains the analysis and development of a better model for estimating heating loads, and for normalizing actuals for comparison to forecasts. The model was developed through an extensive investigation into the relationship of the conventional heating load model based on heating degree days calculated from an outside temperature of 18°C to actual observed heating loads using load research customer sample data and detailed analysis of historical customer billing data. This new model is calibrated to the observed relationships between temperature and heating using customer billing data, rather than using an assumed relationship based on a temperature base of 18°C. The calculated balance points developed from customer billing data were compared to the balance points using load research sample data for confirmation of the proposed method.

This proposed method is called the balance point method. This refers to the fact that rather than assuming a heating load starts at 18°C, the actual temperature at which heating load occurs is calculated from billing records. This analysis has no impact on the Ontario Energy Board's approved degree days forecasting methodology, it only varies the sales response to those degree days.

Analysis of customer bills and load research customer data by the three weather zones found that each zone has unique balance points of 14.8, 14.6, and 15.3 for Central Zone, Eastern Zone and Niagara Zone respectively. These balance points are more appropriate for estimating heating loads than using an assumed base of 18°C.

2 Introduction

The Company regularly reviews its procedures for setting volumetric forecasts and normalization of actual volumes to those forecasts in its ongoing effort to improve. Heating demand is currently estimated and normalized using the classic engineering model for heating end uses. This model assumes that the demand for heat increases uniformly as the temperature drops below 18°C. Technical literature[1] suggests that this is not necessarily so, and refinements can be developed to improve the performance of the heating load model.

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1 1989 ASHRAE Handbook Fundamentals SI Edition (ISBN 0-910110-57-3), American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. Atlanta, Ga. ch. 28

Canadian Climate Normals 1951 - 1980 Volume 4, Environment Canada, Atmospheric Environment Service, Ottawa, On.

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Advances in technology have enabled the Company to research the appropriateness of the model and propose improvements to it. This research was undertaken by the Load Research section of the Rates department and has been enabled through end-use metering. The result of this work is a statistically adjusted engineering model calibrated to the different heating markets.

3 The Heating Load Model

The conventional heating load model is a simple linear model founded on the basic energy flow equation:

$$Q = U\Delta E \qquad (1)$$

In this equation, the quantity flowing Q is equal to the product of a constant value U and an energy differential ΔE. This equation underpins many basic behaviours, such as electrical flow through wire and gas flow through pipe. Such equations are called linear for they explain increases in flow as a uniform response to increases in the energy differentials. That is to say, in a gas distribution pipe, flow will uniformly increase as the pressure differential increases.

Applying this equation in a simple manner to heating load, the equation becomes:

$$Q = U\Delta T \qquad (2)$$

Where: Q is the quantity of gas demanded

U is a constant

$\Delta T = (T_i - T_o) \qquad (3)$

and; T_i is the inside temperature of a building

T_o is the outside temperature of a building

This equation 2, the heating load model, expresses heating load as a linear relationship with the temperature differential $(T_i - T_o)$. With such a model, the *increase* in natural gas usage will be the same for a temperature change from 8°C to 7°C as for a change from -8°C to -9°C. The model is constrained so that $Q = 0$ for T_o greater than T_i.

4 Analysis of the Model

The model expressed by equation 2 conceptually is a relationship between average natural gas demand for heating use per temperature and temperature. This analysis of the model, and suggestions for improvements, is based on understanding its two components, the variable temperature differential ΔT, and the constant U.

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Through load research the outside temperature and furnace load can be independently observed and from those observations improvements have been suggested.

The Temperature Differential

The temperature differential, when calculated on a differential referenced to a standard base temperature, is called heating degree days. Heating degree days is a measure of coldness and takes into account that resistance to heat flow out of a building is impeded by the insulation in the building's envelop. It has been historically assumed at Consumers Gas that because of insulation, an outside temperature below 18°C is needed for heating load demand. Thus degree days are calculated from 18°C rather than from the inside temperature of a structure as stated in equation 3. This means that, on a day when the outside temperature averages 17°C, one degree day is calculated.

The temperature below which heating load begins is referred to as the balance point. This refers to the fact that the energy flows into and out of the structure are in balance: no additional heating is required to maintain the inside temperature.

The Constant

For a specific building, the constant will reflect that building's heat energy efficiency, and the characteristics of the use of the building. For example, the energy efficiency of a home will reflect, among other things: the efficiency rating of the furnace, the level of maintenance of the furnace, and the building code, which is a reflection of the standard for insulation to which the house was built. For the same home, characteristics such as: thermostat setting, number and age of occupants, and size, number, and level of use of other sources of heat gain (stoves, showers, other appliances) are typical factors that affect the constant. Although these factors can change, it is assumed in the model that, for the period of time analyzed, they do not change to any significant degree.

The constant factor is called the "average use per degree day".

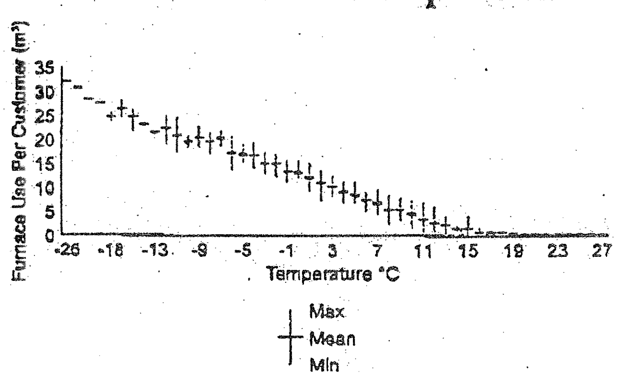
Observations

Observations of sample data on furnace loads from load research show that the assumption: natural gas demand for heating is linear with temperature, is essentially correct as illustrated in Figure 1. In this figure the actual average furnace loads from a sample of customers with end use metering is shown. In this plot the observed range between the average highs and lows for furnace loads at each temperature are illustrated as well as the means.

By observing the means, a near linear progression of increased furnace load as the

Figure 1

Furnace Load vs Temperature



Note: Data based on a sample of Central Zone

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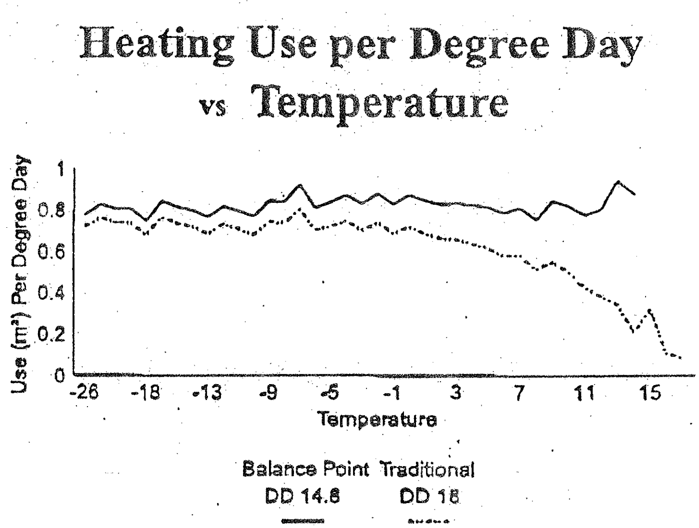
temperature declines can be seen. This actual relationship lends support to the assumption employed in the model that use is linear with respect to temperature.

However, this graph also illustrates that heating load essentially becomes zero around 15°C, as opposed to 18°C, as assumed for the purposes of determining heating degree days in the model. This shows that the model should employ a balance point other than 18°C.

Figure 2 presents this latter point from a use per degree day perspective using load research data of actual customer heating demands. This figure is a plot of the average use per degree day arising from the sample. The research data indicates that use per degree day is close to constant when a balance point of 14.8 degree days is used. When 18°C is used to define the balance point, the results are not constant.

Figure 2



Note: Data based on a sample of Central Zone

These observations displayed in figure 1 and figure 2, which are derived from the actual monitored uses, illustrate that a balance point of 18°C is an incorrect assumption for the average heating response, and will therefore lead to a model that is not as accurate as it would be with a more appropriate balance point. This is because response is non-linear when referenced from 18°C.

5 Recommended Model Refinement

Based on the above observations, analysis was undertaken to develop a method that would yield a more linear relationship between consumption and degree days. This analysis resulted in a method whereby heating responsive degree days reflect the observed balance point in the Company's markets, yielding a near linear relationship between use and temperature. This method is referred to as the balance point methodology. A methodology was developed to implement this approach to the forecasting and normalizing processes of the Company. The proposed methodology does *not* change the Ontario Energy Board's approved weather forecasting methodology. It merely changes the assumed temperature at which heating load will be estimated to begin.

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Balance Point Degree Days

The recommended refinement is called the balance point degree day method. This method uses historical customer billing data to calculate the correct balance point and the appropriate constant - the average use per degree day. The method is a simple iterative process where a regression of average use versus temperature below an assumed balance point is compared to another similar regression. The difference between the two regressions is that the assumed balance point is lower in one than the other. As the assumed balance point drops from 18°C, the relationship between heating load and temperature becomes more linear. When the relationship specified in the regressions begins to deteriorate, the balance point in that equation is then considered to be below optimal for the market and no further reductions are regressed. At this point the optimal balance point for the purposes of determining degree days has been found. The correct balance point is the balance point for the regression with the best fit.

Heating loads by weather zone were developed from analysis of historical customer billing data and compared to the recorded zone weather for the billing period. Significant differences in average balance points were found between the three Zones: Central, Eastern and Niagara. Table 1 lists the proposed balance points by Zone:.

Table 1

Proposed Balance Points

Zone	Balance Point
Central	14.8
Eastern	14.6
Niagara	15.3

These points are the weighted average balance points for the last five years. They will be reviewed annually and as long as the balance point remains within two standard errors (which is approximately ± 0.3 °C), no change to these balance points will be proposed in future applications. Only when the five year weighted average of a balance point falls outside this range will a change be proposed. This approach has been confirmed as stable and reasonable through historic analysis over time.

Average Use per Degree Day

The development of average use per degree day is based on historical customer billing data. Annual heating use developed from customer billing data divided by incurred degree days derives the average use per degree day.

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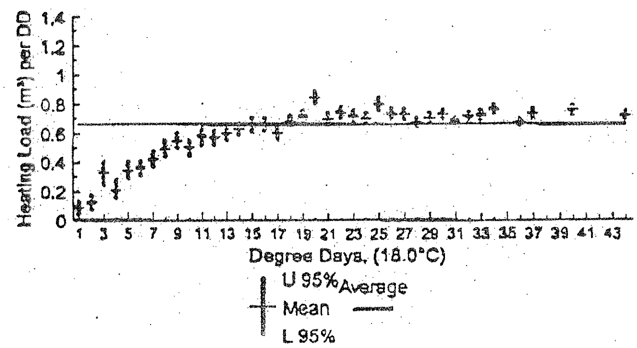
Figure 3 is a plot of average use per degree days versus degree days based on 18°C using customer sample data. The range between the upper and lower sample accuracy bounds at 95% confidence are indicated. The means are also indicated on this plot. This curved plot shows that when heating load is assumed to start at 18°C, a non-linear relationship exists between use per degree day and degree days. The average value is 0.66 m^3 per degree day and is illustrated by the horizontal line. As can be seen, the constant, or average, will over estimate at some temperatures and under estimate at other. Such a relationship will cause estimating and normalizing problems unless it is taken into account in some other less statistical fashion.

Figure 3

Use per Degree Days vs Degree Days

(Degree Days base 18°C)



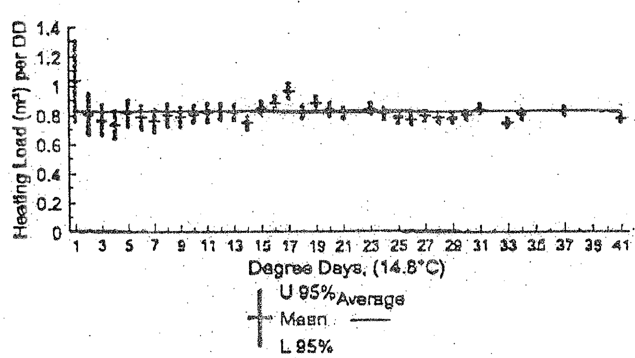
Note: Data based on a sample of Central Zone

Figure 4 is a similar plot to that of Figure 3. It is a plot of the observed relationship using customer sample data between use per degree days and degree days with the balance point method. In this plot the average is 0.83 m^3 per degree day and is illustrated by the horizontal line. The plot indicates a near linear average use per degree day. The variations about the mean can be explained largely by: other weather factors, such as wind and sunshine, diversity of individual customer behaviour, and geographical relationship between the weather station and the customer. These factors are not explicitly taken into account by the model. Additional work is underway to expand the model to include other weather factors.

Figure 4

Use per Degree Days vs Degree Days

(Degree Days base 14.8°C)



Note: Data based on a sample of Central Zone

Another factor that contributes to the variations is that the sample data employed in these figures covers the period from October 15, 1992 to January 19, 1994. As a result, for some temperatures there are few days to observe customer demands. Because of this, other factors play a larger role, for an average range of effects of the other factors is not available. However, the

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improvement in relationship between average use and temperature is clearly observable when 14.8°C is used for the balance point.

By reducing the balance point, the number of degree days utilized to explain heating decreases. It is therefore axiomatic that by using the balance point approach, average use per degree days increases from that based on 18°C. This explains the increase in average use per degree days between the two methods illustrated in figure 3 and figure 4.

The effect of this is that, on days when the temperature is predicted to be 16°C or 17°C, no heating volumes are being estimated by the model. This is supported by the observations of Figure 1. It is equally true that when temperatures are very low, greater sales will be estimated. Figure 2 confirms that this is an appropriate relationship as well.

Weather Forecast

The Company's weather forecasting method is not being changed. The Company has found this method to be a good means for forecasting weather and the Ontario Energy Board has reviewed and approved the method in the past. The forecasted annual degree days developed from this method are base 18°C, and are developed consistently for each of the three zones. The proposed method applies the calculated balance points to the day-by-day degree day distribution throughout the year by zone that is developed from the approved forecast, and calculates the number of degree days falling below the respective balance points. This is performed by weather zone.

6 Testing the Balance Points

To test the reliability of the approach, that is the billing system analysis will produce reasonable balance points, load research sample data was analyzed to see if the average balance points developed from the billing data were statistically within the estimated range of the sample. Table 2 illustrates the results.

Table 2

Balance Point Test

Zone	Billing Data	Sample Range
Central	14.7	14.4 - 15.2
Eastern	14.6	13.7 - 14.9
Niagara	14.8	14.3 - 15.4

The period for comparison in this test was January 1, 1993 to December 31, 1993 as opposed to the fiscal year of October 1, 1992 to September 30, 1993 which is a component year of the development of the balance points presented in Table 1. The sample data indicated are the upper and lower accuracy bounds at 95% confidence. This means that the actual balance points of the heating markets will fall within these ranges determined from sampling 19 out of 20 times. This table shows that the billing analysis resulted in balance points within that sample range. Thus using billing data is a reasonable approach for determining balance points.

By comparing the sample range in Table 2 to the proposed balance points in Table 1, it can be seen that the balance points using a five year weighted average based on fiscal years is within the sample range from calendar 1993. This indicates that the five year weighted balance points calculated from billing data is a reasonable and stable means to calibrate the heating model.

7 Recommendations

It is recommended that the basic engineering model for determining heating load using an estimated 18°C as the point at which heating load begins be replaced with a statistically adjusted engineering model which calibrates balance points to the various heating markets by zone. The effects of doing so will be better forecasts and better normalizations. This is due to the fact that models calibrated to actual customer uses from billing data better reflect customers' behaviour.

The Company's current method for forecasting degree days based on an approved method by the Ontario Energy Board is to continue. That forecast is to be used to determine the number of degree days occurring at temperatures below the balance point calibrated by zone for the forecast year, using a simple mathematical calculation.

Analysis should continue to develop a means to incorporate other factors such as other weather measures.