The Use of EDD for Weather Normalisation

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Table of Contents

List of Tables and Figures

List of Tables

List of Figures

1. Introduction

The purpose of this paper is to:

- Set out the history of the adoption and use of Effective Degree Days ("**EDD**") in weather normalisation for the purpose of gas demand forecast submissions to the Australian Energy Regulator ("**AER**") in eastern Australia;
- Outline the key differences between the EDD normalisation method used by Core and other normalisation methods used in gas demand forecasts in Eastern Australia;
- Demonstrate Core's view that EDD is the most appropriate method of normalisation to use in gas demand forecasting for the Mid-West and South-West Gas Distribution System ("**MWSWGDS**") for submission to the Economic Regulation Authority ("**ERA**"), making reference to previous submissions using EDD including Core's previous report for Envestra's Victoria network (2013-17).

2. Weather Normalisation Methods

The impacts of weather on gas demand must first be taken into account before assessing the underlying historical growth in demand. The approaches most commonly used in demand forecasts revolve around the choice of using one of two weather measurements - Heating Degree Days ("**HDD**") and EDD.

2.1 HDD

A HDD approach uses a single weather component (average temperature) to adjust demand for weather fluctuations. HDD is calculated as the negative difference between the average daily temperature and a threshold of 18 degrees celsius (i.e. the temperature below which gas would start to be used for heating), as illustrated by the equation below:

Daily HDD = MAX[18 - (T_{max} – T_{min})/2,0]

Daily HDD is then totalled annually to arrive at a yearly HDD figure.

The general process of weather normalising demand using HDD is outlined below:

- Using historical temperature data at the most relevant weather station, determine the trend in historical HDD;
- determine an appropriate 'normalised' HDD figure for each year (either a trending series or, if no trend in HDD is apparent, the average yearly HDD) which represents normal weather conditions;
- Compare the actual HDD recorded each year to the normalised HDD figure for that year to obtain the 'abnormal' HDD;
- Use regression analysis to determine the sensitivity of demand to HDD in each year, multiplying this factor by the abnormal HDD figure to arrive at total annual abnormal gas demand due to weather;
- Subtract abnormal demand from actual demand to arrive at weather normalised demand.

2.2 EDD

EDD has been used extensively in the Victorian gas industry since its development in the 1970s. The EDD approach extends the concept of HDD by taking other measurable weather factors into consideration (namely wind velocity, sunshine and seasonal variations in heating propensity) in addition to temperature. The inclusion of these additional factors seeks to observe changes in consumer behaviour resulting from these parameters and how they influence gas consumption for space and water heating.

Specifically the components that make up EDD are:

- Temperature (as measured by degree days);
- Wind chill (i.e. the impact of wind velocity to increase heating propensity);
- Insolation (i.e. the effect of outside sunshine in lowering heating propensity); and
- A seasonal component (i.e. the effects of the above factors are more pronounced in winter and less in summer – e.g. turning off appliances altogether in summer months regardless of temperature etc.)

Once the calculation of EDD has been specified, the process of weather normalising demand using EDD is outlined below:

- Using historical temperature data at the most relevant weather station, determine the trend in historical EDD;
- determine an appropriate ‘normalised’ EDD figure for each year (either a trending series or, if no trend in EDD is apparent, the average yearly EDD) which represents normal weather conditions;
- Compare the actual EDD recorded each year to the normalised EDD figure for that year to obtain the ‘abnormal’ EDD;
- Use regression analysis to determine the sensitivity of demand to EDD in each year, multiplying this factor by the abnormal EDD figure to arrive at the total abnormal gas demand due to weather for each year;
- Subtract abnormal demand from actual demand to arrive at weather normalised demand.

2.3 Ideal Measure for MWSWGDS

Core’s belief is that EDD is a superior measure for gauging weather conditions than HDD and gives a more accurate representation of the consumer’s demand response to changing weather conditions. The reasons for this view include:

- EDD considers other weather factors in addition to daily temperature alone which can be reliably measured on a daily basis, which provides a model framework which fits more closely to actual daily demand.
- EDD Factors such as wind chill and insolation capture physiological effects beyond the explanatory power of temperature. Measuring the extent to which gas load increases on a windy day, or decreases on a sunny day, provides a more robust insight into the drivers of a network’s gas demand.
- Statistically Core has found a higher goodness-of-fit between actual and predicted daily demand when using EDD rather than HDD. This is discussed further in Section 4.

The following sections outline Core’s methodology for weather normalisation of MWSWGDS gas demand using EDD.

3. AEMO 2012 Weather Standards for Gas Forecasting

In April 2012 the Australian Energy Market Operator ("**AEMO**") reviewed its quantitative modelling of the relationship between gas demand and weather for Victoria.

Three models using EDD (differing mainly by the starting time of a 'gas day' and/or adjusting the weighting of morning weather observations) and one using HDD were tested against AEMO's existing 2009 EDD_{312} model.

AEMO's findings were the following:

- *"The EDD_{312} index performs better than the EDD_{66}, the EDD_{129}, the EDD_{63} and the HDD_{312} index for modelling Victorian medium to long-term gas demand, as a result, Energy Forecasting will continue to use the EDD_{312} 2009 index.*
- *The Long-Term Trend Projection method for the Annual EDD_{312} standards and the EDD Simulation method for the Peak Day EDD_{312} standards are more accurate and more stable".*[1]

Core believes that an adaptation of the AEMO EDD_{312} index to normalise historical gas demand in the MWSWGDS would be more accurate than a similar approach using HDD for modelling the underlying trend in WA gas demand, due to the considerations of additional weather factors which affect daily gas demand. This is discussed further in Section 4.

AEMO's EDD_{312} index is specified in Figure 3.1 below:

Figure 3.1 AEMO EDD_{312} Index.

Daily demand =		a + b_1 * **EDD** + b_2 * **Friday** + b_3 * **Saturday** + b_4 * **Sunday**,
Where **EDD** =		
Temperature		Degree Day (**DD_{312}**)
Wind Chill	*plus*	**Wind Chill Coefficient** * **DD_{312}** * **$Wind_{312}$**
Insolation	*minus*	**Insolation Coefficient** * **Sunshine Hours**
Seasonality	*plus*	**Seasonality Coefficient** * Cosine(2π(**Day** - **Seasonality Factor**)/365)

Where:

- **DD_{312}** is the Heating Degree Day calculated using the average of eight three-hourly Melbourne temperature readings (in degrees celsius) from 3am to 12am the following day as measured by the Bureau of Meteorology's ("BOM") Melbourne Station. The gas day begins at 6am so this EDD specification implies a three-hour lag in demand to any changes in ambient temperature.
- **Wind Chill Coefficient** equals **0.037**. **$Wind_{312}$** is the wind speed calculated using the average of the eight three-hourly wind observations from 3am to 12am the following day inclusive measured at the Laverton and Moorabbin Stations.
- **Insolation Coefficient** equals **0.144**. **Sunshine Hours** is the number of hours of sunshine above a standard intensity as measured at the Weather Bureau's Tullamarine Station between 12am to 9pm inclusive.

[1] AEMO (2012); Weather Standards for Gas Forecasting, p4.

- **Seasonality Coefficient** equals **2**, **Seasonality Factor** equals **201**, and **Day** is the day of the year. This component models the seasonal nature in consumer response to different weather. AEMO states that "It indicates that residential consumers more readily turn on, adjust heaters higher or leave heaters on longer in winter than in the shoulder seasons for the same weather or change in weather conditions.".[2] This factor implies that given the same weather conditions, heating demand is higher in winter than would be the case in other seasons.

In its analysis, AEMO tested a number of EDD indices (specifying different time periods for a 'gas day') and compared their accuracy to a HDD index specification. AEMO found that the EDD_{312} index mentioned above provided the best fit between predicted and actual gas demand, as measured by the Multiple R (the square root of the more commonly known R^2 value, measuring goodness of fit between predicted and actual data) shown in Table 3.1 below.

Table 3.1 **Multiple R – AEMO EDD and HDD Indices.**

Index Specification	EDD_{312}	EDD_{66}	EDD_{129}	EDD_{63}	HDD_{312}
Multiple R (Winter)	96.6%	95.3%	95.9%	95.8%	91.9%

Source: AEMO 2012 Weather Standards for Gas Forecasting, p9.

Core notes that the use of EDD to predict Victorian daily gas demand, regardless of gas day specification, provides a significantly better fit with actual demand (i.e. a higher Multiple R) than HDD and therefore more accurate weather normalised demand.

[2] AEMO (2012); Weather Standards for Gas Forecasting, p8.

4. Core's EDD Methodology for MWSWGDS

4.1 Methodology

Core believes an EDD methodology applied to the MWSWGDS that is consistent with AEMO's "2012 Review of Weather Standards for Gas Forecasting" (i.e. a measurement of EDD defined by AEMO's EDD_{312} index) would be the most appropriate weather normalisation approach. This process involves using regression analysis to determine the coefficients of each variable in the EDD index described in Figure 2.1 that correspond to Western Australia.

Core has conducted this analysis which is presented in Figure 4.1 below, with statistical validation provided in Section 4.3.

Figure 4.1 Core EDD Index for the MWSWGDS.

Daily demand =		a + b_1 * **EDD** + b_2 * **Friday** + b_3 * **Saturday** + b_4 * **Sunday**,
Where **EDD** =		
Temperature		MAX(**Threshold** - **Temperature**, 0)
Wind Chill	*plus*	**Wind Chill Coefficient** * MAX(**Threshold** - **Temperature**, 0) * **Wind**
Insolation	*minus*	**Insolation Coefficient** * **Sunshine Hours**
Seasonality	*plus*	**Seasonality Coefficient** * Cosine(2π(**Day** - **Seasonality Factor**)/365)

Where:

- **Threshold** equals **22.36** degrees Celsius, as determined through regression analysis.
- **Wind Chill Coefficient** equals **0.024**, as determined through regression analysis.
- **Insolation Coefficient** equals **0.196**, as determined through regression analysis.
- **Seasonality Coefficient** equals **4.98**, as determined through regression analysis.
- **Seasonality Factor** equals **205**, as determined through regression analysis.
- **Temperature** is the average of eight three-hourly temperature readings in degrees Celsius as measured at the Perth Airport weather station.
- **Wind** is the average of eight three-hourly temperature readings in km per hour as measured at the Perth Airport weather station.
- **Sunshine** is the number of hours of sunshine on a gas day above a standard intensity as measured at the Perth Airport weather station.
- **Day** is the day of the year. Friday, Saturday and Sunday are dummy variables to model the change in base load for Fridays, Saturdays and Sundays relative to Monday to Thursday base load respectively.

4.2 Choice of Degree Day Threshold

Core notes that while prior submissions to the AER use a threshold temperature of 18 degrees Celsius, regression analysis of ATCO daily demand data has provided evidence that the threshold temperature is approximately 22.36 degrees. Core has chosen not to use an 18 degree threshold and relied upon the WA specific temperature of 22.36 degrees for modelling weather normalised demand.

Traditionally, a common assumption of 18 degrees as the universal thermometer setting has been used to measure HDD. When the average daily temperature drops below this point, heating is assumed to be used and positive HDD are then recorded.

In reality, no universal threshold temperature exists. Since ATCO's network region in WA is a much hotter region on average relative to other states (such as VIC where EDD is also used in gas forecasting) consumers are not accustomed to cooler temperatures. As a result, they may be expected to start using their hot water or space heating at higher temperatures than would be the case in colder states like Victoria, where consumers are more accustomed to colder weather. For this reason Core believes a dynamic threshold temperature is most appropriate for weather normalisation of individual networks and thus a threshold which provides the best fit statistically to actual demand is preferred.

Table 4.1 compares the historical normalised demand under Core's EDD index using a 22.36 degrees threshold versus an 18 degree threshold. The normalised demand under both methods aligns closely, normalising actual demand in the same direction for all Reference Tariffs in all years of data.

Table 4.1 **Normalised Demand – 18 Degree Threshold vs 22.36 Degrees.**

Normalised Demand (GJ)	2007	2008	2009	2010	2011	2012	2013
Tariff A1							
Actual	15,598,230	12,346,218	12,468,626	12,565,313	11,844,817	12,180,788	11,518,867
Normalised (18 Degree EDD)	15,596,897	12,332,689	12,467,152	12,550,524	11,869,535	12,188,132	11,529,656
Normalised (22.36 Degree EDD)	15,591,021	12,333,127	12,466,206	12,560,578	11,860,811	12,187,534	11,528,377
Tariff A2							
Actual	2,102,575	1,952,502	1,895,698	1,924,409	2,011,649	2,110,137	1,988,651
Normalised (18 Degree EDD)	2,101,859	1,945,259	1,894,910	1,916,372	2,026,626	2,114,554	1,994,940
Normalised (22.36 Degree EDD)	2,098,725	1,945,542	1,894,414	1,921,853	2,021,272	2,114,165	1,994,155
Tariff B1							
Actual	1,694,774	1,606,857	1,607,679	1,644,214	1,532,391	1,607,901	1,627,808
Normalised (18 Degree EDD)	1,693,414	1,593,179	1,606,143	1,628,235	1,560,739	1,616,513	1,640,607
Normalised (22.36 Degree EDD)	1,687,740	1,594,204	1,605,268	1,639,323	1,549,925	1,615,463	1,638,592
Tariff B2							
Actual	1,137,422	1,161,746	1,168,145	1,183,588	1,162,513	1,219,321	1,223,594
Normalised (18 Degree EDD)	1,137,018	1,157,486	1,167,648	1,178,222	1,172,424	1,222,432	1,228,398
Normalised (22.36 Degree EDD)	1,135,396	1,157,925	1,167,388	1,181,995	1,168,458	1,221,970	1,227,519

Normalised Demand (GJ)	2007	2008	2009	2010	2011	2012	2013
Tariff B3							
Actual	10,179,506	10,455,396	10,539,649	10,295,438	9,410,070	9,837,109	9,815,347
Normalised (18 Degree EDD)	10,160,933	10,267,048	10,518,880	10,082,526	9,786,171	9,950,048	9,983,151
Normalised (22.36 Degree EDD)	10,081,298	10,277,275	10,506,315	10,228,808	9,647,902	9,938,493	9,959,900

Source: Core Energy Group.

4.3 Validation

To test the effectiveness of the EDD index against HDD, Core performed the following analysis:

- On a monthly basis, determine the R^2 value to measure the goodness of fit between actual residential (B3) gas demand and predicted gas demand using Core's EDD index versus HDD; and
- On a daily basis, determine the R^2 value between ATCO's total gas demand and predicted gas demand using Core's EDD index versus HDD.

On a monthly basis, the EDD index provides a tighter fit to actual residential demand than using HDD, indicated by the higher R^2 value. This implies that the additional factors contained within the EDD specification are significant and provide a more accurate method of normalising historical WA demand.

Table 4.2 Goodness of Fit: EDD vs HDD (Monthly B3 Demand).

R-Squared	EDD	HDD
Total monthly B3 demand	94.24%	91.95%

Source: Core Energy Group.

On a daily basis, Core used ATCO's total daily demand to perform a similar exercise to that described above. R^2 values are understandably lower due to the presence of non-residential demand which is less sensitive to daily changes in weather. The noticeable increased R^2 of EDD relative to HDD reinforces the results in Table 5.1, implying EDD will provide a more accurate method of normalising historical WA demand than HDD.

Table 4.3 Goodness of Fit: EDD vs HDD (Daily Total Demand).

R-Squared	EDD	HDD
Total daily demand	87.89%	76.89%

Source: Core Energy Group.

The results above show that the inclusion of relevant EDD factors add explanatory power to changes in demand. Core believes there is sufficient evidence to conclude that using Core's EDD index specification which is consistent with AEMO's previously accepted methodology will provide more accurate weather normalised demand than using HDD.

5. AER Responses to EDD Normalisation

Table 5.1 below shows the weather normalisation methods adopted in the most recent round of gas distribution access arrangements in eastern Australia. The method of weather normalisation is agreed upon by the distribution network and its consultant. The AER has not given any indication of a preferred method to date, provided the process is transparently described and is arrived at on a reasonable basis.

Table 5.1 **Normalisation Methods of Previous Gas Access Arrangements.**

Access Arrangement	State	Weather Normalisation Method
Jemena NSW 2010-15	NSW	HDD
Envestra Wagga Wagga 2010-15	NSW	HDD
ActewAGL 2010-15	ACT	HDD
APT Allgas 2011-16	QLD	Not specified
Envestra QLD 2011-16	QLD	Not specified
Envestra SA 2011-16	SA	EDD
Envestra Albury 2013-17	VIC	HDD
Envestra Victoria 2013-17	VIC	EDD
Multinet gas 2013-17	VIC	EDD and SDD[3]
SP Ausnet 2013-17	VIC	EDD

Source: Access Arrangements on AER website.

Section 5.1 outlines the AER's response from Core's use of EDD for weather normalisation in the Envestra Victoria 2013-17 Access Arrangement.

5.1 Envestra Victoria 2013-17

In its Draft Decision for the Envestra Victoria 2013-17 Access Arrangement, the AER stated the following regarding the use of an EDD normalisation method:

> *"The AER approves Envestra's forecasting methodology as a reasonable basis for determining its forecasts."*[4]

It should be noted the proposed demand forecasts were not accepted in the Draft Decision due to the dataset used for calculations; the EDD data was based on annual projections of EDD derived by the CSIRO between 2005 and 2011 instead of actual historical EDD, published by AEMO following its "2012 Review of Weather Standards for Gas Forecasting".

ACIL Tasman, the Consultant to the AER for the submission, stated in its response to the Demand Forecast:

> *"Given the short time series of available data and the difficulties involved in reliably estimating the coefficients associated with each of the variables in a fully specified demand function, it is not clear that a more rigorous*

[3] SDD refers to Summer Degree Days, which is treated inversely to HDD. It is used to measure gas demand for cooling rather than heating.
[4] AER (2012); Envestra (VIC) Access Arrangement Final Decision, p63.

> *approach would necessarily produce a more reliable forecast.*
>
> *Accordingly, while recommending that consideration be given in future to the methodological issues identified, we consider that in the current circumstances the approach used by Core to develop the Envestra Victoria demand forecasts is acceptable."*[5]

Given this support of methodology from the AER, and the statistical evidence for the appropriateness of using EDD outlined in Section 4, Core believes that adopting an EDD methodology consistent with that accepted by the AER for the MWSWGDS is acceptable and satisfies the overarching criteria set out in the National Gas Rules, namely Rule 74 (2) which states:

> *"A forecast or estimate:*
> *(a) must be arrived at on a reasonable basis; and*
> *(b) must represent the best forecast or estimate possible in the circumstances."*

5.2 Other Submissions

Other demand forecast submissions to the AER have chosen to use EDD in their weather normalisation methodology. These most recently include:

- SP Ausnet 2013-17;
- Multinet Gas 2013-17;
- Envestra (SA) 2011-16;

These submissions used EDD normalisation methodologies that were either consistent with AEMO's EDD modelling or some variant (e.g. NIEIR incorporated the used of Summer Degree Days in conjunction with EDD).

The AER's responses to each submission in its final decisions are stated below.

Multinet

Multinet's demand forecasts, which were prepared by NIEIR and used EDD for weather normalisation, were accepted by the AER:

"The AER accepts the demand forecasts proposed by Multinet for the 2013-17 access arrangement period for the reasons set out in its draft decision. The AER considers that the proposed demand forecasts are arrived at on a reasonable basis and represent the best forecasts possible in the circumstances."[6]

SP Ausnet

SP Ausnet's demand forecasts were prepared by the Centre for International Economics. The AER's response in its final decision was the following:

[5] ACIL Tasman (2012); Review of Demand Forecasts for Envestra Victoria, p21-22.
[6] AER (2012); Multinet 2013-17 Access Arrangement Final Decision, p40.

"The AER does not accept SP AusNet's revised demand forecasts because the proposed demand forecasts do not represent the best forecasts possible in the circumstances. While the AER accepts that the forecasting methodology is reasonable, it considers that:

- *the projection of Effective Degree Day (EDD) that SP AusNet used to generate the weather–sensitive gas demand forecasts is not the best estimate in the circumstances. The AER proposes to adjust the proposed demand forecasts by using AEMO's projection of EDD.*
- *there are technical errors in the demand forecast spreadsheet that affect the resulting forecasts. The AER proposes to adjust the proposed demand forecasts by correcting these technical errors."*[7]

This ruling mirrors that which was described in the Draft Decision for Envestra (Victoria) in Section 4.1 – i.e. "historical" EDD data was based on annual projections of EDD derived by the CSIRO between 2005 and 2011 instead of calculated actual historical EDD. The AER subsequently stated AEMO's EDD methodology (consistent with that outlined in Section 3 of this Report) should be adopted.

Envestra (SA)

Envestra's demand forecasts were prepared by NIEIR. The AER's response in its final decision was the following:

"The AER accepts the proposed demand forecasting approach in general appears reasonable, and that the revised residential customer numbers forecast as presented in table 10.4 is reasonable. However, the AER does not approve Envestra's proposed demand forecasts as they do not meet the requirements of r. 74 of the NGR.

The AER considers that the economic outlook adopted by Envestra to prepare Tariff C consumption and Tariff D MDQ forecasts is not reasonable, and propose forecasts based on a more realistic outlook as discussed in section 10.4.2. The AER considers the revised forecasts derived on this basis, as shown in table 10.6, represent the best forecasts possible in the circumstances."[8]

Core notes that the AER does not call into question the reasonableness of the EDD weather normalisation methodology (which appears to have been accepted); rather the AER had not accepted Envestra's proposal based on certain economic outlook assumptions which do not relate to weather normalisation.

Summary

The rulings above draw the following conclusions:

- The AER has previously accepted an EDD weather normalisation methodology, provided it complies with AEMO's EDD methodology outlined in Section 3 of this Report; and
- The AER has previously accepted an EDD weather normalisation methodology outside of Victoria (where the AEMO EDD methodology was originally derived).
- Core's analysis in Section 4 shows that by following this methodology, a better fit is achieved with actual data than HDD.

Core is therefore confident that using AEMO's EDD methodology and determining coefficients for WA (which for SA has previously been accepted) is the most reasonable and accurate approach to weather normalisation for the MWSWGDS.

[7] AER (2012); SP Ausnet 2013-17 Access Arrangement Final Decision, p.
[8] AER (2011); Envestra (SA) 2011-16 Access Arrangement Final Decision, p107.

6. Limitations

Limitations of EDD and HDD for weather normalisation are outlined below.

6.1 Limitations Specific to EDD

- The sourcing of the relevant data requires a complete set of daily measurements for 3-hourly temperature, sunshine hours and wind velocity. While all of this data can be sourced from the Bureau of Meteorology ("**BOM**"), readings for these additional weather factors do not go back as far as temperature data alone (which is all that is required for measuring HDD). This can affect the size of historical data available for EDD normalisation relative to a HDD methodology when undertaking analysis of long term weather trends.

6.2 Limitations Specific to HDD

- A weather normalisation model using HDD implies that any marginal change in daily demand can be fully explained by changes in temperature. While temperature accounts for a large portion of daily demand changes, numerous other factors exist (both quantifiable and unquantifiable) which contribute to changes in demand, as evidenced by the additional variables contained in EDD.

6.3 Limitations Shared by EDD and HDD

- Omitted variable bias may exist, whereby important variables are excluded from the specified model (due to lack of data or the ability to be reliably quantified) which may overstate or understate the effects of the included variables on gas consumption. Ideally, one model would be derived which incorporates every variable that affects daily demand, but due to the inability to identify or accurately quantify these factors omitted variable bias will be present.

- Non-linearity in demand is not captured in the regression model. For example, the model Core has specified implies that demand may not change by a constant percentage to changes in temperature, sunshine or wind speed.

While Core acknowledges these limitations are present, the impacts of these limitations on the accuracy of the resultant weather normalised demand are extremely difficult to quantify with confidence.

References

- ACIL Tasman Demand Forecast Reviews for Multinet, Envestra (VIC), Envestra (SA), SP Ausnet; various.
- AEMO, “Retail Market Procedures (Victoria)”; October 2013.
- AEMO, “2012 Review of Weather Standards for Gas Forecasting”; April 2012.
- AER, Draft and Final Decisions for gas distribution networks; various.
- CIE, Demand Forecast for SP Ausnet; March 2012.
- NIEIR, Demand Forecasts for Envestra (SA) and Multinet; various.

Glossary

AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
BOM	Bureau of Meteorology
EDD	Effective Degree Day
ERA	Economic Regulation Authority
HDD	Heating Degree Day
MWSWGDS	Mid-West and South-West Gas Distribution System
SDD	Summer Degree Days