NIEIR Review of EDD weather standards for Victorian gas forecasting

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1. Introduction

This report follows on from reviews completed by AEMO and VENCorp for the Effective Degree Day index with a particular focus on the development of new weather standards for annual gas consumption and peak day.

This report covers:

- background to weather normalisation and how the EDD index is formulated in Section 2. The results from previous reviews are also summarised;
- the annual EDD standards are reviewed in Section 3 with an analysis of the warming trend on annual EDDs in Victoria;
- the Peak Day EDD standards are reviewed to a 1-in-2 and 1-in-20 standard. Warming trends on the coldest day of the year are also analysed in Section 4; and
- monthly standards are estimated for gas consumption and peak day in Section 5.

2. Background

This section reviews the Effective Degree Day (EDD) Index used for Victorian gas forecasting purposes. The review has a particular focus on the most recent EDD_{312} index formulation.

2.1 Weather standards

An important aspect of energy forecasting is the ability to weather normalise historical data. Weather normalisation is used to separate the short-term climate impacts from the underlying demand drivers to be able make more meaningful year-to-year comparisons. For example, an overly cold winter will cause consumers to use more heating, while a warm winter will have less use of space heating equipment. Without normalising weather, comparisons between the actual annual gas consumption between a cold winter and a warm winter will overstate the fall in consumption.

On this basis a normal or standard year of weather must be developed. This is usually done by making an assessment of weather conditions over a long period of time. Once standards have been developed, the gas demand due to abnormal weather conditions is able to be removed and more meaningful year-to-year comparisons can be made.

The EDD index is used to develop these normal weather standards. These standards are reviewed and estimated in section 3. The impact of climate change on a standard year is also covered.

For gas consumption, annual and monthly standards are developed. For peak day, demand standards are developed to for a 1-in-2 peak day and 1-in-20 peak day standard on an annual and monthly basis. These represent standards of a peak day exceeding a standard demand with a 50 per cent chance, and a peak day exceeding a standard demand with a 5 per cent chance respectively.

2.2 Effective Degree Day Index

Temperature is one of the main drivers behind the demand for energy. For gas, this will typical be through space and water heating requirements. As temperatures get colder, consumers use gas heating more intensively to maintain a level of comfort indoors. To this end, Heating Degree Days (HDDs) are a popular index for analysing the impact of temperature on energy demand. Heating Degree Days are an index of the temperatures below a threshold value of 18, and are set to zero for temperatures above 18.

The Effective Degree Day (EDD) index was introduced to capture the impact of additional weather effects on Victorian gas demand. The EDD index also uses wind, sunshine and includes a seasonal effect as well as temperature. This is because the demand for heating is typically stronger on windier days, than calmer days. Consumers also tend to use more heating on cloudier days, than sunnier days. The seasonal effect is a measure of consumer preference to use heating appliances more intensively during the later stages on winter, and minimally during the summer months.

Over the years there have been many different versions of the EDD index representing necessary corrections to raw weather station data, changes to the Victorian gas day, and updates to the parameters in order to apply indices more accurately to the demand-weather relationship with Victorian gas demand.

Currently, four types of the EDD index are calculated by AEMO[1]:

1. EDD_{312} (2012);
2. EDD_{312} (2009);
3. EDD_{66}; and
4. EDD_{129}.

AEMO currently prefers to use the EDD_{312} (2012) index for medium to long-term gas forecasting purposes. In AEMO's *2012 Review of the Weather Standards for Gas Forecasting* they find this to provide the best fit to gas demand. EDD_{312} (2012) represents a marginal improvement over the previous EDD_{312} (2009) index developed in 2009.

The general formulation of the EDD index is as follows:

Effective Degree Day =	Degree Days	(Temperature Effect)
	+ α_1 * (Degree Days)* β_1(Wind Speed)	(Wind Chill)
	+ α_2 * (Sunshine Hours)	(Sunshine)
	+ 2*Cosine (2π(day - β_2)/365)	(Seasonality)

Where the parameters for EDD_{312} (2012) are:

$\alpha_1 = 0.037$
$\alpha_2 = 0.144$
$\beta_1 = 0.604$
$\beta_2 = 190$

The EDD_{312} (2012) index uses three hourly intervals starting from 3am on the current gas to 12am of the following gas day to compile the average $Temperature_{312}$. All temperatures are given an equal weighting. Temperature data is taken from three hourly recordings at Melbourne Regional Office, and Melbourne's Olympic Park since the closure of Melbourne Regional Office in January, 2015.

Similarly, the $Wind_{312}$ variable uses 3 hourly intervals between 3am on the current gas day to 12am of the following gas day. A correction to the wind data is made at $\beta_1 = 0.604$ to account for the windier conditions at Moorabbin Airport and Laverton RAAF weather stations. This is required due to the previous Melbourne wind station that was closed in 1999. Moorabbin Airport and Laverton RAAF are given an equal weighting.

Degree $days_{312}$ are calculated by using a threshold value of 18 degree Celsius.

Degree Day_{312} = 18 – $Temperature_{312}$ if $Temperature_{312} < 18$; and
0 if $Temperature_{312} >= 18$

Sunshine hours are presented on a daily basis as the number of hours per day above a certain sunshine intensity at Melbourne Airport weather station.

Table 2.1 provides the summary statistics for the various EDD indices and the component variables of the EDD_{312} index. Over 1970 to 2015 the mean of the EDD_{312} (2012) index is 1,493 without considering warming impacts over time. Note the maximum number of EDDs occurs very early during the sample period and the minimum number of EDDs occurs recently.

[1] For more details see http://www.aemo.com.au/Gas/Planning/Victorian-EDD-Weather-Standards.

Table 2.1	Effective Degree Day Index summary statistics for annual standards 1970 to 2015							
Summary Statistic	**T312**	**DD312**	**W312**	**Sunshine Hours**	**EDD_{312} (2012)**	**EDD_{312} (2009)**	**EDD66**	**EDD129**
Mean	5,646	1,267	3,353	2,311	1,493	1,463	1,474	1,459
Median	5,642	1,266	3,319	2,322	1,494	1,464	1,476	1,458
Standard deviation	194	130	307	122	144	145	142	144
Minimum	5,340	990	2,706	1,926	1,197	1,168	1,181	1,169
Maximum	6,060	1,466	4,116	2,560	1,750	1,734	1,742	1,727
Year of minimum	1986	2014	1978	1992	2014	2014	2014	2005
Year of maximum	2007	1995	1971	2007	1971	1971	1971	1971

2.3 Previous EDD reviews

The Australian Energy Market Operator (AEMO), and previously VENCorp, has reviewed the EDD index and EDD standards every two to three years since 2000. These reviews typically include:

- a review of alternative EDD indices and their suitability for forecasting Victorian gas demand;
- the impact of climate change on weather standards;
- the development of new annual and monthly EDD standards for forecasting gas consumption; and
- the development of new annual and monthly 1-in-2 and 1-in-20 Peak Day EDD standards for forecasting gas Peak Day demand.

Table 2.2 provides a summary of the outcomes of previous reviews since 2000. Standards developed by AEMO have typically been fixed over the years following a review. Each review since 2000 has seen the weather standards either stay the same or revised downwards due to the impacts of warming. This would suggest that standards should be decreasing due to warming, and that using fixed standards has overstated demand in forecast years.

Table 2.2	Previous EDD standards from EDD reviews						
Standards	**2000**	**2001**	**2003**	**2005**	**2006**	**2009**	**2012**
Annual EDD	1,504	1,445	1,396	1,396	1,340	1,314	1,309
1-in-2 Peak Day EDD	15.15	15.15	14.60	14.60	14.35	14.55	14.21
1-in-20 Peak Day EDD	17.25	17.25	16.75	16.75	16.50	16.80	16.49

Source: AEMO, *2012 Review of the Weather Standards for Gas Forecasting*.

In the AEMO 2015 National Gas Forecasting Report, which was released in December 2015, AEMO increased the annual EDD standard used in their modelling to 1,340. AEMO found in their analysis, there to be little evidence of warming over 2000 to 2014 and assumed the median over this period as the standard. This approach does not appear to be consistent with scientific evidence on global and urban warming.

3. Review of annual EDD standards

The section's review of the annual EDD weather standard includes:

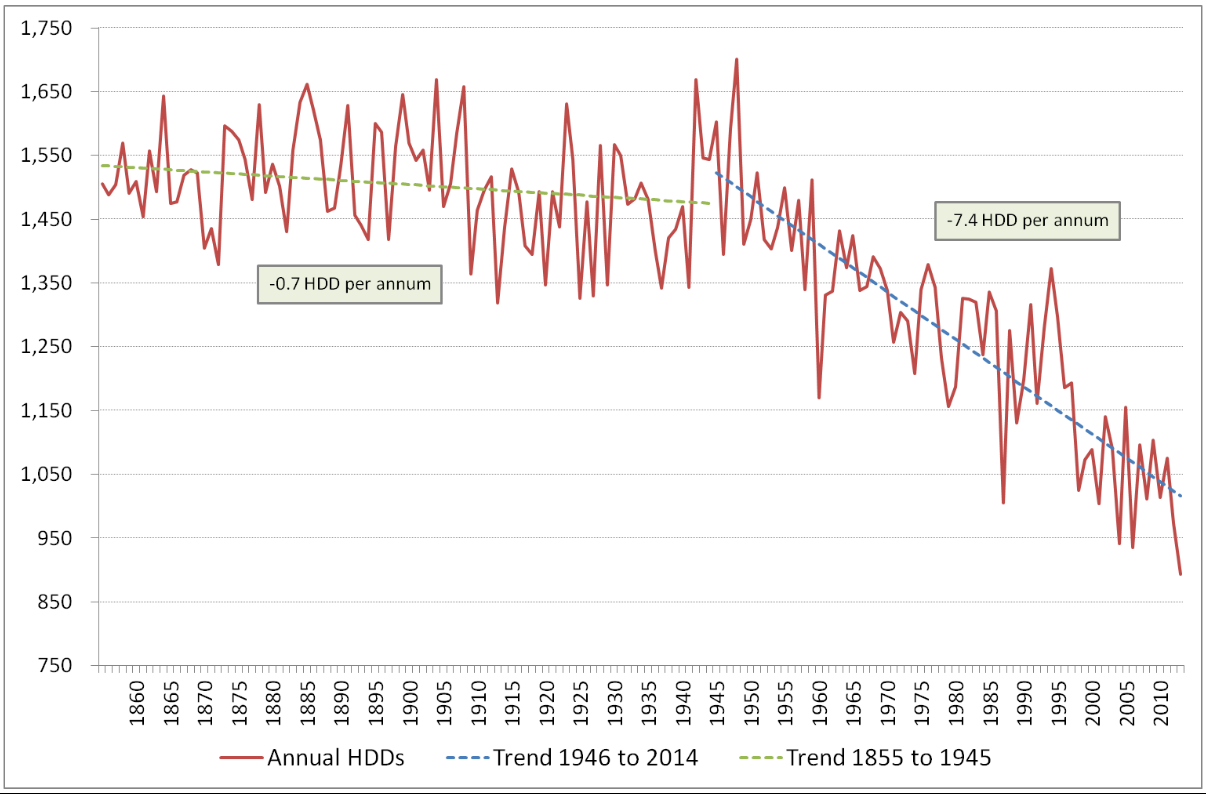
- a long-term and short-term analysis of local annual warming trends in Melbourne weather; and
- projections of annual EDD weather standards using the long-term and MAT9 methods.

3.1 Warming trend in the annual EDD Index

Temperatures in Australia and around the globe have been rising for a number of years. This trend is projected to continue with forecast increases of 0.6 to 1.5 degrees Celsius by 2030 compared to temperature levels over 1980 to 1999 (CSIRO, State of the Climate 2014). Temperature increases within Australia have also been stronger within the minimum temperatures, compared to the maximum temperatures. These trends have implications on the levels of space and water heating used by households and businesses. This also means that the standard weather year is subject to change as the overall temperature increases.

Figure 3.1 summarises the local warming trends within Melbourne as measured by the Melbourne Regional Office weather station.

Figure 3.1: Melbourne Regional Office 1855 to 2014 – Annual HDDs per annum



Since the weather station started recording in 1855 to the mid-1940s, Melbourne temperatures were relatively stable. There was only a small warming trend of -0.7 HDDs per annum. Melbourne temperatures started experiencing significant warming after World War II ended. Over 1946 to 2015 the trend has been an annual decrease of -7.4 HDDs per annum. Over this time, carbon dioxide emissions have also increased rapidly since the mid-1940s as rebuilding and industrial activity increased post-World War II, and more fossil fuel power stations are built to support historically strong world economic growth.

Over the past 45 years this warming trend has continued. Table 3.1 shows the warming trend for the EDD_{312} index estimated over various spans of time.

Over 1970 to 2015, the warming trend has continued at a reduction of 7.6 EDDs per annum. This is a similar amount to the reduction in HDDs per annum over 1946 to 2015. Note the EDD trend will also be impacted by trends in wind and sunshine which lead to a net increase to EDD values in comparison to HDDs. Still the warming trend in these time periods is relatively consistent.

The long-term trend was also taken from 1970 to other recent years. The trend reduction in EDDs was -8.0 EDDs per annum over 1970 to 2014 and -7.7 EDDs per annum over 1970 to 2011. Even with additional years of data, the coefficients remain similar.

When shorter periods of time are assessed for a warming trend, the estimates have much more variation. Over 1970 to 1985 there appears to be stronger warming of around -9.8 EDDs per annum. While over 2000 to 2015, the warming trend appears to have slowed down to -2.8 EDDs per annum. The high p-value over 2000 to 2015 also indicates that the warming trend is not significant during this time.

Also note that over shorter time periods the standard deviation of the coefficient increases. Over 45 years, the standard deviation is around 1.1. Over thirty years this increases to 2.1. The standard deviation on the 15 year time spans ranges from 3.9 to 6.8. This emphasises heightened climate volatility over the short-term. For example, over 1985 to 2000 the warming trend is between -17.5 and -2.1 with a 95 per cent confidence level. The warming trend is more certain in the long-term with the 1970 to 2015 warming trend being between -9.8 and -5.4 with 95 per cent confidence. **NIEIR recommends that an annual warming trend of 7.6 EDD's per annum, based on the 1970 to 2015 period, be used for Victorian gas forecasting.**

Table 3.1 Annual EDD_{312} long-term trend statistics over selected spans

Years	Coefficient (EDD_{312} per annum)	Std. Dev	95% Confidence Interval	p-value
1970 to 2015	-7.6	1.1	(-9.8; -5.4)	0.00
1970 to 2014	-8.0	1.2	(-10.3; -5.8)	0.00
1970 to 2011	-7.7	1.2	(-10; -5.4)	0.00
1970 to 2004	-6.5	1.7	(-9.8; -3.1)	0.00
1970 to 2000	-5.2	2.1	(-9.3; -1.2)	0.01
1970 to 1985	-9.8	3.9	(-17.5; -2.1)	0.01
1985 to 2000	-8.8	6.8	(-22.1; 4.6)	0.10
2000 to 2015	-2.8	5.1	(-12.7; 7.2)	0.29

3.2 Trends in EDD_{312} index component variables

The Effective Degree Day index is intended to be a broader measure of the impact of weather conditions on gas demand. As such, the index also includes sunshine hours and wind speed which have the potential to change over time, and may impact the EDD index. NIEIR finds there to be only small trends in these tertiary weather variables.

Table 3.2 contains the annual trends in these variables. The temperature related 312 variables are also included in the table for comparison. Note the EDD_{312} index is decreasing by approximately 7.6 EDDs per annum.

- $Temperature_{312}$ is presented as the annual degree average of the daily average temperatures. Annual average Temperature312 is increasing by 0.029 degrees per annum in Melbourne. This equates to a total trend increase of 1.3 degrees on the average temperatures over the year since 1970.
- The annual sum of Degree Day_{312} is decreasing by 7 HDDs per annum.
- The annual sum of $Wind_{312}$ is decreasing by 1.8 knots per annum. However, this has a high p-value, so the trend could be zero.
- Annual sunshine hours are increasing by 2.5 hours per annum.

With all else being equal, sunnier years contribute to the EDD warming trend by about 0.36 EDDs per annum. The reduction in Degree Day_{312} also feeds back through the wind chill factor for an additional contribution to the decrease in EDD_{312} of about 0.26 EDDs per annum (with wind evaluated at the mean). Summing the contributions of the temperature, wind chill and sunshine (-7.0, -0.26 and -0.36) gives the total trend reduction in the EDD_{312} index of 7.6 EDDs per annum.

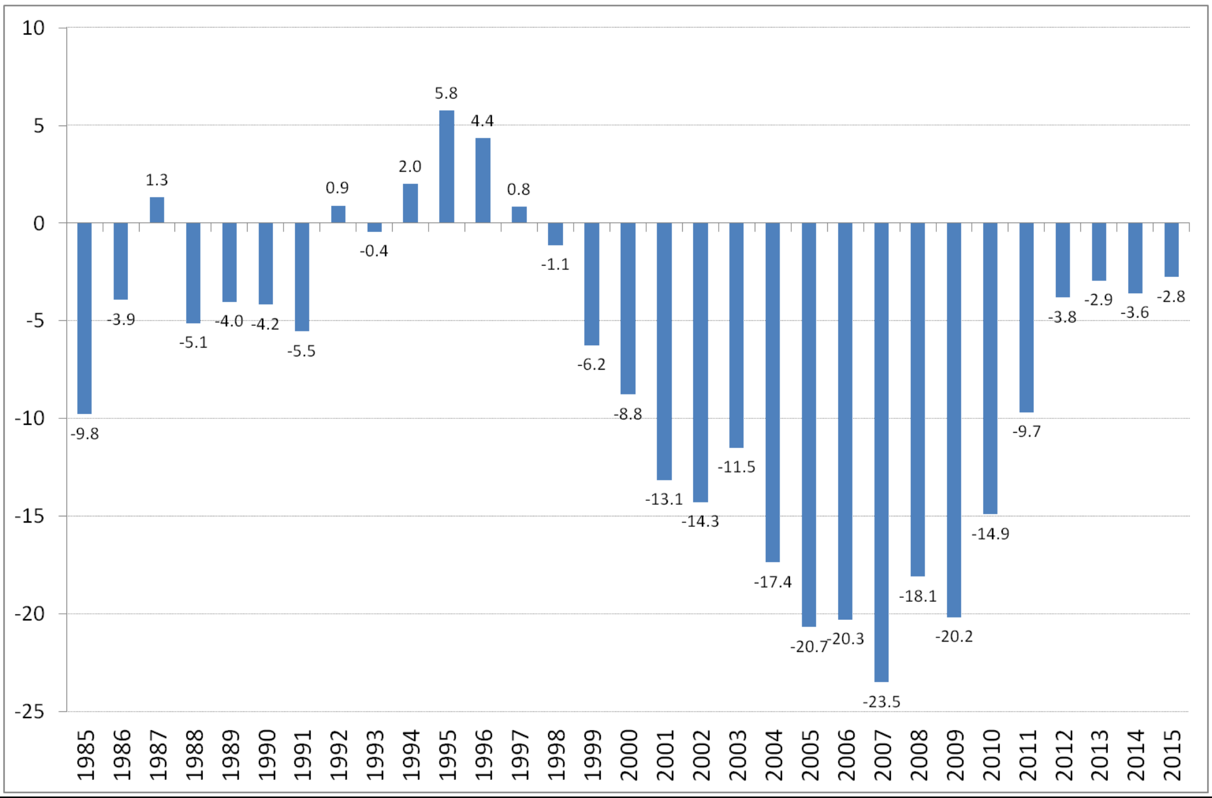
Table 3.2 Long-term trends in component variables of the EDD_{312} index 1970 to 2015

Variable	Units	Coefficient	Std. Dev	95% CI	p-value
Temperature 312	Degrees Celsius	0.029	0.004	(0.021; 0.037)	0.00
Degree Day 312	HDD	-7.0	1.0	(-8.9; -5)	0.00
Wind 312	Knots	-1.8	2.1	(-5.8; 2.3)	0.20
Sunshine Hours	Hours	2.5	1.3	(-0.1; 5.1)	0.03

3.3 Short-term versus long-term trends in EDD_{312}

Figure 3.2 demonstrates the volatility of climate trends over shorter time periods. Trends in climate change need to take a longer term approach to avoid making short sighted conclusions based on only recent historical data. Figure 3.2 shows 15 year linear trends for each year across 1985 to 2015. For example, the 2015 year is the coefficient on a linear trend over 2000 to 2015. Similarly, 2000 is the coefficient on a linear trend over 1985 to 2000.

Figure 3.2: Rolling 15 year linear trend 1985 to 2015 (EDD_{312} per annum)



It appears that over the past four years the warming trend present in the EDD index has slowed compared to the long-term trend. From 1970 to 2015 the long-term trend is a decrease of 7.6 EDD_{312} per annum. While over 2000 to 2015 is below the long-term trend with a decrease of only 2.8 EDD_{312} per annum. Caution should be used when using short-term trends to interpret long-term trends in climate change within the EDD_{312} index. If medium-term (15 years) trends were to be used in other years throughout history the following conclusions could be made at the minimum and maximum since 1985:

- in 1996 there would be global cooling, with a trend increase of 5.8 EDD_{312} per annum; and
- in 2007, at the height of a period of drought in Melbourne, there is a trend decrease of 23.5 EDD_{312} per annum;

In addition, from 1985 to 2015 there appears to be medium-term climate cycles that would distort trend analysis over shorter time periods. There are periods (approximately 10 years to 15 years) of warming broken up by shorter periods of cooling, or lesser warming in between these cycles. An analysis on Heating Degree Days over 158 years of weather data from Melbourne Regional Office shows a similar cycling pattern (Figure A.1 in Appendix A). However, prior to World War II the cycles of warming periods and cooling periods were relatively balanced. Subsequent to World War II, the periods of warming are longer and stronger, while the periods of cooling have grown shorter or turned into periods of minor warming instead. Based on these cycles, Melbourne could be within a period of minor warming before a continuation of stronger warming conditions.

3.4 The long-term trend projections for annual EDD standards

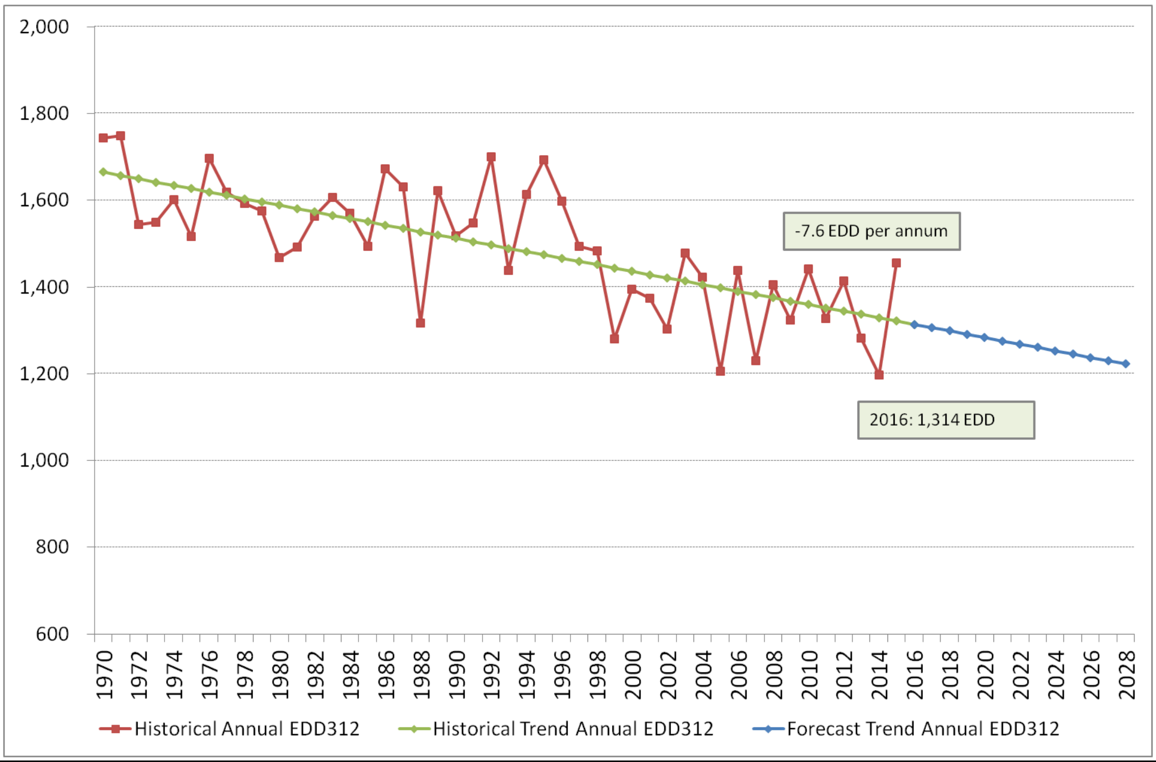
The long-term trend projections for the annual EDD standards involve the following stages:

- establishing the historical time series for annual EDDs;
- deriving the linear trend using regression analysis through calendar and financial years 1970 to 2015; and
- forecasting annual EDD standards from the historical linear trend over 2016 to 2026.

The warming trend is derived from the coefficient on the time variable of the linear regression.

Figure 3.3 shows the historical annual EDD_{312} and the results of the historical and forecast trend annual EDD_{312}. This demonstrates that 2015 was a cooler year than average, with 136 EDD_{312} in excess of the 2015 standard. While the actual EDDs in 2014 were 132 EDD_{312} below the long-term standard, which indicates a warmer year than average. The first year of projections has an EDD_{312} standard of 1,314 EDD_{312}. Each subsequent year represents a reduction in the EDD_{312} standard by 7.6 EDD_{312} per annum.

Figure 3.3: Long-term trend analysis of annual EDD_{312} weather standards



The long-term trends were also calculated for alternative EDD indices as shown in Table 3.3. The warming trend within each of these standards is similar at around -7.6 EDDs per annum. The annual standard levels differ depending on the index parameters and composition.

Table 3.3	Long-term trend annual standard projections in alternative EDD indices							
	Equation Parameters			Annual Standards				
EDD Index	Coefficient	Std. Dev	95% CI	2015	2016	2017	2018	2019
EDD_{312} (2012)	-7.62	1.14	(-9.85; -5.4)	1,322	1,314	1,306	1,299	1,291
EDD_{312} (2009)	-7.65	1.14	(-9.89; -5.41)	1,291	1,284	1,276	1,268	1,261
EDD_{66}	-7.59	1.12	(-9.78; -5.4)	1,303	1,296	1,288	1,280	1,273
EDD_{129}	-7.63	1.14	(-9.87; -5.39)	1,287	1,280	1,272	1,265	1,257

3.5 The MAT9 projections for annual EDD standards

The MAT9 method for calculating weather standards was first introduced into an EDD review by VENCorp in 2006 and has been presented in subsequent reviews by AEMO and VENCorp in 2009 and 2012.

MAT9 is an alternative method for establishing the first forecast year annual weather standards by taking the moving average of the nine most recent years of data, and adding four years of warming trend.

The difference between the long-term projection method and the MAT9 method is that the MAT9 method places a greater emphasis on recent years in creating the first year standard. While the first projection year in the Long-term projection method is a continuation of the long-term trend. MAT9 was formulated as a means to capture both medium-term and long-term climate variations.

Figure 3.4 shows the MAT9 projections. The historical trend is derived by subtracting the warming trend from the first forecast year (2016). The 2016 MAT9 annual standard is 1,311 EDD_{312}.

Figure 3.4: MAT9 analysis of annual EDD weather standards

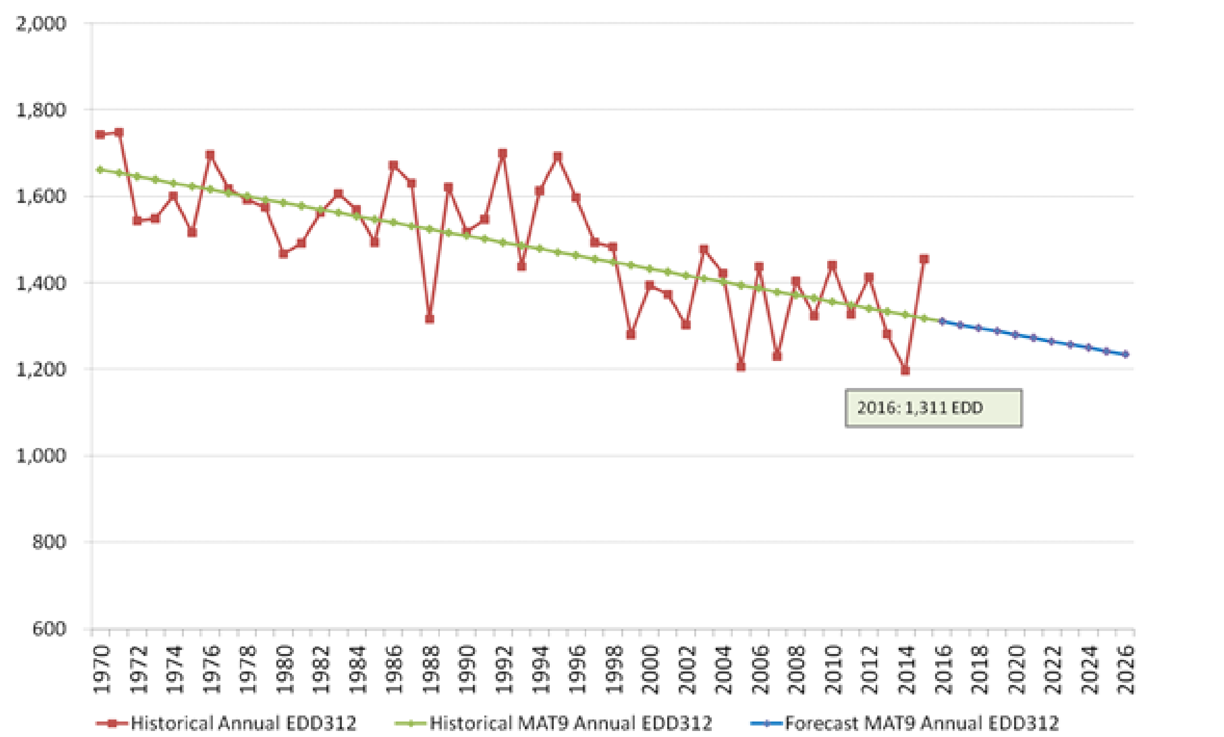


Table 3.4 contains the 2015 historical annual standard for MAT9 and short-term projections of the annual EDD standards for alternative specifications of EDD indices. The coefficients used for the warming trend projections are the same as contained in Table 3.3.

Table 3.4 MAT9 annual standards for alternative EDD indices

	2015	2016	2017	2018	2019
EDD_{312} (2012)	1,319	1,311	1,304	1,296	1,288
EDD_{312} (2009)	1,290	1,282	1,274	1,267	1,259
EDD_{66}	1,303	1,295	1,288	1,280	1,273
EDD_{129}	1,286	1,279	1,271	1,264	1,256

3.6 Summary of projected annual EDD standards

Table 3.5 contains a summary of the annual weather standards out to 2026. The long-term trend and MAT9 methodologies are summarised by calendar and financial years.

The difference between the long-term trend method and the MAT9 method for annual EDD standards is minimal on a calendar year basis. In 2016 the Long-term Trend produces a first year forecast standard of 1,314 EDD, compared to 1,311 in the MAT9 method (a constant difference of 2.73 EDD per annum over each year). There is a slightly larger financial year difference between the long-term trend method and the MAT9 method. This is a margin of 10.32 EDDs for each year. **Based on the discussion and analysis above, NIEIR recommends that the long-term trend method be used for Victorian gas forecasting. This implies an annual reduction EDD standard of 7.6 EDD's per annum.**

Table 3.5 Summary of projected annual EDD_{312} standards 2016 to 2026

	Calendar Year (1970 to 2015)			Financial Year (1970-71 to 2014-15)		
Year	Long-term trend	MAT9	Difference	Long-term trend	MAT9	Difference
2016	1,314	1,311	2.73	1,315	1,305	10.32
2017	1,306	1,304	2.73	1,307	1,297	10.32
2018	1,299	1,296	2.73	1,300	1,289	10.32
2019	1,291	1,288	2.73	1,292	1,282	10.32
2020	1,284	1,281	2.73	1,284	1,274	10.32
2021	1,276	1,273	2.73	1,276	1,266	10.32
2022	1,268	1,266	2.73	1,269	1,258	10.32
2023	1,261	1,258	2.73	1,261	1,251	10.32
2024	1,253	1,250	2.73	1,253	1,243	10.32
2025	1,245	1,243	2.73	1,246	1,235	10.32
2026	1,238	1,235	2.73	1,238	1,227	10.32

4. Review of Peak Day EDD standards

This section reviews Peak Day standards and includes:

- a long-term and short-term review of warming trends in the coldest days of the year;
- the development of 1-in-2 Peak Day standards using the long-term trend and MAT9 methodologies; and
- the development of 1-in-20 Peak Day standards by using standard deviations from the 1-in2 standards.

While the Peak Day for gas demand may not always occur on the coldest EDD day of the year (e.g. the coldest day may occur on a weekend or public holiday), the Peak Day for gas demand is temperature driven and often does occur on the coldest EDD day. Hence throughout this section the coldest EDD day is used as a close proxy to the EDD on the Peak Day for gas demand. Standards are developed on this basis.

4.1 Warming trend in the Peak Day EDD Index

Weather standards for peak day can be more difficult to analyse than annual weather standards. Annual standards draw data from every day of the year, whereas peak day by definition is only observed once every year. This can lead to a more volatile time series of weather.

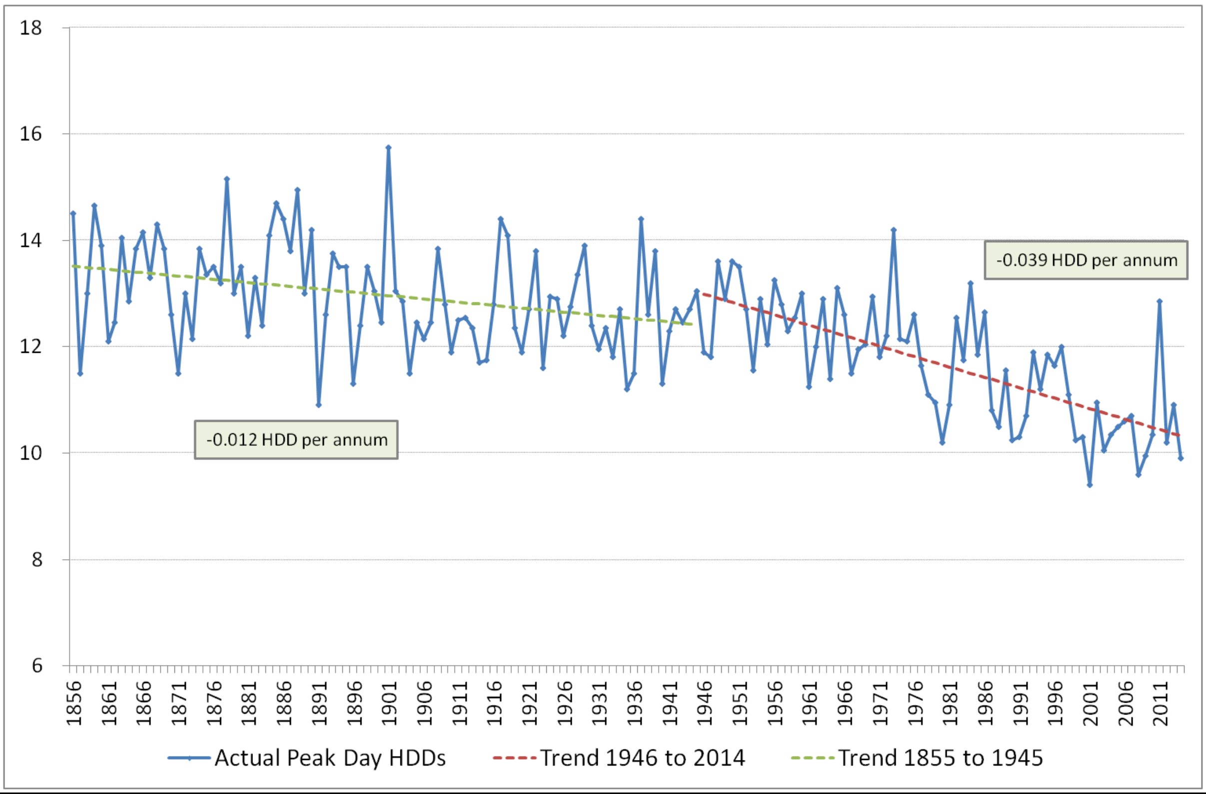
Warming trends around the globe are often expressed in terms of trends upon the average temperatures; these inherently include distributional information (min, max) across the days. Peak Day for gas demand occurs during the coldest periods during the year, and often on the coldest day of the year. Therefore trends in the minimum temperatures have a greater importance than the average temperatures, or in degree day indices, the minimum average temperature of the year.

Figure 4.1 shows the coldest HDD days since 1855 as measured at Melbourne Regional Office. Over 1856 to the mid-1940's there was only a minor (non-significant) warming trend of a decrease to the coldest HDDs of -0.012 per annum. Post World War II, the warming trend in coldest HDD day has accelerated with an annual decrease of 0.039 HDD per annum.

Table 4.1 shows the warming trends in Peak Day EDD_{312} standards over the past 45 years. The 1970 to 2015 tend reduction in EDD_{312} has been -0.048 EDD per annum. This coefficient has remained relatively stable for the spans listed from 1970 to more recent years (2014, 2011, and 2004). However, this represents a greater warming trend than found in the long-term trend in HDDs since 1946 (-0.039 vs. -0.048). Assuming the trends in sunshine and wind have had a negligible impact on Peak Day trends, the 1970 to 2015 trend is stronger by 0.09 per annum.

For comparison, the HDD trend taken over 1970 to 2014 is found to be -0.049 HDDs per annum. This is similar to the trend reductions found in EDD_{312} Peak Day. This may indicate a strengthening of the warming trend in the coldest temperatures over more recent years.

Figure 4.1: Melbourne Regional Office 1855 to 2014 – Peak Day HDDs per annum



Linear trends for shorter time periods during the past 45 years are found to be more volatile. In Table 4.1, 15 year trends range between -0.005 and -0.012. The 30 year trend from 1970 to 2000 is about half that of the 45 year trend.

Table 4.1 Peak Day EDD_{312} long-term trend statistics over selected spans

Years	Coefficient (EDD_{312} per annum)	Std. Dev	95% Confidence Interval	p-value
1970 to 2015	-0.048	0.013	(-0.073; -0.022)	0.000
1970 to 2014	-0.048	0.014	(-0.075; -0.022)	0.000
1970 to 2011	-0.049	0.014	(-0.076; -0.022)	0.000
1970 to 2004	-0.049	0.021	(-0.09; -0.008)	0.013
1970 to 2000	-0.024	0.026	(-0.074; 0.026)	0.180
1970 to 1985	-0.010	0.055	(-0.119; 0.099)	0.428
1985 to 2000	-0.005	0.085	(-0.172; 0.162)	0.478
2000 to 2015	-0.012	0.050	(-0.111; 0.087)	0.406

4.2 The long-term trend projections for Peak Day EDD standards

Peak Day EDD_{312} standards for the 1-in-2 Peak Day are developed by using the long-term trend method. This involves:

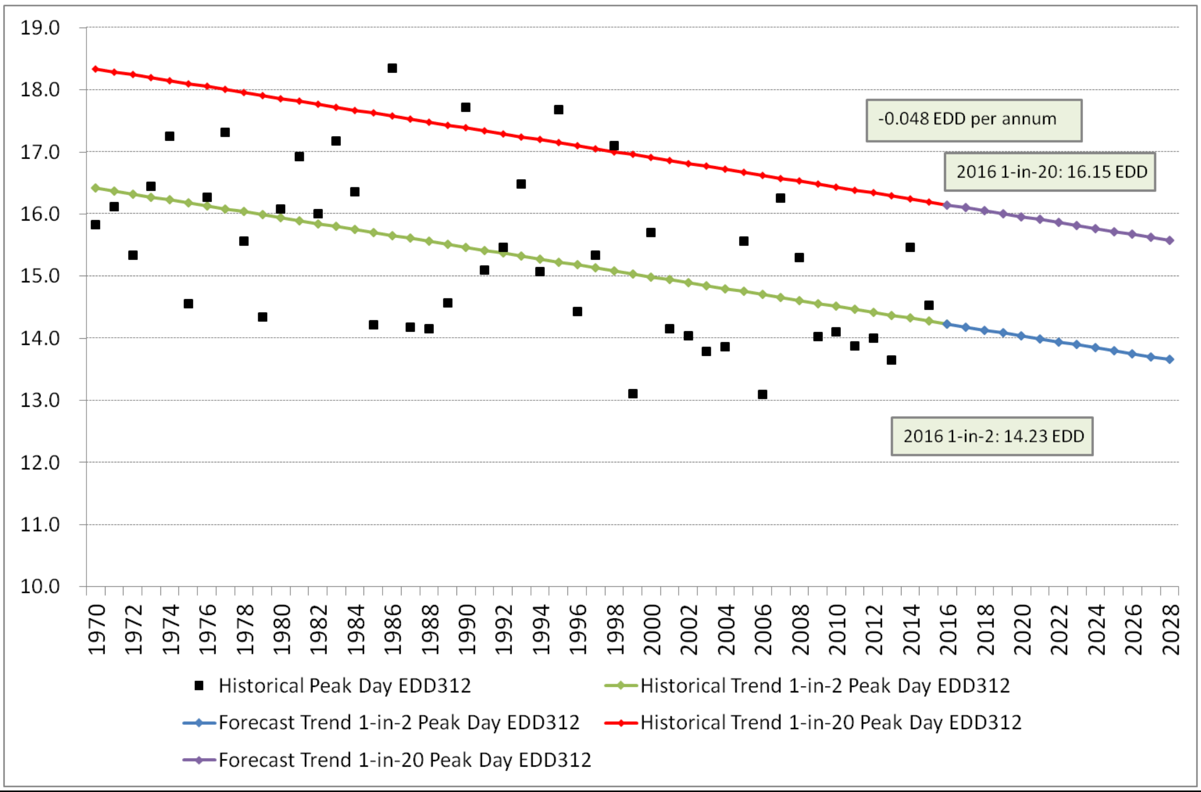
- selecting the maximum EDD_{312} actual value for each year since 1970 (coldest day of the year);
- deriving a linear trend from 1970 to 2015 using regression techniques on the historical time series; and
- forecasting 1-in-2 Peak Day standards by extrapolating the linear trend over 2016 to 2026.

Peak Day EDD_{312} standards for the 1-in-20 Peak Day are developed by using the long-term trend method by:

- taking the results of the 1-in-2 Peak Day standards;
- deriving the standard deviation of the historical differences between the actual value and the 1-in-2 Peak Day standards; and
- estimating the 1-in-20 Peak Day standards by adding 1.645 times the standard deviation to the 1-in-2 Peak Day standards. This will give the 95% percentile value on the standard normal distribution (5 per cent of values exceed this level, or 1-in-20).

Figure 4.2 gives the results of the long-term trend projections. The historical peaks are displayed alongside the historical and projected 1-in-2 and 1-in-20 Peak Day standards.

Figure 4.2: Long-term trend analysis of Peak Day EDD_{312} weather standards



A good fit for the Peak Day standards would provide the following characteristics on the historical data:

- 1-in-2 (or 50 per cent) of historical EDDs will exceed the 1-in-2 standard, and therefore 50 per cent will not exceed the 1-in-2 standard; and

- 1-in-20 (or 5 per cent) of historical EDDs will exceed the 1-in-20 standard, and therefore 95 per cent will not exceed the 1-in-20 standard.

The long-term projections provide 22 data points (47.8 per cent) exceeding the 1-in-2 and 4 (8.7 per cent) exceeding the 1-in-20 standards. This shows that there have been some exceptional cold peak days over the past 45 years, more than would be expected.

Table 4.2 and 4.3 summarise the long-term trend method projections for 1-in-2 and 1-in-20 annual peak day standards for alternative EDD indices.

Table 4.2 Long-term trends (1970 to 2015) in 1-in-2 Peak Day standards for alternative EDD indices

	Equation Parameters			1-in-2 Peak Day Standards				
EDD Index	Coefficient	Std. Dev	95% CI	2015	2016	2017	2018	2019
EDD_{312} (2012)	-0.048	0.013	(-0.073; -0.022)	14.28	14.23	14.18	14.13	14.09
EDD_{312} (2009)	-0.048	0.014	(-0.075; -0.022)	14.21	14.16	14.11	14.07	14.02
EDD_{66}	-0.039	0.013	(-0.064; -0.014)	14.45	14.41	14.37	14.33	14.29
EDD_{129}	-0.049	0.013	(-0.075; -0.023)	14.12	14.07	14.02	13.97	13.93

Table 4.3 Long-term trends (1970 to 2015) in 1-in-20 Peak Day standards for alternative EDD indices

	2015	2016	2017	2018	2019
EDD_{312} (2012)	16.20	16.15	16.10	16.05	16.01
EDD_{312} (2009)	16.20	16.15	16.10	16.05	16.00
EDD_{66}	16.32	16.28	16.24	16.21	16.17
EDD_{129}	16.06	16.01	15.96	15.91	15.86

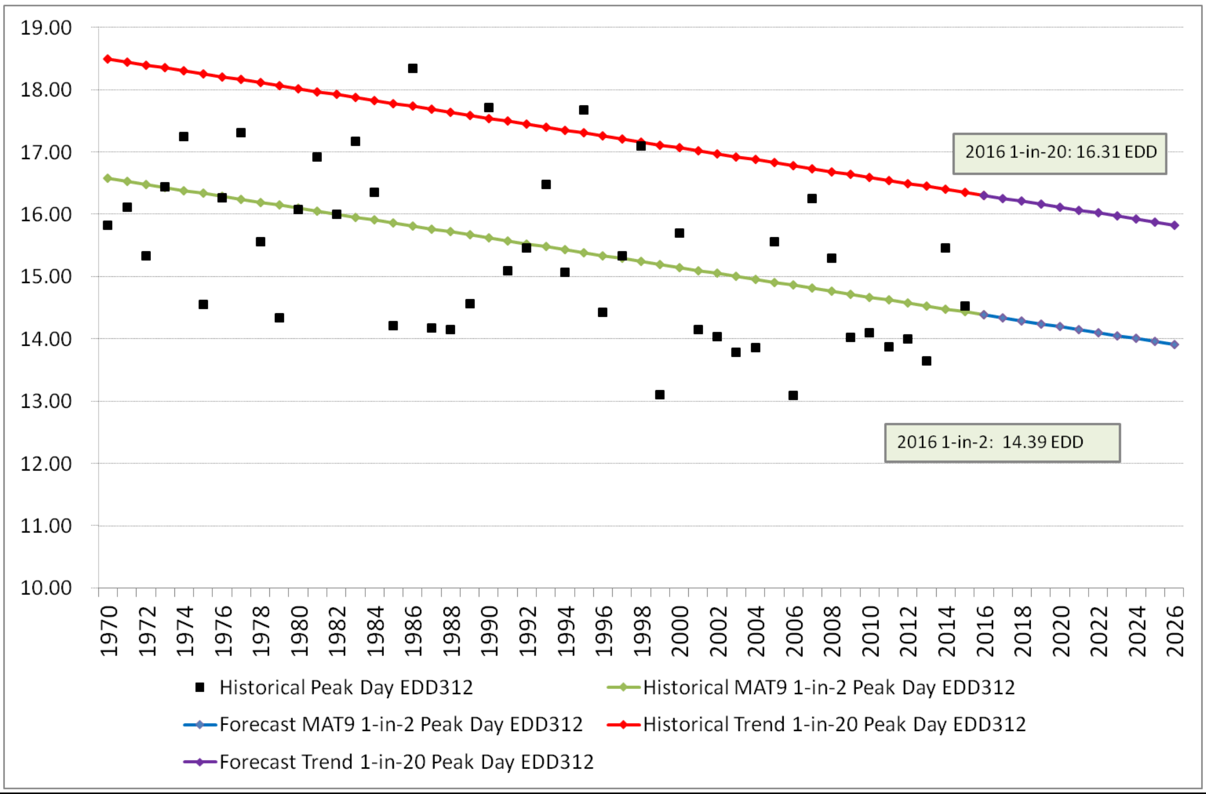
4.3 The MAT9 projections for Peak Day EDD standards

The MAT9 projections for Peak Day EDD standards involve the following steps:

- establish the first year forecasting by taking the moving average of the 9 most recent years and adding four years of warming trend; and
- estimate historical and forecast standards by extrapolating the warming trend backwards and forwards.

Figure 4.3 shows the actual peak day EDDs alongside the historical and projected 1-in-2 and 1-in-20 Peak Day standards. In 2016 these standards are 14.39 for the 1-in-2 standard and 16.31 for the 1-in-20 standard.

Figure 4.3: MAT9 analysis of Peak Day EDD_{312} weather standards



Tables 4.4 and 4.5 summarise the MAT9 method projections for 1-in-2 and 1-in-20 annual peak day standards for alternative EDD indices.

Table 4.4	MAT9 (1970 to 2015) in 1-in-2 Peak Day standards for alternative EDD indices				
	2015	2016	2017	2018	2019
EDD_{312} (2012)	14.44	14.39	14.34	14.30	14.25
EDD_{312} (2009)	14.40	14.35	14.30	14.25	14.20
EDD_{66}	14.69	14.65	14.62	14.58	14.54
EDD_{129}	14.35	14.30	14.25	14.20	14.16

Table 4.5	MAT9 (1970 to 2015) in 1-in-20 Peak Day standards for alternative EDD indices				
	2015	2016	2017	2018	2019
EDD_{312} (2012)	16.36	16.31	16.26	16.22	16.17
EDD_{312} (2009)	16.38	16.33	16.29	16.24	16.19
EDD_{66}	16.56	16.53	16.49	16.45	16.41
EDD_{129}	16.29	16.24	16.19	16.14	16.09

4.4 Summary of projected Peak Day EDD standards

Table 4.6 summarises the 1-in-2 and 1-in-20 Peak Day Standards for the alternative methodologies. There is a small difference of -0.16 between the two approaches for EDD_{312}. **Based on the discussion and analysis above, NIEIR recommends that the long-term trend method be used for Victorian gas forecasting. This implies an annual reduction EDD peak day standard of 0.05 EDD's per annum.**

Table 4.6 Summary of projected annual EDD_{312} standards 2016 to 2026

Year	1-in-2 Peak Day EDD_{312}			1-in-20 Peak Day EDD_{312}		
	Long-term trend	MAT9	Difference	Long-term trend	MAT9	Difference
2016	14.23	14.39	-0.16	16.15	16.31	-0.16
2017	14.18	14.34	-0.16	16.10	16.26	-0.16
2018	14.13	14.30	-0.16	16.05	16.22	-0.16
2019	14.09	14.25	-0.16	16.01	16.17	-0.16
2020	14.04	14.20	-0.16	15.96	16.12	-0.16
2021	13.99	14.15	-0.16	15.91	16.07	-0.16
2022	13.94	14.11	-0.16	15.86	16.03	-0.16
2023	13.90	14.06	-0.16	15.82	15.98	-0.16
2024	13.85	14.01	-0.16	15.77	15.93	-0.16
2025	13.80	13.96	-0.16	15.72	15.88	-0.16
2026	13.75	13.91	-0.16	15.67	15.83	-0.16

5. Monthly EDD standards

NIEIR has also developed monthly weather standards for Victorian gas demand forecasting. These are developed in a similar manner to the annual EDD_{312} standards and the Peak Day EDD_{312} standards, except the time period has been restricted to the month, rather than year.

5.1 Monthly energy EDD_{312} standards

Monthly EDD_{312} standards for gas consumption have been developed using two allocation methods.

- an average monthly distribution (1970 to 2015) is used to allocate the annual long-term trend results; and
- long-term trends are estimated for each individual month and trends are applied to the forecasts.

Using a monthly profile based on the long-term average monthly distribution to allocate the annual long-term trend EDD_{312} standards implies that each of the months will have the same proportional warming trend as each other. This means that the warming trend is the same (in percentage terms) for each month across each year.

When the long-term projection method is performed on individual months, there is less of a warming trend during the winter months. When monthly energy EDD standards are distributed via long-term monthly profiles, the warming trend is disproportionately assigned to the winter months. The long-term trend method on individual months shows that the shoulder months have the strongest signs of warming.

Table 5.1 summarises the EDD_{312} standards using the average monthly profiles, and Table 5.2 summarises the individual month long-term trend results.

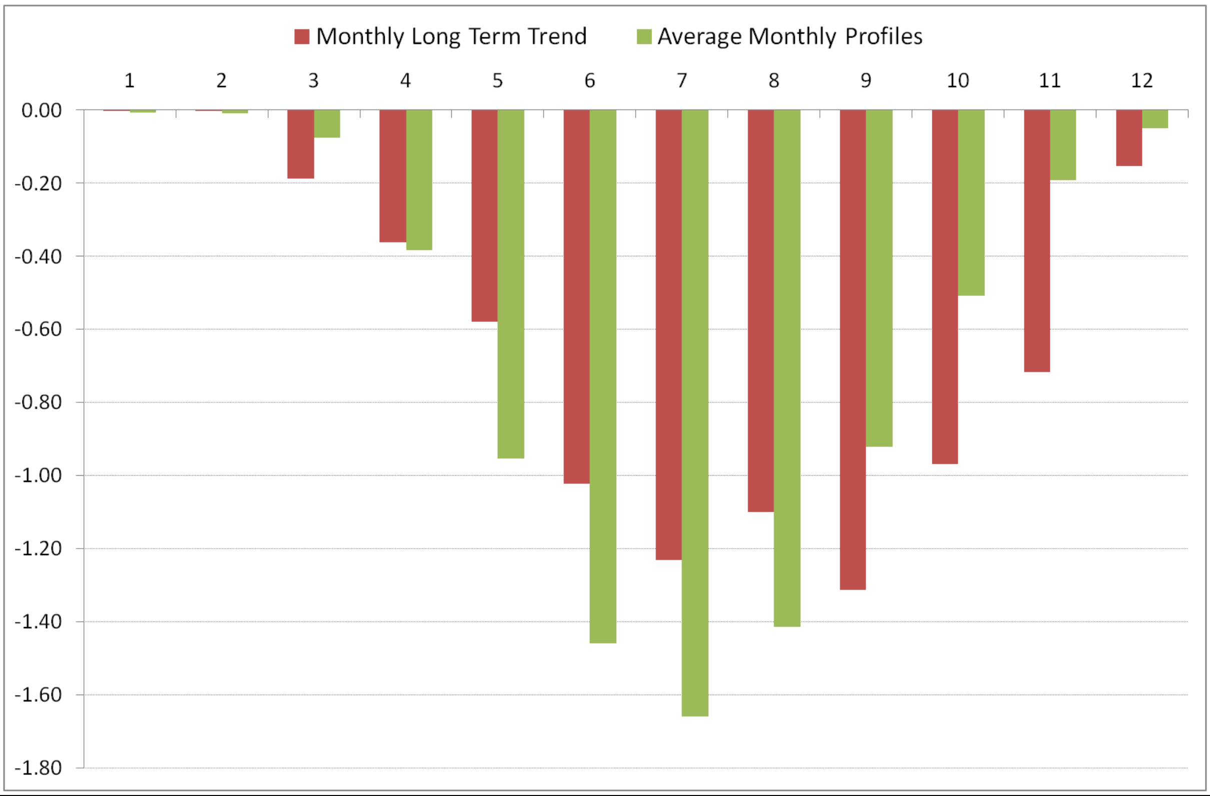
Table 5.1 Monthly energy EDD_{312} standards using average monthly profiles (1970 to 2015)

Year	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
2016	1.3	1.6	13.0	66.1	164.2	251.2	285.7	243.6	158.5	87.4	33.1	8.4
2017	1.3	1.6	12.9	65.7	163.2	249.7	284.0	242.2	157.6	86.9	32.9	8.3
2018	1.3	1.6	12.8	65.4	162.3	248.3	282.4	240.8	156.7	86.4	32.7	8.3
2019	1.3	1.6	12.7	65.0	161.3	246.8	280.7	239.4	155.7	85.9	32.5	8.2
2020	1.3	1.6	12.7	64.6	160.4	245.4	279.1	237.9	154.8	85.3	32.3	8.2
2021	1.3	1.6	12.6	64.2	159.4	243.9	277.4	236.5	153.9	84.8	32.1	8.1
2022	1.3	1.5	12.5	63.8	158.5	242.5	275.7	235.1	153.0	84.3	31.9	8.1
2023	1.3	1.5	12.4	63.4	157.5	241.0	274.1	233.7	152.1	83.8	31.7	8.1
2024	1.3	1.5	12.4	63.1	156.6	239.5	272.4	232.3	151.1	83.3	31.6	8.0
2025	1.2	1.5	12.3	62.7	155.6	238.1	270.8	230.9	150.2	82.8	31.4	8.0
2026	1.2	1.5	12.2	62.3	154.7	236.6	269.1	229.5	149.3	82.3	31.2	7.9

Table 5.2	Monthly energy EDD_{312} standards using the long-term trend method											
	Month											
Year	1	2	3	4	5	6	7	8	9	10	11	12
2016	1.6	1.8	10.4	67.2	172.8	260.0	294.6	250.4	150.3	77.3	21.4	6.2
2017	1.6	1.8	10.3	66.9	172.2	259.0	293.4	249.3	149.0	76.3	20.7	6.0
2018	1.6	1.8	10.1	66.5	171.6	258.0	292.2	248.2	147.6	75.4	20.0	5.9
2019	1.6	1.8	9.9	66.1	171.1	256.9	290.9	247.1	146.3	74.4	19.3	5.7
2020	1.6	1.8	9.7	65.8	170.5	255.9	289.7	246.0	145.0	73.4	18.6	5.6
2021	1.6	1.8	9.5	65.4	169.9	254.9	288.5	244.9	143.7	72.5	17.9	5.4
2022	1.6	1.8	9.3	65.0	169.3	253.9	287.3	243.8	142.4	71.5	17.1	5.3
2023	1.6	1.8	9.1	64.7	168.7	252.8	286.0	242.7	141.1	70.5	16.4	5.1
2024	1.6	1.8	8.9	64.3	168.2	251.8	284.8	241.6	139.8	69.6	15.7	5.0
2025	1.6	1.8	8.8	64.0	167.6	250.8	283.6	240.5	138.5	68.6	15.0	4.8
2026	1.6	1.8	8.6	63.6	167.0	249.8	282.3	239.4	137.2	67.6	14.3	4.7

Figure 5.1 presents the warming trends for each month implied from both methods. The monthly Long-term trend method shows greater warming across September to November. The warming trend is 0.4 to 0.5 greater over these months than implied by the average monthly profiles. During the winter months, June to August, the warming trend in the monthly long-term trend method is 0.3 to 0.45 less than the average monthly profile method.

Figure 5.1: Implied warming trend (EDD per year) for alternative monthly methods



5.2 Monthly Peak Day EDD_{312}

The monthly Peak Day standards are developed using long-term trends by month using a similar methodology set out in Section 4.2. To remain consistent with AEMO, June to September is set to the annual Peak Day which represents an equal probability that Peak Day could occur within any of these months.

As expected the strongest EDD peaks occur during the winter months and are minimised in the months closer to summer.

Table 5.3 presents the 1-in-2 monthly Peak Day standards, and Table 5.4 presents the monthly 1-in-20 Peak Day standards.

Table 5.3 Monthly 1-in-2 Peak Day EDD_{312} standards

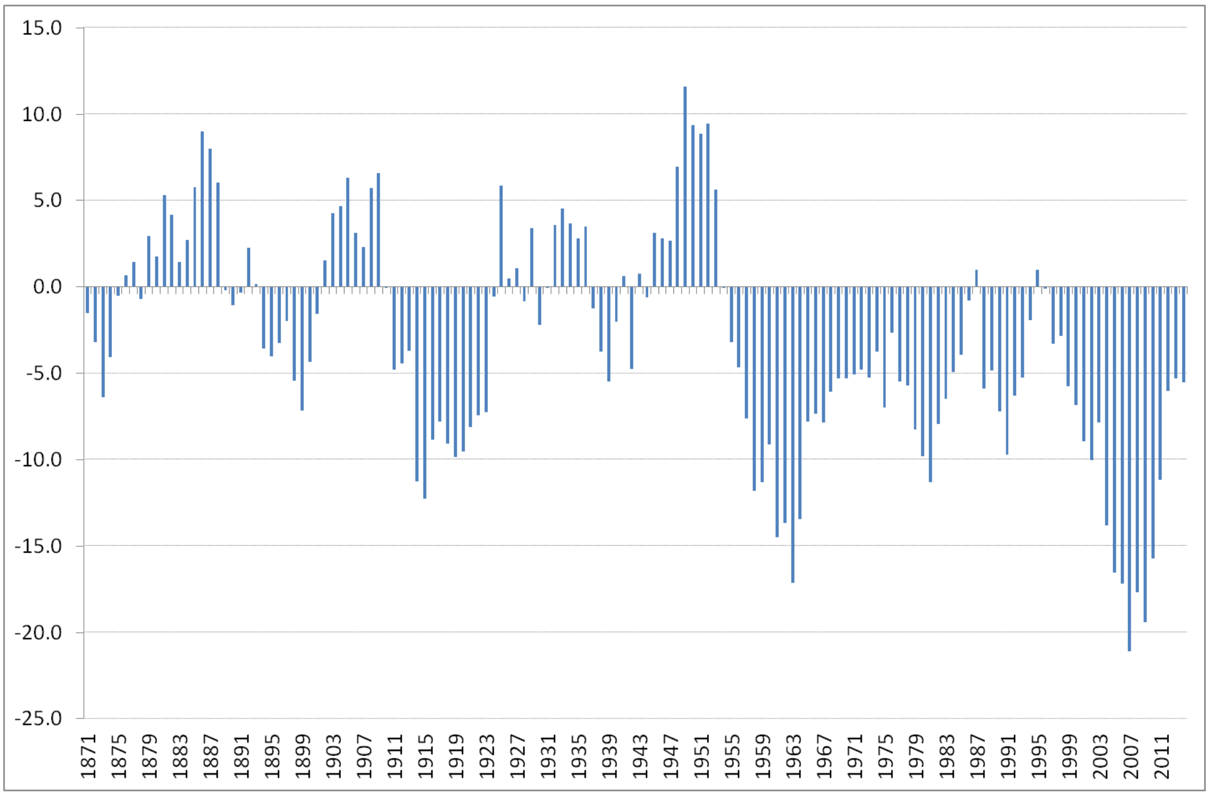
	Month											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2016	0.48	0.70	2.97	6.32	10.00	14.23	14.23	14.23	14.23	7.63	5.02	2.79
2017	0.46	0.69	2.95	6.28	9.97	14.18	14.18	14.18	14.18	7.59	4.98	2.79
2018	0.44	0.68	2.94	6.24	9.93	14.13	14.13	14.13	14.13	7.54	4.94	2.78
2019	0.42	0.66	2.92	6.20	9.90	14.09	14.09	14.09	14.09	7.49	4.90	2.78
2020	0.41	0.65	2.90	6.16	9.87	14.04	14.04	14.04	14.04	7.45	4.86	2.77
2021	0.39	0.64	2.88	6.12	9.83	13.99	13.99	13.99	13.99	7.40	4.83	2.76
2022	0.37	0.63	2.86	6.08	9.80	13.94	13.94	13.94	13.94	7.36	4.79	2.76
2023	0.36	0.61	2.85	6.04	9.77	13.90	13.90	13.90	13.90	7.31	4.75	2.75
2024	0.34	0.60	2.83	6.00	9.73	13.85	13.85	13.85	13.85	7.27	4.71	2.75
2025	0.32	0.59	2.81	5.96	9.70	13.80	13.80	13.80	13.80	7.22	4.67	2.74
2026	0.30	0.57	2.79	5.92	9.67	13.75	13.75	13.75	13.75	7.18	4.63	2.74

Table 5.4 Monthly 1-in-20 Peak Day EDD_{312} standards

	Month											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2016	1.94	3.06	5.87	9.28	13.02	16.15	16.15	16.15	16.15	10.39	7.98	5.62
2017	1.92	3.05	5.85	9.24	12.99	16.10	16.10	16.10	16.10	10.34	7.94	5.61
2018	1.91	3.03	5.83	9.20	12.95	16.05	16.05	16.05	16.05	10.29	7.90	5.61
2019	1.89	3.02	5.81	9.16	12.92	16.01	16.01	16.01	16.01	10.25	7.86	5.60
2020	1.87	3.01	5.79	9.12	12.89	15.96	15.96	15.96	15.96	10.20	7.83	5.60
2021	1.85	2.99	5.78	9.08	12.85	15.91	15.91	15.91	15.91	10.16	7.79	5.59
2022	1.84	2.98	5.76	9.04	12.82	15.86	15.86	15.86	15.86	10.11	7.75	5.59
2023	1.82	2.97	5.74	9.00	12.79	15.82	15.82	15.82	15.82	10.07	7.71	5.58
2024	1.80	2.95	5.72	8.96	12.75	15.77	15.77	15.77	15.77	10.02	7.67	5.58
2025	1.78	2.94	5.70	8.92	12.72	15.72	15.72	15.72	15.72	9.97	7.63	5.57
2026	1.77	2.93	5.68	8.88	12.69	15.67	15.67	15.67	15.67	9.93	7.59	5.56

Appendix A: Additional figures and tables

Figure A.1: Melbourne Regional Office rolling 15 year linear trend 1856 to 2014 (HDD per annum)



Appendix B: Adjustments to Melbourne weather station

From 1855 until 5th January 2015 the Melbourne Regional Office weather station served as Melbourne's official weather station. This was located within the Melbourne CBD near the intersection of La Trobe Street and Victoria Parade. The new Melbourne Olympic Park weather station opened in June 2013 to allow a period of overlap to adjust for any bias between the old and new weather stations. By comparison, the Olympic Park weather station is located near the sporting precinct south of Melbourne and the Yarra River, a much less urbanised environment. Olympic Park became the official weather station on 6th January 2015.

Due to the change in location a correction has to be made for these temperature series to remain consistent. NIEIR has elected to apply a monthly correction to the temperature component of the EDD index, rather than an annual adjustment. This maintains the seasonal and monthly variation within the year.

The correction parameters are found over each month by finding the value that minimises the sum of the absolute differences between the actual recordings at Olympic Park and Regional Office for a given month. This analysis was performed over minimum, maximum and average temperatures on an annual, seasonal and monthly basis. The correction parameters for this study were performed on the $Temperature_{312}$ variable from the EDD_{312} index, which is the average temperature of 3 hourly intervals between 3am and 12am the following day.

In the National Gas Forecasting Report (AEMO, 2015) an annual adjustment of 1.028 (2.8 per cent bias) is applied to temperature. NIEIR finds a similar adjustment of 1.0263 (2.63 per cent bias) is required if applied on an annual basis.

However, significant variation is found between the months. The variation between the Regional Office and Olympic Park weather stations is stronger during summer when temperatures are higher, and minimised during winter when temperatures are lower. This is partly explained by urban warming effects, as urban surfaces retain more heat than non-urban surfaces[2].

An annual correction may bias the temperature component of the EDD index by over correcting during winter, and less importantly for the EDD, under correcting during summer.

An overcorrection during winter will reduce the number of EDDs and marginally increase the warming trend in EDDs.

The annual and monthly correction parameters are summarised in Figure B.1. As 6 months are only observed once during the overlap period, monthly estimates are subject to more volatility. On this basis, NIEIR has applied a polynomial function to smooth out the monthly parameters.

The function was then applied at a daily level to provide the final adjustments to Olympic Park. Daily parameters were allocated with the monthly polynomial function, however, part of November, December and January were held fixed at 1.035 given differences should peak over these months (Figure B.2), rather than fall.

[2] For example, see KK Guan (2011), Surface and ambient air temperatures associated with different ground material: a case study at the University of California, Berkeley.

Figure B.1: Monthly and annual weather correction coefficients from Regional Office to Olympic Park

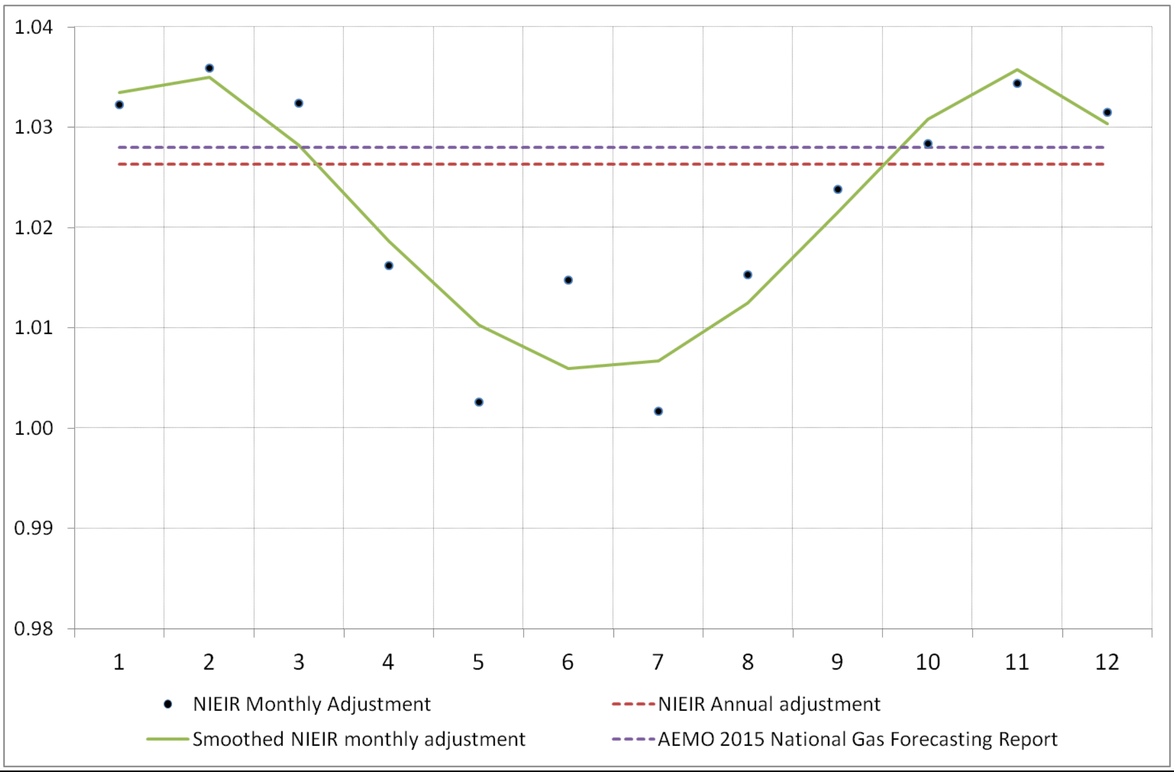
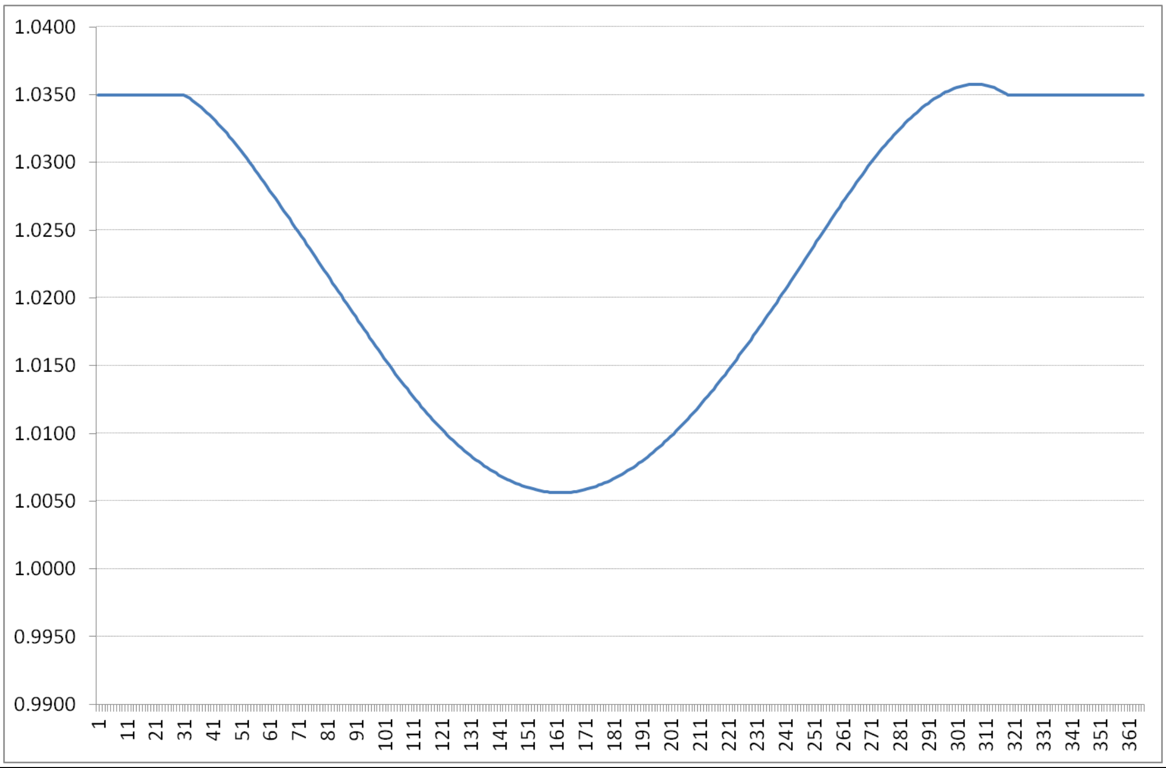


Figure B.2: Daily weather correction coefficients from Regional Office to Olympic Park



Appendix C: List of Abbreviations

Term	Definition
AEMO	Australian Energy Market Operator
BOM	Bureau of Meteorology
CDD	Cooling Degree Day
CI	Confidence Interval
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EDD	Effective Degree Day
HDD	Heating Degree Day
MAT9	9-year Moving Average
NGFR	National Gas Forecasting Report
NIEIR	National Institute of Economic and Industry Research
Std. Dev	Standard Deviation
VENCorp	Victorian Energy Networks Association

Appendix D: About NIEIR

The National Institute of Economic and Industry Research was founded in 1984 as a private economic research and consulting group. With around 30 years applied economic and consultancy work behind it, NIEIR has built up a considerable body of intellectual capital. NIEIR has a long history of energy forecasting and energy policy analysis spanning its entire history. In the 1980s and early 1990s, NIEIR prepared economic and energy projections for consolidated state-owned energy utilities. In line with the restructuring of the Australian energy supply industry, NIEIR's client base changed. Today, NIEIR has a client base that includes:

- energy retailers;
- distribution and transmission network businesses;
- industry planner and energy markets operators;
- government departments and agencies; and
- business and community groups.

NIEIR is the premier energy demand forecaster in Australia; NIEIR regularly prepares energy demand forecasts for:

- medium- and long-term network planning;
- budgeting and capital expenditure planning;
- regulatory price reviews, including new tariff designs (time-of-use, cost reflective);
- uptake of disruptive technologies such as plug-in electric vehicles, photovoltaic systems, and electricity storage systems;
- strategic and investment planning decisions;
- energy efficiency and climate change policy studies;
- in-house research and analysis; and
- due diligence process in asset acquisition process.

As part of these services, NIEIR prepares:

- energy forecasts;
- demand (peak-day issue or maximum daily/hourly quantity) forecasts; and
- customer number forecasts.

These metrics are disaggregated into various segments including:

- sectoral and industry classifications;
- geographical dimensions (including national, state, regional and sub-regional level);
- tariff and customer type; and
- technology type (hot water, space conditioning, etc.)

NIEIR also develops projections of national, state and local economic drivers underlying all of the energy and maximum demand models using NIEIR's proprietary suite of economic forecasting models. Energy price forecasts are developed from our own research on future developments in wholesale, network, retail and green scheme costs in both electricity and gas markets. We develop projections of other important indicator variables such as air conditioners sales and the take up of solar hot water systems using separate purpose-built models. We also model the impact of government energy efficiency, carbon reduction programs and new technologies on electricity and gas demands.