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Subject **Temperature correction – A Sensitivity Analysis**

Introduction

The aim of this study is to analyse different temperature correction methods used for instance in monitoring energy statistics and the National Energy Outlook (NEO). The corrections are based on degree-days methods with underlying assumptions. We are going to analyse the sensitivity of some of these assumptions, namely the base temperature and temperature measurement location. Thereafter, we will investigate the influence different temperature correction methods have on the natural gas consumption of households in the Netherlands.

What is temperature correction?

Temperature corrections a.k.a climatic corrections are used to normalize energy consumption for weather conditions (mainly the outside air temperature) on a periodical time scale, for example weekly, monthly or annually. Weather normalization makes it possible to compare the energy consumption in different periods on an equal basis and to see if improvements in energy efficiency have been made. Temperature corrections are used to normalize the heat consumption for space heating and the electricity consumption for space cooling. A temperature-correction is also used on the heat supply o low temperature heat distribution networks (e.g. district heating). Temperature corrections are relevant in energy statistics and energy scenarios of households, the tertiary sector (non-residential) and the agricultural sector.

How is it calculated?

Temperature corrections are based on degree-days methods. There are **heating and cooling degree-days**. Heating degree-days provide a measure of how much (in degrees), and for how long (in days), the outside air temperature was below a chosen base temperature. For example: For a given day at a certain location the average temperature determined from measurements is 14 degrees Celsius and the base temperature is 18 degrees Celsius, then there are 4 heating degree-days. Vice versa, cooling degree-days provide a measure of how much (in degrees), and for how long (in days), the outside air temperature was above a chosen base temperature. The chosen base temperature indicates the temperature at which heating or cooling starts. The base temperature for heating and cooling do not necessarily have to be the same.

For any chosen time interval degree-days or fractions of it can be calculated with:

$$Heating\ degree\ days\ =\ base\ temperature\ heating -\ measured\ outside\ air\ temperature$$

$$Cooling\ degree\ days\ =\ measured\ outside\ air\ temperature - \ base\ temperature\ cooling$$

Whereby negative outcomes are set to zero.

The usefulness of degree-days is that they can be added together. Simply add up all the daily degree-days in a year and this gives the annual number of degree-days. We can compare this to the degree-days of another year to see if the year was warmer or cooler on average. In temperature corrections we compare the degree-days in one year to the degree-days of a reference climate. A reference climate means the “normalized” or “average” climate in a given period for a given area. Choices for the period of the reference climate vary, with 30 years being the most common.

To give an example of the calculation of a reference climate: for each year, take the annual average of the degree-days over the last 30 years, then:

$$Reference\ climate = Moving\ average\ _{year} = \frac{\sum_{year-31}^{year-1} degree\ days_{year}}{30\ years}$$

The temperature correction gives the energy that would have been consumed under reference climate conditions. The yearly temperature-correction factor is calculated with:

$$Temperature\ correction\ heating_{year}\ =\ \frac{Reference\ heating\ degree\ days_{year}}{Heating\ degree\ days_{year}}$$

And similarly for cooling:

$$Temperature\ correction\ cooling_{year}\ =\ \frac{Reference\ cooling\ degree\ days_{year}}{Cooling\ degree\ days_{year}}$$

What are the issues with temperature corrections?

Despite its usefulness in temperature corrections, some problems with degree-days based methods have been identified (Energy Lens, 2016):

1. **Chosing the right base temperature**. The number of degree-days is highly dependent on the chosen base temperature.

   Note: As a consequence of the base temperature dependency, determining the “temperature independent” base load energy consumption - for energy functions other than heating and cooling - can be difficult sometimes because the “temperature independent” base load depends on the chosen base temperature. In **Figure 1**, the base load rectangle will become smaller or larger depending on the chosen base temperature. Note that this is purely a theoretical approach.

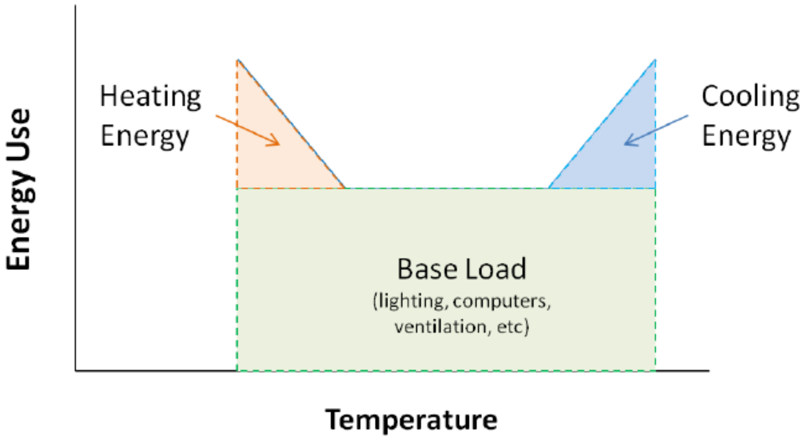

Figure 1: Impression of a building profile for energy and temperature (Energy Star, 2016)

2. **Intermittent heating**. Many buildings are only heated during occupancy hours, however degree-days take into account outside temperatures during a whole day. Cold nights only have a partial effect on heating during daytime, as the buildings retains some of its heat, but are fully included. Also, as is the case for many (non-residential) buildings, degree-days during weekends, public holidays, and shutdown periods are irrelevant as the building is not heated, however these are included as well.
3. **Ideal temperature**. The combination of the "base temperature problem" and "intermittent heating problem" leads to another problem. In theory there is an "ideal" outside temperature at which no heating and cooling is needed. For example, say at exactly 18°C. When the outside temperature is close to the ideal temperature, degree-days based methods become less accurate. The reason is because the cold nights can indicate heating is needed during daytime, while in fact the higher daytime temperatures offset this and heating is not needed.
   In case of a building with both heating and cooling, energy efficient behaviour would mean to turn on the cooling at a few degrees higher than the temperature to turn on the heating. This implies there is a so called "confort zone" at which there is no heating or cooling demand. See **Figure 1**. The temperature range of the confort zone is typically about 2 degrees. The "confort zone" is currently not taken into account in degree-days based methods.
4. **Meter readings.** To make it possible to compare or correlate energy consumption with degree-days, meter readings are needed that are taken at the start of each week or month. In practice these data are not always available. Monthly degree-days comparison can also lead to calendar mismatches. For example: the month February has less days in it than March and can not be compared directly.

Choices need to be made when determining the temperature correction factor
We see that different methods will lead to different results. It is important to choose the most appropriate method and to base this decission on the purpose of the research. The purpose can be monitoring statistics or modelling a scenario.

- Note that degree-days can be **weighted** or **unweighted**. Weighted degree-days are used to correct for seasonality (e.g. to account for differences in monthly solar irradiation) and indicate that degree-days in a winter month contribute more to the total than those in a summer month. The reason being that degree-days mean more for heating of buildings in winter than in summer time. In the calculation this is done as follows: degree-days in November-February get a weigth factor of 1.1, degree-days in March and October get a weight factor of 1 and April-September get a weight factor of 0.8.
- For the outside air temperatures, the daily average temperatures are often used due to lack of available data or preference for a method with less data requirement. Note that degree-days can also be calculated using for instance hourly or half hourly temperatures.
- Different choices for the measurement locations for the temperatures can be made.
- Also different choices for the reference climate can be made.

Scope
Out of the above-mentioned issues, this study addresses issue 1. It does not address issue 2, 3 and 4. Issue 2 and 3 are recommended to analyse in further research because the correction factors for heating and cooling are influenced by it. All of the above-mentioned issues play a role when correlating energy consumption with degree-days.

Sensitivity analysis

Introduction

Temperature corrections are based on degree-days methods which are dependent on underlying assumptions. The assumptions may have a significant effect on the correction factors. Therefore it is interesting to analyse the sensitivity of these assumptions.

Main points that are addressed here are:

- The influence of the base temperature.
- The influence of different temperature measurement locations.

The influence of the base temperature

In the Netherlands, the base temperature is usually chosen at 18°C (Visser, 2005). This value is also used in the degree-days corrections of the National Energy Outlook. Theoretically speaking, it means that space heating is required at days when the average outside temperature is below 18°C.

Base temperature assumptions differ between countries as shown in **Table 1**.

For example: In the UK, the most readily available heating degree-days come with a base temperature of 15.5°C. While in the USA, it's 65°F (18.33°C) (Energy Lens, 2016). The reason behind 15.5°C is that a building needs to be heated to 19°C, but the internal heat load will already cause a temperature rise of 3.5°C (hence: 19-3.5=15.5°C) (Energy Lens, 2016). Here we see the importance of taking into account both the internal heat load and required temperature in the building. We will not analyse the internal heat load further, but focus on the value of the base temperature[1].

Table 1: Base temperature assumption in different countries

Country	Base temperature (°C)
Netherlands	18
United Kingdom	15.5
United States of America	18.33
Denmark	17
Finland	17
Switzerland	12

The number of degree-days per year is highly dependent on the base temperature. **Table 2** shows the number of degree-days per year and how this depends on the base temperature. The degree-days are derived from daily average temperature measurements at weather station de Bilt. The degree-days are unweighted. **Table 3** shows the 30 year moving-average heating degree-days. A decreasing trend in the moving-average is visible over the years. This indicates an increase in annual average temperatures. Using the values in **Table 2** and **Table 3** annual correction factors are calculated. The correction factors are shown in **Table 4**. Percentages higher than 100% mean those years have been warmer on average than the 30-year average. The temperature-corrected natural gas consumption will be higher in those years.

[1] The level of insulation of the building also plays a role. The higher the level of insulation, the lower the base temperature.

It can be seen that if the period used for the reference climate is 30 years, the correction factors typically deviate not more than a few %'s on an annual basis compared to a base temperature of 18°C. Exception is 15.5 and 10.5°C which show larger deviations compared to 18°C. A base temperature of 10.5°C does not seem realistic looking at the large differences in correction factors compared to 18°C.

The sensitivity of cooling degree-days to the base temperature is analysed in **Appendix A**. Note that total energy used for space cooling in the Netherlands is much lower than the energy used for space heating. This makes temperature-corrections for cooling less relevant from a total energy system perspective.

Table 2: Heating degree-days at different base temperatures

Heating degree-days (unweighted)

Base temp (°C)	10.5	15.5 UK	17 DK	17.5	18.0 NL	18.33 US	18.5
2011	804	1850	2293	2455	2622	2735	2794
2012	947	2117	2562	2719	2879	2987	3043
2013	1141	2319	2761	2918	3078	3185	3241
2014	617	1640	2072	2226	2385	2492	2548
2015	732	1912	2369	2526	2686	2794	2850
2016	962	2073	2481	2630	2785	2889	2944

Table 3: 30 year moving-average heating degree-days at different base temperatures

30 year moving-average heating degree-days (unweighted)

Base temp (°C)	10.5	15.5 UK	17 DK	17.5	18.0 NL	18.33 US	18.5
2011	1020	2182	2629	2787	2950	3058	3115
2012	1006	2163	2609	2767	2929	3038	3094
2013	1001	2159	2605	2763	2925	3034	3090
2014	1005	2161	2608	2766	2928	3037	3093
2015	990	2137	2582	2740	2901	3010	3066
2016	965	2113	2557	2714	2875	2983	3040

Table 4: Heating degree-days correction factors a different base temperatures

Correction factors (%)
with respect to the 30 year moving-average

Base temp (°C)	10.5	15.5 UK	17 DK	17.5	18.0 NL	18.33 US	18.5
2011	127%	118%	115%	114%	113%	112%	111%
2012	106%	102%	102%	102%	102%	102%	102%
2013	88%	93%	94%	95%	95%	95%	95%
2014	163%	132%	126%	124%	123%	122%	121%
2015	135%	112%	109%	108%	108%	108%	108%
2016	100%	102%	103%	103%	103%	103%	103%

What is the effect on gas consumption?

The annual natural gas consumption of households (without temperature-correction) is taken from CBS. The share for space heating is taken from ECN. Only the share of natural gas consumption used for space heating is temperature-corrected.

Table 5 and **Table 6** show the temperature corrected natural gas consumption at different base temperatures as well as the difference between unweighted and weighted degree-days. The reference climate used is a 30-year moving average.

The effect of the base temperature on the natural gas consumption of households is generally in the order of a few PJ. Choosing base temperatures between 17 and 18.5°C gives a maximum range of 0-10 PJ per year during the period 1995-2015. For 10.5 and 15.5 °C differences are larger.

Table 5: Temperature-corrected natural gas consumption households using unweighted degree-days

	Natural gas consumption using unweighted degree-days (PJ)						
Base temp (°C)	**10.5**	**15.5 UK**	**17 DK**	**17.5**	**18.0 NL**	**18.33 US**	**18.5**
2011	384	361	353	350	348	346	345
2012	355	344	343	343	343	343	342
2013	323	339	342	343	344	345	345
2014	397	333	321	318	315	313	312
2015	365	312	306	305	303	303	302

Table 6: Temperature-corrected natural gas consumption households using weighted degree-days

	Natural gas consumption using weighted degree-days (PJ)						
Base temp (°C)	**10.5**	**15.5 UK**	**17 DK**	**17.5**	**18.0 NL**	**18.33 US**	**18.5**
2011	380	357	350	348	346	344	343
2012	355	344	343	343	343	343	343
2013	326	340	344	344	345	346	346
2014	391	331	319	316	313	312	311
2015	367	316	309	308	307	306	306

What is the effect on the trend of gas consumption?

Figure 2 shows the temperature-corrected natural gas consumption trend of households calculated at different base temperatures. Weighted degree-days were used in this case. The 18 °C represents the typical base temperature. Other values for the base temperature result in a similar trend except the 10.5 and 15.5°C lines which have larger deviations. The 10.5 and 15.5 °C trend deviate most from 18 °C because they compensate relatively more for the years that have a larger deviation from the reference climate.

For comparison the temperature-corrected natural gas consumption (SJV) as provided by CBS is also shown in the figure. We see that the temperature-corrected values are not the same as the SJV.

Other correction factors were used by CBS based on a different method. We will look into this later on. Noticable is that the SJV results in a more gradual trend. In relatively warm years the temperature corrections result in lower or similar values as the SJV, in relatively cold years the temperature corrections result in higher values than the SJV.

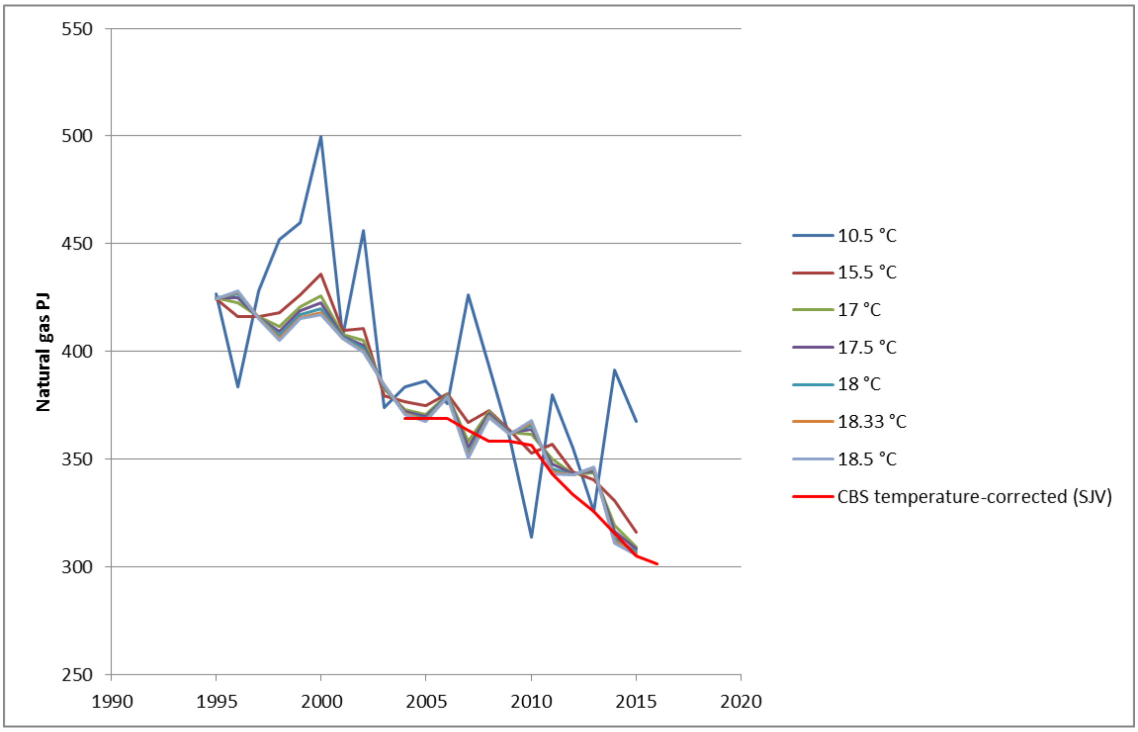

Figure 2: Temperature-corrected natural gas consumption households at different base temperatures and corrected with respect to a 30-year moving average

The influence of different temperature measurement locations

The national degree-days are based on temperature data from the weather station located at De Bilt. It might be argued that De Bilt is not representative for temperature-averages of the Netherlands. Therefore, it is interesting to compare the number of degree-days to degree-days derived from weather stations on different locations. Taking a weighted average possibly results in a more accurate representation.

Daily mean temperature series were taken from the following KNMI weather stations:

- De Kooy/Den Helder (first measurements in 1906)
- Eelde/Groningen (first measurements in 1906)
- De Bilt (first measurements in 1901)
- Vlissingen (first measurements in 1906)
- Beek/Maasstricht (first measurements in 1906)

These five locations have homogeneous dataseries which are corrected when the weather station was replaced or relocated. Therefore these data are suitable to analyse trends.

The weighted average degree-days can be calculated in number of ways depending on preference, for instance:

Method 1: Give each weather station an equal weight (5 stations, 20% each).

Method 2: A weighted average based on households/dwellings/population density per region.

Method 3: A weighted average based on natural gas consumption per region.

In this section, degree-days come at a base temperature of 18°C and are unweighted. The calculated annual degree-days per weather station are shown in **Figure 3**.

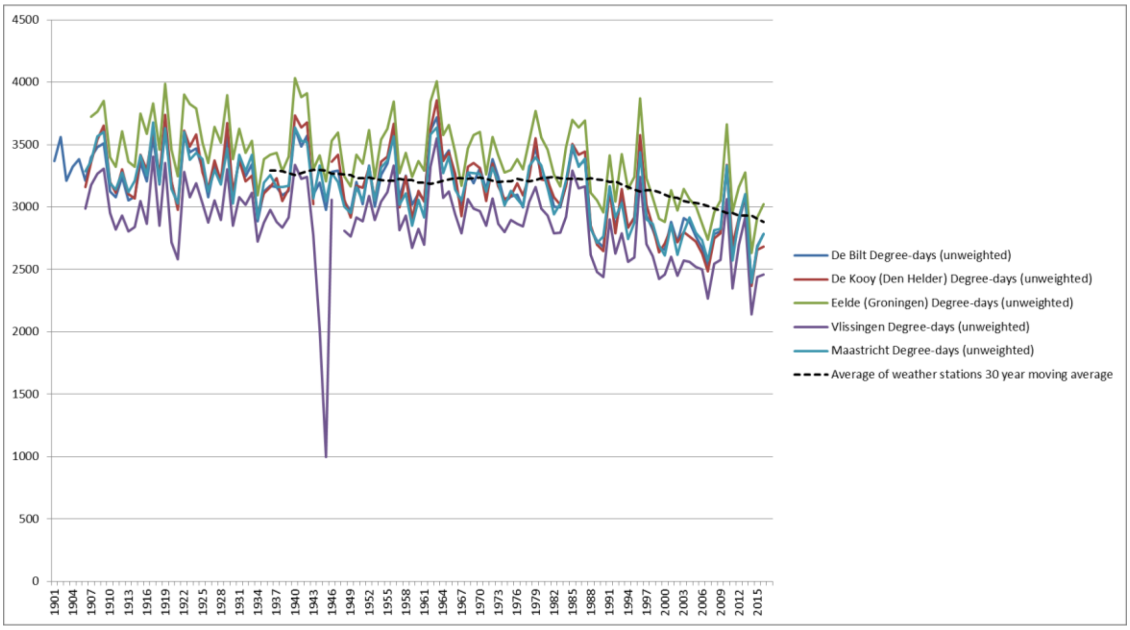

Figure 3: Heating degree-days for five different weather stations

Method 1: Give each weather station an equal weight (5 stations, 20% each)

Table 7 shows the results of method 1.

Table 7: Heating degree-days and correction factors using method 1

	Degree-days (unweighted)	30 year moving average (unweighted)	Correction factor (%) with respect to 30-year moving average
Base temp (°C)	**18.0 NL**	**18.0 NL**	
2011	2638	2952	112%
2012	2913	2933	101%
2013	3092	2930	95%
2014	2383	2933	123%
2015	2674	2906	109%
2016	2746	2879	105%

Compared to using data from De Bilt only, method 1 gives a difference in correction factor of 1-2% per year. We see that the higher degree-days at Eelde get compensated by lower degree-days at Vlissingen. De Bilt is somewhere in de middle of the degree-days range.

Method 2: A weighted average based on number of dwellings

The degree-days per weather station are given a weight that is proportional to the number of dwellings per province closest to the weather station. In this way, the densely populated regions with higher gas consumption contribute more to the degree-days than the less densely populated areas. In order to do so, the provinces in the Netherlands were allocated over the five weather stations as shown in **Table 8**. In this way, temperature measurements at De Bilt and Vlissingen are most determining for the average and measurements in Den Helder contribute less. The weight factors of the stations are kept constant over the years.

Table 8: Weighing the weather stations

Weather station	Allocated provinces	Dwellings in 2015 x 1,000,000	Weight (%)
De Bilt	Utrecht, Overijssel, 1/2 Noord-Holland, Flevoland, 1/2 Zuid-Holland, Gelderland	3.6	47%
De Kooy (Den Helder)	1/2 Noord-Holland	0.7	9%
Eelde (Groningen)	Groningen, Friesland, Drenthe	0.8	10%
Vlissingen	Zeeland, 1/2 Noord-Brabant, 1/2 Zuid-Holland	1.6	20%
Beek (Maastricht)	Limburg, 1/2 Noord-Brabant	1.1	14%
Total		7.7	100%

Table 9 shows the results of method 2.

Table 9: Heating degree-days and correction factors using method 2

	Degree-days (unweighted)	30 year moving average	Correction factor (%) with respect to 30-year average
Base temp (°C)	**18.0** **NL**	**18.0** **NL**	
2011	2600	2926	113%
2012	2879	2907	101%
2013	3070	2903	95%
2014	2360	2906	123%
2015	2655	2880	108%
2016	2734	2853	104%

Compared to data from De Bilt only, method 2 gives a difference in correction factor of 0-1% per year. This is a consequence of the high weight De Bilt has in the calculation.

What is the effect on level of gas consumption?

Table 10 shows the effect of the location method on the temperature-corrected gas consumption of households. Compared to "De Bilt" the annual differences in natural gas consumption caused by the method are typically in the range 0-2 PJ. The maximum difference in the period 1995-2015 is 8.3PJ (method 1) and 5.6PJ (method 2) in 2003.

Table 10: Effect of location method on temperature-corrected natural gas consumption households

Location method	Natural gas (PJ) De Bilt	Natural gas (PJ) method 1	Natural gas (PJ) method 2
2011	347.6	346.0	347.7
2012	342.6	339.8	340.5
2013	344.3	343.4	342.9
2014	314.7	315.3	315.5
2015	303.5	304.9	304.4

What is the effect on the trend of gas consumption?

We can see in **Figure 4** that the location method has almost no influence on the trend.

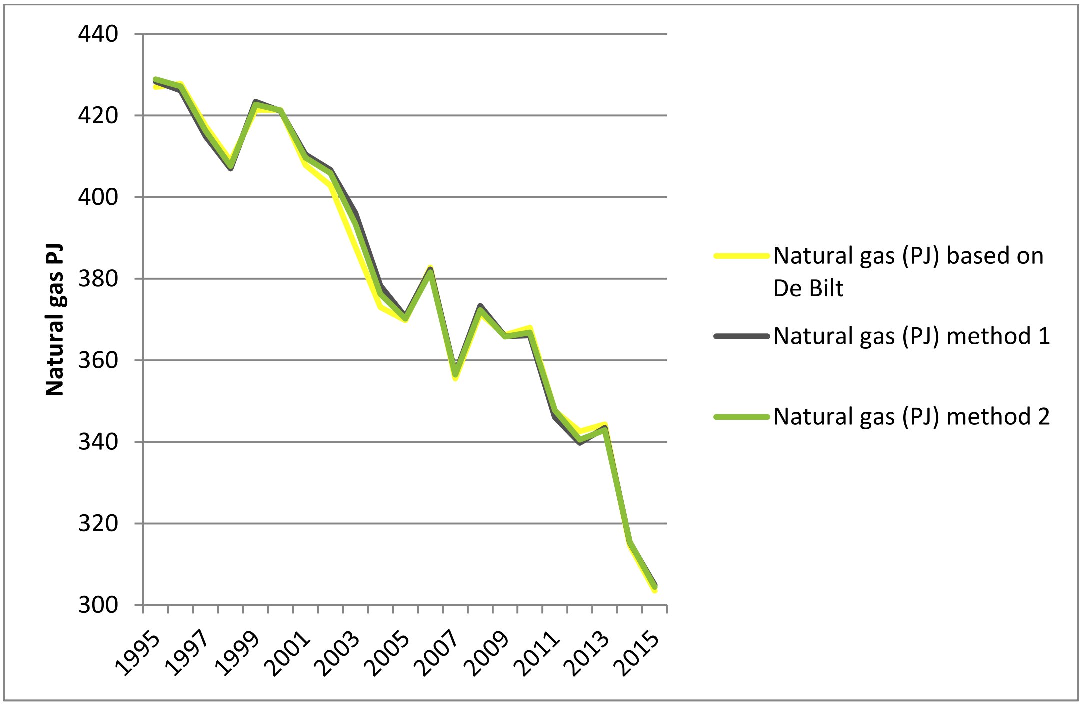

Figure 4: Effect of location method on temperature-corrected natural gas consumption households

Conclusion about measurement locations

The results show that the Bilt is fine to use as location for heating degree-days based methods representing the Netherlands. Methods 1 and 2 give deviations in correction factors of 0-2% per year compared to "De Bilt only". In general this leads to differences of 0-2PJ per year in the natural gas consumption of households.

The result of Method 3 is not shown. Note that degree-days corrections on a regional level require regional gas consumption data which is not available via CBS (only via the klimaatmonitor of Rijkswaterstaat). The weight factors of the weather stations would be nearly the same as the ones used in method 2, thus lead to the same conclusion.

Cooling degree-days methods are more sensitive to where the temperatures are measured. This is analysed in **Appendix B**. The reason is that the number of cooling degree-days is relatively low compared to heating degree-days. Method 1 and 2 lead to deviations of 0-4% on an annual basis compared to “De Bilt only”. For the relatively cold or warm years, differences are larger.

Conclusions about sensitivity

The effect of the base temperature on the temperature corrected natural gas consumption of households is typically in the order of a few PJ per year. Choosing base temperatures between 17 and 18.5°C gives a maximum range of 0-10 PJ per year in the period 1995-2015. At base temperatures 10.5 and 15.5 °C the annual differences are larger.

Choosing multiple weather station locations and taking a weighted average gives almost the same results as using De Bilt. The annual devation in correction factor is 0-2% per year. This corresponds to a natural gas consumption of about 0-2PJ. This indicates that De Bilt is fine to use as a measurement location representing the Netherlands.

Comparison of different methods

Introduction

For the natural gas consumption of households in the Netherlands, we make a comparison between (I) the temperature-corrected CBS statistics (SJV), (II) the temperature correction based on a reference climate with a moving average, and (III) the temperature correction used in the scenario of the National Energy Outlook.

Standaard jaarverbruiken (SJV)

CBS has statistics about the annual natural gas consumption of households in the Netherlands. The data are delivered to CBS by energy suppliers as "Standaard jaarverbruiken" (SJV).

The SJV of a consumer is defined as (ACM, 2013):
The expected annual consumption in m^3 of a consumer(-profile) in a standard year.

A standard year means a year with average climate conditions and standard pressure in the gas network.

CBS converts the SJV back to annual natural gas consumption. In doing so, CBS undoes the temperature-correction. CBS determines the correction factors on the basis of hourly consumer-profiles (Dutch: "*profielenmethodiek*").

The annual natural gas consumption and SJV in the period 2011-2015 are shown in **Table 11**. The annual natural gas consumption is varying over the years as it depends on the weather conditions in those years. Though, looking at the SJV a decreasing trend is visible indicating more efficient use of energy.

Table 11: Number of dwellings and natural gas consumption of households in period 2011-2015 (source: CBS)

	Number of dwellings x 1,000	Natural gas (PJ)	Natural gas temperature-corrected (PJ) (SJV)	Correction factor used by CBS (%) *profielenmethodiek*
2011	7,385	316	343	109%
2012	7,449	338	333	99%
2013	7,535	359	326	91%
2014	7,588	268	315	118%
2015	7,641	285	305	107%

For comparison, we calculated the temperature-corrected values using the annual natural gas consumption from CBS, the fraction used for space-heating and correction factors based on weighted degree-days at De Bilt at a base temperature of 18 °C and with respect to the 30-year moving average. The results are shown in **Table 12**. It gives a difference in annual consumption of -0.6% to 5.6% per year during period 2011-2015. The year 2013 differs most with 19.5PJ.

Table 12: Temperature-corrected natural gas consumption households based on (weighted) degree-days at 18°C base temperature and with respect to a 30-year moving average.

	Natural gas (PJ) Source: CBS	Natural gas not used for space-heating (PJ) Source: ECN	Temperature correction factor used for space-heating (%)	Natural gas temperature-corrected (PJ)
2011	316	63	112%	346
2012	338	67	102%	343
2013	359	64	95%	345
2014	268	61	122%	313
2015	285	58	110%	307

The difference between the SJV and the temperature-corrected trend calculated with a 30-yr moving average can be visualised in **Figure 5**. The "marginal" difference between weighted and unweighted degree-days is also shown. The graph A. CBS is the annual natural gas consumption as calculated by CBS. The years 1996, 2010 and 2013 were relatively cold years. The years 2007, 2011 and 2014 were relatively warm years. It is visible that the SJV gives a more gradual trend than the other methods. Furthermore we note there is a slope discontinuity in the SJV at 2010, while the other methods don't have this.

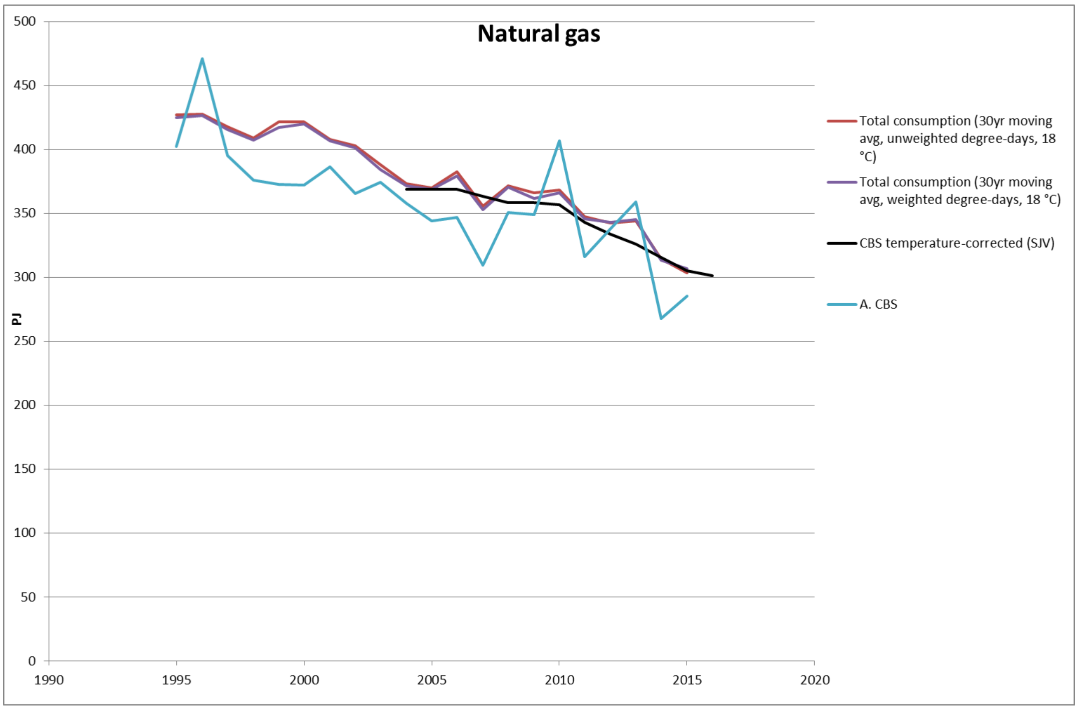

Figure 5: Natural gas consumption of households, SJV, and temperature corrections based on degree-days at 18°C base temperature and a 30-year moving average

Table 13 shows the differences on a yearly basis. During the period 2011-2015 the total decrease in natural gas consumption would read 39 PJ using weighted degree-days, 44PJ using unweighted degree-days, and 38 PJ according to the SJV.

Table 13: Difference between the SJV and temperature-correction with a 30-year moving average

	Weighted degree-days		Unweighted degree-days	
	Difference with the SJV (PJ)	Difference with the SJV (%)	Difference with the SJV (PJ)	Difference with the SJV (%)
Base temp (°C)	**18 °C**	**18 °C**	**18 °C**	**18 °C**
2011	2.5	0.7%	4.5	1.3%
2012	9.5	2.8%	9.2	2.7%
2013	19.5	5.6%	18.4	5.3%
2014	-1.9	-0.6%	-0.7	-0.2%
2015	1.9	0.6%	-1.5	-0.5%

Profielenmethodiek

The profielenmethodiek is a temperature correction on hourly basis. It compares the consumption-temperature profile in a particular year to a standard year profile. This gives the correction factor.

A profile describes the gas consumption pattern in relation to the hourly temperature. It gives the fraction of annual gas consumption (profile fractions) for every hour in a year.
A profile includes (ACM, 2013):

- the hourly fraction that is temperature-dependent (e.g. space heating)
- the hourly fraction that is temperature-independent (e.g. cooking, hot water)
- a base temperature above which there is no temperature-dependent consumption
- the hourly temperature

Temperatures are measured at De Bilt. The "effective temperature" is used which takes into account daily average windspeed.

The standard year profile is usually taken as the average year profile of period 1988-2002.
CBS indicated the following:

- The natural gas consumption is temperature-corrected with respect to the average year profile of the fixed period 1988-2002 for the years 2010 and earlier.
- The natural gas consumption is temperature-corrected with respect to moving-average year profile for years 2011 and later.

The change in method explains why there is a slope discontinuity in the SJV at the year 2010, leading to a steeper decline after 2010. CBS explained that it is possible that the profielenmethodiek does not correct suffiently for the warmer winters of recent years.

More information on the profielenmethodiek can be found in *"Informatiecode Elektriciteit en Gas"* (ACM, 2013). The method also distinguishes different categories of small consumers (<170.000 m^3/yr). The calculations are made by the grid operators using regional natural gas consumption data and hourly weather data. Currently, these data are not available to ECN. Hence the SJV calculation could not be reproduced.

National Energy Outlook
Reference climate degree-days in the National Energy Outlook are taken from the climate scenarios developed by the Royal Netherlands Meteorological Institute (KNMI). The name of the used scenario is the "KNMI 2030 scenario". This scenario can be interpreted as an average of the four KNMI 2014 climate scenarios: G_L, G_H, W_L and W_H. The scenarios provide annual mean temperatures.

Using the linear formula from Visser (2005), we are able to estimate the degree-days per year as a function of annual mean temperature.

$$HDD_{year} = 6369 - 337 \times Annual\ mean\ temperature_{year}$$

For the annual mean temperature the 30-year (moving) average temperature was taken. This is done to correct for possible outliers. For example, for the mean temperature of 2000, the mean temperature of period 1986-2010 was used. Linear regression was done. This results in **Figure 6**.

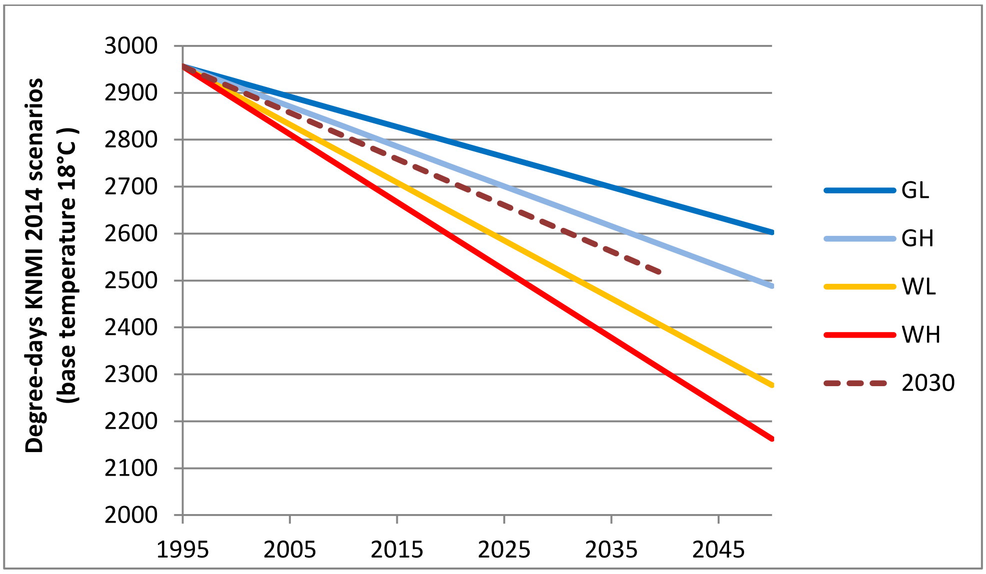

Figure 6: Heating degree-days in the KNMI 2014 scenarios

The historical years are corrected towards the trend. The temperature-correction is calculated with:

$$Temperature\ correction_{year} = \frac{KNMI\ 2030\ scenario\ degree\ days_{year}}{unweighted\ degree\ days_{year}}$$

Whereby historical degree-days are calculated from daily mean temperatures measured at De Bilt (see **Table 2**).

Note: The linear formula from (Visser, 2005) is used instead of the KNMI 2030 scenario degree-days. Both are possible, although for the purpose of the NEO a simple approach in the form of a linear trend is prefferable in order to avoid yearly fluctuations. Using scenario degree-days would also make the decission on which time horizon to focus in the scenarios relevant. This is because the KNMI scenario temperatures are dependent on the chosen time horizon.

Effect on historical gas consumption

Here we compare the different methods to the National Energy Outlook scenario. **Figure 7** shows the historical natural gas consumption of households, in which:

- A. CBS is the natural gas consumption of households provided by CBS.
- C. is a temperature-correction on A. with the 30-year average of the fixed period 1960-1990 as reference climate. The base temperature is 18°C and unweighted degree-days were used.
- The "30-yr moving average" is a temperature correction on A. using unweighted degree-days at a base temperature of 18°C (see **Table 2**).
- CBS temperature-corrected is the Standaardjaarverbruik (SJV).
- C3. is a temperature-correction on A. and is corrected for the heating degree-days trend of the KNMI 2030 scenario. The base temperature is 18°C and unweighted degree-days were used.
- NEO scenario VV2 is the the National Energy Outlook scenario.

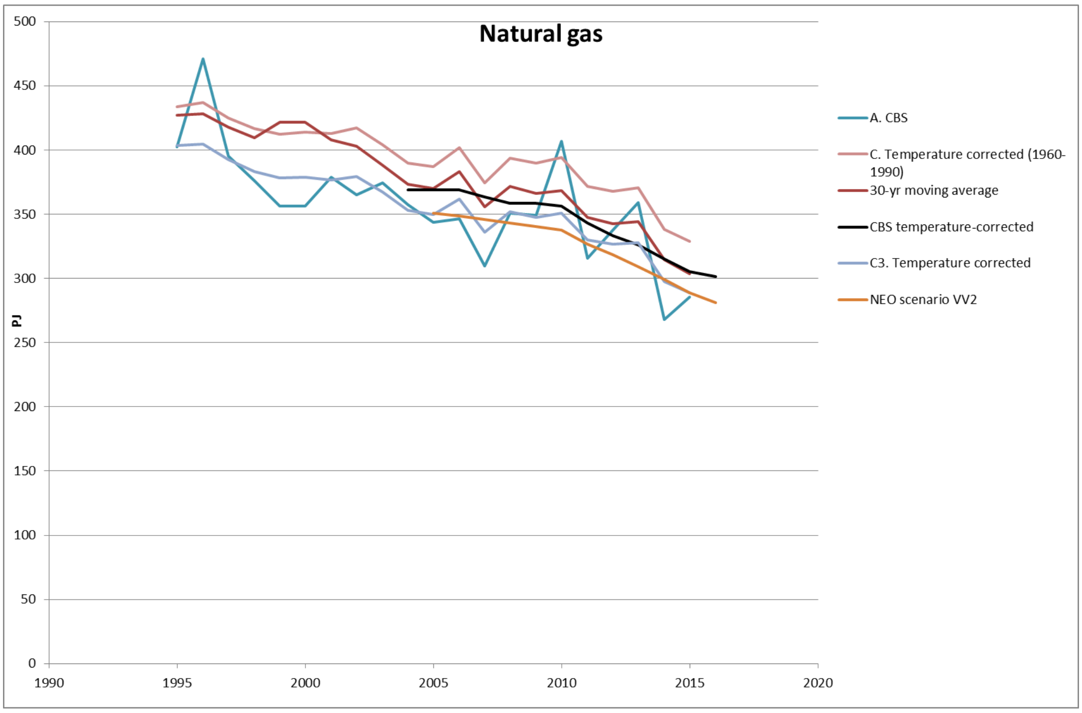

Figure 7: Natural gas consumption households with different temperature corrections

The following can be seen:

- The fixed reference climate used for C. has more degree-days (3200) in comparison to the degree-days of recent years, which results in a higher natural gas consumption.
- The "30-yr moving average" lies well below C. because the reference climate has less degree-days.
- The CBS temperature-corrected (SJV) values are lower or come close to the "30-yr moving average". This difference can be partially explained by the reference period. The period 1988-2002 has on average 2883 (unweighted) degree-days per year, which is lower than the 30-yr moving averages shown in **Table 3**.
- The C3. scenario lies well below the "30-yr moving average" because the KNMI 2030 scenario degree-days are lower than the degree-days derived from De Bilt, which results in a lower correction factor. The average difference in PJ between C3. And the "30-yr moving average" is about 20 PJ per year. The same holds for the NEO scenario.

Effect on the trend of gas consumption

Figure 8 shows the natural gas consumption scenario of households in the NEO and different linear projections through the historical data that was shown in **Figure 7**. More natural gas is saved over the years than would be expected by the decrease in degree-days on its own. The difference is caused by energy saving measures and energy efficiency behaviour changes.

A linear trendline fitted to C3. (shown in blue) and the "30-yr moving average" (shown in green) shows that the two lines intersect near 2030. The SJV projection (shown in black) eventually reaches lower values than C3. and the "30-yr moving average" caused by the steeper decline after 2010. The NEO scenario does not behave in a linear fashion, it has a slope discontinuity at 2010 and near 2020. The slope discontinuity at 2010 was added manually to fit the CBS statistics. The other one is a model result.

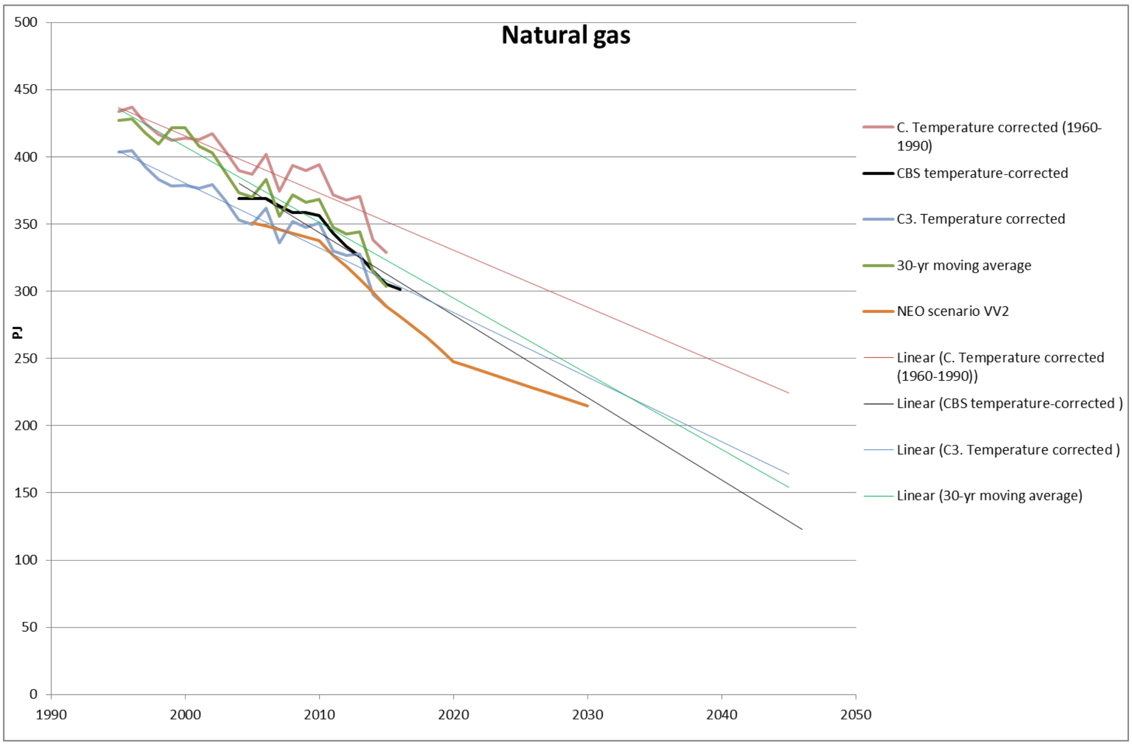

Figure 8: Temperature-corrected natural gas consumption households - NEO scenario and linear projections of historical data

Conclusion

The difference in PJ between C3. And the "30-yr moving average" is about 20 PJ per year in period 1995-2015. Though, both methods are correct. The difference stems from the chosen reference climate. It is reasonable to use degree-days derived from measured temperatures for monitoring studies. However, such methods look back to historical years and thus result in a higher energy consumption (for space heating) compared to a scenario which takes into account the future warming trend. An energy scenario requires the use of a degree-days trend for future years and historical statistics are thus corrected for the trend.

The *profielenmethodiek* gives the most accurate results and a more gradual trend because it is a temperature correction on hourly basis. Therefore it is the preferred method to observe historical saving trends. Methods based on daily average temperatures are approximations, however they are easier to calculate and require less data.

Recommendations

- For monitoring statistics, the reference climate should be based on a longterm period. The *profielenmethodiek* correction factors are recommended and will result in the most gradual trend whereby efficiency improvements can be visualised most easily.
- For scenario modelling keep using the KNMI 2030 scenario degree-days trend as there currently is no alternative with regard to the base temperature assumption.
- The formula of (Visser, 2005) can only be used if the base temperature is 18°C. Currently it is not possible to use another base temperature. It is recommended to develop degree-days formulas based on lower base temperatures in further research. This is because the insulation levels of buildings are expected to improve further in future years and this will lower the base temperature.

What is the best choice for the Energy Outlook?

To determine the annual degree-days in the Netherlands, daily average temperatures measured at de Bilt are fine to use as an approximation. The preferred method for the reference climate is to use a decreasing trend for the heating degree-days. This simulates the effect global warming will have on energy consumption for space-heating. Vice-versa for cooling degree-days an increasing trend is preferrable to determine the effect on space-cooling. The historical statistics will be corrected in such a way that they are in accordance with the trend. The reference climate can be a linear trend. Currently, the degree-days and reference climate degree-days come at a base temperature of 18°C. The base temperature is dependent on insulation levels of buildings so this value will probably need to be reconsidered coming years.

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Appendix A: Sensitivity cooling degree-days to base temperature

Cooling degree-days-based methods are effected by the base temperature of the degree-days used. The base temperature for cooling is usually chosen at 18°C. In chosing a base temperature for cooling it is important to take into account the amount of available free cooling (e.g. opening of windows). The lower the base temperature for cooling, the lower the amount of free cooling that is assumed.

Table 14 shows the cooling degree-days derived from temperature measurements at weather station de Bilt. The cooling degree-days shown are unweighted. A higher base temperature leads to lower numbers of cooling degree-days and vice versa. A base temperatures of 20°C causes cooling degree-days to decrease by a factor 2-3 compared to a base temperature of 18°C . At a base temperature of 25-26°C, there would be no cooling degree-days.

The 30-year moving-average is given in **Table 15**. It can be seen that the moving average cooling degree-days is increasing over the years and that most of last years have been warmer on average than the 30 year moving-average. The annual cooling correction factors at different base temperatures are given in **Table 16**. Correction factors lower than 100% mean that the year has been warmer on average than the 30-year moving average. Depending on the chosen base temperature, the annual deviations in correction factors are 1-7%. The year 2011 was an exeption as this year was colder on average. A base temperature of 21°C does not seem realistic looking at the deviation in correction factors compared to 18 °C.The sensitivity of cooling degree-days to the base temperature is relatively higher than for heating degree-days as a result of the fact that the amount of cooling degree-days in the Netherlands is lower compared to the number of heating degree-days.

Table 14: Cooling degree-days at different base temperatures

	Cooling degree-days (unweighted)						
Base temp (°C)	**17**	**17.5**	**18.0 NL**	**18.5**	**19**	**20**	**21**
2011	79	58	43	33	24	14	7
2012	136	110	87	68	54	33	16
2013	150	125	102	82	65	40	24
2014	143	114	91	71	56	33	18
2015	144	118	95	78	62	36	20
2016	177	142	114	90	71	40	21
Total	829	667	532	421	332	194	106

Table 15: 30 year moving-average cooling degree-days at different base temperatures

30 year moving-average cooling degree-days (unweighted)

Base temp (°C)	**17**	**17.5**	**18.0 NL**	**18.5**	**19**	**20**	**21**
2011	132	108	87	70	55	34	20
2012	133	108	88	70	55	34	20
2013	132	107	87	69	55	34	19
2014	131	106	86	68	54	33	19
2015	133	108	87	69	54	33	19
2016	135	110	89	71	56	34	20

Table 16: Cooling degree-days correction factors at different base temperatures

Correction factors (%) with respect to the 30 year moving-average

Base temp (°C)	**17**	**17.5**	**18.0 NL**	**18.5**	**19**	**20**	**21**
2011	168%	186%	201%	216%	230%	250%	284%
2012	98%	99%	102%	104%	103%	105%	124%
2013	88%	86%	85%	84%	83%	84%	82%
2014	92%	93%	95%	96%	95%	99%	106%
2015	92%	91%	91%	89%	88%	94%	97%
2016	77%	77%	78%	79%	79%	85%	93%

Appendix B: Sensitivity cooling degree-days to measurement location

The cooling degree-days derived from the daily average temperatures measurements at five different weather stations are shown in **Figure 9**.

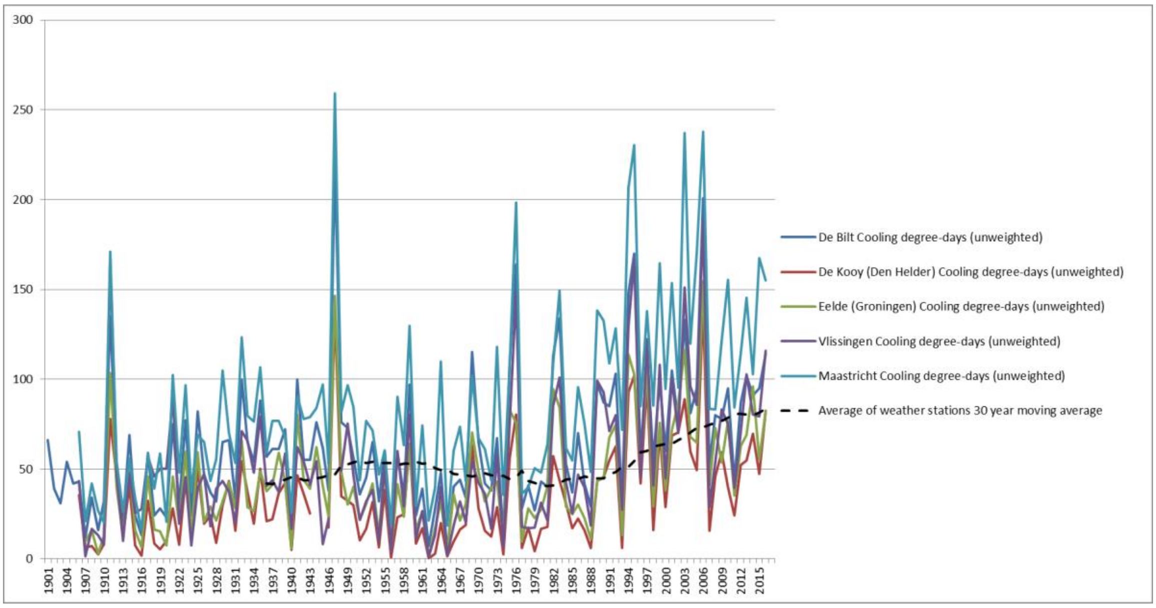

Figure 9: Cooling degree-days for five different weather stations

Table 17 shows the results of method 1 to weigh the weather stations.

Table 17: Cooling degree-days and correction factors using method 1

	Cooling degree-days (unweighted)	30 year moving average	Correction factor (%) with respect to 30-year moving average
Base temp (°C)	**18.0 NL**	**18.0 NL**	
2011	45	81	178%
2012	77	81	104%
2013	95	80	85%
2014	88	80	91%
2015	89	82	92%
2016	110	83	76%

Conclusion method 1 for cooling:

This method leads to differences in correction factors of 1-4% per year compared to data from De Bilt only. For the year 2011 the difference is larger caused by the lower amount of cooling days.

Table 18 shows the results of method 2 to weigh the weather stations.

Table 18: Cooling degree-days and correction factors using method 2

	Cooling degree-days (unweighted)	30 year moving average	Correction factor (%) with respect to 30-year average
Base temp (°C)	**18.0 NL**	**18.0 NL**	
2011	46	85	186%
2012	82	85	104%
2013	101	85	84%
2014	89	84	94%
2015	94	85	91%
2016	114	87	77%

Conclusion method 2 for cooling:
Compared to data from "De Bilt only", this method gives a difference in correction factor of 0-2% per year, for the year 2011 the difference is larger caused by the lower amount of cooling days.