

A good practice guide to energy monitoring and targeting



March 2019

About SEAI

SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with Government, homeowners, businesses and communities to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

SEAI is funded by the Government of Ireland through the Department of Communications, Climate Action and Environment.

The large Industry Energy Network

The Large Industry Energy Network is one of the world's leading energy efficiency networks, made up of prominent organisations operating in Ireland, all working towards a strategic approach to energy management. Some 200 of Ireland's largest energy users are members of the network and together they account for 55% of Ireland's industrial Primary Energy Requirement. Network members are companies with annual energy bills of €1 million or over. Supported by SEAI, they work together to improve their energy performance and inspire others to follow.

A special working group was established to address energy use in a variety of utilities. This special working group worked on a number of projects, one of which was a review of best practice for energy monitoring and targeting.

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Introduction

The old adage ‘You can’t manage what you don’t measure’ is particularly apt for energy management. Effective energy management starts with measuring how much energy is being consumed and where it is being consumed. Energy consumption data must be collected and analysed to understand the potential for energy performance improvement. Targets for energy consumption can then be set and actual energy consumption can be measured against the targets. This, in essence, is monitoring and targeting (M&T).

Monitoring and targeting has enormous potential worldwide for saving energy without capital investment.

This guide gives a brief introduction to techniques that can be used for effective monitoring and targeting.

What is monitoring and targeting?

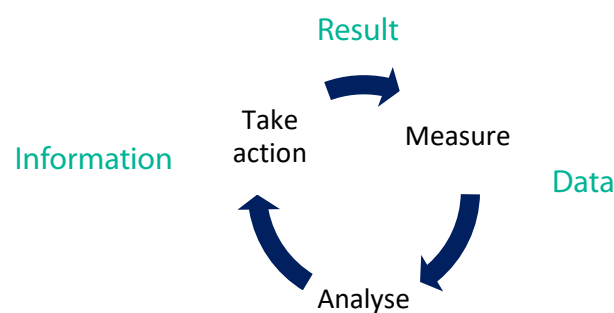
Energy monitoring and targeting is a technique for managing energy that uses energy consumption data and other data as a basis to eliminate waste, reduce and control energy consumption and improve operating practices.

At a factory level, it typically involves the following steps.

1. Identify where energy is consumed within the factory.
2. Record energy consumption at site level and at the major consumers.
3. Analyse the data in order to:
 - Highlight consumption trends;
 - Identify relevant variables that influence energy consumption at process or site level; and
 - Identify and investigate periods of apparent excess consumption.
4. Develop energy-consumption baselines that represent typical or expected energy consumption.
5. Set targets for energy consumption with reference to the baselines and/or external benchmarks.
6. Monitor consumption versus the targets to identify when and why it is different from the ‘norm’ and take action as appropriate.

Monitoring and targeting is a tool used in a continuous improvement cycle as shown in *Figure 1*.

Figure 1: The continuous improvement cycle



Why monitoring and targeting?

Monitoring and targeting has been found to have multiple benefits for industry, such as:

- Energy cost savings, typically 5–15%, due to the ability to identify and rectify excessive consumption as it occurs;
- Improved data for justifying capital investment;
- Improved product costing;
- Improved budgeting due to better prediction of future energy consumption;
- Better productivity, quality, maintenance, and equipment lifetime due to the ability to identify irregularities – effective monitoring and targeting acts as an early warning system that can highlight issues before they have a significant impact;
- Waste avoidance – not just energy, also water and materials;
- Ability to benchmark against competitors and sister companies;
- Measurement and verification of savings from capital investment activities; and
- Compliance with ISO 50001 requirements.

How to conduct monitoring and targeting?

Data collection

Energy consumption data should be collected for all significant energy sources at site level: electricity, thermal fuels, transport fuels etc. Data should also be collected for the significant energy consumers on site, for example boilers, furnaces, steam generators, dryers, major processes. Data should include energy consumption and data on the relevant variables that may drive energy consumption up or down – production throughput, product mix, weather etc. The frequency of data collection should be the same for both consumption and relevant variable data.

When an organisation starts implementing monitoring and targeting they are unlikely to have the data required to develop a comprehensive system. However, there is usually enough data available to start an imperfect system; the data and the system can be expanded over time, but it is generally advisable to start monitoring and targeting with the data that is readily available rather than waiting for all of the desirable data to be generated.

Data analysis

Once we have collected data we need to analyse it to generate useful information in order to establish:

- Are we using too much energy?
- Is energy performance improving?
- Have we used more energy than we did in previous periods?
- Have we used more energy than we normally would or should, taking into account the relevant variables that affect energy consumption?

There are several techniques for analysing energy consumption data.

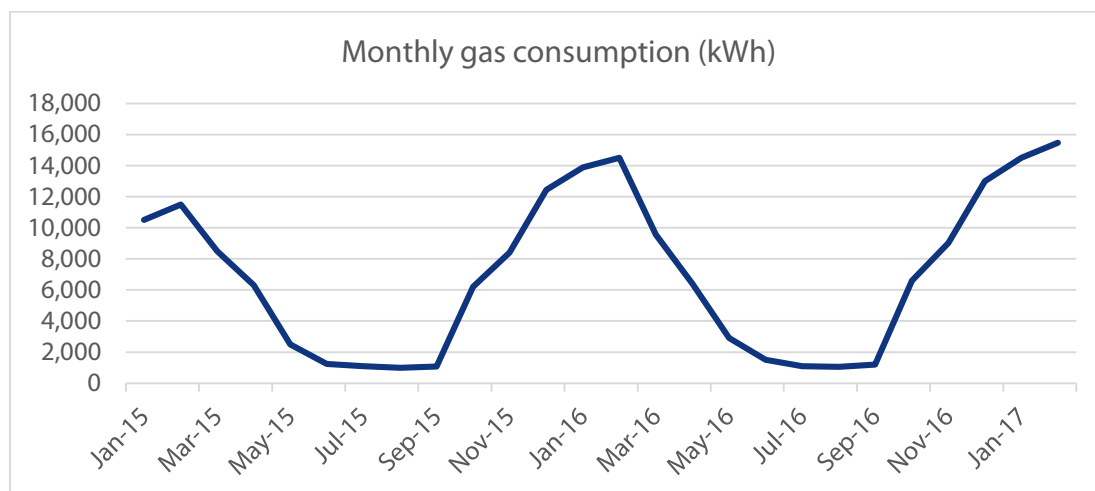
Monitoring the thermodynamic efficiency of specific plant

This can be an effective way of monitoring energy consumption for specific equipment – boilers, refrigeration equipment, CHP plant, etc. Energy output is compared with energy input to give a conversion efficiency ratio, which is then compared to previous performance, design efficiency, or both. If boiler efficiency or chiller co-efficient of performance is changing, then this can be investigated to identify whether it is due to a problem with the system or process, or whether it is due to a change in the load on the system. Appropriate action can then be taken.

Comparing current energy consumption to previous energy consumption

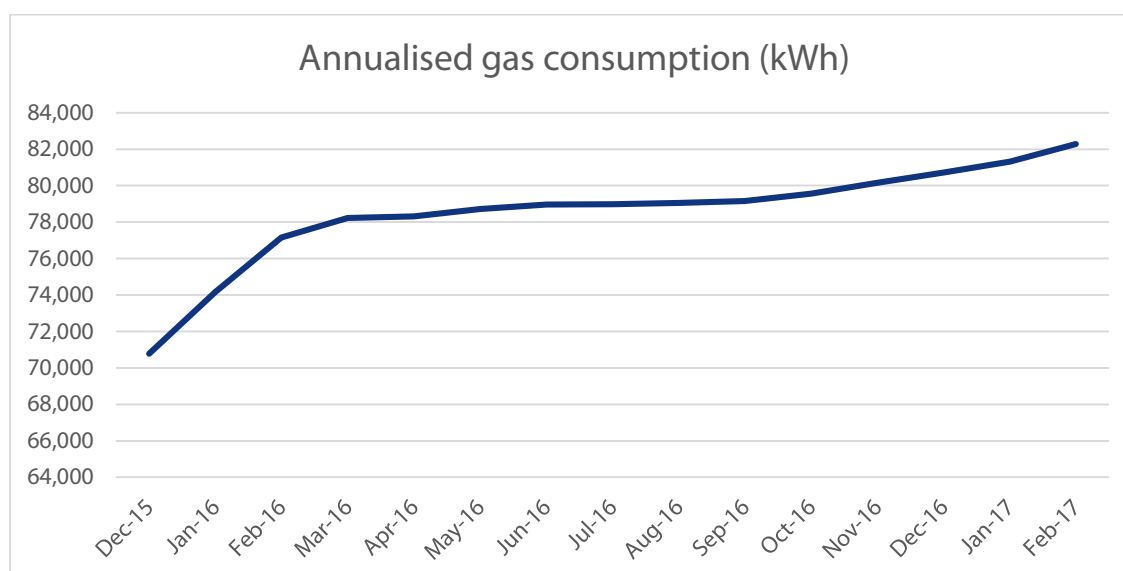
This is data analysis at its most basic. It tells us whether energy consumption is rising or falling, but little else. This can be presented in graphical form as in *Figure 2*, which shows monthly gas consumption.

Figure 2: Basic data analysis



The same data can be accumulated over time – for example rolling 12-month consumption – which can show longer-term trends and can remove seasonal effects such as weather. *Figure 3* shows a rolling total of the gas consumption for the previous 12 months with the data from *Figure 2* and gives us better information. It shows a clear upward trend in energy consumption, although it does not indicate why the trend is upward. For instance, it could be that the boiler is actually performing better than last year, but a colder winter is driving an increase in gas consumed for heating – further analysis is required to verify energy performance.

Figure 3: Rolling total data



Monitoring specific energy consumption

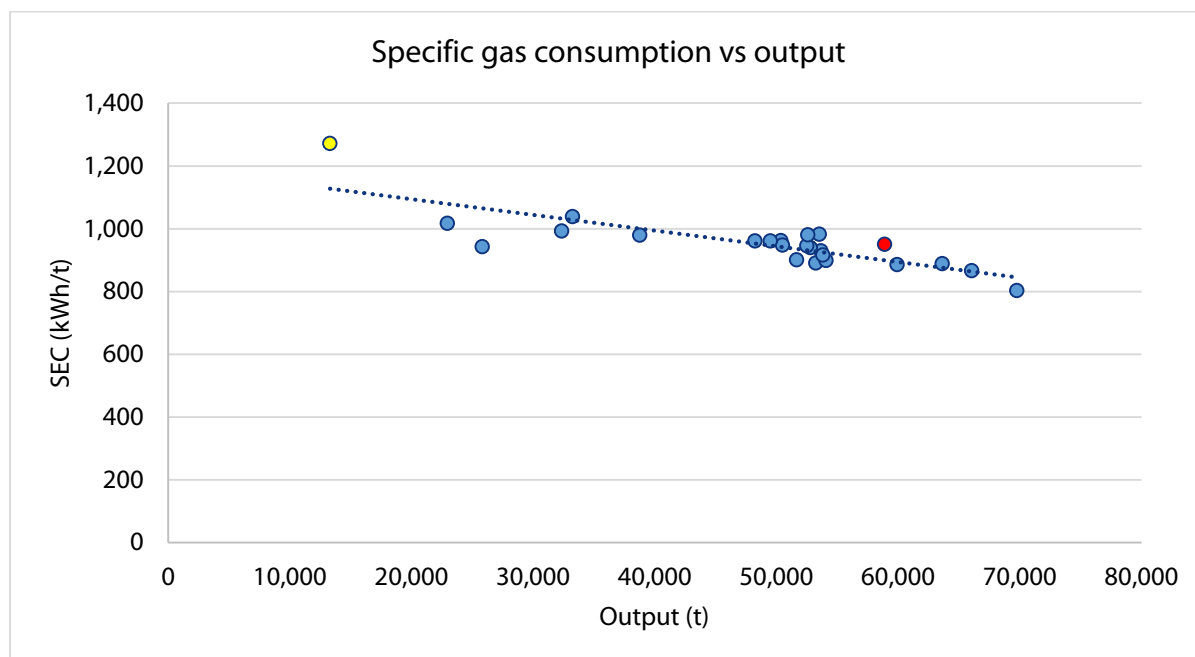
Specific energy consumption – generally measured as energy consumption per unit of output – is often used to indicate energy performance. It can be useful for benchmarking against other companies producing in a similar environment, and for identifying trends at global, country or industry level. It is generally an indicator of energy intensity – as specific energy consumption rises, the energy consumed per unit of output is rising and vice versa – but for monitoring energy performance it needs to be used with care. If we wish to validate whether our energy efficiency initiatives are driving energy performance improvement, specific energy consumption is often a poor indicator. This is because it may improve purely due to higher demand from the market, rather than due to energy saving initiatives being undertaken.

The reason for this is as follows. For most processes energy consumed consists of a) a fixed amount (also called the 'baseload') which is consumed irrespective of output, and b) a variable amount which increases as output increases. When calculating specific energy consumption:

$$\begin{aligned} \text{Specific energy consumption} &= \frac{\text{Energy consumption}}{\text{Output}} \\ &= \left[\frac{\text{Fixed consumption (baseload)}}{\text{Output}} \right] + \left[\frac{\text{Variable consumption}}{\text{Output}} \right] \end{aligned}$$

Generally, as output increases the first term in the equation (baseload/output) falls, whereas the second term (variable/output) remains constant. This means that specific energy consumption usually falls as output increases. For example, *Figure 4* shows the specific energy consumption of an electric arc furnace and clearly shows a downward trend as output increases.

Figure 4: Specific energy consumption of an electric arc furnace



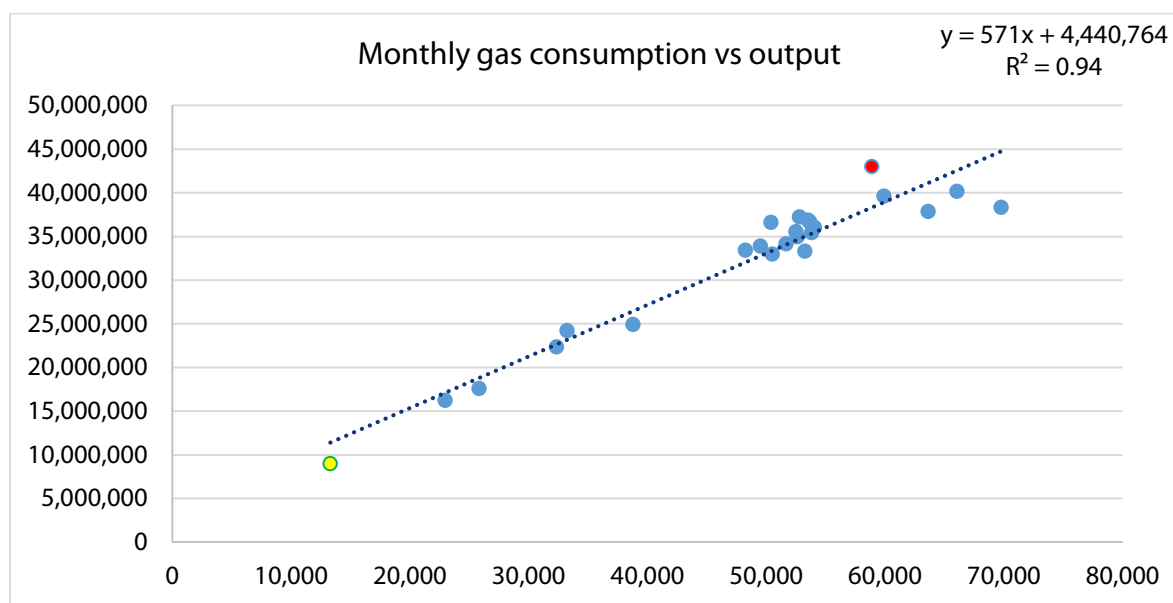
Therefore, specific energy consumption is an imperfect indicator of energy performance. In order to verify whether the energy management activities being implemented in an organisation are driving improvement in energy performance, other indicators are required.

Monitoring energy consumption against a baseline using regression analysis

To overcome the problem with specific energy consumption for processes that have a significant baseload we can use regression analysis to identify the normal relationship between energy consumption and the variables that drive energy consumption – also known as ‘drivers’. In industry the main driver is often output. We use regression analysis to determine the ‘normal’ relationship between energy consumption and output – this tells us the normal or expected energy consumption for a given level of output. We then compare the actual energy consumption with the normal energy consumption. If the energy consumption is less than the norm for that level of output this indicates good energy performance, if the energy consumption is greater than the norm for that level of output this indicates poor energy performance.

Figure 5 takes the same data used for *Figure 4* but plots monthly energy consumption versus output in a scatter diagram with a line of best fit drawn through the data using regression analysis. Two corresponding points are highlighted in yellow and red in *Figure 4* and *Figure 5*. In the former, the yellow dot is a point with high specific energy consumption, which looks like poor energy performance; the same yellow dot in *Figure 5* is below the norm (that is, consumption was lower than normal for this level of output), which indicates good energy performance. On the other hand, the red dot in *Figure 4* indicates a month with low specific energy consumption; the same red dot in *Figure 5* shows that energy consumption is above the norm for this level of output, indicating poor energy performance.

Figure 5: Regression analysis of an electric arc furnace



The equation for a straight line is: $y = mx + c$

Or, in the case of energy consumption driven by output: Energy = (slope x output) + intercept

In this equation, the intercept represents the energy consumption as output trends towards zero – the baseload – and the slope represents the incremental energy consumed per unit of output. A high baseload can indicate big potential for energy savings by focusing on why so much energy is consumed even when production trends towards zero.

The R^2 parameter shown under the equation in *Figure 5* is the regression coefficient, and is an indicator of the distance between the points in the graph and the line of best fit. A high R^2 indicates that the line of best fit is close to the points and therefore the equation closely represents the data. A low R^2 indicates that the points are far from the line and the equation does not closely represent the data. Higher R^2 values give us a higher degree of confidence in the energy performance model generated from the equation.

The equation developed using regression analysis is called the 'baseline equation'. This 'baseline' represents the norm against which we will measure improvement, so it should be based on data from a period when production levels and energy consumption are both relatively normal.

In *Figure 5*, the baseline equation is:

$$y = 571x + 4,440,764$$

That is:

$$\text{Energy consumed per month} = 571 * \text{output} + 4,440,764$$

According to this baseline there is a monthly baseload of 4,440,764 kWh, and a variable consumption which increases by 571 kWh for each extra unit of output. The R^2 value is 0.94 so we can have a high degree of confidence in this baseline equation representing normal energy consumption.

Let's assume that in January we consumed 25,000,000 kWh when the output was 40,000t and we wish to analyse whether this was good energy performance. The baseline equation would predict that the normal level of energy consumption for an output of 40,000t is:

$$\begin{aligned} \text{Baseline energy consumption} &= 571 \times \text{output} + 4,440,764 \\ &= 571 * 40,000 + 4,440,764 = 27,280,764 \text{ kWh} \end{aligned}$$

In this case, the actual consumption of 25,000,000 kWh is less than the baseline consumption. This indicates good energy performance.

Monitoring energy consumption against a baseline using multivariate regression analysis

Often there is more than one variable that drives energy consumption. If so, we can use multivariate regression to establish a baseline equation describing the normal relationship between energy consumption and the drivers. For example, in a bakery that consumes gas to provide space heating and to heat the ovens that bake the bread, gas consumption is likely to be driven by oven throughput. It is also likely to be driven by the average external temperature; the lower the temperature, the more gas will be required to heat the ovens and to heat the bakery. Therefore, the relationship is likely to be in the form of:

$$y = m_1x_1 + m_2x_2 + C$$

That is:

$$\text{Gas consumption} = (\text{co-efficient 1} * \text{throughput}) + (\text{co-efficient 2} * \text{average external temperature}) + \text{Constant (i.e., the baseload)}$$

Table 1 shows the relevant baseline data collected over eight typical months for the bakery.

Table 1: Eight-month baseline data for a bakery

Month	Gas consumption (kWh)	Production (tons)	Heating degree days
Jan	1,752,927	1,645.3	560
Feb	1,775,279	1,776.9	709
Mar	1,708,707	1,791.4	351
Apr	1,487,739	1,618.1	194
May	1,476,904	1,744.0	73
Jun	1,340,669	1,669.5	28
Jul	1,402,126	1,666.1	7
Aug	1,038,774	1,224.9	2

Heating degree days is a measure of how far the average external temperature for the month was below the temperature level normally recommended for turning on the space heating (15.5°C). If the average temperature each day was 10.5°C for 30 days, then the heating degree days is calculated as the number of days for that month multiplied by the difference between the average temperature and the temperature at which space heating is required. In this case:

$$\text{Heating degree days} = 30 \times (15.5 - 10.5) = 150 \text{ HDD}$$

Analysing the data in Excel using the regression function in the data analysis tool under the 'Data' tab yields the results in *Table 2*. (Note if the data analysis tool does not appear in your Data tab it can be uploaded to Excel as an 'Option'.)

Table 2: Excel regression function results

<i>Regression statistics</i>		
Adjusted R square	0.938	
	<i>Coefficients</i>	<i>P-value</i>
Intercept	152,788.4	
Production (ton)	737.2	0.003867
Heating degree days	559.7	0.002096

The adjusted R^2 of 0.938 indicates a 93.8% correlation between the variation in gas consumption and the drivers: production and heating degree days. The equation that describes this relationship is obtained from the coefficients in the table:

$$\text{Gas consumption} = 737.2 \times \text{Production} + 559.7 \times \text{Heating degree days} + 152,788.4$$

The P-value is a measure of the likelihood that there is a relationship between the energy consumption and the two 'drivers' – production and heating degree days. If the P-value is low (ideally below 0.05), then it is very likely that there is a relationship. In this case both P-values are below 0.05, so we can be confident there is a relationship between energy consumption and both drivers. We can now monitor energy performance by comparing actual energy consumption with the baseline energy consumption predicted by this equation. Let's assume we consumed 1,800,000 kWh in January when the production was 1600t and the heating degree days was 600. The baseline equation would predict that the normal level of energy consumption under these conditions is:

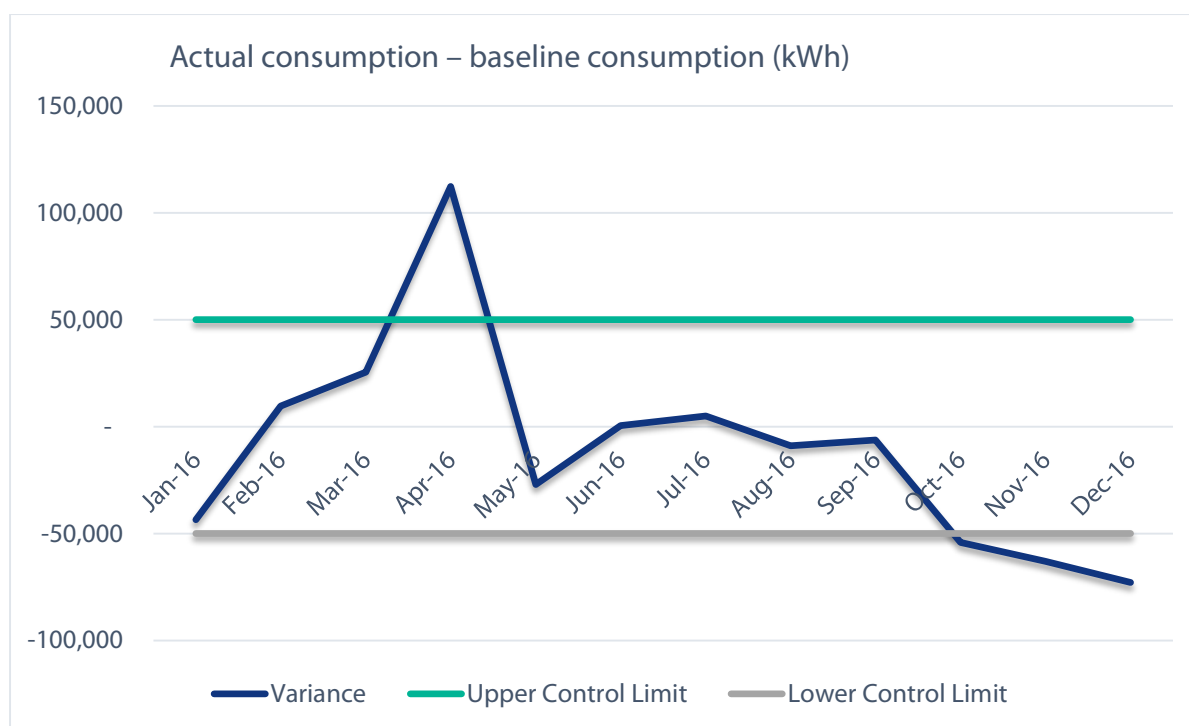
$$\begin{aligned} \text{Baseline energy consumption} &= 737.2 \times 1600 + 559.7 \times 600 + 152,788.4 \\ &= 1,668,128 \text{ kWh} \end{aligned}$$

In this case the actual consumption of 1,800,000kWh is greater than the baseline consumption. This indicates poor energy performance.

Control charts

When a reliable baseline has been developed, the relationship between the actual consumption and the consumption predicted by the baseline can be used to track energy performance. The difference between actual consumption and baseline consumption can be plotted in a control chart with upper and lower limits set to reflect normal variation in energy consumption. If it deviates above the upper limit, this indicates an abnormal event and should provoke an investigation to identify the cause of poor performance and correct it. If it deviates below the lower limit, this is again abnormal and should provoke an investigation into the cause of improved performance and see if the circumstances which caused it can be repeated and standardised as normal practice. In *Figure 6*, Apr-16 stands out as a period of poor performance which needs investigation to prevent recurrence, whereas Dec-16 stands out as a period of good energy performance which also merits investigation.

Figure 6: Control chart example

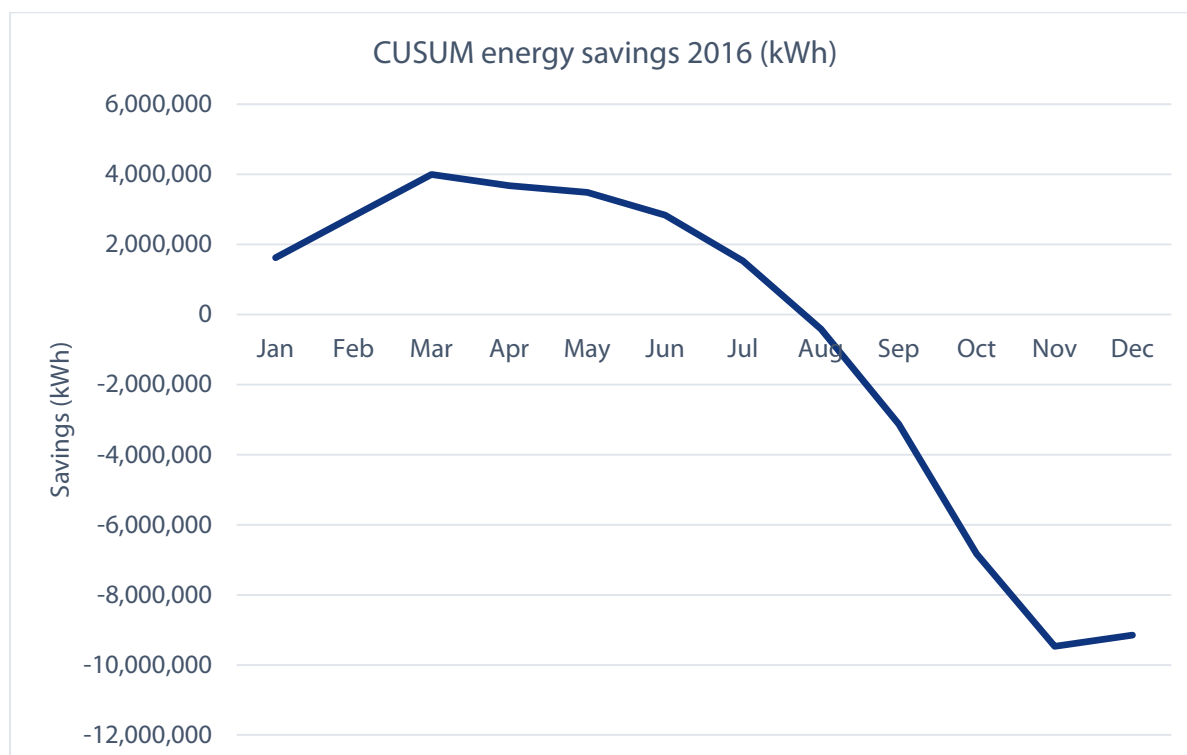


CUSUM charting

CUSUM (cumulative sum control chart) is a powerful technique for illustrating energy performance of a plant or energy-consuming system – a steam system, kiln etc. Energy consumption is monitored and compared to a weekly/monthly baseline, as indicated in *Table 3*. The CUSUM is the cumulative sum of the difference between the actual consumption and the baseline; *Figure 7* illustrates an electric arc furnace example.

Table 3: A CUSUM chart example

	Output	Baseline energy consumption	Actual energy consumption	Actual consumption - baseline consumption	CUSUM
Month	ton/month	kWh/month	kWh/month	kWh/month	kWh
January 2016	53,233	34,836,841	36,452,987	1,616,146	1,616,146
February 2016	51,649	33,932,248	35,126,987	1,194,739	2,810,885
March 2016	53,655	35,077,716	36,259,665	1,181,949	3,992,834
April 2016	48,222	31,975,616	31,656,578	-319,038	3,673,796
May 2016	59,899	38,643,278	38,456,966	-186,312	3,487,484
June 2016	54,058	35,308,125	34,656,252	-651,873	2,835,611
July 2016	52,780	34,578,369	33,268,564	-1,309,805	1,525,806
August 2016	50,371	33,202,447	31,256,445	-1,946,002	-420,196
September 2016	25,801	19,173,214	16,459,785	-2,713,429	-3,133,625
October 2016	66,038	42,148,680	38,452,154	-3,696,526	-6,830,151
November 2016	63,622	40,768,671	38,125,689	-2,642,982	-9,473,134
December 2016	69,758	44,272,342	44,598,764	326,422	-9,146,711

Figure 7: CUSUM electric arc furnace example

The CUSUM graph in *Figure 7* can then be analysed to detect significant events affecting energy performance. If consumption conforms to the norm then differences between the actual consumption and the baseline will be small and randomly positive or negative, and the CUSUM will trend towards zero over time. However, when a change in performance occurs, it will show up on the graph as a change in direction/angle of the line: upwards for a fault until it is resolved – at which point the graph should revert to horizontal – or downwards for an improvement, with the line continuing in that direction as long as the improvement is sustained. The CUSUM graph therefore consists of straight sections separated by angles; each angle is associated with a change in performance, and each straight section is associated with a time when the performance is stable. In *Figure 7*, we can see that energy performance was worse than the baseline during Q1 2016. It gradually improved during Q2. This was followed by a period that was significantly better than the baseline up to November 2016. During December 2016, something occurred to reverse this trend and energy performance was again worse than the baseline, as indicated by the fact that the line is again trending upwards.

Monitoring frequency

The frequency of monitoring is an important consideration. Although monitoring can be automated, it still takes time to implement the monitoring and to review the results. Excessive monitoring is wasteful; however, if monitoring is too infrequent energy waste may continue for an extended period without being corrected.

Frequent monitoring also makes it easier to identify causes of waste that may disappear in data that is aggregated over a longer period. In general, the energy consumers that cost most to run should be monitored more frequently than smaller consumers. The level of variation should also be taken into account; loads that vary regularly should be monitored more frequently than loads that generally remain predictable over a long period of time. Typically, it is recommended to monitor significant energy users at least weekly in order to prevent extended periods of excess consumption.

Targeting

Once energy consumption is being monitored effectively, the information collected should be used to set targets. Actual energy consumption should then be compared to the target.

Targets can be set based on:

- Thermodynamic minimum plus a percentage to allow for imperfect processes and for the percentage loading.
- Manufacturers' recommendations.
- A benchmark against companies carrying out similar activities.
- A percentage improvement versus the previous shift/day/week/month/year, taking relevant variables into account.

In practice, taking the relevant variables into account using regression analysis is often the most effective method of developing targets that are achievable and justifiable.

The CUSUM technique detailed previously can be used to identify sustained periods of good performance, which can then be set as a target. For example, in *Figure 7*, it may be possible to set the period from August to November – where there is a sustained period of savings versus the baseline – as a targeted norm for the future, and an equation can be developed to model this period of good performance. Future consumption can then be compared to this target performance.

Reporting

Different audiences require different information at different frequencies. The operator of a large energy consumer should be aware of their energy performance indicators in real time; they should be alerted to any change so that they can address it as it occurs. Supervisors will typically need to know the energy performance indicators on a daily basis for major energy consumers. Engineering and maintenance personnel will need to be aware of anomalies as they occur so they can be investigated and corrected. Senior management will generally not need to be made aware of the indicators in real time – more likely on a quarterly or annual basis – and will be more interested in variances expressed in monetary amounts.

Reports should indicate clearly to the audience whether or not they need to take action. Reporting by exception, whereby only energy consumption that is outside of the norm is reported, can help to focus attention on the areas that need action and avoid problems/opportunities getting lost in the noise of too many reports.

The energy performance indicators can be reported in the following formats.

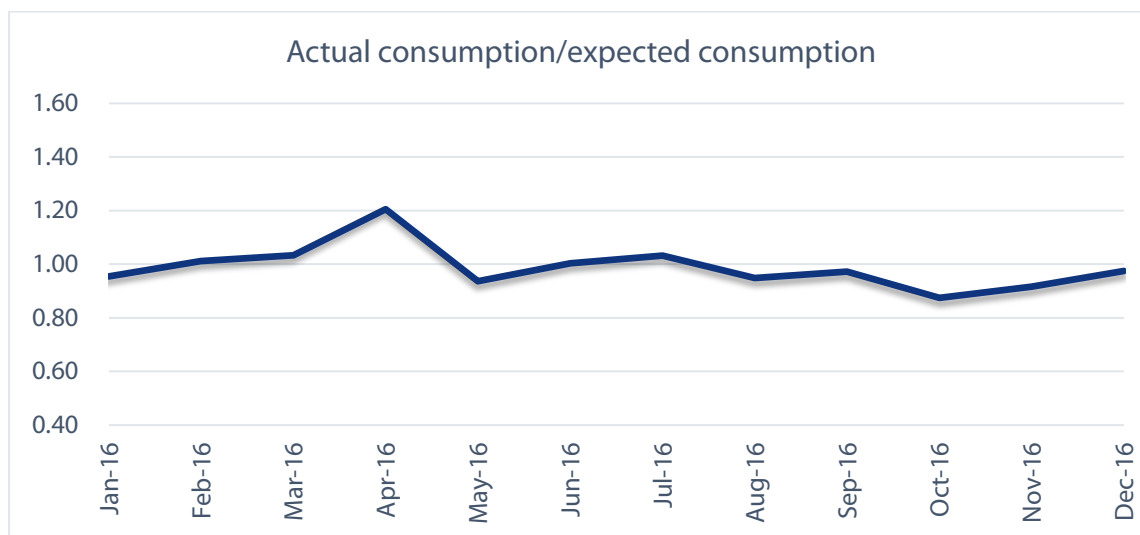
Absolute consumption

The most basic format for energy performance reporting is a graph of absolute energy consumption versus time as shown previously in *Figure 2*. A more sophisticated format is the annualised graph of energy consumption (*Figure 3*) which can effectively highlight trends in energy consumption.

Actual consumption vs budget/target/baseline

The difference between actual consumption and budget/target/baseline can be recorded and shown graphically. It can also be reported as a ratio between actual consumption and budget/target/baseline, as in *Figure 8*. As detailed above in section 4.2.6 the difference between actual and expected consumption can also be effectively highlighted using a CUSUM chart.

Figure 8: Ratio between actual consumption and budget/target/baseline



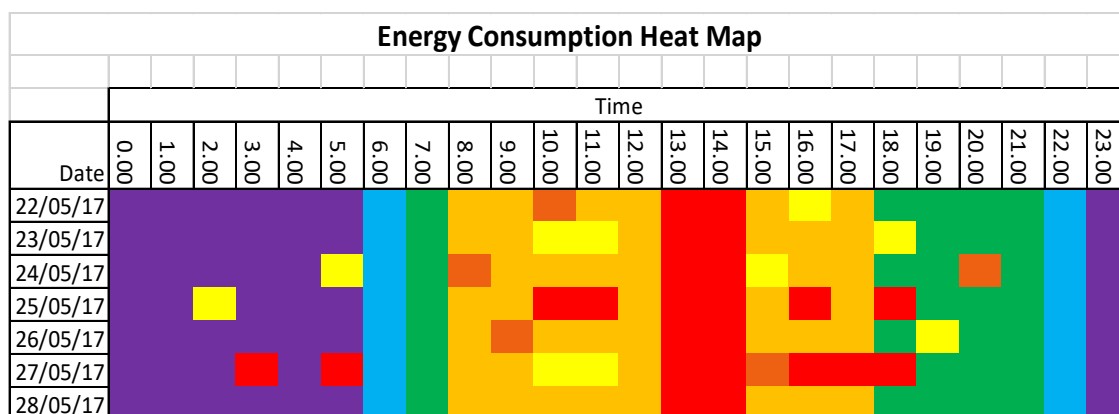
Control charts

Actual consumption, or the difference between actual and baseline consumption, can be displayed in a control chart (see *Figure 6*) with upper and lower limits. Deviations outside the control limits prompt investigation. This is easy to understand and also changes regularly, which is helpful in maintaining people's attention. It can be very effective when employed at shop floor level to communicate with operators and supervisors.

Heat maps

The magnitude of the energy consumption can be colour coded so that red indicates high energy consumption/cost versus the baseline, whereas blue indicates low energy consumption/cost versus the baseline (*Figure 9*). This can be a very effective method of communication to senior management – particularly when it is based on cost.

Figure 9: Colour-coded energy consumption heat map



Overspend league table with traffic lights

This technique ranks the energy consumers in order of overspend so that the plant that is costing the most versus its budget or baseline is highlighted and listed at the top. This can be used in conjunction with control charts, where processes with variances that are outside the normal control limits are highlighted in red or green for priority investigation. It is especially useful for senior management, who are particularly interested in the bottom line. In *Table 4*, red indicates consumption above the control limit, yellow indicates consumption within the control limit and green indicates consumption below the control limit.

Table 4: Overspend league table

	Overspend vs baseline (€)	Overspend vs baseline (kWh)	Within control limits?
Grinder 1	4,500	50,000	●
Grinder 2	3,800	42,222	●
Extruder 4	3,200	35,556	●
Extruder 6	2,450	27,222	●
Boiler 3	1,580	45,143	●
Chiller 2	900	10,000	●
Mixer 3	500	5,556	●
Mixer 2	-590	-6,556	●
Chiller 4	-1,985	-22,056	●
Grinder 3	-2,357	-26,189	●
Extruder 2	-2,400	-26,667	●
Boiler 1	-2,450	-70,000	●
Chiller 1	-2,890	-82,571	●

Revising energy performance indicators

Energy performance indicators are not set in stone; they should change when appropriate. For example:

- If the energy source for a site or a process changes, this will require a new indicator
- The processes that were significant energy users may not continue to be significant energy users and hence may no longer need their energy performance indicators monitored. Other processes that were not significant energy users last year may become significant energy users this year.
- Process changes may require the relationship between energy consumption and the relevant variables to be reassessed and a new baseline to be developed. If a major upgrade is made to the process, then initially the consumption should be measured against the existing baseline to verify savings. When savings have been verified over a given time period, it usually makes sense to develop a new baseline using energy consumption and relevant variable data for the period following the upgrade.
- Energy performance indicators should be re-examined annually if they have not been revised for other reasons within the year. For example, if the baseline is set in 2014, and the indicator shows an improvement of 10% in 2016 versus the baseline this may be interpreted as progress. However, if the indicator showed a 15% improvement in 2015 versus the 2014 baseline, then 2016 is actually a worse performance than 2014. This confusion can be avoided by revising baselines annually.

Monitoring and targeting software

There are many software packages available that can be very useful in facilitating monitoring and targeting, particularly in cases where there are multiple processes, variables, and people who need to be involved or informed. The software will typically collect energy consumption data from energy meters via data loggers.

Cost and relevant variable data are collected from the enterprise database or the internet. The software analyses the data to generate useful information, including energy consumption and cost trends, baselines developed using regression analysis, control charts, CUSUM graphs and heat maps.

Information is automatically distributed depending on need such that energy managers, engineers, supervisors, financial controllers and general managers may all receive different information at different frequencies from the system.

It must be noted that a standard Excel package can deliver most of the functionality that the monitoring and targeting software packages deliver. However, a good software package used wisely can save the organisation a lot of time and, as a result, can be very cost effective.

Conclusion

Monitoring and targeting is a vital element in every effective energy management programme. It has the potential to deliver substantial energy savings and it can also act as an early warning system that can improve quality, reliability and health and safety. In general, it is neither expensive nor complicated to implement. All organisations with significant energy consumption should be practising monitoring and targeting using some of the techniques outlined in this guide.



e info@seai.ie
w www.seai.ie
t +353 1 808 2100



Rialtas na hÉireann
Government of Ireland