Module 7: Energy Monitoring, Targeting & Reporting

Energy information management is the next issue raised in the energy management matrix, and it is especially important as a component of any effective energy management strategy. The experience of industries in Canada and the UK, for example, is that monitoring, targeting and reporting (MT&R) alone can lead to significant energy reductions. This Module develops a practical working knowledge of the techniques known as MT&R, including the computational methods used to correlate energy consumption to the key energy use drivers such as production, the analysis of consumption patterns using the CUSUM technique, the determination of reduction targets, and the development of control mechanisms for production-floor management of performance.

Module 7 Learning Objectives

After completing this module, you will

- Understand how MT&R can produce the information you need to manage your energy consumption downward;
- Appreciate the immediate actions that you can take to better understand the information that can be derived from existing energy data.
- Describe the difference in purpose and activity of M&V and M&T

7.1 A Rationale for Monitoring, Targeting and Reporting (MT&R)

Why look back?

The energy used by any business varies as production processes, volumes, and inputs vary. Determining the relationship of energy use to key performance indicators will allow you to determine:

- Whether your current energy use is better or worse than before;
- Trends in energy consumption that reflect seasonal, weekly, and other operating patterns;
- How much your future energy use is likely to vary if you change aspects of your business;
- Specific areas of wasted energy’
- Comparisons with other businesses with similar characteristics. This “benchmarking” process will provide valuable indications of the effectiveness of your operations as well as an indication of energy use;
- How your business reacted to changes in the past;
- How to develop performance targets for an energy management program.

Source: Energy-wise Practice 12, NZ Energy Efficiency and Conservation Authority

There are many ways for industrial companies to improve their energy performance. These typically include:

- Identification of savings opportunities through energy surveys or audits, involving the physical inspection of plant facilities and process equipment;
- Employee-focused activities, such as campaigns to increase awareness, motivation and involvement in energy management activities throughout the company;
- Organisational practices, such as the formulation of policy, the assignment of energy responsibilities, the provision of training, etc.
- Facility and process retrofits, incorporating more efficient technology;
- Implementation of operational and maintenance practices that take into account the energy efficiency impacts.

MT&R is not a substitute for these actions, but it does complement them. It can often provide useful information when implementing these other approaches, thus making them more effective. It also closes the "accountability loop" by providing feedback on performance improvement measures that have been implemented, even to the point of assessing the return on investment in terms of savings achieved.

Increasingly used in Canada, monitoring and targeting has a long history in the UK, having been launched as a national program in 1980. Over 50 industry sector studies have demonstrated the benefits of monitoring and targeting repeatedly. These benefits include:

- **Energy cost savings**, typically 5 to 15% as a direct consequence of the MT&R program, with concomitant reductions in emissions of CO_2 and other pollutants;

- **Co-ordination of energy management policy**, through targeting of initiatives that achieve the maximum benefit, and sustaining savings over the long term;

- **Assisting with the acquisition of financing for energy efficiency projects,** through the accurate determination of baseline energy use levels for energy efficiency project proposals, and verification of savings;

- **Improved product and service costing**, by the definition of the energy content of products and services;

- **Improved budgeting**, by providing a basis for the more accurate projection of future energy use for given levels of activity;

- **Better preventative maintenance,** by increasing the availability of performance data on energy systems;

- **Improved product quality,** by increasing the level of control on production processes;

- **Waste avoidance,** by the extension of the principles of MT&R to other environmental management issues, such as water consumption, materials management, plant downtime, and so on.

MT&R is the management information basis for achieving energy efficiency gains.

A Case Study: Toray Textiles (Europe) Ltd.

The Bulwell factory of Toray Textiles (Europe) has been a textile plant since the 19th century. The site produces around 20 million metres of fabric per year, with a sales value of £40 million, and employs about 200 staff. Operations on the site include scouring, bleaching and dyeing; three open-width scouring machines, 18 pressurised jet dyeing machines and two stenters are used.

Toray Textiles acquired the site in 1989 and initiated a major energy efficiency drive. Over the period 1989 - 1993 the site achieved an **energy reduction of 27%, with half of the savings being generated through measures involving little or no capital expenditure**.

The new energy management programme was based on:
- Monitoring &Targeting;
- staff motivation,
- training;
- good housekeeping;
- modem management techniques;
- capital investment.

In the new programme, the site's engineering manager was responsible for collecting weekly energy consumption data. These were then indexed to production to give a measure of energy efficiency.

Involvement of all staff was seen to be crucial to the success of the energy-saving programme. Toray Textiles set up Small Group Activities that were based on management and workforce meeting regularly to discuss problems and suggest improvements. This approach has had a significant impact on reducing energy use, in particular through good housekeeping and the identification of the following major energy-saving projects:
- heat recovery from the scouring machines;
- insulation of dyeing vessels:
- economisers for boiler feed water;
- improvements in condensate return system;
- inverter drives on various machines.

The Monitoring and Targeting system used energy data from steam, electricity and water meters. The engineering manager was able to use the system to:
- track energy performance;
- monitor overall energy savings (using CUSUM) and determine the contribution made by specific energy efficiency actions to these overall savings.

By December 1993, the energy management initiatives implemented by Toray Textiles had saved nearly **75 million kWh**. This equates to about one year's energy consumption for the site and is clearly significant in terms of the company's operating costs and profits.

Source: Good Practice Guide 148: Monitoring and Targeting in the textiles industry, UK Best Practice Programme

7.2 The Scope and Information Sources for MT&R

Depending on the nature of your organisation, there may be available, or obtainable, a hierarchy of information related to energy use with levels such as the following:

- **Plant** level information can be derived from financial accounting systems—the utilities cost centre.

- **Plant Department** information can be found in comparative energy consumption data for a group of similar facilities, utility billings, service entrance meter readings, building management system data, correlated with building use and production data.

- **System** (for example, boiler plant) performance data can be determined from sub-metering data, subjected to regression analysis against key independent variables.

- **Equipment level** information can be derived from nameplate data, run-time and schedule information, sub-metered data on specific energy consuming equipment.

The important point to be made here is that all of these data are useful; all can be processed to yield information about facility performance. It is only after cataloguing the available data, that decisions should be made about taking steps to augment the database.

The scope of MT&R is also a function of its purpose. If energy monitoring is being implemented to verify savings in the context of internal accounting or third-party energy performance contracting requirements, the scope of the program also needs to take into account:

- **Acceptable levels of uncertainty**, in view of the reality that all data are subject to error and that energy consumption is typically impacted by a complex of factors;

- **Cost of implementation,** in recognition of the fact that additional measurement has a cost—both the measurement technology and time costs for personnel—and that the cost needs to be a reasonable proportion of the overall savings achieved;

- **The complexity of energy use variables,** or the degree to which certain factors can be safely assumed to be constant or inconsequential;

- **The number of energy saving measures being monitored,** and whether the impact of each separately or all collectively is of importance.

Often these issues are more important in the context of measurement and verification of savings for energy performance contracting.

7.3 Definitions

Energy monitoring, target setting, and reporting (MT&R) is the activity which uses information on energy consumption as a basis for control and managing consumption downward. The three component activities are distinct yet inter-related:

- **Monitoring** is the regular collection of information on energy use. Its purpose is to establish a basis of management control, to determine when and why energy consumption is deviating from an established pattern, and as a basis for taking management action where necessary. Monitoring is essentially aimed at preserving an established pattern.

- **Target setting** is the identification of levels of energy consumption, which is desirable as a management objective to work toward.
- **Reporting** involves “closing the loop” by putting the management information generated from the monitoring process in a form that enables ongoing control of energy use, the achievement of reduction targets, and the verification of savings.

Monitoring and target setting have elements in common and they share much of the same information. As a general rule, however, monitoring comes before target setting because without monitoring you cannot know precisely where you are starting from, or decide if a target has been achieved. The reporting phase not only supports management control, but also provides for accountability in the relationship between performance and targets.

7.4 Data and information

Within the activity of M&T, data and information are distinct entities. The activity of monitoring a facility, system or process encompasses both measurement and analysis. Data are raw numbers such as would be the result of a measurement. Information is the result of some type of analysis upon data.

Figure 7.1 illustrates the distinction between data and information for a production situation. In this case, energy consumption and production of a melt furnace are routinely measured and recorded.

What refines performance data into management information is analysis—the key feature of the monitoring function. Management information provokes questions about performance that would not be evident in the raw data, and can lead to actions for correction of problems or optimisation of performance.

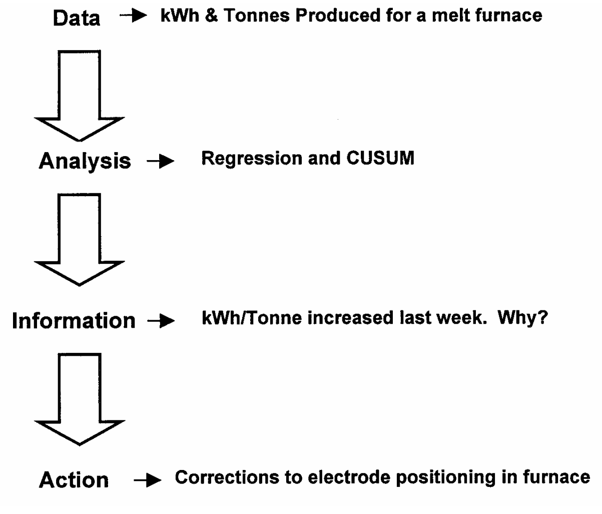

Figure 7.1: Data and Information for a Production Situation

Figure 7.1 suggests that the process is linear; however, we prefer to think in terms of a continuous improvement cycle, as Figure 7.2 illustrates. The action of Figure 7.1—correcting the positioning of the furnace electrode—leads to a new round of monitoring and analysis to ensure that the change has been effective and is being sustained. New optimisation actions typically result, and so the cycle—measure-analyse-action—continues indefinitely, true to the intent of continuous improvement.

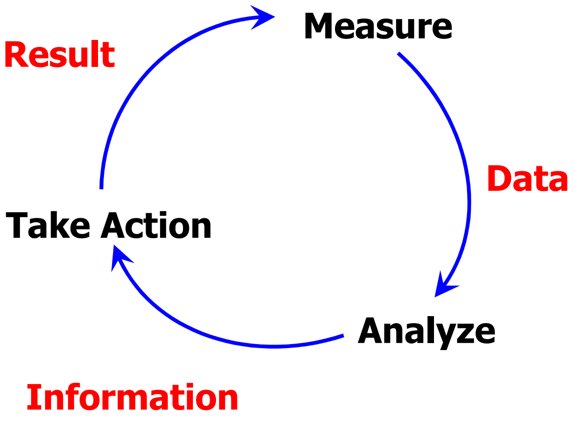

Figure 7.2: The Measure-Analyze-Action Cycle

7.4.1 Information Needs for MT&R

Energy monitoring is used to find out how much energy is costing your organisation, and for developing information to use as a basis for controlling consumption. It is a technique that relies on quantitative—not just qualitative—information about energy use. There are qualitative indicators, to be sure: in many manufacturing processes, the characteristics of the product are determined by the changes, which the input of energy brings about (for example, the colour in a loaf of bread or the dryness of ink).

These qualitative indicators are sensitive and detectable, but not easily quantified and often depend on subjective impression. Energy monitoring requires quantitative information, usually measured, such as:

- Energy billings data, including electrical demand and consumption, fuel consumption, costs.
- Consumption measurements at some level (for example, the entire building, a production department, an individual energy-consuming system).
- Key independent variables that influence energy consumption, such as production of a manufacturing system.

In essence, energy monitoring is the technique of quantitatively relating consumption information to the critical independent variables.

7.4.2 Interpreting Energy Consumption Data

Look at the energy consumption data in Table 7.1 and presented in Figure 7.3. These are two ways of presenting performance data, expressed as electrical energy consumption in kWh and specific energy consumption in kWh/tonne, over time. The form of presentation of these data is quite common practice in industry; the data appear in time series order and the graph uses the energy use per tonne to indicate how energy use depends on the level of production.

Now consider some simple questions, answers to which are contained in these data:

- ♦ How many energy saving measures have been introduced?

- When did each take effect?
- How much energy has each measure saved?
- Are all the energy saving measures still working?
- Have any breakdowns been restored?
- How much energy will be required for a budgeted production of 120 tonnes a week in the next quarter?
- What further savings can be achieved?

Although all this information is available from the data set, it can only be accessed if the right kinds of analyses are applied. To find out what has been going on in this furnace we have to deal separately with two key questions:

- How does energy use vary with production?
- How does the relation between energy use and production change with time?

The methods of discovering answers to these kinds of questions are addressed in the following sections. We are looking for a general procedure that can be used to relate energy consumption to whatever key parameters are determinant, usually production, and/or weather.

7.5 Application: Establishing the Energy Relationship

7.5.1 Energy and production – a theoretical basis

Energy used in production processes typically heats, cools, changes the state of, or moves material. Obviously it is impossible to generalise, as industrial processes are both complex and widely varied. However, a theoretical assessment of specific processes leads to the conclusion that energy plotted against production will produce a straight line of the general form:

$$y = mx + c \qquad \textbf{(Equation 7.1)}$$

or

Energy = slope x production + intercept.

where c, the intercept (and, no load or zero production energy consumption), and m, the slope, are empirical coefficients, characteristic of the system being analysed. While there are certainly situations where this linear model is inadequate, and either a multivariant relationship exists (production and weather, for example), or non-linear functions enter the model, this relationship serves well in the vast majority of cases. *(As one's knowledge of these techniques grows, the special circumstances of other more complex relationships can be accommodated; for the purpose of this course, we are limiting the discussion to single-variant linear relationships.)*

7.5.2 Finding the energy performance model

We have established the principle that energy use data alone are of very limited usefulness in understanding the nature of the energy system, identifying opportunities for efficiency improvement, and controlling energy use in the future. Refining data to information that facilitates these functions involves analysis, following steps illustrated here.

The first step in the analysis process is to determine the functional relationship between energy consumption and the key determining parameters, a relationship of the form of Equation 7.1. This is illustrated for the production situation for which data are given in Table 7.1.

Table 7.1: Energy Use and Production Data

Week	Production (tonnes)	Energy kWh	Specific Energy (kWh/Tonne)
1	150	140726	938
2	80	103223	1290
3	60	90764	1513
4	50	87567	1751
5	170	146600	862
6	180	154773	860
7	120	121575	1013
8	40	81436	2036
9	110	115586	1051
10	90	105909	1177
11	40	83916	2098
12	50	86272	1725
13	140	125892	899
14	155	138966	897
15	165	139922	848
16	190	152274	801
17	40	77788	1945
18	55	82711	1504
19	150	124317	829
20	80	94677	1183
21	63	84628	1343
22	110	108041	982
23	70	89115	1273
24	170	136388	802
25	190	141428	744
26	160	141215	883
27	120	118319	986
28	190	152506	803
29	80	99267	1241
30	90	94468	1050
31	180	140188	779
32	70	91262	1304
33	50	78248	1565
34	155	128005	826
35	167	131003	784
36	120	109192	910

Step 1: Plot energy consumption against production:

A so-called "scatter plot" of the energy consumption – production data can easily be produced using a spreadsheet program such as Excel. When this is done for the data set of Table 7.1, Figure 7.3 results.

Preliminary examination of Figure 7.3 suggests that the energy/production points do fall into a roughly linear pattern, energy increasing with production. The scatter of points is not unexpected when one considers the many complexities that could have a relatively small impact on the energy relationship. As well, any measured data is subject to error based on the way in which the measurement is made or the accuracy of the instruments used to take measurements. However, there may also be some significant factors at work, rather than just “noise”. The challenge is how to distinguish between these significant factors and the “noise”.

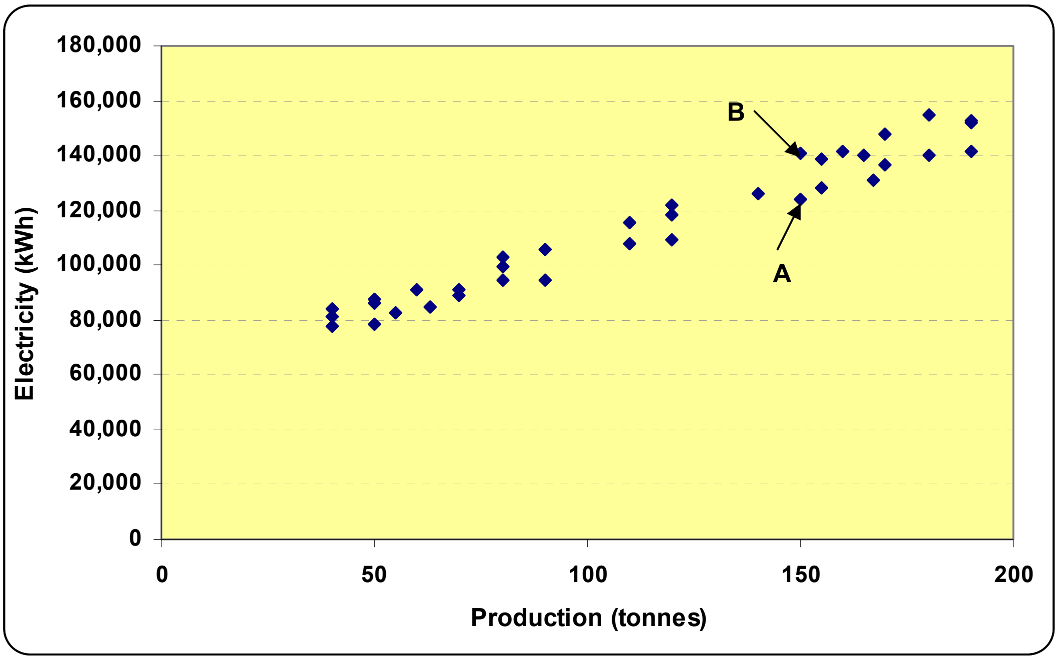

Figure 7.3: Energy vs. Production Scatter Plot

The critical question from a monitoring point of view is, why, for the same level of production, do points A and B have quite different energy consumption? What we need is some means of sorting this out; the technique that does this is called **CUSUM** analysis. CUSUM is a technique for determining whether a specific measured level of consumption varies significantly from the expected level, or whether the variation is just random “noise”.

In Table 7.1, we have calculated the “specific energy”, or energy consumed per tonne. It is very common to do this, but for reasons that will become clearer, it is of very limited usefulness. Even a time series plot of specific energy doesn’t tell us very much (See Figure 7.4).

Step 2: Determine the base-line relationship.

The data plotted in Figure 7.3 show an upward trend, but it is impossible to say whether the scatter observed is just noise or whether something significant has happened to cause it. The difference in energy consumption between points A and B may be random variation, or a real, explainable change in performance.

Again, with the assistance of Excel, we are able to determine a functional relationship between consumption and production by means of the linear regression tool. Asking Excel to place a trend line on the scatter plot, and to show the algebraic expression that defines the line, we get Figure 7.5.

According to this regression, the energy performance model for the entire data set is:

Electricity consumed/week (kWh) = 476.48 x production (tonnes) + 59611
(Equation 7.2)

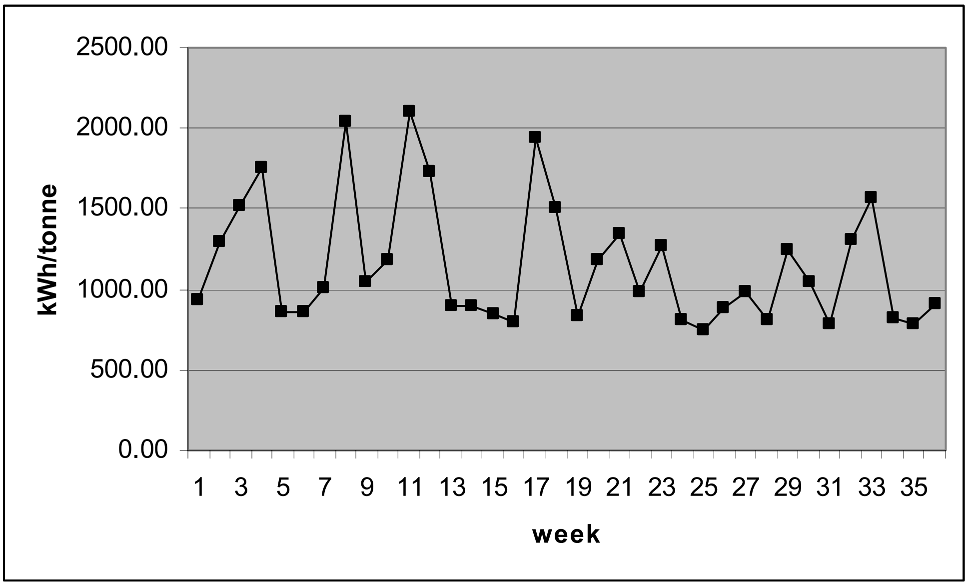

Figure 7.4: Energy Intensity Time Series Plot

There are two parameters in this model:

- the slope, 476.48, represents the incremental energy consumed per tonne of production;
- the y-axis intercept, 59611, represents the "no-production" energy consumption, or base load.

The **physical significance** of these parameters is essential to an understanding of how energy is consumed in the plant, and where efficiencies may be found. It is especially important to recognise that average energy intensity—in this case, kWh/tonne—is a very rough indicator of performance only because it is a value that inevitably will decrease as production increases due to the fact that the base load is being spread over more production.

> While many companies focus on their energy intensity, we hold the view that the more detail provided in this analysis—especially the division of total energy into incremental and base loads—is essential if consumption is to be managed downward.

The R^2 parameter also indicated is a measure of how well the trend line fits the points; 1.0 is a perfect fit. R^2 values of 0.75 or more give us a high degree of confidence in the energy performance model generated.

However, this model is of limited usefulness for either historical analysis (looking back in time) or management control (real time looking forward) if it is possible that there has been one or more changes in performance during the period being analysed.

What we need is a period of consistent performance that can serve as a **baseline**, or a basis for comparison of all other periods.

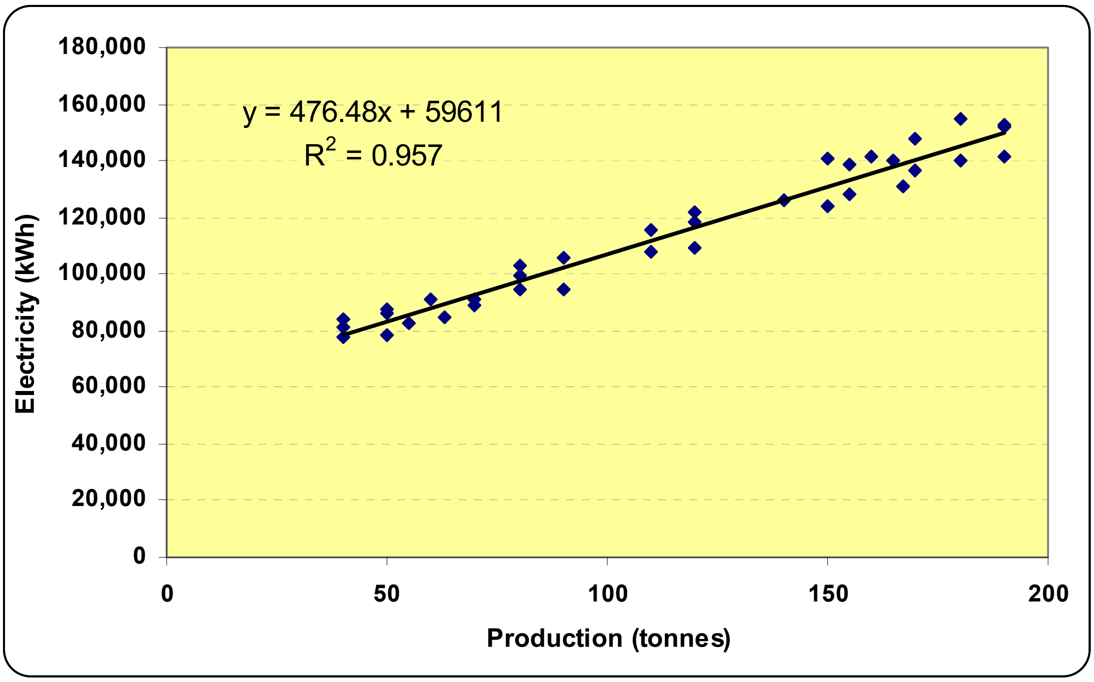

Figure 7.5: Linear Regression of Entire Data Set

The determination of a suitable baseline often is an iterative process in which the baseline regression – CUSUM sequence is repeated until a useful analysis emerges. However, knowledge of the plant circumstances can often point to a particular period as performing consistently, the main criterion for a useful baseline. That is, if it is known that no improvements that relate to energy efficiency were made, and no malfunctions occurred (control system problems, for example), and the production rate was typical for the plant, then that period will probably serve as a good baseline.

As we will see later, the full use of this technique may lead to several baselines being identified for different purposes.

As a starting point, the first third of the data set—that is, the oldest portion of the data—is often a useful first attempt at finding a baseline. In the example of Table 7.1, let's assume that we know that the first 11 weeks exhibited typical and consistent performance. A linear regression on the first 11 points yields Figure 7.6 and a new energy performance model:

Electricity consumption/week (kWh) = 515.8 x production (tonnes) + 60978
(Equation 7.3)

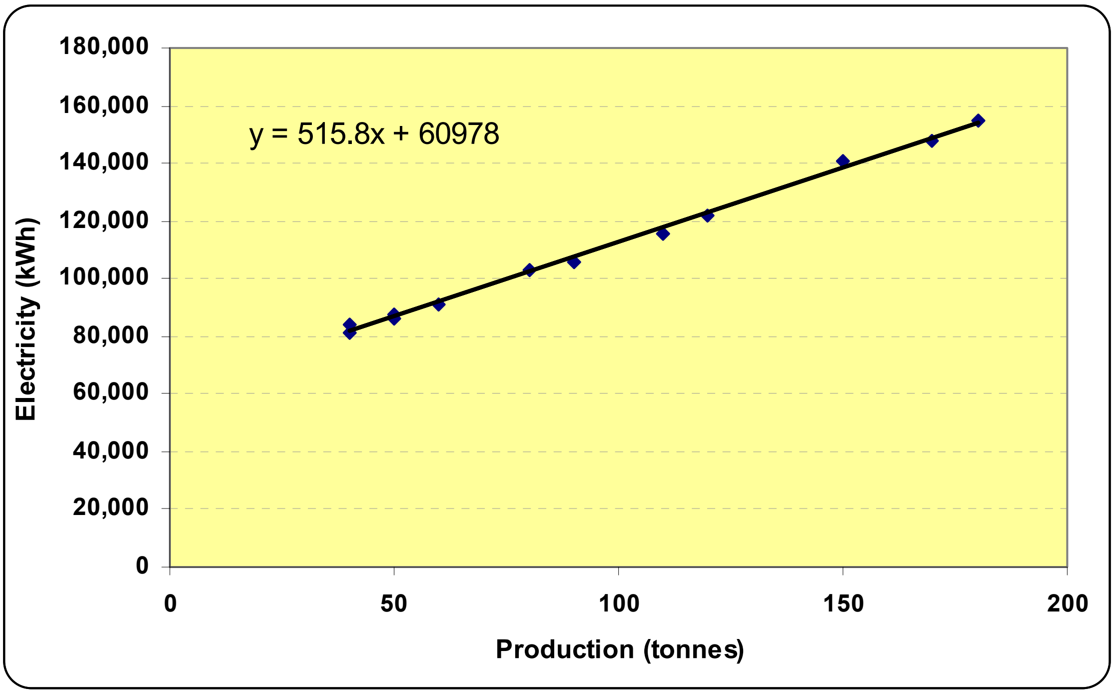

Figure 7.6: Linear Regression of the Baseline Period

In comparing the two performance models, we see:

Table 7.2: Comparison of Energy Performance Models – Total and Baseline

Model	Incremental load, kWh/tonne	Base load, kWh
total data set	476.48	59611
baseline	515.8	60978

The fact that the incremental load and base load for the total data set are both lower than the corresponding values for the baseline indicates that some improvement in performance must have occurred after the baseline period. CUSUM analysis will shed more light on this.

7.6 CUSUM

CUSUM is a powerful technique for developing management information regarding the energy performance of a plant, or an energy-consuming system such as an oven or furnace, for example. It distinguishes between significant events affecting performance—faults or improvements—and noise.

CUSUM stands for 'CUmulative SUM of differences', where 'difference' refers to differences between the actual consumption and the consumption you expect on the basis of some established pattern—what we have called the energy performance model. If consumption continues to follow the established pattern, the differences between the actual consumption and the established pattern will be small and randomly either positive or negative. The cumulative sum of these differences over time, CUSUM, will stay near zero.

Once a change in pattern occurs due to the presence of a fault or to some improvement in the process being monitored, the distribution of the differences about zero becomes less symmetrical and their cumulative sum, CUSUM, increases or decreases with time. The

CUSUM graph therefore consists of straight sections separated by kinks; each kink is associated with a change in pattern, each straight section is associated with a time when the pattern is stable.

Step 3: Calculate the CUSUM

The baseline relationship is used to calculate expected energy consumption for any given production level. It is the difference between this and the actual value that is critical in this analysis.

Equation 7.1 is used to calculate a **predicted** consumption for each week by substituting the production for that week in the formula. If the production was 150 tonnes then

energy = 60 978 + 515.8 x 150 = 138,348 kWh

Subtract the actual consumption from the predicted consumption for each week to find the difference. Add the difference up for all the weeks up to the present to obtain CUSUM.

Again, this is easily done in an Excel spreadsheet, as Table 7.3 shows.

A plot of CUSUM against time is then produced, as shown in Figure 7.7.

Table 7.3: CUSUM Data for Production Example

Measured Data				Baseline		
Week	Production (T)	Specific Energy (kWh/T)	Total Energy (kWh)	Predicted Energy (kWh)	Difference (kWh)	CUSUM (kWh)
1	150	938	140726	138020	2706	2706
2	80	1290	103223	102250	973	3679
3	60	1513	90764	92030	-1266	2413
4	50	1751	87567	86920	647	3060
5	170	862	146600	148240	-1640	1420
6	180	860	154773	153350	1423	2843
7	120	1013	121575	122690	-1115	1728
8	40	2036	81436	81810	-374	1354
9	110	1051	115586	117580	-1994	-640
10	90	1177	105909	107360	-1451	-2091
11	40	2098	83916	81810	2106	15
12	50	1725	86272	86920	-648	-633
13	140	899	125892	132910	-7018	-7651
14	155	897	138966	140575	-1609	-9260
15	165	848	139922	145685	-5763	-15023
16	190	801	152274	158460	-6186	-21209
17	40	1945	77788	81810	-4022	-25231
18	55	1504	82711	89475	-6764	-31995
19	150	829	124317	138020	-13703	-45698
20	80	1183	94677	102250	-7573	-53271
21	63	1343	84628	93563	-8935	-62206
22	110	982	108041	117580	-9539	-71745
23	70	1273	89115	97140	-8025	-79770
24	170	802	136388	148240	-11852	-91622
25	190	744	141428	158460	-17032	-108654
26	160	883	141215	143130	-1915	-110569
27	120	986	118319	122690	-4371	-114940

28	190	803	152506	158460	-5954	-120894
29	80	1241	99267	102250	-2983	-123877
30	90	1050	94468	107360	-12892	-136769
31	180	779	140188	153350	-13162	-149931
32	70	1304	91262	97140	-5878	-155809
33	50	1565	78248	86920	-8672	-164481
34	155	826	128005	140575	-12570	-177051
35	167	784	131003	146707	-15704	-192755
36	120	910	109192	122690	-13498	-206253

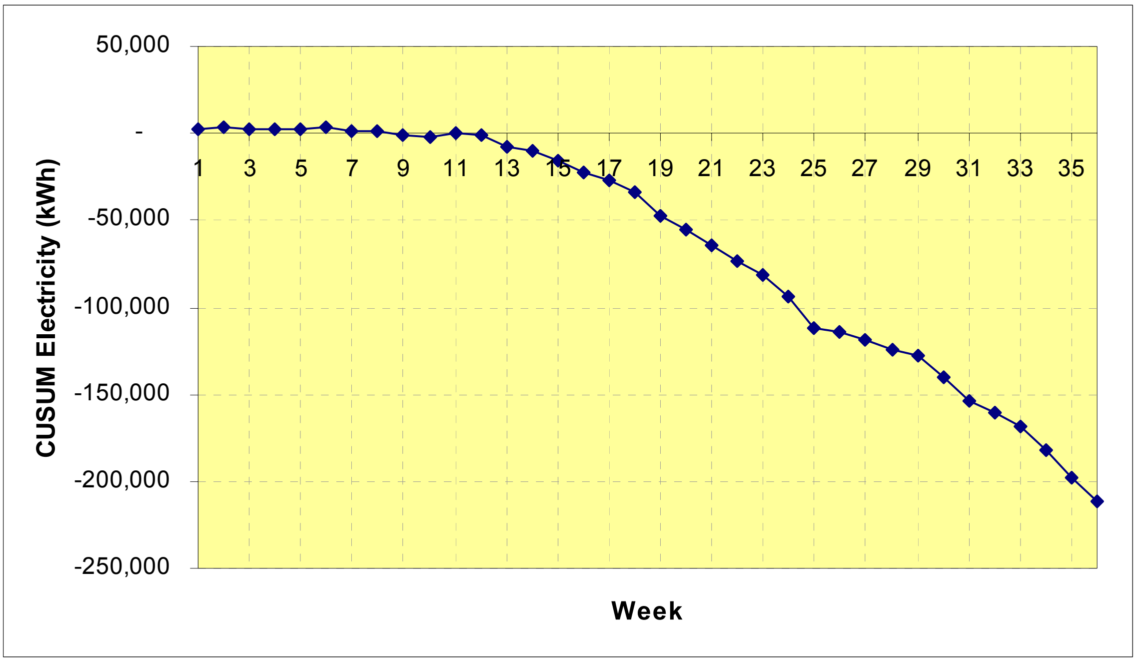

Figure 7.7: CUSUM Graph for Production Example

Step 4: Interpret the CUSUM Graph

The critical points on the CUSUM graph are the changes in slope of the line. These can be easily seen, and more precisely located by laying straight lines over the more or less constant slope sections, as illustrated in Figure 7.8. We see that these slope changes occurred at weeks 12, 18, 25 and 30.

More specifically in terms of the process being analysed, the graph indicates:

- There have been two measures to reduce consumption; one took effect in week 12 and one in week 18.
- The first measure had saved 73,500 kWh and the second measure had saved 36,800 kWh by the time the second measure broke down in week 25.
- This second measure was restored in week 30 and by the end of data series the combined measures had saved 201,300 kWh.

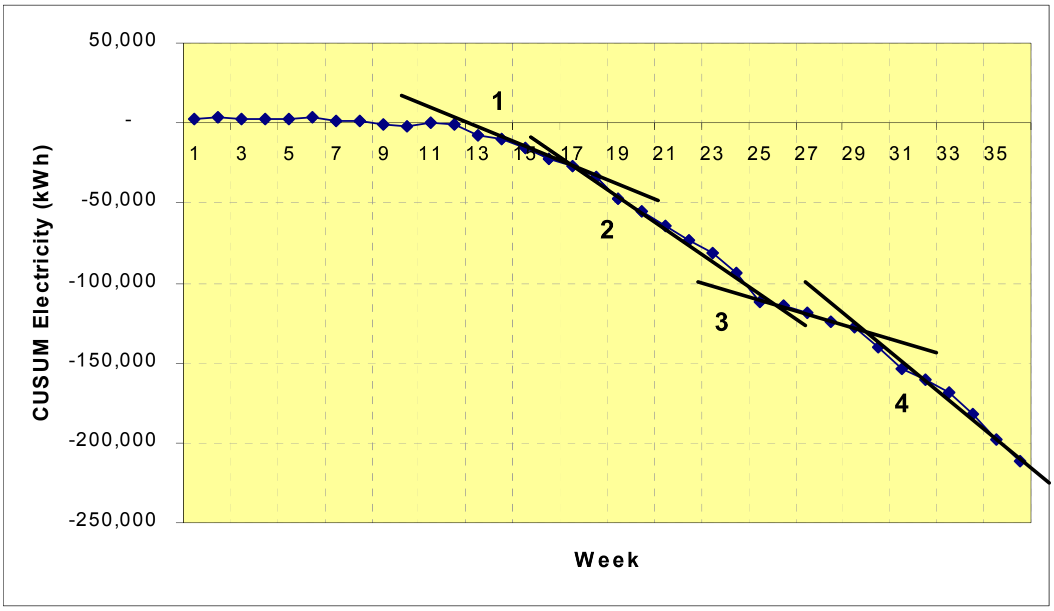

Figure 7.8: Interpreting the CUSUM graph

Now it is clear why the points A and B in Figure 7.4 had such different consumption values. **A** is for week 1, which is in the baseline, but **B** is week 19, and occurs after two energy saving measures had been introduced.

7.7 Summary: Regression and CUSUM

We have seen how to:

- Plot energy use against the independent variable that applies (e.g. production or weather).
- Carry out regression analysis to determine the functional relationship between energy consumption and the independent variable.
- Determine the baseline relationship from the regression analysis.
- Use the baseline relationship to calculate “predicted” energy consumption for real values of the independent variable.
- Determine the difference between the predicted and the actual energy consumption, and the cumulative sum of the differences (CUSUM).
- Construct and interpret the CUSUM plot.

All of this can be done with only a basic understanding of the use of Excel.

7.8 The Control Chart

It is now possible to choose periods of better performance as targets for future performance. This target period may be the most recent weeks in our sample data set, or it may be some other portion of the data set that exhibits desired efficiency. Whatever the choice of target period, we need a new baseline against which to control energy consumption into the future.

Determining a new functional relationship involves exactly the same procedure as used in the original CUSUM analysis, except that the baseline period is now the selected portion of the data set. For example, our CUSUM analysis indicates that the best performance—as indicated by the fastest rate of savings—occurred in weeks 17 through 25 and 30 through 36 (line segments 2 and 4 respectively). In these two periods, the rate of savings appears to be the same, which could be confirmed by doing regression on each of them in turn and comparing the slope and intercept parameters.

To illustrate, regression on weeks 30 to 36 yields Figure 7.9 and the energy performance model:

Energy = 55,607 + 460.48 x production (Equation 7.3)

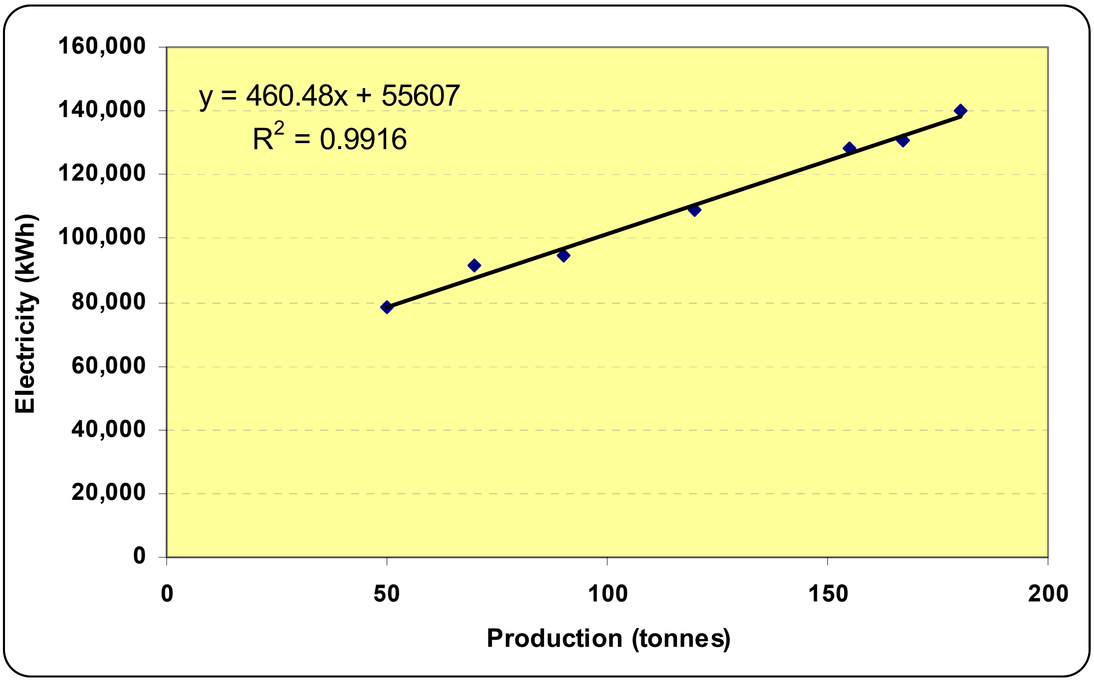

Figure 7.9: Regression on Target Period

Revisiting Table 7.2, we now have:

Table 7.4: Energy Performance Models Comparison – total, baseline and target

Model	Incremental load, kWh/tonne	Base load, kWh
total data set	476.48	59611
baseline	515.8	60978
target	460.48	55607

Now the reason that the total data set parameters are lower than the baseline is clear. During the target period—and apparently in the earlier period noted above—performance was at the target performance level indicated by an incremental load of 460.48 kWh/tonne—compared to 515.8 kWh/tonne in the baseline period—and a no-production load of 55 607 kWh—compared to 60 978 kWh in the baseline period. Apparently improvements were made to both the efficiency of the operation and the amount of energy waste not related to production.

The target pattern can now be used as a basis for managing energy performance into the future. In each period, we calculate the energy use expected from the current pattern formula for the production or degree days in that period and subtract this from the actual energy use in that period. Table 7.5 gives the results.

The difference is plotted as a time series for the weeks in the full data set, giving the graph of Figure 7.10. This graph becomes a control chart with the addition of bands to represent the limit where, if the energy use resulted in a difference beyond the bands, some investigation would be initiated to find the cause. This limit would be decided on the basis of experience, but if residual scatter is truly random, a good value for the control level is 1.4 times the average of the differences in the current pattern ignoring the signs. In this example, the average difference in the period week 30 to 36 is 1755, and 1.4 times this is 2457. Control limits of +/- 2500 would be reasonable under most circumstances.

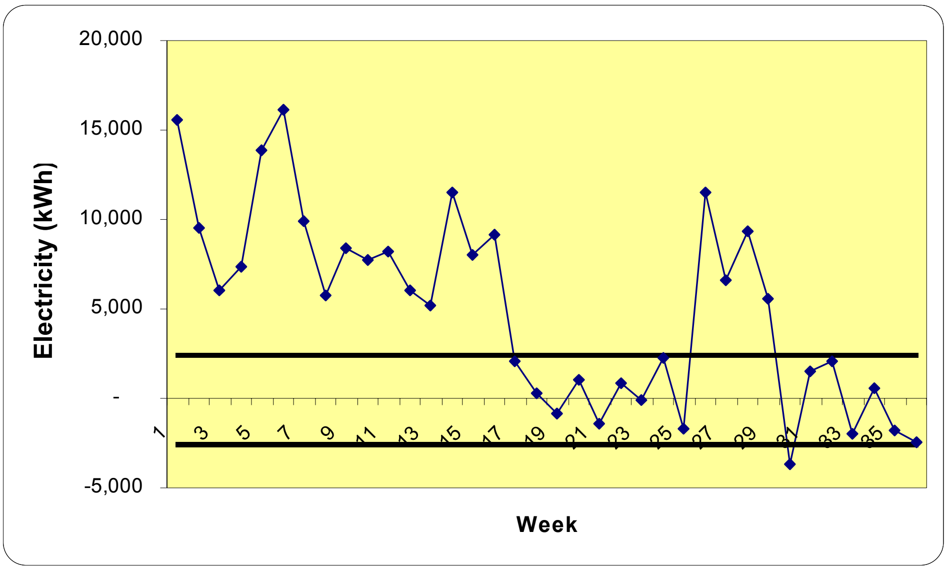

Figure 7.10: Control Chart for Production Example

Examination of the control chart shows that the variances were well outside the control range for the first 18 weeks, although the improvement began around week 16. During the period week 18 to 25, the process was operating within the control limits, but in week 25 something went wrong and energy consumption increased. Control was regained around week 30.

This is information that we already had as a result of the CUSUM analysis. What the control chart does is present the information in such a way that those who are responsible for operations can monitor performance so that problems become apparent very quickly. (Note that the time interval for the control chart could be day by day, shift by shift, or batch by batch).

Table 7.5: Control Chart Data Set for Production Example

Measured Data				Baseline			Control Chart	
Week	Production (T)	Specific Energy (kWh/T)	Total Energy (kWh)	Predicted Energy (kWh)	Difference (kWh)	CUSUM (kWh)	Control Chart Predicted (kWh)	Difference (kWh)
1	150	938	140726	138020	2706	2706	124679	16047
2	80	1290	103223	102250	973	3679	92445	10778
3	60	1513	90764	92030	-1266	2413	83236	7528
4	50	1751	87567	86920	647	3060	78631	8936
5	170	862	146600	148240	-1640	1420	133889	12711
6	180	860	154773	153350	1423	2843	138493	16280
7	120	1013	121575	122690	-1115	1728	110865	10710
8	40	2036	81436	81810	-374	1354	74026	7410
9	110	1051	115586	117580	-1994	-640	106260	9326
10	90	1177	105909	107360	-1451	-2091	97050	8859
11	40	2098	83916	81810	2106	15	74026	9890
12	50	1725	86272	86920	-648	-633	78631	7641
13	140	899	125892	132910	-7018	-7651	120074	5818
14	155	897	138966	140575	-1609	-9260	126981	11985
15	165	848	139922	145685	-5763	-15023	131586	8336
16	190	801	152274	158460	-6186	-21209	143098	9176
17	40	1945	77788	81810	-4022	-25231	74026	3762
18	55	1504	82711	89475	-6764	-31995	80933	1778
19	150	829	124317	138020	-13703	-45698	124679	-362
20	80	1183	94677	102250	-7573	-53271	92445	2232
21	63	1343	84628	93563	-8935	-62206	84617	11
22	110	982	108041	117580	-9539	-71745	106260	1781
23	70	1273	89115	97140	-8025	-79770	87841	1274
24	170	802	136388	148240	-11852	-91622	133889	2499
25	190	744	141428	158460	-17032	-108654	143098	-1670
26	160	883	141215	143130	-1915	-110569	129284	11931
27	120	986	118319	122690	-4371	-114940	110865	7454
28	190	803	152506	158460	-5954	-120894	143098	9408
29	80	1241	99267	102250	-2983	-123877	92445	6822
30	90	1050	94468	107360	-12892	-136769	97050	-2582
31	180	779	140188	153350	-13162	-149931	138493	1695
32	70	1304	91262	97140	-5878	-155809	87841	3421
33	50	1565	78248	86920	-8672	-164481	78631	-383
34	155	826	128005	140575	-12570	-177051	126981	1024
35	167	784	131003	146707	-15704	-192755	132507	-1504
36	120	910	109192	122690	-13498	-206253	110865	-1673

7.9 Targeting

Targets

- Are a statement of what management wishes to achieve
- Are determined from a position of knowledge
- Must challenge the organization but be achievable
- Convey management priorities
- Have two essential components:
  - ✓ an amount
  - ✓ a time

From Energy-Wise Practice 6, NZ Energy Efficiency and Conservation Authority

Targeting is a vital part of energy management as it encourages us to determine how low a level of energy consumption is achievable. In this section we are concerned with how to decide on an appropriate target.

Targeting is quite distinct from monitoring, although from the foregoing we see that they are clearly related. In monitoring you are trying to maintain an existing level of efficiency. In targeting you decide to what level energy consumption can be reduced. However, in some cases the target performance may be a period of superior performance demonstrated previously, as was the case in the example. But targeting need not stop there.

All targets have two elements:

- measure of the level to which consumption can be reduced

- the time by which the reduction will be achieved.

To be worthwhile, these must be realistic. Targets related to those achievable by better, or more skilled operators and management need to be distinguished from those that involve capital investment.

Targeting should become a dynamic process in which continued monitoring acts as an input to the fine-tuning of medium- and long-term targets. This is an element of a continuous improvement cycle.

7.9.1 Performance Benchmarks

As noted earlier, energy intensity, or Specific Energy Ratio (SER), is often used by industry. It is simply the energy used divided by an appropriate production measure (e.g. tonnes of steel, number of widgets). It can be calculated for any fixed time period, or by batch. SERs need to be treated with care because their variability may be due to factors such as economies of scale or production problems, rather than energy management *per se*.

There are many process benchmarking schemes based on SER and their ease of use makes them attractive to many companies. However, some practitioners are strongly averse to SER, regarding it as too simplistic and flawed.

An illustration for glass melting is shown in Figure 7.11.

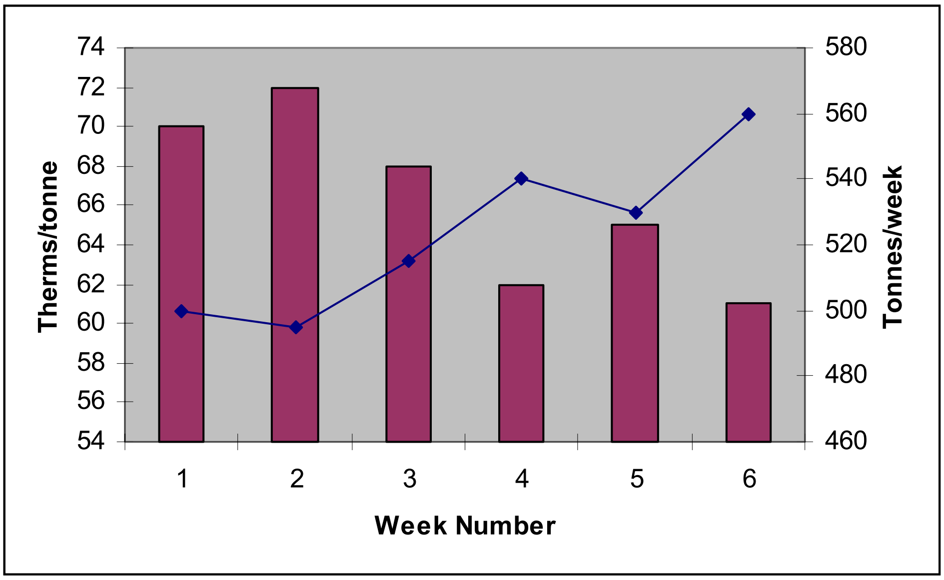

Figure 7.11: SER for glass melting

7.9.2 Preliminary Targets

When setting up M&T, it is often appropriate to use a selected period from the CUSUM analysis as the target, at least for the first few weeks. The rationale for this is that the plant was capable of delivering this performance for a period of time in the past, so it should be able to do it again into the future.

7.9.3 Revision of Targets

After M&T has been in operation for a while, the preliminary target based on past performance will be easily attainable and should be reset. This can be done in a number of ways, including:

- Defining best historical performance as the target.
- Basing a target upon an agreed upon set of actions designed to yield specific and quantifiable savings in both the incremental and the base loads..

Setting a target for an arbitrary percentage improvement upon current performance. Although arbitrary, if chosen properly this target will be attainable. If this target exceeds the best historical performance it will likely not be attainable and therefore avoided. This method is not recommended.

Whichever method is used, it is essential that the personnel from each department are involved in the process of setting the targets and in fact have input to what is or is not realistic. Otherwise, key personnel may not “buy-in” to the M&T approach and targets will not be achieved.

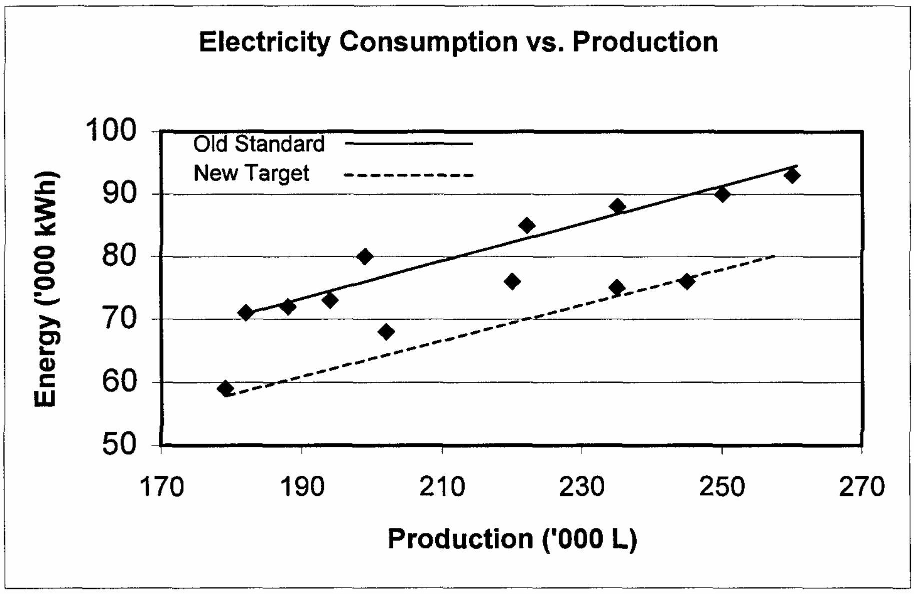

Figure 7.12: Target Setting on Best Historical Performance

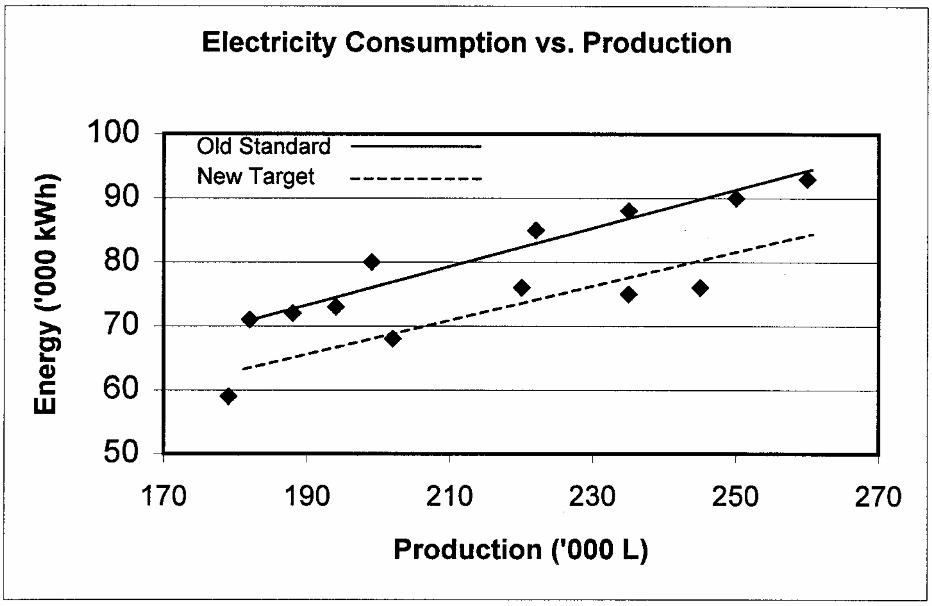

Figure 7.13: Target Setting on Arbitrary 10% Reduction

7.9.4 Target Setting and Performance Variability

When monitoring a site, a system, or an individual piece of equipment there are four levels of energy use that can be considered. They are:

- the energy consumption of the equipment
- the energy consumption of the system of which the equipment is a part
- the theoretical or minimum attainable level of consumption (for example, the specified optimum performance of the equipment, or the thermodynamic minimum for the physical transformations taking place)

- and the actual, observed consumption.

In a production situation:

- **Theoretical kWh/Tonne** is defined as the energy required when the optimum amount of equipment is operating at design efficiency.
- **Equipment kWh/Tonne** is defined as the energy consumed by the equipment working at its actual current efficiency
- **System kWh/Tonne** is defined as the energy required when the operator and machine influences are included - this takes into account operational techniques and maintenance practices.
- The **Actual kWh/Tonne** is the energy use taking into account any responses of the operators and supervisors to variations and external influences and the time lag in responding.

The actual energy consumption is normally subject to variability from period to period, as illustrated in Figure 7.14.

The distinction between these levels represents a potential for energy use reduction. One of the objectives of energy management is to reduce or eliminate this variability. Other savings opportunities are found in equipment and system improvements that increase efficiency. Although it may not be possible to achieve the theoretical or ideal consumption level with a real process, there exists a realistic target to which consumption could be reduced. An energy audit or assessment on each process area would examine each of these levels and the associated factors influencing consumption.

The audit or assessment outcome will often include a set of actions encompassing both operational and technological aspects. The operational actions typically address the variability and system consumption levels, while the technological actions would reduce the equipment consumption levels. It is expected that over time, as actions are implemented, the various consumption levels would drop, and actual consumption would approach the target level for the process as suggested by Figure 7.15.

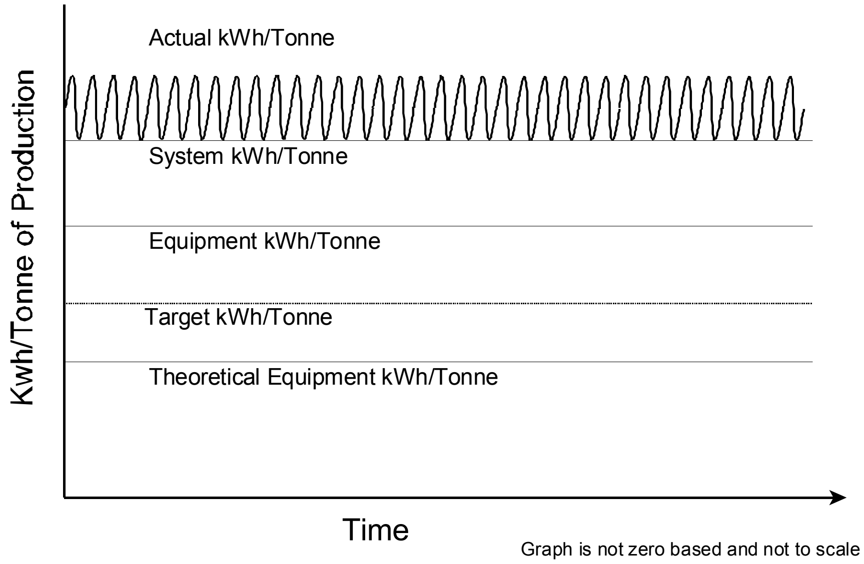

Figure 7.14: Energy Consumption in an Industrial Process

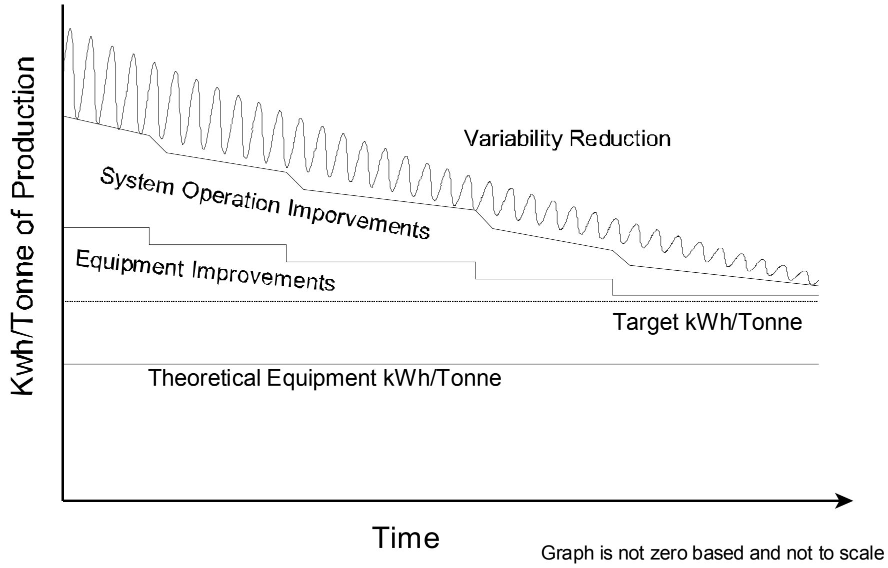

Figure 7.15: Energy Consumption Reduction

The monitoring of actual energy consumption reveals actual consumption levels and the variability that characterises them. This information together with insight to the potential system and equipment improvements leads to a realistic, achievable reduction target.

7.10 Reporting

Reporting within a monitoring and targeting system has a number of functions:

- to create motivation for energy saving actions;

- to report regularly on performance;
- to monitor overall utility costs;
- to monitor cost savings.

In planning a reporting structure, there are two basic questions that need to be answered:

Question 1: Who needs energy information?

Answer: All those individuals that can influence energy performance.

It could be argued that everyone in the organisation needs to receive some energy information, since everyone has some impact on energy use. As environmental management and climate change requirements become more a part of corporate life, it may also be necessary to consider stakeholders such as shareholders, external regulatory agencies, interested groups, and the public at large.

Question 2: What information do recipients need?

Answer: The minimum necessary to enable them to improve energy performance.

Not everyone needs to know everything. The information communicated should be the minimum required to achieve the desired results. Table 7.6 suggests the kind of information needed by various levels of the organisation.

Table 7.6: Information Needs
(Source: Best Practice Program GPG 231)

	Annual Report	**Monthly Report**	**Weekly Report**	**Key Indicators**	**Exception Report**
Chief Executive	🗁			🗁	
Accountant	🗁	🗁		🗁	
Department Heads	🗁		🗁	🗁	🗁
Purchasing	🗁			🗁	
Supervisors		🗁	🗁	🗁	🗁
Workforce				🗁	

Within most organisations the need for the type of information generated by a monitoring and targeting system varies with level and responsibility. Typically as the need moves from the operational level in the plant to the senior management level, the requirement for detail diminishes, as does the frequency of reporting.

Table 7.7 summarises the relationship between level of decision making and information needs. For example, a report for an operational manager needs to be written with precision by someone within the organisation. It must be delivered on time and with very short notice since it may be used for the purpose of forecasting problems in the plant.

In terms of the information available from a monitoring system, operations staff need energy control information to stimulate specific energy savings actions. Senior managers need summary information with which to guide the organisation's energy management effort. This is depicted in Figure 7.16. One report for all will not result in actions being and decisions being made.

Examples of the types of reports that might be used are provided here. These are only samples and you will want to design reports that are suited to your organisation and its energy management system.

Table 7.7: Information Needs
(Source: Best Practice Program, UK)

Level of Decision Making				
	Information	**Operational Control**	**Managerial Control**	**Strategic Planning**
Information Needs	**Source**	internal	internal	external
	Precision	high	medium	Low
	Timing	exceptional	periodic	Irregular
	Notice	sudden	Anticipated	none
	Nature	warning	results	Predictive

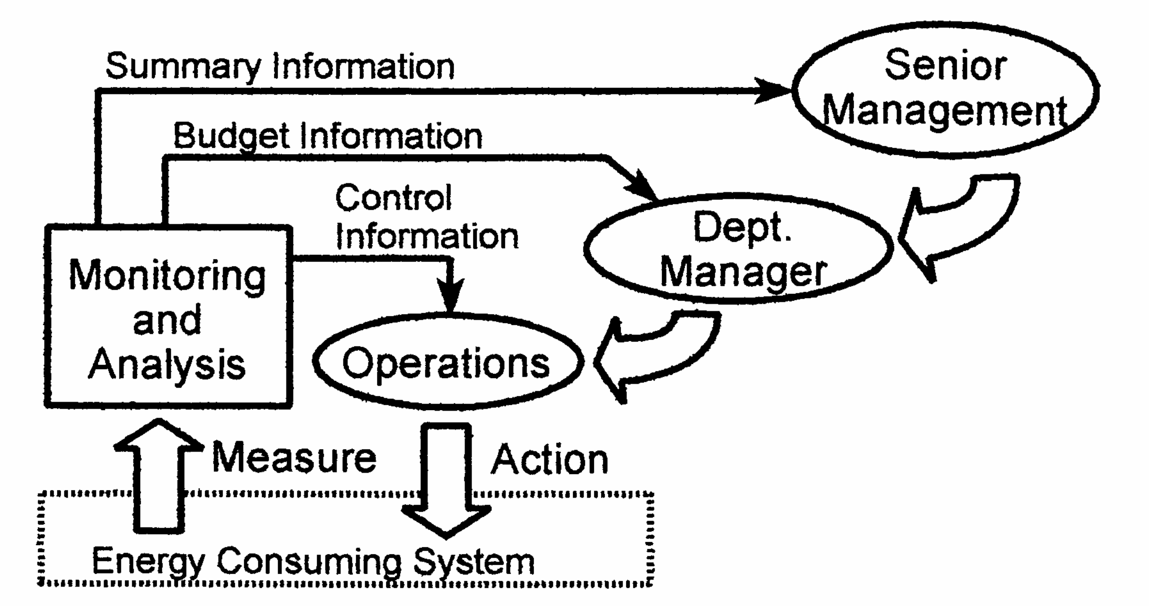

Figure 7.16: A Model for Reporting

7.10.1 Report Examples

The report depicted in Table 7.8 could be prepared on a weekly basis to allow department managers to direct energy savings actions.

Table 7.8 Weekly Consumption Report

Area of Use	**Actual (kWh)**	**Target (kWh)**	**Variance (%)**
Office	32000	28000	14.2%
Boiler Room	79000	71000	11.2%
Process -1	134000	120000	11.7%
Process -2	160000	170000	-5.8%

An Action List resulting from the manager's analysis of the consumption report as depicted in Table 7.9 could be distributed to operational personnel.

Table 7.9 Action Report

Area of Use	Action	Operator
Office Area		
1	Ensure lights are off at night.	SD
Process -1		
2	Turn off fans after production end.	JR
3	Shut down pump #3 at break.	GH

A Variance Graph could be prepared on a weekly basis as shown in Figure 7.17. This would be useful to budget holders in determining financial performance. Similarly a daily or per shift variance chart of energy consumption could be posted to inform operational personnel of the impact of actions on a more frequent basis.

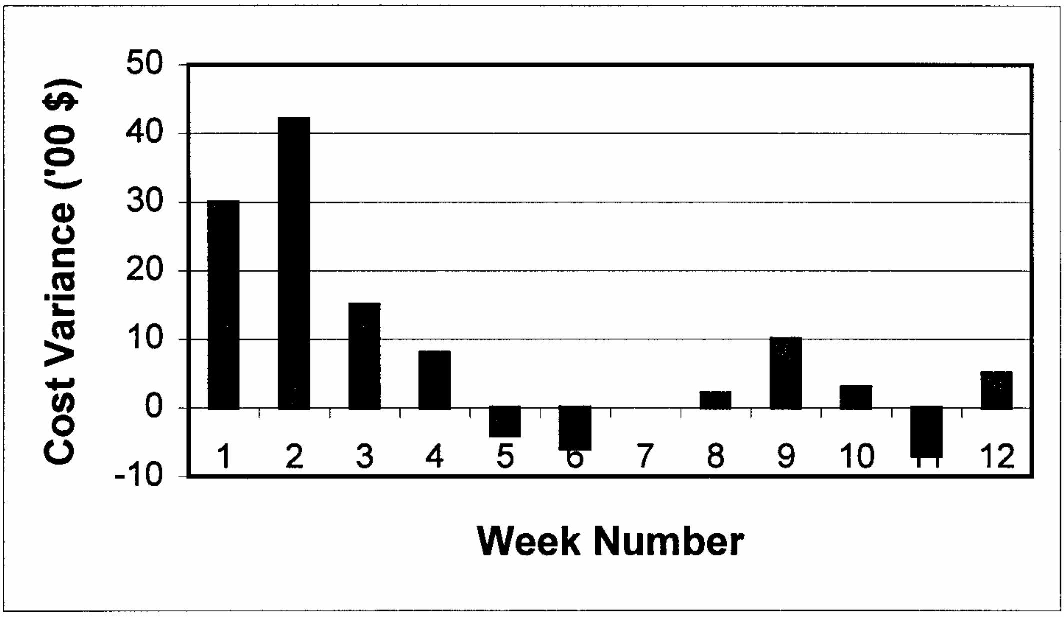

Figure 7.17: Cost Variance Graph

A detailed analysis of process energy usage could result in a batch by batch CUSUM chart that provides valuable control information to furnace operators. Such a chart is provided in Figure 7.18.

Finally, senior managers could be kept apprised of site consumption with a weekly summary report similar to that shown in Table 7.10.

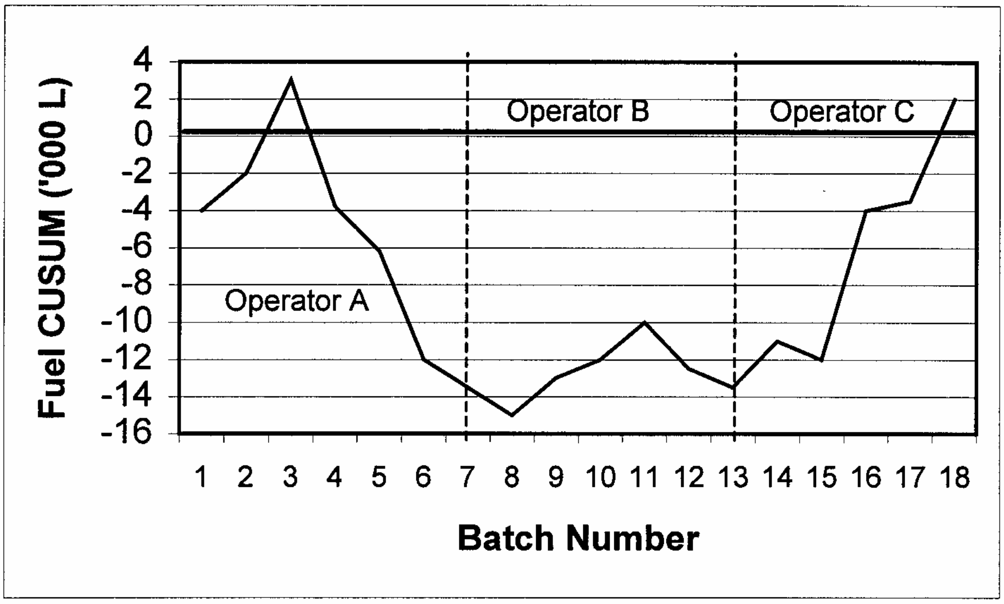

Figure 7.18: Detailed CUSUM Analysis

Table 7.10: Utility Summary Report

Utility	Actual Cost ($)	Variance ($)	Variance (%)
Electricity	145000	9700	6.7
Oil	42000	-1700	-4.1
Total	**187000**	**8000**	**4.2**

7.11 Measurement and Verification: Formalised Monitoring and Targeting for Energy Retrofits

Where MT&R is a basis for ongoing management control of energy use, M&V uses the same statistical tools to verify savings from measures that have been implemented.

While MT&R may be used for detecting and acting upon for expected and unexpected changes in energy consumption levels, M&V is primarily focused on detecting expected changes in energy consumption.

Whereas establishing an MT&R system involves extensive organisational involvement, implementation of M&V requires a structured plan and tends to follow a widely accepted industry protocol.

Fully developed MT&R systems are typically integrated into an organisation's management system and operate indefinitely; M&V activities commonly form the basis for savings verification in Energy Performance Contracts and operate for a defined term as established by the contract.

The central purpose of M&V is to **verify the energy savings achieved by building retrofits**, either to satisfy internal financial accounting and reporting requirements, or to meet the terms of third-party contracts for project implementation and management.

7.11.1 Working Definitions

The statistical analysis of energy consumption is commonly done for two reasons:

- ***Measurement and Verification***: this is a process of quantifying energy consumption before and after an energy conservation measure is implemented in order to verify and report on the level of savings actually achieved.

- ***Monitoring and Targeting***: this is a management technique that can—and should—be utilised with or without specific facility retrofits in order to “keep operations efficient”, and to “monitor utility costs”; these are management strategies designed to drive energy costs downwards as a continuous improvement cycle.

The statistical principles that are used are the same regardless of the purpose of the analysis. Because of its importance in energy performance contracts, and increasingly, in Clean Development Mechanism (CDM – under the Kyoto Protocol) projects involving greenhouse gas emission reduction credits, M&V methodology has been standardised in the International Performance Measurement and Verification Protocol (IPMVP).

7.11.2 M&V Protocols

The two most widely recognised M&V protocols are the IPMVP and ASHRAE Standard 14. The IPMVP and ASHRAE 14 are complementary documents that provide guidance and instruction to those interested in quantifying the results from energy savings projects.

International Performance Measurement and Verification Protocol (IPMVP).

The IPMVP:
- is a framework of definitions and broad approaches
- makes a provision for limited metering under Option A.
- Provides a perspective on balancing of Uncertainty and Cost are enhanced by ASHRAE’s

IPMVP Volume I: Concepts and Options for Determining Energy and Water Savings and ***Volume II: Concepts and Practices for Improved Indoor Environmental Quality*** can be downloaded at no charge from www.ipmvp.org

ASHRAE Guideline 14-2002 (ASHRAE 14)

ASHRAE 14:
- requires metering for all options.
- provides detail on implementing M&V plans with the framework.
- defines ways to quantify uncertainty so that M&V design decisions can consider costs in light of the best available methods for quantifying uncertainty.”
- details methods for IPMVP Option B, C and D, and provides details on metering and the computing and expressing of uncertainty.

ASHRAE Guideline 14-2002*: Measurement of Energy and Demand Savings* can be downloaded for a charge from www.ashrae.org

The above distinctions are found in the document IPMVP Statement on Relationship to ASHRAE 14.

7.11.3 Why Measure & Verify?

M & V is an additional cost in the retrofit project—what is the payoff?

The **IPMVP** offers six answers to this question:

- M & V increases energy savings.
- M & V reduces the cost of financing projects.
- M & V encourages better project engineering.
- M & V helps to demonstrate and capture the value of reduced emissions from energy efficiency and renewable energy investments.
- M&V increases public understanding of energy management as a public policy tool.
- M & V helps organisations promote and achieve resource efficiency and environmental objectives.

Spend more to reduce costs? . . . This isn't a contradiction in terms. The **IPMVP** explains that a thorough M & V process designed into the project helps to reduce the total cost of a financed project by:

- Increasing the confidence of funders that their investments will result in a savings stream sufficient to make debt payments
- Thereby reducing the risk associated with the investment
- Thereby reducing the expected rate of return of the investment—and your costs of borrowing.

7.11.4 General Approach to M&V – The IPMVP

In principle, M&V simply quantifies energy savings by comparing consumption before and after the retrofit. The "before" case is defined as the "baseline performance", and the "after" case is referred to as the post-installation period. In its simplest form,

Savings = (Baseline Energy Use)$_{adjusted}$ – (Post-installation energy use)

The complicating factors concern:

- what adjustments to the Baseline performance are required, and how are they carried out;
- what measurements are required to determine post-installation performance, and how are they carried out.

The International Performance Measurement & Verification Protocol (IPMVP), published by the US Department of Energy, defines four approaches to M&V that determine how these factors are addressed. These approaches are termed M&V Options A, B, C and D. A critical decision in M&V planning is the selection of one of these options.

7.11.4.1 M&V Options

IPMVP M&V Options A, B, C and D are summarised in Table 7.11. They differ one from another in terms of:

- the degree to which the retrofit can be measured separately from other facility components;
- the extent to which performance variables can be measured.

Option A applies to a retrofit or system level assessment where performance or operational factors can be spot or short-term measured during the baseline and post-installation periods. Factors that cannot or are not measured are “stipulated”, based on assumptions, analysis of historical performance, or manufacturer’s data. Stipulation is the easiest and least expensive method of determining savings, but is also subject to the greatest level of uncertainty.

Option B applies to a retrofit or system level assessment where performance or operational factors can be spot or short-term measured at the component or system level during the baseline and post-installation periods. In this Option, the performance of the retrofit can be measured separately from other measures or performance factors. No factors are stipulated; consequently, Option B involves more end-use metering than Option A and is correspondingly both more expensive and less subject to uncertainty.

Option C applies to the impact of a “bundle” of retrofit measures on a facility. It relies on baseline and post-installation total building energy performance data typically obtained from the utility meter at the service entrance, and involves regression analysis against independent performance variables such as weather factors, facility usage, or production (as in water pumping stations or wastewater treatment facilities).

Option D uses computer simulation models of component or whole-building energy consumption to determine project energy savings. Simulation inputs are linked to baseline and post-installation conditions; some of these inputs may be determined from performance metering before and after the retrofit. Long-term whole-building energy use data may be used to calibrate the simulation models.

Table 7.11: Overview of M&V Options
(Source: U.S. Department of Energy, M&V Guidelines: Measurement and Verification for Federal Energy Projects)

M&V Option	Performance and Operation Factors[1]	Savings Calculation	M&V Cost[2]
Option A – Stipulated and measured factors	Based on a combination of measured and stipulated factors. Measurements are spot or short-term taken at the component or system level. The stipulated factor is supported by historical or manufacturer's data.	Engineering calculations, component, or system models.	Estimated range is 1% - 3%. Depends on number of points measured.
Option B – Measured factors (Retrofit isolation)	Based on spot or short-term measurements taken at the component or system level when variations in factors are not expected. Based on continuous measurements taken at the component or system level when variations are expected.	Engineering calculations, components, or system models.	Estimated range is 3% - 15%. Depends on number of points and term of metering.
Option C – Utility billing data analysis (whole building)	Based on long-term, whole-building utility meter, facility level, or sub-meter data.	Based on regression analysis of utility billing meter data.	Estimated range is 1% - 10%. Depends on complexity of billing analysis.
Option D – Calibrated computer simulation	Computer simulation inputs may be based on several of the following: engineering estimates; spot, short-, or long-term measurements of system components; and long-term, whole-building utility meter data.	Based on computer simulation model with whole-building and end-use data.	Estimated range is 3% - 10%. Depends on number and complexity of systems modelled.

[1] Performance factors indicate equipment or system performance characteristics such as kW/ton for a chiller or watts/fixture for lighting; operating factors indicate equipment or system operating characteristics such as annual cooling ton-hours for chillers or operating hours for lighting.
[2] M&V costs are expressed as a percentage of measure or project energy savings.

Notes to Table 7.11

1. **Option A—partial retrofit isolation with stipulation—is best used when**:

- the magnitude of savings is relatively low for the entire project or the portion of the project to which this M&V Option is applied;
- the risk of not achieving projected savings is low, or ESCO payments are not directly tied to the actual savings.

2. **Option B—retrofit isolation—is typically used when:**

- energy savings from equipment replacement projects are less than 20% of the total facility energy use;
- energy savings arising from individual measures must be determined;
- interactive effects of multiple measures are deemed unimportant;
- the independent variables that affect energy use—for example, operating schedule—are neither complex nor difficult to monitor;
- sub-meters already exist to measure the energy use of the systems being considered for retrofit.

3. **Option C—whole building, billing analysis—is used when:**

- the retrofit project is complex, involving a number of systems;
- predicted energy savings are relatively large (greater than 10% to 20% of total facility energy use);
- the measurement of energy savings arising from individual measures is not required;
- interactive effects of multiple measures are to be included in the analysis;
- the independent variables that affect energy use may be complex, and are difficult or expensive to monitor.

4. **Option D—calibrated simulation—is used in situations similar to Option C, or when:**

- new construction projects are involved (i.e. there is no historical data for baseline determination);
- energy savings per measure are required;
- Option C tools cannot assess particular measures or their interactions when complex baseline adjustments are anticipated.

7.11.5 A Quantitative Basis for M&V

7.11.5.1 The Performance Model

The performance model of energy consumption is developed based upon the existing historical data and knowledge of the energy consuming systems present. The techniques used to develop a performance model for M&V are essentially the same as those statistical techniques used to develop the relationship between energy and its drivers in the practice of M&T described in section 3. In M&V this practice is often referred to as determination of the energy consumption baseline or standard. Given this baseline relationship it is possible to make future comparisons to determine changes in energy consumption, taking into account changes in the influencing factors.

Three basic methods exist for establishing a model:

- **previous year's data** - simply using last year as a predictor of this year's consumption. Typically only useful when there are no significant factors of influence.

- **regression analysis** - a statistical approach based upon historical consumption and the factors of influence.

- **simulation model** - using complex numerical computer models to simulate the energy consumption.

The most common method for a basic system is regression analysis. This technique determines an equation between the energy and the variable(s) that influence it. **As with any statistical technique it must be used carefully. The reliability of the result depends upon the factors chosen and the quality of the data used.** The reader is referred to any basic statistics textbook or the HELP function of most common spreadsheets for more background on regression analysis. Section 3 also provides some basic instruction.

For many situations, the performance model will be an equation of the form:

Baseline Energy Use = Base load Energy + Use Factor x Factor of Influence

Most popular spreadsheets can perform this type of analysis.

7.11.5.2 Baseline Definition

The definition of the baseline conditions involves not only quantifying energy consumption data, but also specifying those factors that affect energy consumption. Data and information required for a complete baseline definition include:

- ✓ **Energy consumption data:**
  - Electricity consumption information—bills and derived information (kW, kVA, PF), meter readings (especially for subsystem measurements), demand profiles;
  - Fuel consumption information—bills, monthly consumption profiles, fuel-by-fuel data (quantity, calorific value of fuels consumed, etc.);
  - Water consumption information
  - Other energy sources—e.g. purchased steam, etc.

- ✓ **Independent variable data:**
  - Weather factors—HDD or CDD;
  - Facility occupancy or usage data—operating hours, number of patrons, etc.;
  - Throughput or production—as in volume of water pumped or wastewater treated;
  - Space conditions—set points on heating/cooling systems;
  - Equipment malfunctions—records of outages.

7.11.5.3 Baseline Adjustments

The fundamental relationship for savings verification includes "adjustment" of the baseline performance. Baseline adjustments potentially represent the most contentious aspect of energy performance contracts, and may be the most difficult aspect of savings verification to quantify. Simply put, "adjustment" places the baseline energy performance on a "level playing field" with post-installation performance in terms of those independent variables that affect energy consumption.

ESCOs must specify as part of their M&V plan how they will adjust the baseline if the post-installation operating conditions are different from those used to determine the baseline. These specifications should address the independent variables listed above, as relevant to the project.

The following are examples of baseline adjustments:

- **Changes in production or weather** : adjustments might include recalculating the baseline consumption rates using post-installation period production and/or weather data (HDD or CDD) based on the mathematical expression of how energy consumption depends on these factors;

- **Changes in operating schedule or process changes**: the real impact of the retrofit project is independent of decreases or increases in operating hours of the facility or system and, therefore, the baseline consumption needs to be scaled up or down to correspond to such changes if any occur; similarly, process changes— or new loads, improved lighting levels unrelated to the retrofit itself, etc.—that may increase energy consumption in the post-installation period must be separated from the post-installation period performance.

- **Changes in the actual function of the facility**—production space being converted to storage, for example—and their impact on energy performance separate and apart from the retrofit, need to be quantified as adjustments to baseline performance.

The extent to which baseline adjustments need to be considered depends to some extent on the M&V Option being employed:

- Baseline adjustments are less likely to be needed when M&V Option A is being used since many of the performance factors are stipulated.

- Option B or retrofit isolation involves metering of energy consumption pre- and post-installation; non-metered factors that impact on energy performance therefore need to be applied to the measured baseline consumption.

- Option C involves regression analysis to determine a functional relationship between energy consumption and independent variables; adjustment to the baseline performance for changes in these variables is typically carried out by using that functional relationship or performance model.

- Option D accommodates adjustment within the simulation model itself; once calibrated using actual or typical data, no other adjustments should be required.