CHAPTER 3: THE ENERGY MANAGER'S TOOLBOX

"Tools of the trade are those vital instruments without which completion of the tasks required for the job would be very difficult ."

Terry L. Fox

3.1 INTRODUCTION

A basic understanding of common energy management terms and quantities is essential to an energy manager in order to address the four areas-of-activity that were introduced in chapter 2. This chapter is divided into three sections, namely electricity load analysis, electricity tariffs and financial analysis:- electricity load analysis will provide the necessary tools with which to analyse the electrical performance of end-user groups or business units, electricity tariffs will address the tools required with which to determine the cost of electricity consumption and financial analysis will include the necessary information with which to calculate the financial viability of energy management projects.

3.2 ELECTRICITY LOAD ANALYSIS

When analysing the electrical performance of a building, end-user group or entire campus, it is important to extract only relevant information that will assist in the identification of problem areas. In other words, the energy manager must avoid an overload of information in order to eliminate confusion. This section will cover the basic information items that are used in this type of analysis.

3.2.1 Load Profiles

A load profile is a graphical plot of the power consumption for a specified time period (typically a day, week or month) [14]. Two essential elements can be obtained from a load profile. The maximum amount of power consumed (termed *Maximum Demand*) is the point of the greatest power consumption for the period under consideration and the sum of the area under the profile is the amount of energy that is consumed. Load profiles also provide an indication of the times that specific loads are being used as shown in figure 3.1.

Plotting separate loads on top of each other produces a disaggregated load profile. The function of the disaggregated load profile is to gain insight into the load distribution and to display the total load profile [14].

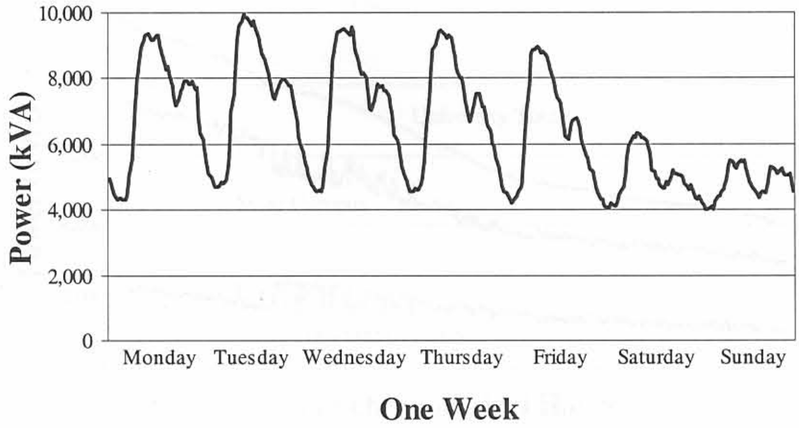

Figure 3.1: Sample weekly Load Profile from the University of Pretoria of the total load

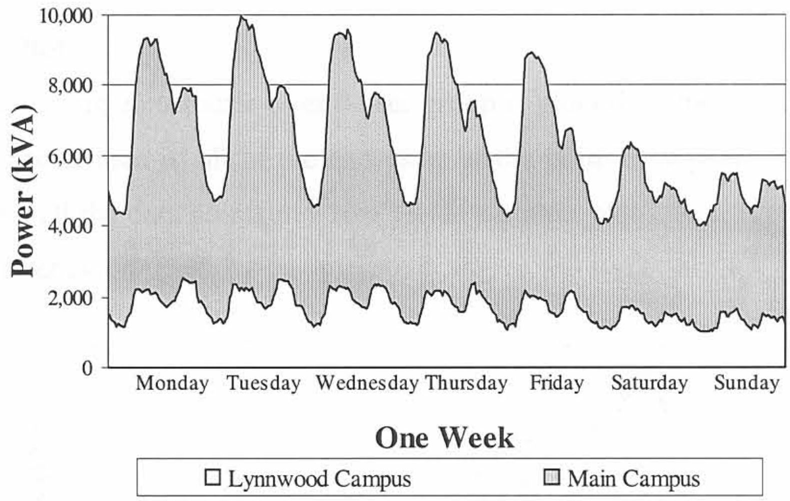

Figure 3.2: Disaggregated Load Profile of figure 3.1

3.2.2 Load Duration Plots

The load duration plot is constructed by sorting the load data from the highest value to the lowest value and then plotting this data against the duration interval. This plot is used to show the load distribution for each total demand value. An almost horizontal curve indicates a constant demand for electricity whereas a more negative curve indicates a time dependent process [14]. Figure 3.3 illustrates the load duration plot of the total University load as presented in figure 3.1. This load duration plot has been disaggregated into its two components, namely Main Campus and Lynnwood Campus (as presented in figure 3.2), which when added together provide the total University load. Figure 3.3 illustrates the interaction between the Main Campus and Lynnwood Campus and the effect that each has on the total University load. The varying gradients imply that that the Main Campus load predominates the total University load and that at the time of the peak of the total load, the Lynnwood Campus has not reached a maximum whereas the Main Campus has.

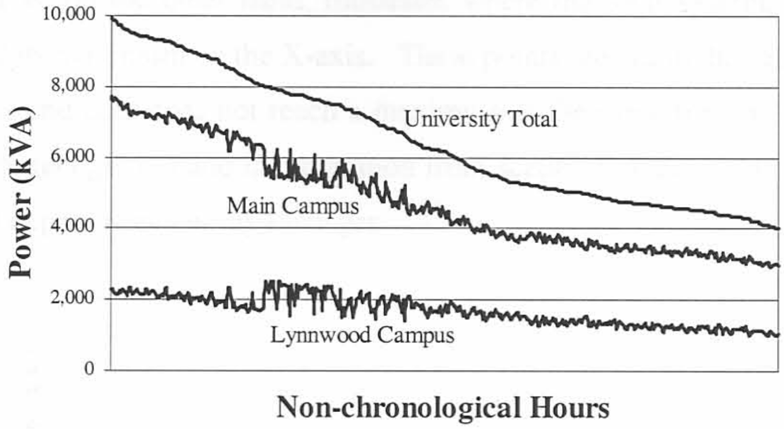

Figure 3.3: Load Duration Plot of the data presented in Figures 3.1 and 3.2

3.2.3 Scatter Plots

The load data of a single customer or end-user group is plotted on the Y-axis and the total load (that is the total load of all of the end-users at the point of supply) is plotted on the X-axis. Plotting all the data points in a row yields a scatter plot. A scatter plot is used to study consumer behaviour [14].

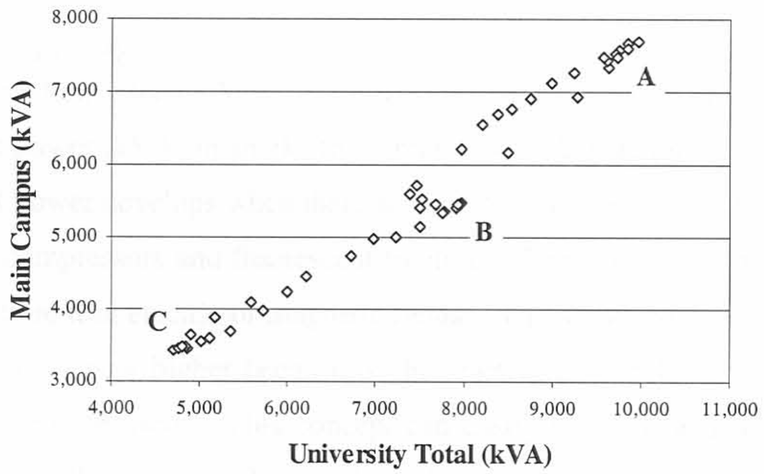

Figure 3.4: Scatter Plot of the Main Campus demand vs. Total University demand

If the dots on a scatter diagram tend to cluster in more than one place, the consumer has more than one regular mode of behavior as illustrated by the points A, B and C in figure 3.4. If the dots are scattered over a wide vertical range, the consumer has a very random behaviour. If the regression line through the dots has a positive slope, the consumer's load reaches a maximum at the same time as the point of supply. A negative slope in the regression line indicates that the consumer does not contribute as much to the overall system demand as the other end-users. For example, point A in figure 3.5 illustrates where this specific customer (Lynnwood Campus) reached its maximum against the

Y-axis. Point B, on the other hand, illustrates where the total system, at the point of supply, reached its maximum on the X-axis. These points are not in the same place, which implies that this end-user does not reach a maximum at the same time as that of the total system. Pattern recognition and interpretation from scatter diagrams is a powerful tool in the hands of an experienced energy manager.

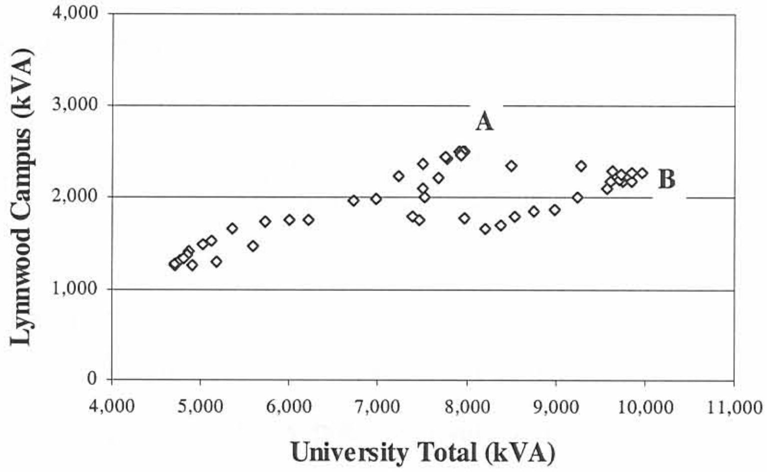

Figure 3.5: Scatter Plot of the Lynnwood Campus demand vs. Total University demand

3.2.4 Power Factor (PF)

Power factor is the term used to describe the ratio between the active or useful power (kW) and the apparent power (kVA) in an electric circuit [14]. A difference in the active power and the apparent power develops when there are inductive or capacitive loads in the circuit such as motors, compressors and fluorescent lighting. These loads do not only consume energy but also store it in electric or magnetic fields. The active power is not affected but the apparent power is now higher because of the reactive power that is developed in this circuit, which cannot be used. This concept can easily be explained on a management level (for tariff and billing purposes) using the following figure:

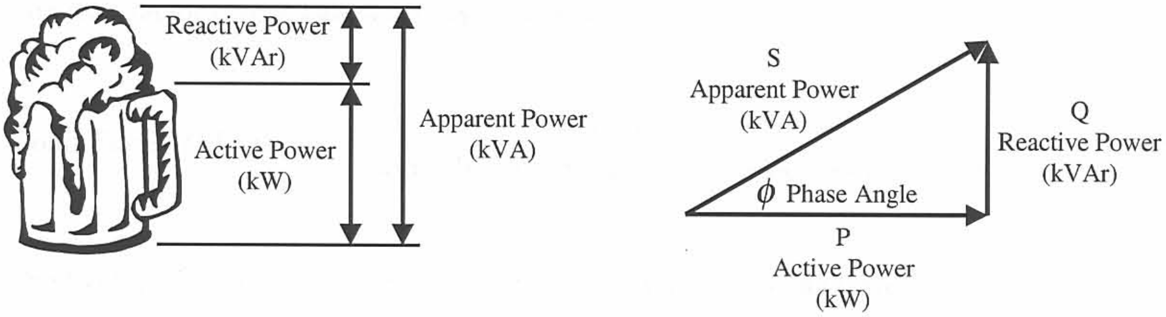

Figure 3.6: Power Factor Explained and the Power Triangle

Suppose the total beer is the apparent power. The tasteful part (or the liquid) represents the active power (P) and the foam that you drink, but does not taste like beer, is the reactive power (Q). One is fooled by the appearance of the beer but you actually get less useful beer. The power is represented by equation 3.1 with reference to the power triangle in figure 3.6 [33]. The power factor has an impact on the amount of power that is dissipated in electric circuits and there are many technical examples in text [33]. The power factor cannot be greater than 1.

$$Power\ Factor\,(PF) = \cos\phi = \frac{P}{S} = \frac{Active\ Power\,(kW)}{Apparent\ Power\,(kVA)} \qquad [3.1]$$

3.2.5 Load Factor (LF)

The load factor is a utilisation factor and is expressed as the ratio of the average demand to the maximum demand [34]. Simply put, the load factor is a ratio between the actual energy consumed during a period and the energy that could have been consumed had the demand remained at the maximum demand for that same period. The value for the load factor cannot be greater than 1.

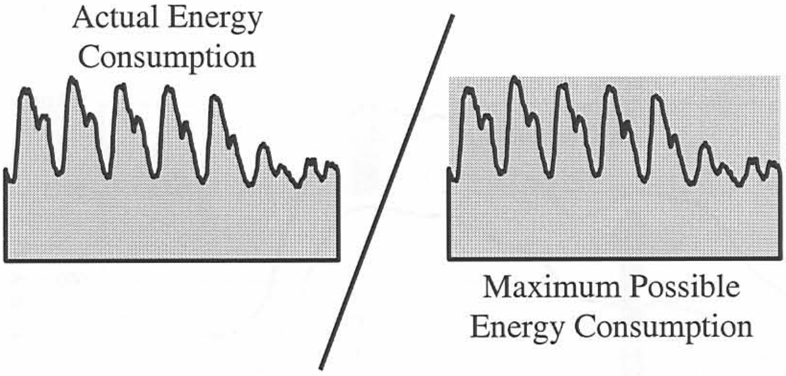

Figure 3.7: Load Factor Explained

The load factor can be calculated using equation 3.2 [35].

$$Load\ Factor\,(LF)_{\ for\ period} = \frac{kWh\ Consumed_{\ in\ period}}{Maximum\ Demand_{\ in\ period} \times Number\ of\ Hours_{\ in\ period}} \qquad [3.2]$$

The load factor for the load profile presented in figure 3.1 is calculated as follows:

$$LF_{\ week} = \frac{1{,}083{,}620\ kWh}{9{,}970\ kW \times 7\ days \times 24\ hours} = 64.70\% \qquad [3.3]$$

Note that active power (in kW) was used for the maximum demand in equation 3.3 in order to arrive at the same units of measurement. In this instance the maximum demand was available in active power but occasionally only the apparent power value (in kVA) is available. This typically occurs when information is being obtained from the electricity account and not from measured load data. In this case using the apparent power value that is available can approximate the load factor. Alternatively, the active power component can be calculated if an average value for the power factor is known.

3.2.6 Coincident Maximum Demand and Diversity Factor

The contribution that individual customers or end-users make towards the maximum demand of the system will vary. The result of this is that the real costs of the system are not necessarily caused by all of the customers connected to that system. For example, the Total University load presented in figure 3.9 is made up of two separate customers, namely Main campus and Lynnwood Campus. The total system peak occurs at point A. The Lynnwood Campus peak (point B) does not contribute to system peak whereas the peak of the Main Campus (point C) is a major contributor. In other words, the maximum demands of the Main Campus and the total system load coincide. This is termed coincident maximum demand.

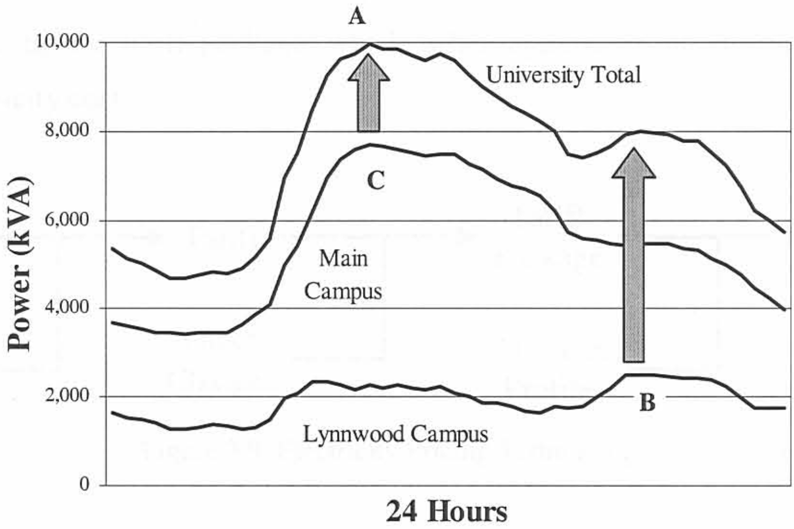

Figure 3.8: Coincident Maximum Demand Explained

The diversity factor of a number of customers, when considered from a single point of supply is defined as the ratio of their separate maximum demands to their combined maximum demand. It is a measure of the real maximum demand on a system at a mutual point of supply and is given by equation 3.4 [34]. The diversity factor is always greater than 1.

$$Diversity\ Factor\,(DF) = \frac{\sum_{i=1}^{n} Maximum\ Demand}{Combined\ Maximum\ Demand} \qquad [3.4]$$

The diversity factor between the separate loads and the total load presented in figure 3.8 is calculated as follows:

$$DF_{\ University\ Total} = \frac{MD_{\ Main\ Campus} + MD_{\ Lynnwood\ Campus}}{MD_{\ Total\ University}} = \frac{7{,}694 + 2{,}503}{9{,}970} = 1.023 \qquad [3.5]$$

3.3 ELECTRICITY TARIFFS

Knowledge of tariff structures is not only beneficial for the energy manager from a supply-side point of view but also from a demand-side perspective in cases where the individual business units or faculties and departments are billed for their electricity consumption.

3.3.1 Tariff Design

A conceptual view of tariff pricing terminology in figure 3.9 [34] illustrates that the tariff structure together with the tariff rates will provide the tariff. This, together with the other charges, makes up the tariff package, which, when applied to the consumption profile, gives the electricity cost.

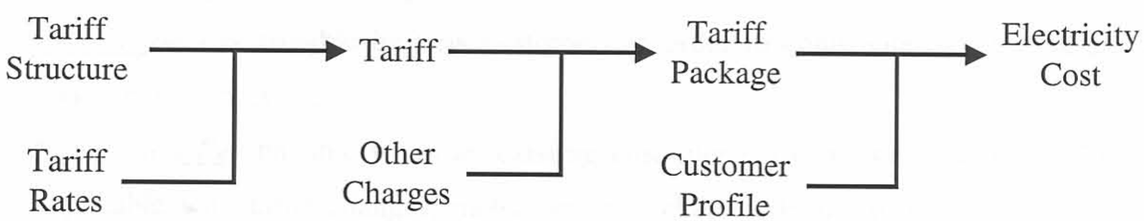

Figure 3.9: Electricity Pricing Terminology

Tariff Structure

- *Fixed charge (Flat rate)* is a fixed payment made per month independent of consumption.
- *Single Energy Rate* is a payment made for consumption only at a fixed rate.
- *Inclining Block Rate* consists of different prices for different energy usage. For example, a low block rate for the first 100 units of consumption and a high block rate for the balance of consumption.

- *Declining Block Rate* is the reverse of the inclining block rate whereby a higher initial rate is charged and a lower rate for the balance of consumption.
- *Demand Tariff* consists of a maximum demand charge and an energy rate.
- *Time-of-use (TOU) Tariffs* apply different rates at different times of the day and for different seasons (high and low demand periods).
- *Real-time Pricing (RTP)* is when the energy price changes in real time (e.g. on an hourly basis).

Tariff Rates

The tariff rates are the actual per unit amounts payable for any of the tariff charges. These tariff charges include:

- *Basic Charge*, a fixed charge (payable every month) irrespective of usage,
- *Energy Charges* for active energy consumption (e.g. kWh), and
- *Demand Charges* levied for the maximum demand.

Other Charges

The supplier will levy certain charges dependant on individual circumstances. Examples are included here.

- *Circuit Breaker Fee*, a fixed fee proportional to the size of a customer's circuit breaker. Usually, the greater the rating on the circuit breaker, the higher the fee payable.
- *Connection Fee* payable by new customers in order to contribute to the cost of the additional connections.
- *Conversion Fee* payable when an existing customer converts their supply. This is applicable with tariff changes, meter changes, changes in the installation or when a supply point is shifted.
- *Capital Charges* are the capital costs of the network that are not recovered through the tariff and are thus recovered through additional capital charges over and above the tariff. This cost may be paid by cash or by means of a monthly capital charge called a monthly rental. A capital interest rate is applied to this additional cost and customers are granted rebates in order to refund that part of the capital costs that are already included in the tariff.
- *Service Charges* include transfer fees when ownership of a conventionally metered point of supply changes hands, a call out fee due to a supply interruption when the fault

is found within the customer's installation, special meter reading fees when done at the customer's request and meter test fees which are charged when a meter is tested at the customers request.

3.3.2 The Demand Tariff (or the Two-part Tariff)

This tariff charges a customer for the amount of energy consumed as well as on the rate at which this energy is consumed. This structure recovers variable costs through a constant consumption charge (e.g. c/kWh) and a capacity cost charge (proportional to rate of use) (e.g. Rand/kW or kVA). This tariff requires metering that is able to log the maximum rate of use in addition to the normal energy metering function [14].

A great deal of information can be obtained from a demand tariff electricity account. Apart from the energy consumption and maximum demand components, other standard charges (typically meter reading fees) are also reflected on the account [36]. The date of the meter reading and the period of the account are usually required for benchmark purposes. If no meter reading date is provided, it may occur that the consumption has been estimated. Some suppliers as a result of manpower limitations have adopted this method. With this approach, the energy consumption is estimated based on historical consumption information or other statistical methods. In this instance, energy benchmarks will help to raise attention to suspect estimations on the part of the supplier. In other words, a way-off benchmark result for a particular month could raise your attention to the fact that the estimated account is incorrect and has been either over estimated or under estimated by the supplier. If discrepancies exist, it is possible to request that the supplier read (or re-read) the meter (occasionally at an additional charge).

3.3.3 The Time-of-Use Tariff

A time-of-use (TOU) tariff applies different energy consumption charges during different periods. The energy rate during each interval closely tracks the actual cost of supply. TOU tariffs recover the actual costs of providing electrical energy more fairly and accurately than two-part tariffs [14].

Energy charges can be made to vary seasonally and/or on a daily basis. TOU tariffs often have demand charges associated with them and the demand charge, like the consumption charge, is also differentiated with time.

3.3.4 Notified Demand Tariff

The notified maximum and minimum demand may be stated on the account. The notified maximum demand is the dictated maximum demand of a customer for the duration of the billing period. In other words, this is the specified maximum demand that a specific customer may not exceed. It is typically used to class customers according to varying tariff rates. The specified minimum demand is a dictated value (as a set percentage of the notified maximum demand) that will be levied as part of a maximum demand charge irrespective if a customer's demand is less than the notified minimum demand [36].

For example a customer has a notified maximum demand of 2,400 kW and a notified minimum demand of 1,680 kW which is obtained as a result of a specified 70% of maximum (i.e. 2,400 x 70%). In this example, if the customer has a maximum demand that is less than the notified minimum demand (1,680 kW), then this customer will be charged for the notified minimum demand.

3.3.5 Equivalent Cost per Unit (c/kWh)

The equivalent cost per unit is used to gain a complete understanding of the actual costs per unit of electricity that is consumed. It is calculated by dividing the sum of all the electricity costs and charges by the amount of units (kWh) consumed. In this manner, the assumptions that the cost of each unit that is consumed is equal to the energy rate only, is avoided because the other charges and costs are also considered. Occasionally the contributions of the other charges (such as those for maximum demand) to the overall electricity cost are more than that of the energy consumption alone.

Consider the electricity account for the main campus of the University of Pretoria during June 1999. During 1999, this campus was billed according to a demand tariff with energy consumption at 8.76 c/kWh and maximum demand at R44.95/kVA as follows:

Energy Consumption:	3,862,699 kWh	338,372.43
Maximum Demand:	9,965 kVA	447,926.75
Meter Reading Fee:		526.00
	Sub-total	R 786,825.18
	VAT (@ 14%)	R 110,155.53
	Grand Total	**R 896,980.71**

In this example the equivalent cost is calculated in equation 3.6.

$$Equivalent\ Cost\ per\ Unit = \frac{338{,}372.43 + 447{,}926.75 + 526.00}{3{,}862{,}699} = 20.37\ c/kWh \qquad [3.6]$$

The equivalent cost of 20.37 cents per unit implies that each unit of electricity that is consumed on this campus does not only cost 8.76 cents (the energy rate) but actually costs 11.61 cents more as a result of meter reading and maximum demand charges.

Normally the tax is not included in this calculation because it is not considered as a business expense and is usually reclaimed from the government. However, if for some reason this is not the case, then this tax should also be included as part of the electricity costs in equation 3.6.

3.4 FINANCIAL ANALYSIS

Some energy management projects might require financial investment in new equipment or the purchase of other material. The aim of economical project analysis is to provide a quantitative financial means of measurement to evaluate investments.

3.4.1 Cash Flow Diagrams

Cash flow diagrams are a graphical description of cash transactions [37]. Receipts are indicated with an upward arrow and disbursements with a downward arrow. The length of the arrow is proportional to the size of the payment and the net cash flow per period is presented. Examples are illustrated in figure 3.10.

3.4.2 Time Value of Money

The value of money is related to time and the concept of the time value of money involves shifting monetary payments to future or present equivalents [37]. The following symbols are used for the basic time value calculations:

- P present value
- F future value
- A uniform series payments
- n number of compounding periods
- i effective interest rate

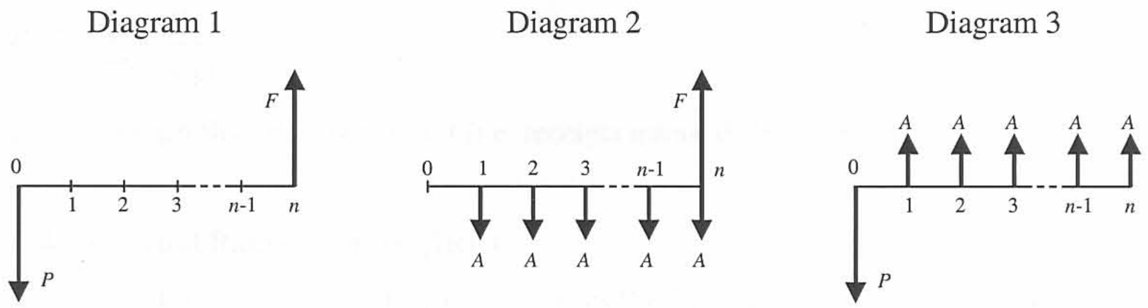

Figure 3.10: Time Value of Money Diagrams

Diagram 1

$$F = P(1+i)^n \quad [3.7]$$

$$P = \frac{F}{(1+i)^n} \quad [3.8]$$

Diagram 2

$$F = A\left[\frac{(1+i)^n - 1}{i}\right] \quad [3.9]$$

$$A = F\left[\frac{i}{(1+i)^n - 1}\right] \quad [3.10]$$

Diagram 3

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \quad [3.11]$$

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \quad [3.12]$$

3.4.3 Net Present Value (NPV)

Present value analysis is a method of measuring costs and savings that will occur at different times on a consistent and equitable basis for decision-making. This method determines the difference between the present values of the project revenues and costs, hence the *net* in net present value. A NPV of zero implies that the project will recover the investment as well as the interest charge on that investment. A NPV higher than zero shows that the project is worthy of further consideration and negative values show that a project will not recover its investment [37].

$$NPV = \sum_{t=0}^{n} \frac{F_t}{(1+i)^t} \qquad [3.13]$$

F_t net cash flow during period t (i.e. receipts minus disbursements)

3.4.4 Internal Rate of Return (IRR)

The internal rate of return (IRR) method solves the NPV equation for an interest rate that yields zero NPV. In other words, the IRR causes the project revenues to equal the project costs. The internal rate of return is thus the rate, i* that satisfies equation 3.14 [37].

$$NPV(i^*) = \sum_{t=0}^{n} \frac{F_t}{(1+i^*)^t} = 0 \; where \; 0 \le i^* \le \infty \qquad [3.14]$$

The computation of the IRR requires a trial-and-error solution. Substituting a few discount rate values until the above equation is satisfied or until the NPV equals zero solves it. The IRR represents the equivalent rate lost (or earned) on the under recovered (or over recovered) balance of the investment. IRR can be calculated for a number of alternative projects in order to rank them. A higher IRR indicates that higher financial merit and negative figures are indicative of financial loss. Consider the sample cash flow in table 3.1.

The expression to calculate the IRR is given by the following equation:

$$NPV(i^*) = -10000 + 4000\left\{\sum_{t=1}^{4}\left[\frac{1}{(1+i^*)^t}\right]\right\} \qquad [3.15]$$

Substituting values for i^* in order to render the NPV equal to zero, yields an IRR equal to 21.86%.

Table 3.1: Sample Cash Flow

Period	Cash Flow
0	-10,000
1	4,000
2	4,000
3	4,000
4	4,000

3.4.5 Payback Period

The payback period is the amount of elapsed time, starting from the time that the initial investment is made, until the benefits exceed the initial investment [37]. Projects with shorter payback periods are definitely preferred over those with longer payback periods. However, this method should not be used as the sole selection criterion of a project unless other methods fail to clearly define the most suitable project among a number of nearly equally advantageous programs. The payback period for the cash flow in table 3.1, using an interest rate of 10% per period is given in table 3.2.

Table 3.2: Calculation of the Payback Period for Sample Cash Flow (i = 10%)

Period	Cash Flow	NPV(10%)
0	-10,000	-10,000
1	4,000	-6,364
2	4,000	-3,058
3	4,000	-53
4	4,000	2,679

The payback period is 4 periods.

3.4.6 Minimum Attractive Rate of Return (MARR)

The MARR is the percentage cut-off rate representing a yield on investments that is considered minimally acceptable [37]. The value of the MARR is usually a management decision determined from the cost of capital within the organisation and the desired percentage return on investment. If the NPV is calculated using the MARR and the result is greater than zero, it indicates that the project is viable. It follows too that if the IRR is greater than the MARR, the project will be acceptable to management.

3.5 SUMMARY

This chapter has covered the basic tools required of an energy manager. It almost goes without saying that these are not the only tools that will be needed by an energy manager but the contents of this chapter have covered those items that are energy management specific. This makes this chapter important if the role of energy manager is bestowed on an existing manager within a facilities management department at an academic institution.

Before a reduction in the energy cost is possible, the energy manager must be able to analyse and interpret the present performance of the entire campus or individual end-users.

Graphical analysis is vital in this regard because it allows for the energy manager to make a conclusion or pinpoint problematic areas very quickly.

An appreciation of the price of electricity only as a major external pressure acting in on the energy management programme of the academic institution is not sufficient. A thorough understanding of the tariff structure will ensure that the energy manager is familiar with all the opportunities with which to reduce the electricity costs per product or business function.

In a similar vein, a basic understanding of quantitative economics will ensure that considering the effects of time on the value of money more accurately plans for potential energy management projects that rely on capital investment.

A solid understanding of the tools in this chapter will enhance the aim of the next four chapters in which each one of the areas-of-activity are discussed.