CHAPTER 5: ENERGY LOAD MANAGEMENT

> *"Nothing can come of nothing: He who has laid up no materials can produce no combinations."*
>
> *Sir Joshua Reynolds*

5.1 INTRODUCTION

Although the Energy Load Management area-of-activity is not the starting point of the energy management programme its importance ranks supreme as it is this activity area that is most likely to produce significant improvements to the cost of energy per product or business function.

This activity area focuses on the management of the electrical load through the process of improving or controlling the equipment that uses the electrical energy. From figure 2.4 there are three buzzwords attached to this area, namely "upgrade", "control" and "install" and each refers to the interaction with the electrical equipment.

Unfortunately a limited amount of investment capital will be available within the academic institution for the implementation of load management projects. For this reason it is important to firstly evaluate all the alternatives in order to determine the best solution and then to evaluate this solution against all the other potential areas requiring investment capital. In this manner projects are evaluated on an intra-project and inter-project level.

To emphasise this methodology, three case studies will be presented in this chapter each relating to one of these activity buzzwords.

5.2 INSIDE THE ENERGY LOAD MANAGEMENT AREA-OF-ACTIVITY

This chapter reacts on the input that is received from the Energy Diagnosis and Energy Maintenance Management areas-of-activity. These commands are received as problems with specific equipment that will require the implementation of one of the buzzwords in order to improve. The first step involves finding a solution and possibly a series of alternatives. These are evaluated against each other based on their financial performance and the most beneficial option is put forward as a potential project. This project is then prioritised along with all the other potential projects in order to ensure the optimal allocation of investment capital. After prioritisation, the selected projects are implemented in order to improve the benchmark performance. This process is illustrated in figure 5.1.

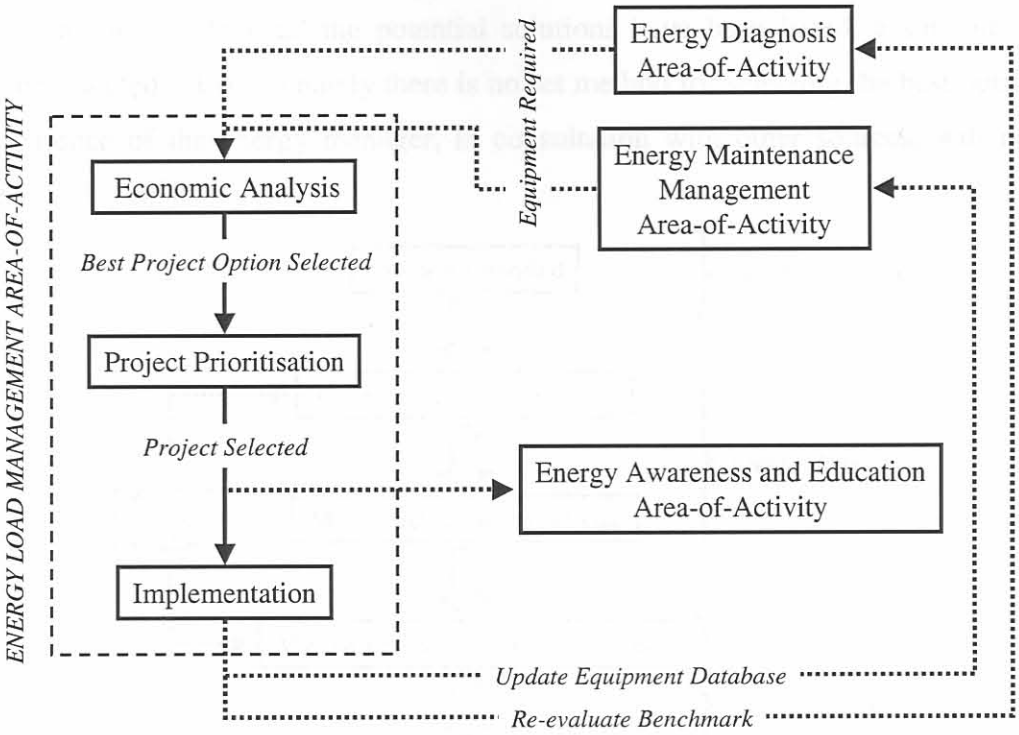

Figure 5.1: Functionality of the Energy Load Management Area-of-Activity

The solid arrows in figure 5.1 indicate internal operation and the dotted arrows indicate operations that occur with the other areas-of-activity as previously illustrated in figures 2.4, 2.5 and 2.6.

5.3 ECONOMIC ANALYSIS

According to Riggs [39], analysis starts with the identification of alternatives and the need to do something originates from asking "What needs to be done?", "What can be done?" and "What should be done?".

The input that is received from both the Energy Diagnosis and Energy Maintenance areas-of-activity is in the form of the identification of a problem relating directly to a piece of equipment. No suggestion as to its improvement is offered and this forms the starting point of the economic analysis. Broadly put, economic analysis focuses on determining various solutions, selecting the most appropriate one, presenting various alternatives and finally selecting the best approach. This process is illustrated in figure 5.2.

Once the problem has been identified, the first step involves the acquisition of all possible solutions. These can be obtained through personal experience and existing knowledge or through consultation with professional specialists both in and outside the institution and at other institutions. Once all the potential solutions have been listed, a suitable option should be selected. Unfortunately there is no set method for selecting the best option and the experience of the energy manager, in consultation with other sources, will need to suffice.

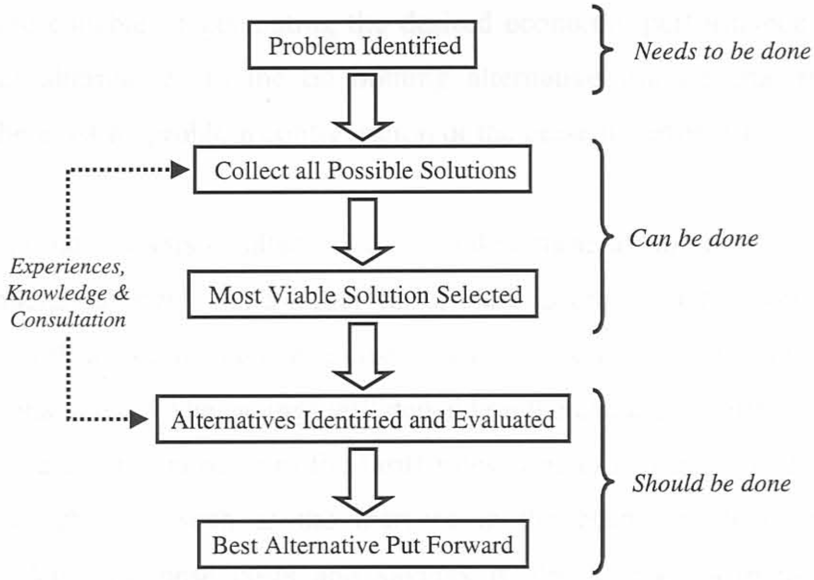

Figure 5.2: Evaluation Process from Problem Identification to Best Alternative

All decisions must bear the energy policy in mind and no option should be considered if it is contrary to the best interests of the energy management programme irrespective of its savings potential. For example, switching off all the power will ensure that the electricity costs would be zero but the production would also be zero which means the programme has failed because the energy cost per product is mathematically equal to infinity. Consider the following example of collecting potential solutions:

After noting a very consistently poor system power factor, some options could be the installation of power factor correction equipment, the reduction in the amount of inductive loads or the increase in the number of resistive loads. The first option is more feasible because it is more practically implementable without sacrificing comfort and services.

With the best solution selected, the next step involves the acquisition and evaluation of various alternatives. This step is essentially the planning phase of each potential project and the output is a fully financially evaluated project in terms of internal rate of return and net present value. This level typically involves the comparison of two or three alternatives against each other and the "do nothing alternative". Thuesen and Fabrycky [37] define the do nothing alternative as the case where the investor will "do nothing" about the projects being considered and that the funds made available by not investing will be placed on other investments that yield an Internal Rate of Return (IRR) equal to the Minimum Attractive Rate of Return (MARR) of the institution. The do nothing alternative does not mean that the funds will be "hidden under a mattress" but rather that they will be used for other projects that are capable of generating the desired economic performance. Comparing various project alternatives to the do nothing alternative implies that they are being compared to the existing problem configuration or the present performance.

The first step in the analysis of alternatives is to determine all the costs involved and the source of financial savings. The initial costs, such as those for the equipment and the installation, as well as the maintenance costs, such as labour costs and replacement costs, should all be considered. The savings will depend on the electricity tariff structure and the tariff rates. The annual increase in the tariff rates should also be considered and where applicable other changes such as the increase in the electricity load should also be considered. With all these costs and savings it almost goes without saying that a spreadsheet must be constructed that not only reflects all these parameters but compensates for their changes too. In this manner a handy tool is constructed that can be updated and used for future projects. The period of the analysis will vary and can be either monthly or annually whichever is easiest. Typically an annually based evaluation is easiest as it simplifies the time value of money calculations.

The aim of the evaluation of various alternatives is to arrive at a cash flow for which the IRR and the Net Present Value (NPV) can be determined at the MARR. Unfortunately in order to calculate the IRR, it is imperative to have a cash flow that swings from negative in the beginning of the project, to positive towards the later stages of the project. This poses somewhat of a dilemma in the case where two or more options are being considered and neither produces any real income. At this point it is necessary to quantify the term "savings". In the energy management context, a financial saving is not an income but rather a reduction in the financial accountability of the institution. In other words, achieving an energy saving simply means that you are giving out less money for energy each month. The point of the matter is that, financially speaking, you have not generated an income but merely slowed the expenditure. It seems very difficult then to arrive at a cash flow that swings from negative to positive. This is overcome by subtracting the one option from the other as shown in table 5.1.

Table 5.1: Example of Creating a Positive Cash Flow

Year	Option A	Option B	A-B
0	-1,000	0	-1,000
1	-200	-550	+350
2	-200	-550	+350
3	-200	-550	+350
4	-200	-550	+350

In this case the performance of A-B is being evaluated for both the NPV and IRR using the following evaluation criteria:

- If the NPV of A-B is greater than zero (i.e. positive), then option A should be accepted. If the NPV is negative, then option A should be rejected and option B should be accepted.
- If the IRR of A-B is greater than the MARR, then option A should be accepted. If the IRR is less than the MARR, then option A should be rejected and option B should be accepted.

If we assume a MARR of 10% for the cash flow in table 5.1, then the following values are obtained for the NPV and the IRR:

$$NPV_{A-B}(MARR) = -1{,}000 + 350\left[\frac{(1+0.1)^4 - 1}{0.1(1+0.1)^4}\right] = -1{,}000 + 1{,}109.45 = 109.45 \qquad [5.1]$$

$$NPV_{A-B}(i^*) = 0, \text{where } i^* = 14.96\% \qquad [5.2]$$

In this case Option A should be selected because the NPV (using the MARR) is greater than zero and the IRR is greater than the MARR. In this example option B would typically be the do nothing alternative because it has no initial costs arising from the investment of new technology.

All the project alternatives can be evaluated in this way to arrive at the selection of one single alternative that is considered the correct approach to the project. Examples of this methodology will be illustrated in the case studies presented in the next three sections.

5.4 EQUIPMENT UPGRADES: A LIGHTING CASE STUDY

This case study involves the upgrade of the existing lighting configuration in the library at the University of Pretoria to more modern efficient lighting. In this instance it was decided to review a total of 3000 luminaires each holding two tubular fluorescent lamps by considering a 5-year project period. The lamps are required throughout the year for 12 hours a day and 6 days of the week. Three alternatives were considered and the characteristics of each are presented in table 5.2 as follows:

Table 5.2: Characteristics of each Alternative - Lighting Case Study

	Alternative A	**Alternative B**	**Alternative C**
Description	2 x 55W, 6-foot lamps	2 x 58W, 6-foot lamps, standard	2 x 58W, 6-foot lamps, with electronic control gear
Number of Lamps per Luminaire	2	2	2
Lamp Power Rating	55 W	58 W	50 W
Lamp Life (based on a 12-hour switching cycle with 5% failures)	5,000 hours	5,000 hours	14,000 hours
Cost per Lamp	R21.00	R6.30	R15.00
Ballast Power Rating	18 W	26 W	10 W
Cost per Control Assembly	Nil	R97.80	R228.25
Power Factor of Complete Fitting	0.85	0.85	0.98

Alternative A in table 5.2 is the do-nothing alternative as where only the lamps are considered for upgrade and not the entire control assembly. The electronic control gear in Alternative C ensures that the lamps are optimally managed and thereby effectively reducing the power rating to 50W after startup [40]. In order to evaluate all three alternatives, the following cost items need to be investigated:

- Initial cost of replacing the existing equipment (alternative A) with newer equipment (alternatives B or C)
- Replacement costs of blown lamps during the 5-year project period
- The energy consumption cost of the luminaire ballast and lamps
- The contribution of the luminaire ballast and lamps to the maximum demand cost

At the time of this case study, in 1999, the University of Pretoria was billed according to a demand tariff with energy charged at a rate of 8.76 cents per kWh and maximum demand at a rate of R44.95 per kVA. These rates are expected to increase with 5% per annum.

The initial costs of each alternative are given in table 5.3 and are calculated by adding the cost of each new lamp and the cost of each new control assembly.

Table 5.3: Calculation of the Initial Costs - Lighting Case Study

	Alternative A	Alternative B	Alternative C
Number of Luminaires Required	Nil	3000	3000
Number of Lamps Required	4493*	6000	6000
Price per Control Assembly	Nil	R 97.80	R 228.25
Price per Lamp	R 21.00	R 6.30	R 15.00
Total Initial Cost	-R 94,353.00	-R 331,200.00	-R 774,750.00

*If option A is the do nothing alternative, it seems strange that there will be some initial cost. This cost is attributed to the cost of lamp replacement within the initial year (i.e. between now and the end of year 0 where the end of year 0 equals the beginning of year 1). Unfortunately, it is not known how long each lamp has been used at the time of the study and for this reason, an assumption is made. The value of 4493 lamps is the average amount of failures per year and will be explained in the next section.

The cost of replacing the lamps when they fail contains two facets, namely the cost of the lamps themselves and the labour costs of the maintenance personnel. The labour is considered because it is a major part of the business overhead at an academic institution.

Table 5.4: Calculation of the Replacement Costs - Lighting Case Study

	Alternative A	Alternative B	Alternative C
Number of Days per Week	6	6	6
Number of Hours per Day	12	12	12
Burning Hours per Year	3744	3744	3744
Lamp Life	5000	5000	14000
Number of Lamp Replacements per Year	4493	4493	1605
Labour Cost per Lamp	R 10.00	R 10.00	R 10.00
Total Lamp Replacement Cost: Year 1	-R 139,276.80	-R 73,232.64	-R 40,114.29
Increase in Lamp Cost and Labour Rate per year	10%	10%	10%

If each lamp will be required to burn for a total of 3,744 hours per year, it seems odd that there will be any lamp replacements in the first year because the life of each lamp is 5,000 hours for alternatives A and B and 14,000 hours for alternative C. Statistically speaking, there may be a few failures in the first year due to production tolerances but these are not being considered here. If a 5-year period is considered, the total burning hours of each lamp would be as follows:

$$\begin{aligned} Total\ Hours_{\ per\ lamp} &= 12\ hours\ per\ day \times 6\ days\ per\ week \times 52\ weeks \times 5\ years \\ &= 18{,}720\ hours \end{aligned} \qquad [5.3]$$

The total number of replacements required for each lamp is obtained from dividing the total number of burning hours of each lamp by the lamp life. For alternatives A and B, this would yield the following result:

$$Replacements_{\ per\ lamp} = \frac{18{,}720}{Lamp\ Life} = \frac{18{,}720}{5{,}000} = 3.74 \qquad [5.4]$$

In other words, over a 5-year period, each lamp would require approximately 4 replacements. Multiplied by the total number of lamps and dividing this over 5 years yields a replacement requirement of 4,493 lamps per year. The replacements for the first year have been included in order to ease the financial calculations and excludes the assumption made for the initial cost of alternative A. The cost of the lamps and the labour rate is expected to increase by 10% per annum. The calculations can be easily amended for cases where the labour cost and lamp costs are expected to increase with differing percentages. The cost of the energy consumption is given in table 5.5.

Table 5.5: Calculation of the Energy Costs - Lighting Case Study

	Alternative A	Alternative B	Alternative C
Ballast Load per Luminaire (kW)	0.018	0.026	0.010
Lamp Load per Luminaire (kW)	0.110	0.116	0.100
Total Load per Luminaire (kW)	0.128	0.142	0.110
Total Load per year of all lamps (kWh)	1,437,696	1,594,944	1,235,520
Cost per Unit (c/kWh)	8.76	8.76	8.76
Total Energy Cost: Year 1	-R 125,942.17	-R 139,717.09	-R 108,231.55
Increase in Energy Rate per Year	5%	5%	5%

The amount of energy that is consumed in table 5.5 is calculated by multiplying the total load per luminaire by the number of luminaires and the number of burning hours in the year.

The final cost that needs to be considered is the contribution of these lamps to the overall maximum demand of the University. The calculation is given in table 5.6. The power factor plays a crucial part in these calculations in order to determine the apparent power (kVA) of the lamps. This is necessary because the maximum demand charge is levied per kVA. The apparent power of the lamps is obtained by dividing the active power (kW) calculated in table 5.5 by the power factor in accordance with equation 3.1.

Table 5.6: Calculation of the Maximum Demand Costs - Lighting Case Study

	Alternative A	**Alternative B**	**Alternative C**
Power Factor	0.85	0.85	0.98
Load per luminaire (kVA)	0.151	0.167	0.112
Total Load (kVA)	451.76	501.18	336.73
Cost per kVA	R 44.95	R 44.95	R 44.95
Total MD Cost: Year 1	-R 243,681.88	-R 270,334.59	-R 181,634.69
Increase in MD Rate per Year	5%	5%	5%
Number of Years	5	5	5

Having calculated all the relevant costs for the first year, a summary table of each alternative can be constructed over the entire project lifetime bringing the increases in electricity tariff into account. Table 5.7 shows the summary table for alternative A.

Table 5.7: Cost Summary Table of Alternative A - Lighting Case Study

Year	**Initial Cost**	**Replacement Cost**	**Energy Cost**	**Demand Cost**	**Total Cash Flow**
0	-R 94,353.00				-R 94,353.00
1		-R 139,276.80	-R 125,942.17	-R 243,681.88	-R 508,900.85
2		-R 153,204.48	-R 132,239.28	-R 255,865.98	-R 541,309.73
3		-R 168,524.93	-R 138,851.24	-R 268,659.28	-R 576,035.45
4		-R 185,377.42	-R 145,793.80	-R 282,092.24	-R 613,263.46
5		-R 203,915.16	-R 153,083.49	-R 296,196.85	-R 653,195.51

The total cash flows for each alternative is given in table 5.8. All the entries are negative and subtracting them from each other produces three cash flows that swing from negative to positive that can be evaluated for NPV, IRR and payback period.

Table 5.8: Resultant Evaluation Cash Flows - Lighting Case Study

Year	Alternative A	Alternative B	Alternative C	B-A	C-A	C-B
0	-R 94,353.00	-R 331,200.00	-R 774,750.00	-R 236,847.00	-R 680,397.00	-R 443,550.00
1	-R 508,900.85	-R 483,284.32	-R 329,980.53	R 25,616.53	R 178,920.32	R 153,303.79
2	-R 541,309.73	-R 511,110.17	-R 348,485.27	R 30,199.56	R 192,824.46	R 162,624.90
3	-R 576,035.45	-R 540,693.47	-R 368,115.82	R 35,341.97	R 207,919.62	R 172,577.65
4	-R 613,263.46	-R 572,158.72	-R 388,948.53	R 41,104.74	R 224,314.94	R 183,210.20
5	-R 653,195.51	-R 605,640.29	-R 411,065.56	R 47,555.22	R 242,129.95	R 194,574.73

Using a MARR of 12%, the results of the NPV and IRR are obtained for each of the resultant cash flows and are presented in table 5.9.

Table 5.9: Financial Evaluation - Lighting Case Study

	B-A	C-A	C-B
NPV	-R 99,676.39	R 54,475.07	R 154,151.47
IRR	-7.82%	15.37%	26.08%
Payback Period	No Payback	5 years	4 years

Using table 5.9, the three alternatives can be easily compared to each other. From the poor performance of alternative B-A, alternative A is better than alternative B. The choice then lies between alternatives C and A of which C is better from the performance of the C-A alternative. The IRR of this evaluation (15.37%) is greater than the MARR of 12%. The last column (alternative C-B) is insignificant because alternative A had already outperformed alternative B even though it has the shortest payback period.

In conclusion it can be said that alternative C has a much lower replacement, energy consumption and demand cost even though the initial costs are dramatically higher than either of the other two options. The improved reliability of the lamps, high efficiency of the ballast and high power factor of the control assembly cause this. All of these factors contribute to its financial superiority.

5.5 DIRECT EQUIPMENT CONTROL: A HOT WATER CASE STUDY

By having load control capability, an institution can reduce the electricity costs of their campus. This is only possible where the tariff structure allows for it. When billed according to a time-of-use (TOU) tariff, the emphasis of load control will primarily be on shifting energy to a cheaper tariff period. When billed according to a demand tariff the emphasis will be on reducing the maximum demand of the total load. The TOU tariff may also have a maximum demand component that will further motivate the ability to control load. The primary reasons for controlling the hot water cylinders in the residential hostels, as opposed to other loads, at the University of Pretoria are as follows:

- The hot water load is a shiftable load (see figure 1.1), which implies that it is able to store energy. This will provide some measure of error leeway when correcting the models (and control strategies) for errors.
- Control of the hot water load is invisible to the hostel residents. This is ascribed to the "psychology of control" [41].

Hot water load control involves the subdivision of the total hot water load into a series of control channels or groups. These groups are switched and manipulated in order to manage the total load. Each group is prioritised according to the installed capacity and the historical dynamics of that group. A "building-block" approach is used to restore each group in a controlled manner so as to limit the effects of the cold-load pickup [42, 43]. Typically a maximum demand control target is set and the channels controlled accordingly [44]. For example, when the total load exceeds the set target, the load controller will begin switching off channels according to a prioritised order. Should the present demand require more than one channel to be shed, the load controller sheds the next channel in the priority list. The length of time that cylinders are shed will depend on the instantaneous load – where necessary the channels will remain off while the demand is high.

In this case study the potential savings from controlling the hot water load at a single hostel at the University of Pretoria, namely Erika hostel, will be considered. During a walk audit it was observed that a total of 240 kW of hot water equipment is installed in this hostel in the form of sixty 4kW cylinders each with a 200-litre capacity. However, after conducting a test of the installed capacity, it was noted that only 191 kW is available to be controlled from the existing centralised relay. This is due to system fatigue where an old outdated system was not maintained and eventually not even used resulting in the system being bypassed during later maintenance work. The results of the installed capacity test are illustrated in figure 5.3.

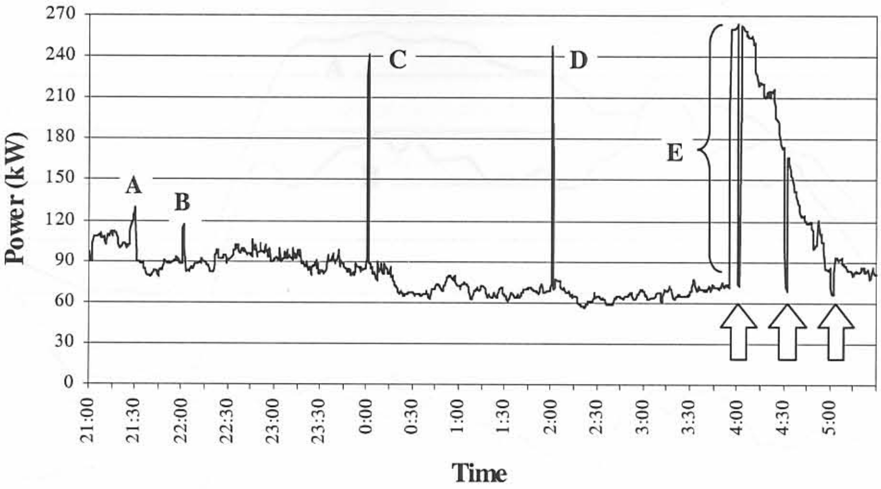

Figure 5.3: Installed Capacity Test of the Hot Water Load at Erika Hostel

This specific test involved switching all the hot water cylinders off at 21:30 (point A) and then conducting three 1-minute spikes at 22:00, 0:00 and 02:00 (points B, C and D respectively). The entire hot water load was restored at 03:55 to ensure that the residents would have enough hot water when they needed it in the morning. The difference between the peak load and the base load (point E) provides the measure of the installed capacity of the hot water load. Figure 5.3 illustrates the load restoration curve that occurs from 03:55, once the load was restored, as the individual cylinders reach their desired temperatures and switch off. The arrows in figure 5.3 indicate where regular half-hourly notches have switched in order to determine the shape of the hot water load profile.

To maximise the savings, it is planned to switch off the entire hot water load available at the time that that the University reaches a maximum. In other words, the contribution that the hot water load of this specific hostel makes towards the overall demand of the University will be zero. The savings is then the difference between what the load was and what it would have been had the cylinders been allowed to operate multiplied by the maximum demand rate of R44.95. The problem lies in trying to determine the amount of load that can be switched off. The hot water load, made up of a diverse array of cylinders, is dependent on the hot water consumption pattern that varies with the different days of the week and seasons. To determine the hot water load, use is made of a series of notch tests [45] where the hot water load is switched off for 2 minutes on the half-hour and the resultant load profile measured. Figure 5.4 illustrates the overall University load on the left-hand axis and the total hostel load and hostel hot water load on the right-hand side for a corresponding sample day.

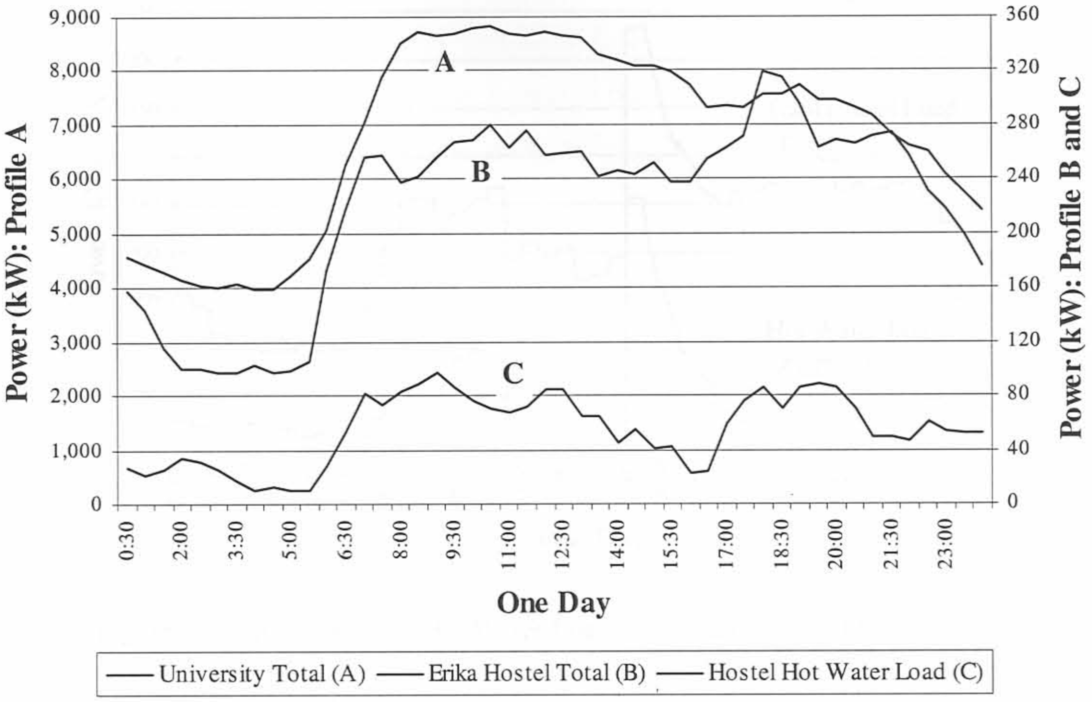

Figure 5.4: Hot Water Load in Comparsion to the Total Hostel Load and Campus Load

On this specific day, the overall University load reached a maximum at 10:30 of 8,808 kW. The contribution of the hot water load of the hostel at that time was 69.65 kW and the total hostel load was 280 kW. Switching off this hot water load component and restoring much later in order to avoid the fairly flat midday profile of the total University load, the resultant hostel profile is illustrated in figure 5.5. As a result of the load being left off between 09:30 and 13:00, the full 191 kW hot water installed capacity is switched on when the load is restored. As the individual cylinders get up to their set temperatures, they start switching off. The model output with a 1-minute resolution and working in 30-minute billing intervals causes the staggered profile illustrated in figure 5.5.

In this example, all the available hot water load is shed at the time of the system peak producing a saving of R 3,130.77 for this specific month. The maximum demand rate in kVA was used and applied to kW values because the model that has been setup to evaluate these savings is based on active power values. This approximation is valid because the power factor at the University is unity as a result of power factor correction equipment. Power factor correction will be discussed in detail in the next case study.

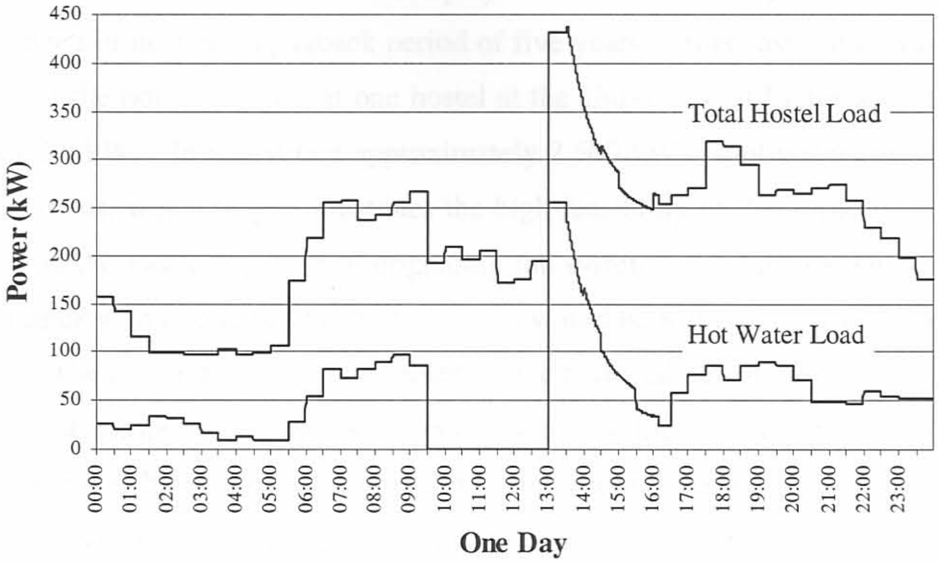

Figure 5.5: The Controlled Hot Water Load and Resultant Total Hostel Load

For the purposes of financial evaluation, the assumption is made that a similar amount of savings can be realised each month of the year. This implies that controlling the hot water cylinders in this hostel alone would produce a total saving of R 37,569.21 in the first year. The annual electricity tariff increase, assumed to be 5%, would ensure that the savings would also increase each year.

The initial cost of the system is based on the requirement for a relay switch per cylinder capable of being activated via radio and the control and communications hardware too. The centralised computer load controller is the most expensive part of the system and is required irrespective of whether a single relay or multitude of relays are being controlled. In this case study, a total of 60 switching relays are required. Table 5.10 shows the summary table for the hot water control equipment.

Table 5.10: Cost Summary Table – Hot Water Control Case Study

Year	Initial Cost	Savings	Total Cash Flow
0	-R 133,000.00		-R 133,000.00
1		R 37,569.21	R 37,569.21
2		R 39,447.67	R 39,447.67
3		R 41,420.05	R 41,420.05
4		R 43,491.06	R 43,491.06
5		R 45,665.61	R 45,665.61

Using a MARR of 12%, the NPV of the project amounts to R 13,414.82. The IRR is 16.31% and the project has a payback period of five years. This case study was based on the control of the hot water load at one hostel at the University of Pretoria with a control capacity of 240kW. In actual fact approximately 2,500 kW of hot water capacity can be found on campus, which further illustrates the high feasibility of this project. It has been estimated that the payback period of upgrading the system to control the entire hot water load on campus with a total of 350 control relays would be just over one year with an IRR of 90.30%. The reason for this improvement in the financial performance is caused by the high fixed cost component of the load control system in the form of the communications and load controller hardware. These systems are required irrespective of the number of control points whereby increasing the number of control relays reduces the fixed cost per point. The control relays or load switches themselves are very cheap in comparison.

5.6 INSTALLATION OF NEW EQUIPMENT: A POWER FACTOR CORRECTION CASE STUDY

This case study concerns the installation of power factor correction (PFC) equipment at the supply point of the Medical Campus of the University of Pretoria. The calculations in this case study are based upon actual monthly load data gathered by the City Council of Pretoria during 1997. This case study reviews the financial implication of installing power factor correction against the case if this equipment is not installed. The latter is the do nothing alternative.

PFC is based on the principle of installing a capacitor bank, which can absorb the reactive power component of the load. Referring to the power triangle in figure 3.6, the concept of power factor correction is easily explained in figure 5.6.

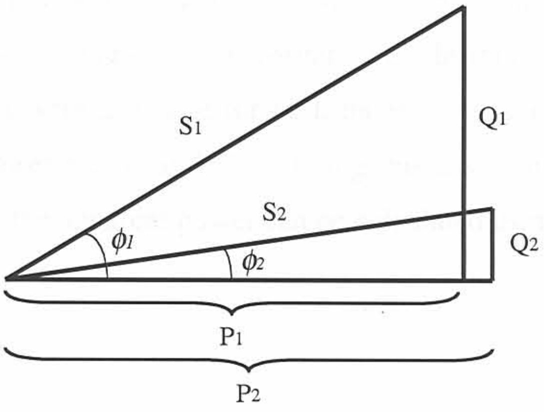

Figure 5.6: Effect of Power Factor Correction on the Power Triangle

Theoretically, to improve the power factor the active power, P_1, stays the same but the reactive power will decrease from Q_1 to Q_2 and the apparent power from S_1 to S_2. In practice however, the PFC equipment consumes active energy too, which results in a marginal increase in the amount of active power from P_1 to P_2. Modern PFC equipment is much more efficient ensuring a much lower energy consumption. The most critical facet to bear in mind is that a charge of R44.95 per kVA is levied on the maximum demand. In other words, improving the power factor (or reducing the amount of reactive power Q) will ensure that the demand (or apparent power S) is also reduced thus producing a financial "saving". From a technical point of view, a low power factor can have the following disadvantages [14, 46, 47]:

- Overloaded generators, transformers and distribution lines causing wear and tear of equipment
- Voltage drops and increased power losses
- Reduced load-handling capability, or capacity, of the electrical system

The following financial factors must be brought into account in order to evaluate the feasibility of PFC equipment:

- Initial cost of the PFC equipment including the installation costs
- Maintenance costs for the servicing of the PFC equipment
- The reduction in the maximum demand charges

To determine the savings, it is necessary to have the measurements for either the active power or the apparent power. Ideally both are required in order to determine the present power factor. In order to ease the calculations, it is assumed that the PFC equipment does not contribute to the total active energy consumption. In this instance both the apparent and active power values were available for each month. It is assumed that the PFC will maintain an average power factor of 98%. Using this assumption and the existing load data, the new values for the apparent power can be calculated using the following equation:

$$S_2 = \frac{P_1}{PF_2} = \frac{P_1}{0.98} \qquad [5.5]$$

Once the new values for the apparent power have been calculated, determining the difference between the maximum demand if no PFC was installed with that should PFC have been in place produces the savings. Figure 5.6 illustrates the load at the Medical Campus during January 1997 without PFC and the potential load had PFC been installed.

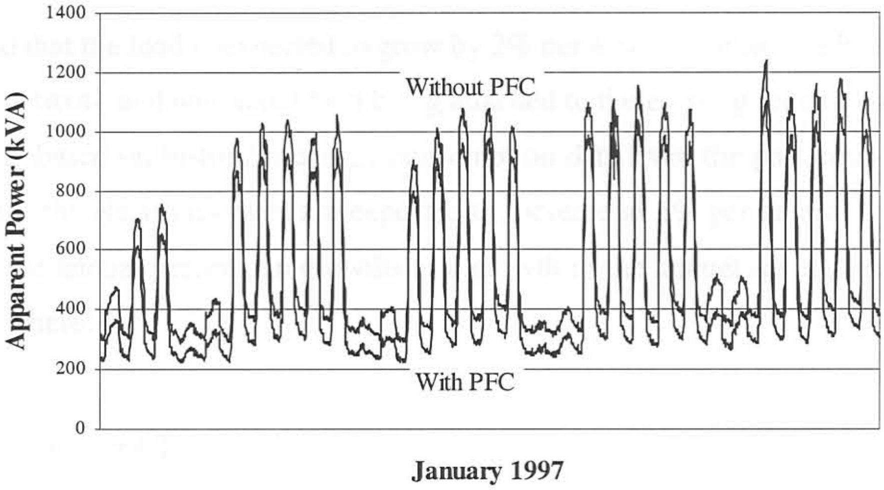

Figure 5.7: Effect of Power Factor Correction on the Load Profile

For the specific month illustrated in figure 5.7, the difference in the maximum demand is 136.82 kVA which would create a saving of R 6,149.90 when multiplied by the maximum demand rate of R44.95 per kVA. Table 5.11 illustrates the savings for each month when calculated in this manner.

Table 5.11: Monthly Savings – Power Factor Correction Case Study

Month (1997)	Load Reduction (kVA)	Savings
January	136.82	R 6,149.90
February	128.78	R 5,788.82
March	128.64	R 5,782.19
April	63.07	R 2,834.92
May	31.07	R 1,396.76
June	38.76	R 1,742.13
July	31.72	R 1,425.72
August	44.82	R 2,014.54
September	104.42	R 4,693.55
October	119.02	R 5,349.94
November	121.01	R 5,439.57
December	105.00	R 4,719.55
	Total Annual Savings	**R 47,337.59**

The values in table 5.11 vary with each month and can be ascribed to the different types of load during the annual seasons. A high inductive air conditioning load is present during the hot summer months and a greater resistive space heater load is present during the colder winter months.

It is assumed that the load is expected to grow by 2% per annum due to an expansion in the reticulation network and additional load being attached to the existing reticulation network. This figure is based on historical energy consumption data from the past couple of years. Added to this, the electricity rates are expected to increase at 5% per annum. In order to transpose these annual percentage growths to a growth in the annual savings, equation 5.6 can be used where:

$$R_n = S \times \left[(1+s)\times(1+t)\right]^n \qquad [5.6]$$

R_n	savings for specific year n (Rand)
S	total savings from the first year (R 47,337.59)
s	annual percentage load growth (2%)
t	annual percentage increase in the maximum demand rate (5%)
n	number of years

The present maximum reactive load that needs to be absorbed is approximately 387 kVAr. Based on the 2% load growth, it is decided to use a 550-kVAr capacitor bank that will have a projected useful lifetime of 17 years. The capital costs of the PFC equipment are in the region of R95 per kVAr and include the supply, installation and commissioning. The total initial cost is therefore estimated at R 52,250.00.

It is estimated that the maintenance of the equipment will require 2 hours a month at a rate of R200.00 per hour. This amounts to R 4,800.00 per year and is assumed to increase at 10% per annum. As previously mentioned, the capacitor bank does consume energy (kWh) while performing its function but this will be neglected due to the size of the capacitor bank in question and the fact that modern equipment of this kind is highly efficient. The salvage value of the capacitor bank is not brought into consideration because it is unknown whether a demand for this type of equipment will exist in the future. Any receipts that are created from the salvage of this equipment should be seen as project bonus and could be used at that time to fund the next project of this nature. Table 5.12 shows the summary table for the PFC equipment.

Table 5.12: Cost Summary Table – Power Factor Correction Case Study

Year	Initial Cost	Maintenance	Savings	Total Cash Flow
0	-R 52,250.00			-R 52,250.00
1		-R 4,800.00	R 47,337.59	R 42,537.59
2		-R 5,280.00	R 50,651.22	R 45,371.22
3		-R 5,808.00	R 54,196.81	R 48,388.81
4		-R 6,388.80	R 57,990.58	R 51,601.78
5		-R 7,027.68	R 62,049.92	R 55,022.24

Using a MARR of 12%, the NPV of the project amounts to R 107,461.44. The IRR is a staggering 82.52% and the project has a payback period of just over one year. This case study considered the financial evaluation of the installation of PFC compared to the case where no equipment was installed or the do nothing alternative. The results of the study show conclusively that this is a highly feasible project.

5.7 PROJECT PRIORITISATION

Having completed the economic analysis, the best alternative of each energy management project is put forward and the next step involves the prioritisation of all of these projects. Prioritising the projects is essential to determine the order in which energy projects will be undertaken and implemented particularly in the light of limited financial resources.

The three case studies that were presented in the previous sections provided three potential projects all of whom are financially viable with good all round performance. The problem lies in deciding which of these projects is more suited to be immediately undertaken. The purpose of prioritising the energy management projects is to ensure that those projects that are selected will maximise the wealth of the institution. This is known as capital rationing [48] and will gain support for the energy management programme and ensure its future sustainability. The object of capital rationing is to select the group of projects that provides the highest overall NPV and does not require more funds than are budgeted. There are two types of approaches to capital rationing, namely the IRR method and the NPV method [39, 48]. Each will be explained using the performance of the three case studies, as summarised in table 5.13, as an example.

Table 5.13: Summary of the Financial Analysis of the Case Studies

	Initial Investment	**NPV (@ 12%)**	**IRR**
Efficient Lighting	R 774,750.00	R 54,475.07	15.37%
Hot Water Control	R 133,000.00	R 13,414.82	16.31%
Power Factor Correction	R 52,250.00	R 107,461.44	82.52%

The IRR approach involves plotting projects in descending order according to their IRR against the amount of initial capital investment. This plot is called the investment opportunity schedule and is illustrated in figure 5.8 for the three projects in table 5.13.

By drawing a horizontal line at the MARR of 12% (line A) and a vertical line at the amount of capital available for investment, the projects most suitable will be selected. If the budgetary amount for projects was limited to R 100,000.00 (line B), then only the power factor correction project should be undertaken. If the budget was set at R 400,000.00 (line C), then, according to the IRR method, both the power factor correction and the hot water control projects should be undertaken.

It is fairly evident that this method is not necessarily the best approach. In the case where the investment amount was limited to R 100,000.00, only R 52,250.00 was required for the power factor correction project leaving an amount of R 47,750.00 unused. If the budget for investment was increased from R 100,000.00 to R 185,250.00 then both the power factor correction and the hot water control projects could have been completed within the budget constraints.

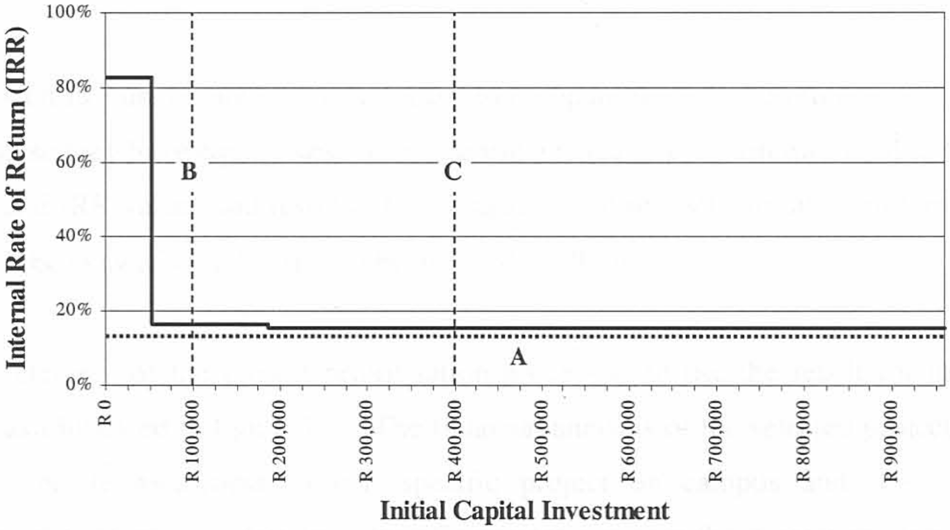

Figure 5.8: Investment Opportunity Schedule for Projects in Table 5.13

The NPV approach is based on determining the combination of projects with the highest overall NPV while still meeting the capital investment budget constraints. Using this method, the combination of projects that will provide the highest overall NPV would be the power factor correction and hot water control projects if R 400,000.00 was available for investment or the power factor correction project if only R 100,000.00 was available for investment. In this example, the results of the NPV method mirror those of the IRR method. Note that the hot water control project is selected above the efficient lighting project even though the NPV of the efficient lighting is much greater. This is done in order to make full use of the investment capital, which is the emphasis of the NPV method.

Although both methods produced similar results, their feasibility becomes more apparent in the light of a greater number of projects. Selecting between three projects such as these is easy but selecting between a hundred is more complex. The question still arises as to which method should be used to provide solid suggestions for investment. According to Droms [49], the answer to the problem is inherent in the mathematics of the methods. Mathematically, the NPV method used here assumes that all cash receipts (or savings) are re-invested at the MARR of the institution. The IRR method assumes that all receipts are re-invested at the IRR of the project. Therefore the selection of the method depends on which assumption is closest to reality. The choice should be based on which re-investment rate is closest to the rate that the institution will be able to earn on the cash flows or savings generated by the project. Following this rule will result in basing decisions on the investments that will maximise the value of the institution. In this specific instance, at the University of Pretoria, the NPV method is the most suitable evaluation method with which to evaluate these three projects.

In conclusion it must be noted that it is easy to compare these three projects against each other because they have equal lives. Considering unequal project lifetimes will affect both the NPV and IRR values and result in the comparison of projects on different terms. The results will be skewed and this should be avoided at all times.

The final element of the project prioritisation process is to use the result for marketing purposes as illustrated in figure 5.1. The financial analysis of the selected projects can be used to generate awareness to that specific project on campus and where needed advertising the intent to undertake a specific project can ease the project implementation. For example, advertising that the office lights in a specific building are to be upgraded could ensure that the building occupants take the necessary security precautions and ensure that the project technicians have access to all the offices. This makes the project implementation phase that much easier and reduces the number of complaints from the occupants.

5.8 IMPLEMENTATION

At this point various options have been considered, alternatives weighed off against each other, quotations and advice has been received, the best alternatives put forward as projects and these projects all weighed off against each other and the availability of investment capital. The energy load management area-of-activity culminates in the implementation of the projects according to their priority.

All the economic planning for each project should already be complete at this stage and all that remains is giving the go-ahead for project implementation. Every institution will have their own set of procedures for the awarding of contracts to external contractors and these must be adhered too. For any project it is essential that a legally binding contract be put into place. South African law defines a contract for the letting and hiring of work as a reciprocal agreement between a provider of work and a contractor in which the latter agrees to build, manufacture, repair, modify or maintain a corporeal thing within an agreed period of time in exchange for remuneration.

The specific aspects of this type of contract are [50]:

- It is an agreement for the completion of a specific piece of work in respect of a corporeal thing.
- The contractor's only duty is to do the work in accordance with the particular specifications of the contract.
- The contractor does the work in exchange for remuneration either in the form of a lump sum or a scale or formula according to which the remuneration is determined.
- The work must be completed within the agreed period of time or a reasonable time.

A contractor commits breach of contract if he fails to perform his contractual duties. In this event the institution is entitled to the following remedies:

- Damages where, for example, a contractor's tender has been accepted and he refuses to start on the project, the institution is entitled to claim the difference, if any, between the contractor's tender price and the new tender price of another contractor.
- Rescission of the contract where the institution may cancel the contract under the circumstances of the contract breach where the timeous performance is of the essence to the contract or where the institution acquires a right to resile by serving a notice of rescission on the contractor. In addition to cancellation, the institution may claim damages.
- Specific performance where the institution withholds a percentage of the contract price, termed retaining fees, as security for the proper performance of the contractor of all of his contractual duties.

On the other hand, the institution could also be in breach of contract, in which case the contractor is entitled to similar remedies, namely cancellation and specific performance combined with a claim for damages. The contractor also has an additional remedy in the form of a lien over the object made by him whereby he may keep the object in his possession until he is remunerated.

Once the contractor has completed the project and the necessary commissioning and hand-over taken place, it is vital that all of the equipment specifications and maintenance requirements are obtained from the contractor in order for them to be passed onto the Energy Maintenance Management area-of-activity. With the completion of the project, feedback should also be made to the Energy Diagnosis area-of-activity in order for the energy benchmarks of the specific product or business process to be re-evaluated

5.9 CONCLUSION

This chapter has explained both the inner workings of the Energy Load Management area-of-activity and the relationship with the other activity areas.

The process from considering many alternatives and the economic analysis of various project options to arrive at a list of energy management projects has been introduced. Although there are many different types of equipment that use electrical energy, the three case studies presented in this chapter all have the potential to reduce costs and provide a measure of savings.

The mistake of ignoring the time value of money is very often made when calculating the economic performance of project. This results in a skewed expectancy that is usually over-optimistic. Considering the effects of the cost capital ensures greater accuracy when it comes to project planning. In fact sometimes a conservative approach will ensure that the projects that are undertaken will provide better results by reducing the energy cost per student or campus building. The positive results will ensure the support from the institution management for the energy management programme.

The implementation phase of the energy management projects must be conducted with the correct internal and external legal and administrative procedures to ensure that there are no financial and equipment losses or delays. Correct planning and respect for administrative delays will help to avoid this.

Although it is possible to say that this activity area is the one requiring the most amount of effort, many institutions fail to expand it to the energy maintenance activity area. Not only does this lead to an incomplete energy management programme but invariably sees the equipment that has been acquired becoming obsolete and unusable rendering the capital investment worthless.

The next chapter will focus on the Energy Maintenance Management area-of-activity and address the maintenance aspects relating to the electrical equipment responsible for generating the electricity costs.