CHAPTER 4: ENERGY DIAGNOSIS

"Don't be content with the what, but get to know the why and the how."
Lord Robert Baden-Powell

4.1 INTRODUCTION

In chapter 1, the diagnosis of the energy consumption was heralded as the starting point of the energy management programme. It is this area-of-activity that determines the present energy performance per product or business unit and analyses reasons for poor performance. In other words, energy diagnosis is the process of accounting for the energy on campus in terms of the financial and technical aspects. Before the energy can be accounted for, it is necessary to develop an understanding of the hierarchy of energy consumption from the individual equipment all the way through to the point of total institution consumption as shown on the left in figure 4.1. An example of each level is provided on the right in this figure.

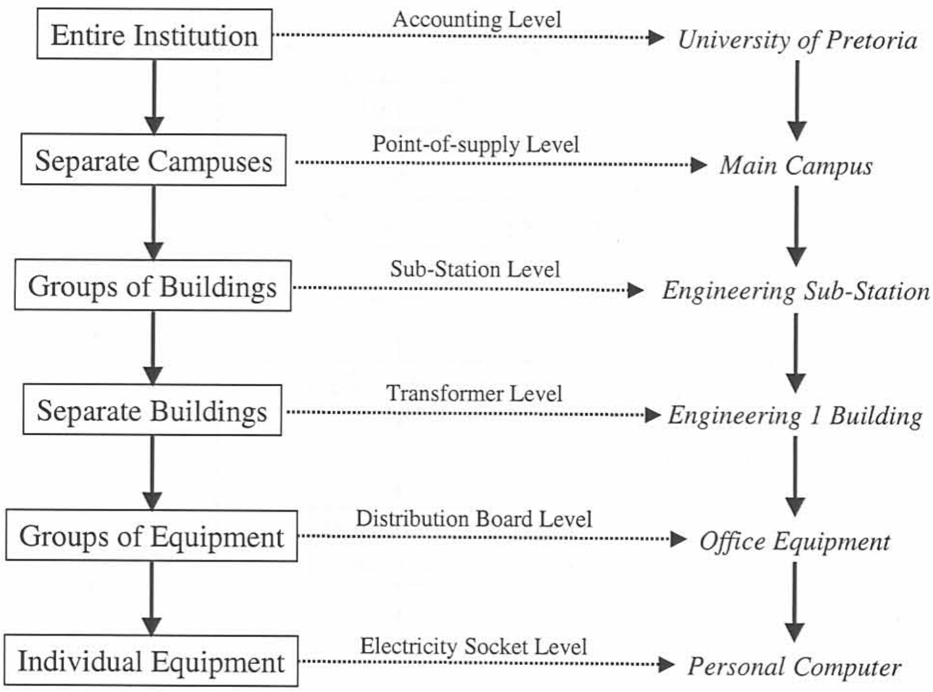

Figure 4.1: Hierarchy of Energy Diagnosis on Campus

From figure 4.1 it follows that managing the energy consumption at any of the levels will result in the management of the electricity cost of the entire institution. The point of departure of this chapter is the dissemination of energy management problems to the other areas-of-activity but before this can be accomplished, the problematic areas that are responsible for a high electricity cost per end-user need to be identified. The energy manager should be aware that not all levels in figure 4.1 are necessarily responsible for high electricity costs per product or business unit. In other words, addressing individual machinery might not be an option and as a result a solution to the electricity cost needs to be sought higher up in the diagnosis hierarchy. On the other hand, discovering faults at higher levels should, were possible, be followed all the way through to determine the source of the problem at the individual equipment level. The hierarchical levels depicted in figure 4.1 are fairly comprehensive and may not be applicable to all academic institutions, dependent on their physical size and geographical organisation.

4.2 INSIDE THE ENERGY DIAGNOSIS AREA-OF-ACTIVITY

This chapter can be divided into four sections, namely determining the specific benchmark to be calculated, acquiring the necessary data, processing this data into information by identifying contributors to the benchmark and finally disseminating it as knowledge to the other areas-of-activity. This process is illustrated in figure 4.2.

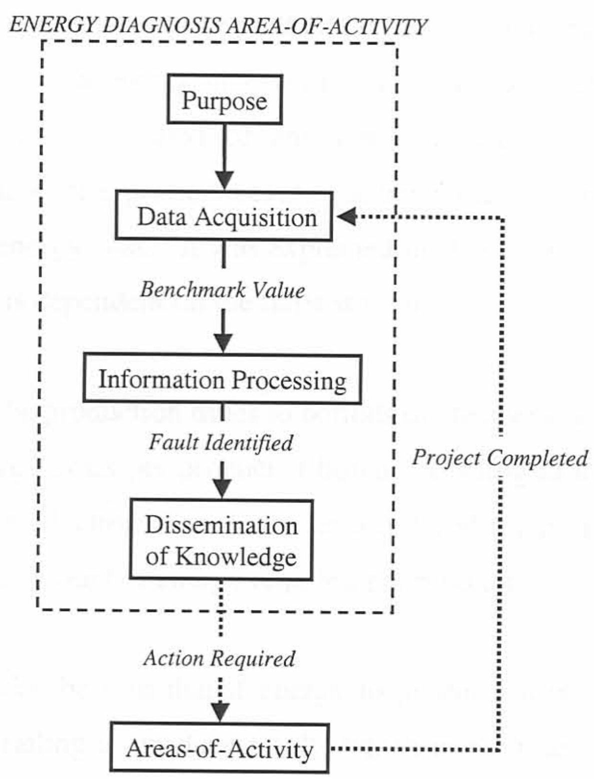

Figure 4.2: Functionality of the Energy Diagnosis Area-of-Activity

The solid arrows in figure 4.2 indicate internal operation and the dotted arrows indicate operations that occur with the other areas-of-activity. In other words, the components included in the dashed block in figure 4.2 fit into the Energy Diagnosis block of figures 2.4, 2.5 and 2.6.

Each of the four sections in the energy diagnosis area-of-activity will be discussed.

4.3 PURPOSE

It has been said that energy diagnosis is the starting point of the energy management programme. The problem lies in determining where to start with the energy diagnosis. It makes no sense in collecting data and then trying to determine where it can be used. For this reason the diagnosis hierarchy presented in figure 4.1 is very useful as a guideline to determining the starting point. The next step is to decide what is going to be calculated or determined. In other words, you need to know what it is you are looking for and the place where you should be looking.

4.3.1 Benchmarks

By definition, a norm or benchmark is a standard or point of reference [1]. It follows then that an energy benchmark at an academic institution is a performance level that links the functions on campus to the cost of energy usage. Traditionally, benchmarks have been used that link the business functions or production levels to the energy consumption only. This is not satisfactory in an energy management programme where the aim is to reduce the energy cost within the context of environmental harmony in order to enhance competitiveness and maximise profits because the benchmark is orientated around energy consumption and not energy cost. It was explained in chapter 1 that the link between the energy usage and cost is dependent on the tariff structure.

For example, altering the production times to periods of cheaper energy rates could provide a reduction in the energy costs per product if billed according to a time-of-use tariff. In this case, altering the production times has indeed reduced the cost of energy per product but has not reduced the amount of energy required per product.

From this example it can be said that if energy to production benchmarks are used, the programme would be failing to produce results which is not true. Using energy cost to production benchmarks would highlight the success of the above example.

Care should be taken not to have too many benchmarks that become very similar and as such not very useful. The other problem that occurs is that the accuracy of the benchmark can become hazy if assumptions need to be made. For example, the energy cost per student per month on a campus is not accurate because an assumption needs to be made regarding the duration and frequency of time spent by students on campus. Table 4.1 can be used as a guide for the selection of benchmarks.

Table 4.1: Benchmark Selection Guide

	Uses	Examples
Institution Level	▪ Verify supplier accounts ▪ Track trends in costs ▪ Comparison to other institutions	▪ Total Cost per Month ▪ Equivalent Cost per Unit ▪ Energy Cost per Student
Campus Level	▪ Verify supplier accounts ▪ Track trends in costs ▪ Comparison between campuses	▪ Total Cost per Month ▪ Cost per Campus per Month ▪ Equivalent Cost per Unit ▪ Energy Cost per Student
Building Level	▪ Apportion costs to buildings ▪ Comparison between buildings ▪ Comparison between different types of facilities	▪ Energy Cost per Building ▪ Energy Cost per unit of Facility Space (Office, Laboratory, Lecturing or Hostel) ▪ Energy Cost per Hostel Resident

The table focuses on two major types of benchmarks, namely those that depict electricity cost per academic facility (or business process) and those that depict electricity cost per student (or product). In this case the students of an academic institution are considered as its product and the facilities of the institution are considered as the business processes.

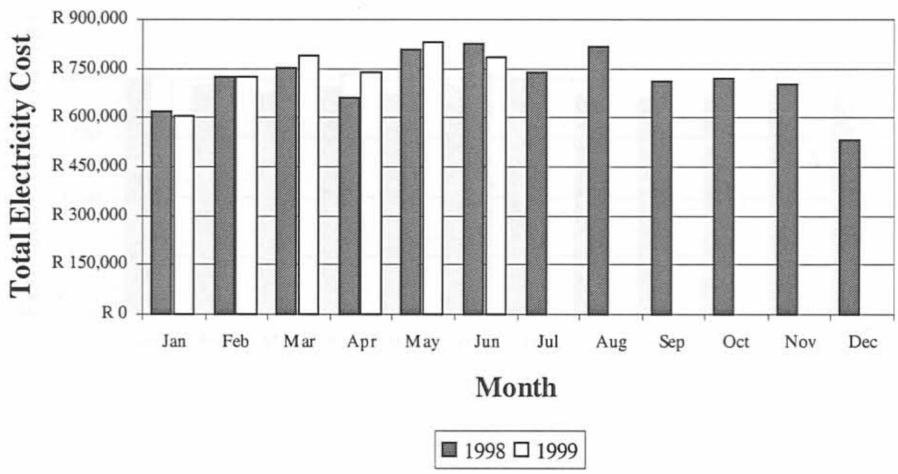

Figure 4.3: An example of the Electricity Cost from Main Campus, University of Pretoria

4.3.2 Benchmark Fluctuations

The energy costs within an academic institution will not remain constant. This is due to various reasons and includes increasing tariff rates, seasonal swing, number of days under consideration and activities on campus at the time.

Seasonal swing is the effect of seasonal change on the consumption of electrical energy [38]. The consequence of seasonal swing is that the amount of electricity, and associated cost, will not remain constant all year round, as it is dependent on the ambient air temperature. For example, the electrical space-heating load will be more prevalent in winter than in summer and vice versa with the cooling load.

The institution calendar also plays a major part. The electricity costs should subside during holiday periods when the number of students on campus is much lower. This is particularly true in cases where there are accommodation facilities for students on campus. This effect is illustrated in figure 4.3 from the University of Pretoria where students are on vacation during the months of January, April, July, September and December. Please note that the electricity costs in figure 4.3 increase from the summer months in the beginning of the year towards the winter months in the middle of the year (June, July and August). Fortunately the high electricity costs in the winter month of July are avoided due to the students being on vacation.

The energy manager must bear these factors in mind before reacting on fluctuations in the energy cost benchmarks. Normalising the benchmarks can avoid this and can be accomplished by calculating averages, such as the equivalent cost per unit, and comparing these to those of previous years or periods.

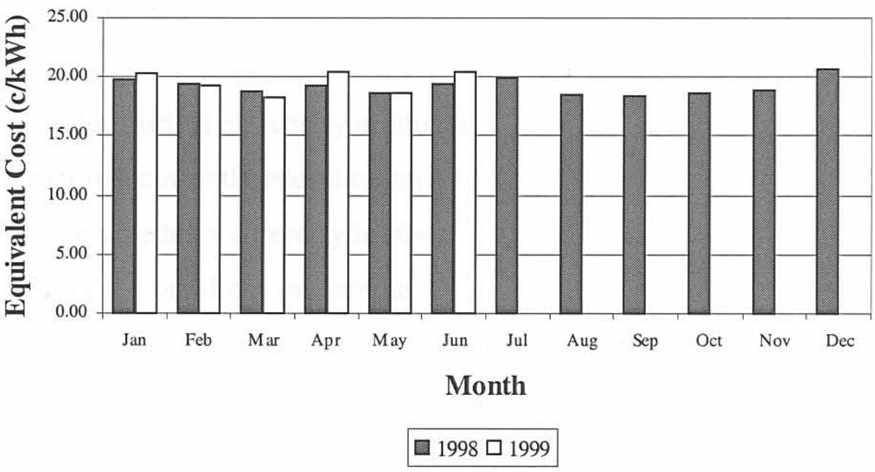

Figure 4.4: An example of Equivalent Cost per Unit of figure 4.3

Examples of benchmark normalisation are illustrated in figure 4.3 and 4.4. Incidentally it is interesting to note that the maximum equivalent cost in figure 4.4 occurs during periods when the electricity costs in figure 4.3 are low. In other words figures 4.3 and 4.4 are almost the inverse of each other. This is caused by the student vacations whereby not as much energy is being consumed during these periods but the maximum demand component of the electricity account is still large.

4.4 DATA ACQUISITION

Once the benchmarks have been selected, the data required for their calculation can be acquired. The activities of data acquisition and information processing in figure 4.2 can collectively be referred to as energy auditing. Energy auditing is a very wide field that can be split into four types namely, documentation, personnel, walk and measurement audits. Not all of the activities of each audit type are relevant to determine the benchmark values and some of them will be used during the information processing activity in order to determine the reasons for the benchmark values. Using this approach, the first step is to determine the type of information that is necessary in order to arrive at a value for the benchmark. You may find that some of the benchmarks can be calculated with relative ease from supplier electricity accounts alone whereas others require deeper analysis.

4.4.1 Documentation Audit

A documentation audit, as the name implies, involves the acquisition of any documentation that has relevance to electrical energy on campus. It may be found that this information is already available on campus but that it may lie with different departments such as the finances and facilities management departments. This type of information is usually acquired first and includes [38]:

- Existing and historical electricity accounts
- Tariff structures currently operating on
- Maintenance schedules currently in place
- The layout of the buildings on campus
- Floor plans of buildings including the amount of office space
- Drawings of the electricity reticulation network
- Electrical equipment data

4.4.2 Personnel Audit

A personnel audit involves the acquisition of information that is resident with the people on campus. This is accomplished through interviews with key personnel, conducting opinion polls and distributing questionnaires. It is very important to interview the appropriate personnel when conducting the audit. For example, it is not possible to determine the maintenance schedule by interviewing the academic staff. In essence, all the members of the campus community should be questioned but it is important to ask the correct questions at the correct level.

A questionnaire should be thoroughly planned well in advance and the information that is acquired will form a platform from where further audits can be launched. This type of audit relies on a great deal of interaction with the university community and care should be taken not to waste the time of those whose opinion is being sought.

4.4.3 Walk Audit

A walk audit is a walk-through tour of the campus in order to observe the major operational and equipment features that are being utilised. The main purpose of the walk audit is to obtain general information. It is good practice to make notes of possible energy management opportunities and faulty equipment during the walk audit. Typically, the following should be looked for during the walk audit [36, 38]:

- *Sources of Energy*

Observe which types of energy sources (e.g. electricity, coal or gas) are utilised for the various activities on campus such as food preparation, cleaning, hot water generation etc. From this the reliance and cost contribution of an operational function on any one particular energy source can be determined.

- *Controllable Equipment*

Identify equipment that can be controlled in order to avoid energy wastage or that can be operated at flexible times. This is usually equipment that is used infrequently or whose use is not necessary during certain times of the day. Examples include using sunlight instead of electrical lighting during the daytime or controlling hot water cylinders during periods of low use such as weekends.

- *Waste heat sources*

Most processes and activities have ample opportunity for waste heat recovery. Waste heat recovery means that wasted heat energy is recovered and used for another purpose such as heating water for other operational processes. Waste heat sources include air conditioners, air compressors, heaters, boilers, ovens, furnaces etc.

- *Equipment Numbers and Ratings*

An inventory should be taken of all energy consuming equipment such as lights, fridges, stoves, air-conditioners etc. In terms of electrical equipment, try and obtain the electrical rating of the equipment.

- *Counteractive Equipment Layout*

Observe the layout of the equipment in an attempt to identify processes that may either adversely affect each other or may be inefficient. Examples could include prepared food that has to be reheated or food that is allowed to air cool, which in turn affects the air-conditioning.

A database should be established of the information that has been acquired during the walk-audit for each building and floor on campus [36].

4.4.4 Measurement Audit

The measurement of the electricity consumption of end-user groups is crucial towards determining their contribution to the total electricity cost. This is even more important in the light that the benchmarks relate to the electricity cost. There are many different types of measurement equipment. These range from simple electro-mechanical energy meters that record the energy consumption only and are manually read to real-time systems that measure many parameters, such as current, voltage, power factor, active power and reactive power, and are read automatically from a central energy monitoring system.

Sometimes only measurements of the supply points are made to pinpoint problems and quantify probable savings. This might be necessary due to financial or purely practical reasons where individual campus activities cannot be measured on their own.

Investment could also be made into a real-time measurement system but this will depend on the availability of capital. Monitoring the end-use of electricity on a real-time basis can lead to many discoveries of ailments in the design or management of energy systems.

4.4.5 Benchmark Calculation Case Study

All the data necessary to calculate a benchmark may not always be available and sometimes it may be necessary to find other methods that will provide very accurate, and possibly precise, answers. This case study is one such example where an alternative approach is used to calculate the energy costs per student for two hostels for the month of June 1999 as a result of only electro-mechanical energy meters being available. This example is based at the University of Pretoria and the metering configuration for these two specific hostels is illustrated in figure 4.5.

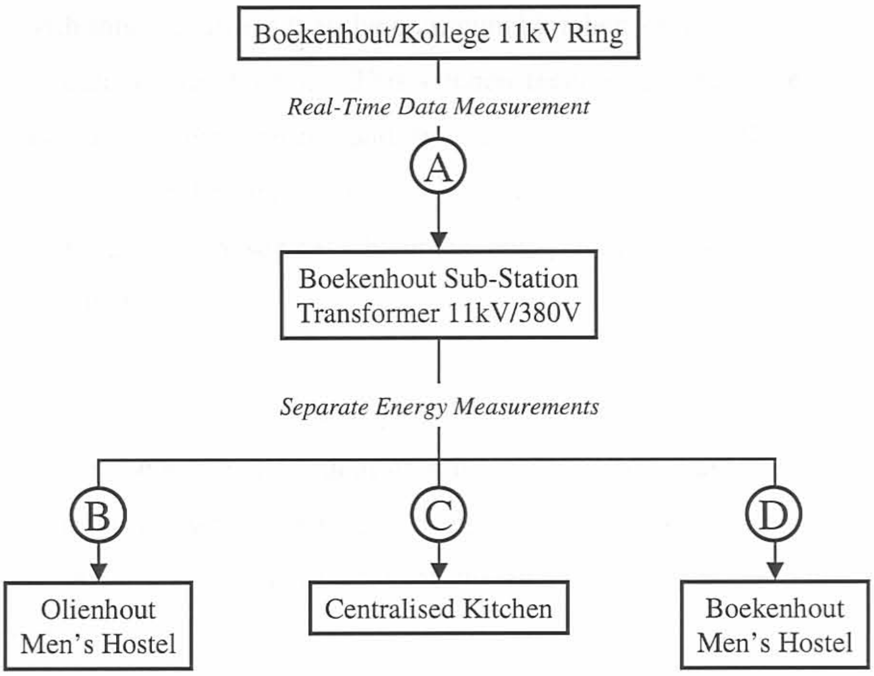

Figure 4.5: Metering Layout for the Benchmark Calculation Case Study

The University of Pretoria is billed according to a demand tariff whereby, during 1999, energy consumption is charged at a rate of 8.76 c/kWh and maximum demand is charged at a rate of R44.95 per kVA. Calculating the energy costs per student for each of these hostels, will require the energy consumption of each hostel and their contribution to the overall maximum demand of the University. Using their energy consumption only will not reflect their true total contribution to the overall cost.

The entire sub-station is measured in real-time with the energy management system of the University of Pretoria (meter A). The real-time meter enables a load profile to be constructed of the sub-station and as such the contribution that is made by this sub-station to the overall demand of the University can be determined. This principle was explained in chapter 3 under section 3.2.6 on coincident maximum demand. For this specific month, the University reached a maximum demand of 9,970 kVA at 09:30 on Tuesday 8 June 1999 of which this sub-station contributed 448 kVA. It is important to remember that only the contribution of this sub-station at the time of the overall University maximum is considered and not its independent maximum which may have occurred at a different time.

Three end-user groups are supplied from this sub-station, namely Olienhout hostel, Boekenhout hostel and their communal kitchen. Each feed point is metered but unfortunately not in real-time. In other words, the energy consumption of each end-user group is measured with an ordinary electro-mechanical energy meter (meters B, C and D).

The problem with this scenario is that the communal kitchen should not be brought into the energy costs calculation (meter C). This kitchen receives a separate electricity account from the University administration and this cost, along with all the other business overheads, is included in the meal costs that are charged to each student. In other words, the kitchen is operated as a separate business entity with the students from these two hostels as its clientele.

The goal is to calculate the energy cost per Olienhout and Boekenhout hostel resident for the month of June 1999 (i.e. R/student/month). Firstly the date and time of the total University maximum demand is needed as well as the tariff rates for energy consumption and maximum demand. Then for each of the two hostels, the following information would be required:

- Occupancy rates for the month
- Energy consumption
- Contribution to the University maximum demand

All the required information is available except the contribution of each end-user group to the overall maximum demand of the University. However, the contribution of this sub-station (meter A) at the time of the University maximum is known as well as the load profile for the entire month. Using this information, the load profile of the sub-station (meter A) is divided by its sum to deliver a factor by which the independent end-user energy measurements (meters B, C and D) can be multiplied. In other words, the total profile is divided into its three components according to their total energy consumption. This approach assumes a unity diversity factor and is based on the premise that all three loads reached a maximum demand at the same time. This method is graphically illustrated in figure 4.6 and can be accomplished using a computer based spreadsheet programme.

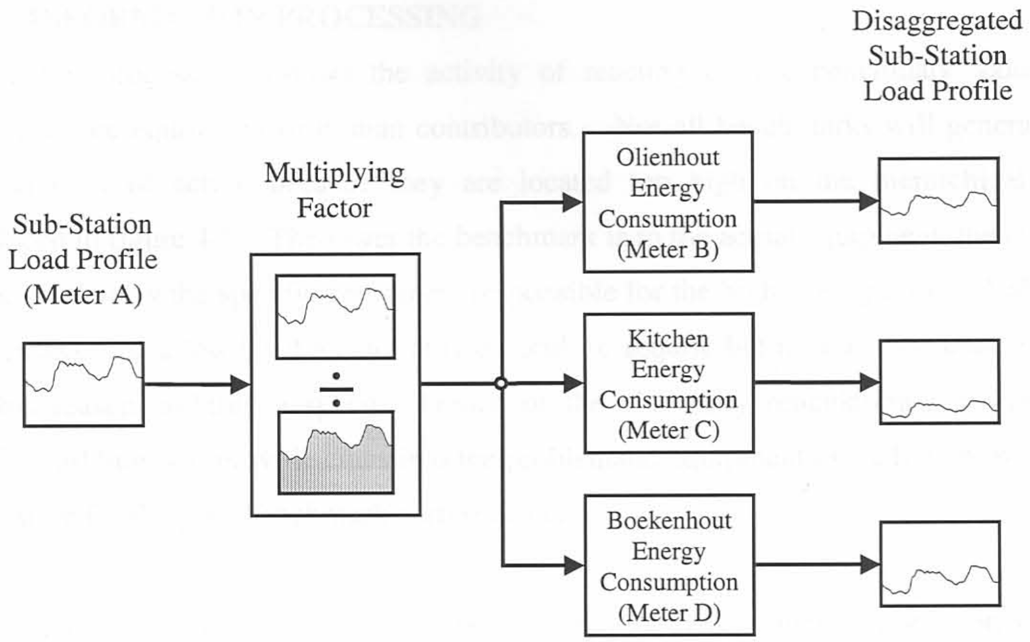

Figure 4.6: Sub-Station Disaggregation for the Benchmark Calculation Case Study

Once the individual load profiles of each end-user group has been constructed, the contribution that each one makes to the overall maximum demand of the University can be obtained. Applying the supplier tariff rates for maximum demand and energy consumption to the maximum demand contribution and separate energy consumption of each end-user group calculates the energy cost contribution of that end-user group. This value need only be divided by the number of students occupying the residence at that time to determine the energy cost per student. The results are provided in table 4.2.

Table 4.2: Results of the Energy Cost per Hostel Resident Benchmark

	Energy (kWh)	Contribution to Maximum Demand (kVA)	Total Electricity Cost	Occupancy for June 1999	Energy Cost per Student (R/student)
Boekenhout	59,160	158	R 12,294.98	271	R 45.37
Olienhout	77,314	207	R 16,067.81	269	R 59.73
Kitchen	31,182	83	R 6,480.39	⇦ Amount Billed to Kitchen	
Total Sub-Station	167,656	448	R 34,843.17	⇦ Overall Cost of Sub-Station	

From the results in table 4.2 it can be said, that for this month, each resident in Boekenhout and Olienhout Hostels cost the University R45.37 and R59.73 in electricity costs respectively. The communal kitchen contributed R 6,480.39 to the overall electricity cost of this sub-station and this sub-station contributed R 34,843.17 to the overall electricity costs of the University during this month (June 1999).

4.5 INFORMATION PROCESSING

Information processing follows the activity of reacting on the benchmark values by identifying the equipment or human contributors. Not all benchmarks will generate the same amount of action because they are located too high on the hierarchical level introduced in figure 4.1. The lower the benchmark is to the actual equipment, the easier it will be to identify the specific equipment responsible for the high energy costs. Value for benchmarks at this low level are not only difficult to acquire but may also be unnecessary. For this reason auditing a specific branch of the electricity reticulation network or a specific building will provide clues into the problematic equipment or inefficient practices responsible for the poor benchmark performance.

Occasionally other approaches can be used to make the task of identifying culprits much easier. These approaches include the use of load factors, diversity factors, scatter plots and disaggregated load profiles. This approach is particularly useful in pinpointing buildings where the benchmark is calculated from a sub-station level and there are many buildings that are supplied from that sub-station. In this manner the buildings can be prioritised and then audited from the most problematic to the least.

On a much lower level, it can also be used to prioritise electricity reticulation network branches within a single building. Figure 4.7 illustrates a disaggregated load profile of the two transformers that supply the Administration building at the University of Pretoria during the week from 14 to 20 June 1999.

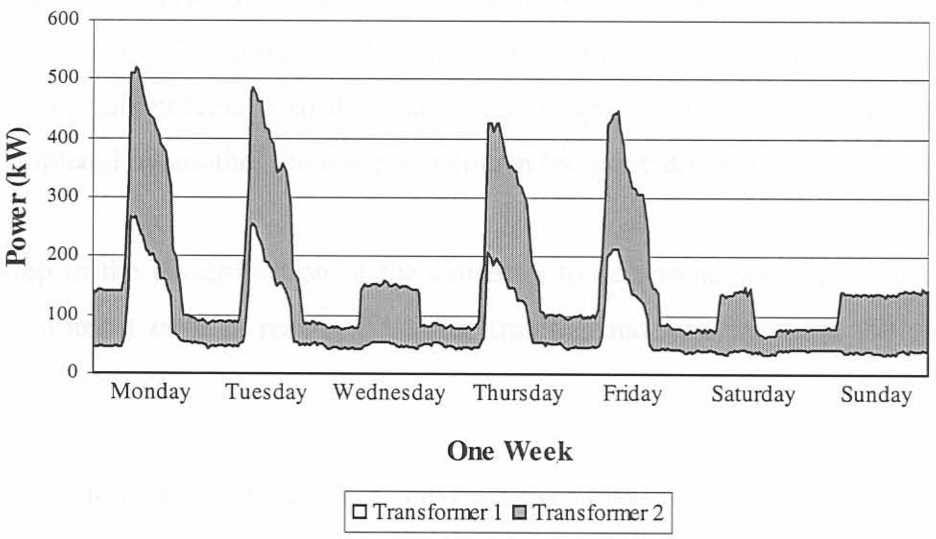

Figure 4.7: Transformers in the Administration Building, University of Pretoria

The Wednesday during this week was a public holiday with no activity on campus. This is evident as the loads on both transformers are drastically reduced. Unfortunately a sizeable portion of the load on transformer 2 is still present although this building was unoccupied during this day. In fact, one would expect the shape of the load on transformer 1 during the Wednesday, Saturday and Sunday to be present on both transformers. After closer scrutiny it has been ascertained that the load on transformer 2 includes the HVAC load from the centralised air-conditioning facility. A timer has been installed on this equipment in order to provide conditioned air during office hours in the week and during the mornings on a Saturday. Unfortunately the timer does not have any built-in intelligence to distinguish public holidays that occur during the week. This specific timer is also configured incorrectly, as the HVAC equipment is operational for the full day during Sundays. The result of this study is that the HVAC system can be identified as one of the contributors of the energy cost of this building and this information can be distributed to the other areas-of-activity.

4.6 DISSEMINATION OF KNOWLEDGE

The Energy Diagnosis area-of-activity culminates in the distribution of knowledge to the other areas-of-activity. From the calculation of a benchmark and consequent audits, the causes of the high electricity costs should have been determined at this point. Needless to say, the cause of high electricity costs in a building for example, could have been created by a multitude of factors that include various types of equipment and faulty operative procedures on the part of their human operators or occupants. A note must be made of all the causes and these passed onto the other areas-of-activity because although all of them may not be immediately addressed, they will all need to ultimately be solved. Another way of viewing this process is to think of it as issuing job numbers relating to work that must be completed by another three departments in the same division.

The first step in the dissemination of the causes is to determine whether each cause is a result of equipment or as a result of lack of training and awareness on the part of the operators or occupants.

If the cause is equipment related, it needs to be further classified according to the fault and possible solution. If the fault lies with the maintenance of the equipment, it must be passed onto the Energy Maintenance Management area-of-activity. If the solution requires existing equipment to be upgraded, controlled or additional equipment installed, then it must be passed onto the Energy Load Management area-of-activity.

Care must be taken to avoid instructions that conflict. For example, the filters on an HVAC plant might need to be cleaned and this would be passed onto the Energy Maintenance Management activity area. In this case the HVAC equipment might also need to be upgraded or possibly replaced and this would be passed onto the Energy Load Management activity area. At the outset it seems rather unwise to be maintaining filters on equipment that might be replaced. However, cognisance needs to be taken of a few points:

- The HVAC system may be replaced in its entirety or it may only be partially upgraded in which case the use of the filters may be continued.
- There is a delay in the purchase of new equipment as a result of the availability of capital that may already be reserved for another Energy Load Management project.
- The energy costs remain high all the time that new HVAC equipment is on order whereas servicing filters can be performed immediately as an interim solution.
- Cleaning and possible replacing filters requires no major capital outlay.
- Referral to the Energy Maintenance Management activity area might raise some flags to maintenance procedures that are not operating properly with other equipment in other parts of the campus.

As a result, both instructions should be dispatched accompanied by high-level communication between these two areas.

Should the cause not lie with the equipment and is ascribed to the equipment operators or building occupants, it must be passed onto the Energy Awareness and Education area-of-activity. This is however not the only reason for passing information onto this activity area. The benchmarks themselves are a great marketable tool that can be used to create awareness and generate interest in the energy management programme. Once projects have been addressed and are re-evaluated as illustrated in figure 4.2, their new benchmark values, in comparison to their initial values (including their causes and subsequent solutions), will be vital pieces of marketing information that should be exploited.

4.7 CONCLUSION

The role of this activity area is a crucial component of the energy management programme. This area does not reduce the energy costs per product or business process. It does however apportion costs to end-users through the calculation of benchmarks and then systematically identifies the reasons for that energy cost benchmark. The causes of the electricity costs are passed onto one or more other area-of-activity so that it may be addressed and solved. Once addressed, this activity of energy diagnosis is repeated in order to track the performance of the benchmark. Attention must however be paid to uncontrollable fluctuations in the benchmark values for the reasons that were explained such as seasonal swing, increases in the tariff rates and student numbers.

In conclusion it must be noted that the supply-side tariff structure and rates must be used to determine the energy cost contribution of end-user groups or per product. The example of benchmark calculation presented in this chapter used the same tariff structure (demand tariff) and rates as that of the supplier when determining the cost contribution per student.

The next chapter will address the Energy Load Management area-of-activity. This area is characterised by the expenditure of capital in order to address the high electricity costs reflected through the benchmarks.