1. PROBLEM IDENTIFICATION AND BACKGROUND

1.1 INTRODUCTION

According to Sherratt [4, p. 9] only two thirds of the world's oil reserves would be left entering the 21st century. This is an alarming statistic considering 59.3 % of the world's energy is produced from oil and coal [5, p. 6]. Governments all over the world have begun to express concern about this depletion, and have begun to impose stringent regulations on the utilisation of this valuable commodity. Compounding the issue, the Arab Oil Embargo in 1973 [6, p. 1], and the increase in global competition and hence the deregulation of energy markets have forced countries to introduce energy-saving measures.

Consuming a little fewer than 180 Terra-Watt-Hours [TWh] in 1996, South Africa ranks high up when electricity consumptions are compared with the rest of the world [5]. The industry, mining and commerce sectors depend heavily on electrical energy and account for nearly 60% of the commercial energy consumption, at a cost of nearly R18 billion in 1995 [7]. Lowering this figure, or at least stunting its growth has become an important issue with the government. This has resulted in the local utility, Eskom, to implement energy optimisation incentives for organizations to curb this growth.

The government does not legislate to the customer but rather forces the utility to implement incentives to optimise energy utilisation. This has led to the concept of Demand-Side Management (DSM). Starting in the USA in the 1970's, demand-side management has rapidly spread throughout the world as a result of rising energy prices. In addition to high energy prices, the cost of building new power stations has also drastically increased. This has resulted in a joint effort between customer and utility to use electricity optimally. Gellings and Chamberlain [8] define DSM as those activities that are either directly caused or indirectly stimulated by the utility on the demand side (customer) of the electricity meter.

Until the introduction of DSM, companies paid their electricity accounts without giving it a second thought. That is, organizations have assumed that what has been printed on the electricity bill is what has to be paid, and that nothing can be done about it. Fortunately since the introduction of energy optimisation incentives and DSM there have been many different ways in which companies can lower their electricity accounts ranging from merely changing light bulbs to complete operational restructuring. According to Delport [2, p. 4] this process of optimising the energy consumption so as to reduce the energy costs has paved the way for what is now known as *Energy Management*.

According to the Oxford English Dictionary [9] the following definitions apply:

- **Energy**: *"ability of matter to do work"*
- **Manage**: *"Handle, wield, control and regulate"*

From these definitions, energy management can crudely be viewed as the handling, controlling and regulation of energy sources and their ability to do work. Not mentioned in this definition however, is the monetary role Energy Management has on the management of energy. Incorporating this aspect into the definition, energy management can be viewed as the handling, controlling and regulation of energy sources and the capacity to minimise the costs associated with this ability to do work. Within this context, we are particularly concerned with the cost minimisation of electrical energy.

Even though this is a relatively new concept, many large and small organizations have seen the necessity to implement a policy that promotes energy awareness. Energy management incorporates this concept and extends it even further to include restructuring of the organization so as to optimise energy consumption, but more importantly lower the electricity bill at the end of the month. Thumann and Mehta [10, p. 377] sum it up neatly when they state energy management is "the judicious and effective use of energy to maximise profits (minimise costs) and enhance competitive positions".

Each company has the potential to lower its energy consumption, but more importantly, lower its energy costs. According to Johansson [1] energy management implies knowledge of existing energy needs, the availability of methods for assessing energy efficiency, and tools for verifying existing energy consumption levels. Decreasing the energy consumption may involve amongst others, altering operating schedules and procedures, reassessment of equipment and manipulation of electrical properties. Lowering energy costs on the other hand, can be done by correct tariff selection, lowering energy consumptions, and alteration of operating schedules.

At this stage it is important to note that lowering the energy consumption is a subset of reducing the energy costs, and that the converse is not necessarily true. That is, reducing the energy consumption does not *necessarily* correlate into an energy cost reduction (this will become evident at a later stage when billing tariffs are discussed). This is particularly important to note when the reduction of the energy costs is the primary objective.

1.2 PRACTICAL ENVIRONMENT

1.2.1 Overview

The study was conducted using South Africa's only fixed-line telecommunication company, Telkom. The company is situated countrywide and supplies communication facilities to the entire population. There are approximately 3600 telecommunication centres (including telephone exchanges and concentrators) situated around the country that provides the necessary infrastructure [3,p. 4]. It is these centres that are intended to be the beneficiaries of the study.

At present the organization is protected by the government from other telecommunication companies entering the market. This period of "exclusivity" is contracted to end in 2002 [11], and there are already prospective bidders. It is for this reason that the organization has implemented an enormous project to improve its infrastructure in the form of "Vision 2000". In addition, to improve and upgrade skills, expertise and funding, the company has merged with US based SBC and Telecom Malaysia who bought a 30% share in 1997 [12]. Telkom is also a 50% shareholder in the country's leading cellular network, Vodacom, who at present control 61% of the cellular market.

1.2.2 Geographical Location

The organization has its head office in Pretoria and is divided up into 7 managerial regions spreading throughout the country, they are:

- **North Eastern Region** Northern province.
- **Eastern Region** North and parts of the South Coast.
- **Central Region** Previously known as Orange Free State.
- **Gauteng Central Region** Gauteng.
- **Western Region** Cape.
- **Southern Region** Eastern Cape and parts of the South Coast.

1.2.3 Operational Statistics

	1998	1999
Main telephone services	4 645 065	5 075 417
Payphones	127 272	153 476
Manual exchanges	127	89
Digital exchanges	2 662	3 388
Analogue exchanges	357	.124
Percent lines connected to digital exchanges	82	92.5
Transmission circuits (1000 Km)	156 000	256 694
Optic fibre circuits (1000 Km)	343	360

1.2.4 Controlling The Network

Telkom has embarked on an intensive two-year programme to upgrade and expand the operations support systems (OSS) so as to offer its customers the highest quality and best service available. The programme involves the construction of a management centre to house the systems and personnel required to manage the company's telecommunications and Information Technology (IT) infrastructure.

The National Network Management Centre (NNMC) which is situated in Technopark, Centurion, affords the opportunity to create an infrastructure that will enable world-class practices and methodologies to be implemented [11]. The centre will act as the focal point for monitoring the status of the entire telecommunications network, and to provide a single point of contact for resolving problems that are affecting service of the network. End-to-end service quality management is an important function of the NNMC. Activities to restore difficulties in the network are to be co-ordinated and controlled from the centre.

1.2.5 Telephone Exchanges

Telkom makes use of two switches (equipment used for the purpose of telecommunicating): the German EWSD (Siemens), and French E10 (Alcatel). These switches are housed in telecommunication centres call telephone exchanges or sites. These exchanges are distributed throughout the country to form the bases of the telecommunications network, which is controlled and co-ordinated via the NNMC.

A typical exchange contains the following energy end-users: (1) switchgear, (2) air-conditioning equipment, and (3) logistical equipment such as computers, lights, elevators etc [13]. Rabie [14, p. 3] mentions that of these, the largest energy consuming equipment is the HVAC (Heating, Ventilation and Air Conditioning) systems, consuming approximately 55% of the total building load. The telecommunication equipment accounts for either 33% or 44% of the total building load depending on the type of exchange (discussed in chapter 2); the logistical equipment consumes the remainder of the energy.

Rycroft [15] presents a detailed illustration of the electrical layout of a typical exchange used by Telkom SA, presented in figure 1.1. The main source of power to the telecom equipment is supplied in the form of DC power, generated by the rectifiers. In the event of the rectifiers failing to supply, battery banks are available on stand-by. An uninterruptible power supply (UPS) supplies power to the computers and control equipment. Most of the energy supplied to the telecom equipment is converted into heat, which is removed by the cooling equipment. The entire plant is powered from the utility in the form of AC power. A back-up generator is always on standby in the event of a utility power failure.

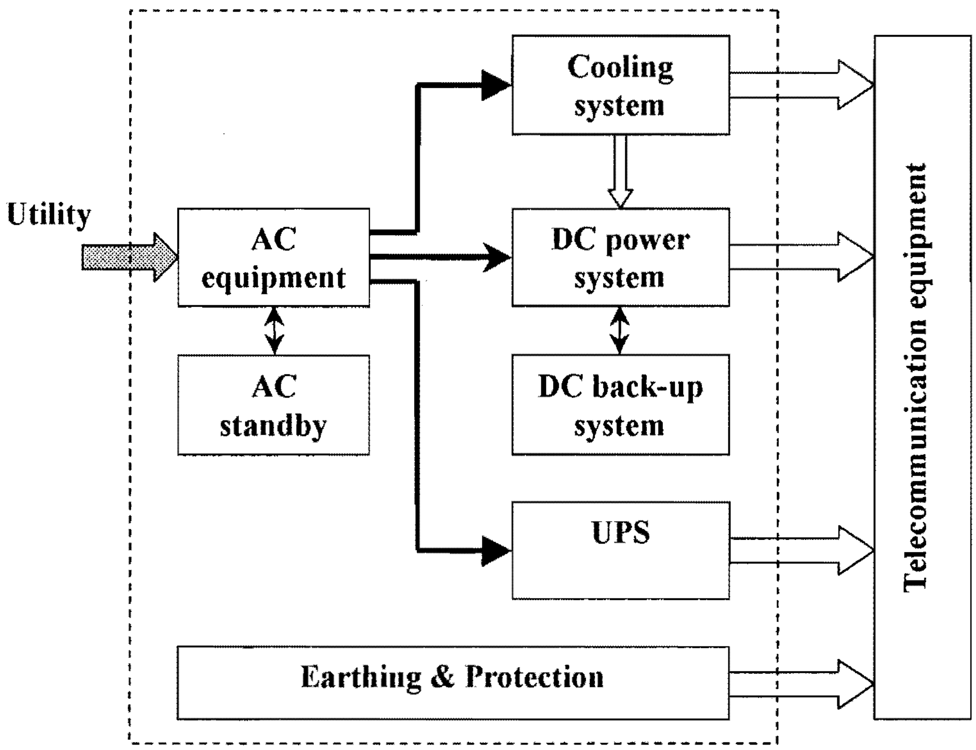

Figure 1.1 Electrical layout of a telecommunications exchange [15]

1.2.6 Climatic Conditions

The purpose of the cooling plant which forms part of the HVAC system, is to maintain the interior environment within specified temperature and humidity limits. The environmental specifications most used by Telkom are the ETSI 300-019 series; most telecommunication company's worldwide design their telephone exchanges to operate within these limits. The specifications are illustrated in figure 1.2 [15].

Traditionally, most telephone exchanges are designed to operate within narrow limits around nominal temperature and humidity values e.g. Telkom's standard is 20°C ± 1°C.

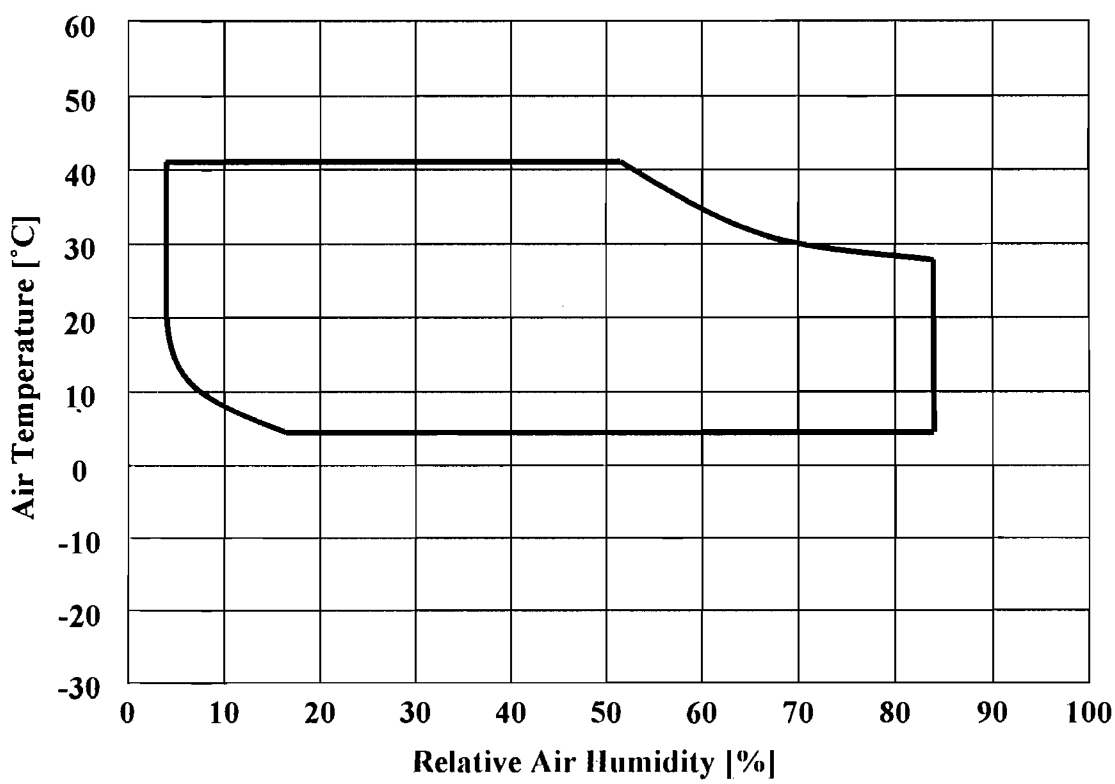

Figure 1.2 ETSI 300-019-1-3 CLASS 3.1 temperature control specifications

1.3 OVERVIEW OF CURRENT LITERATURE

1.3.1 Energy Management

Although energy management is a relatively new concept, much has already been written on this subject. This is not surprising since it is such an important topic in industry today. There is a vast amount of information available in the form of books, journals, articles, and websites dedicated to this subject e.g. [2], [7], [8], [10], [16]. It is this information that will be used as the basis of the study.

Unfortunately, as vast as the literature on this topic might be, the concept of energy management does not extend very far into the telecommunications industry. This became evident when the literature study revealed that a direct link between energy management and telecommunications could very seldom be found. This field of expertise has eluded this environment, and has only very recently started to gain popularity, probably as a result of globalisation and the high cost of energy. Examples of literature relating the management to energy to telecommunications are [1], [15], [17], [18], [19], [20].

This lack of information provides an excellent opportunity to expand the energy management concept into the telecommunications environment. It is this which forms the basis of this study. As a result of the lack of literature, most of the information needed for the explanation and interpretation of energy management is obtained from sources of literature that are either dedicated to the topic, or have been applied to other industries and environments.

1.3.2 Telecommunications Environment

As with the case above, much information pertaining to telecommunications and the actual process of telecommunicating is available, but very little literature relating this industry to energy utilisation exists. There have however been a few articles published on this topic from other telecommunication companies e.g. [1], [3], [13], [14], [15], [17], [18], [19], [20], [21], [22].

Although these references provide valuable data and insight into what other telecommunication companies are doing in terms of their energy usage, they will only be used in limited volumes. The reasoning for this is that the literature approaches reducing the energy consumption with the idea that it equates to an energy cost reduction. However, as mentioned in the opening paragraphs this is not necessarily the case, and for this reason this study will take the approach of *optimising* the energy utilisation rather than merely reducing it (this will become clear in chapter 2).

The bulk of the information needed for this study is thus obtained from books, journals, articles, and reports that are not related to telecommunications, but rather focus on individual pieces of equipment or other processes. For example, references are made from literature that focuses primarily on HVAC, but that have no bearing on telecommunications e.g. [6], [23], [24], [25], [26], [27], [28]. The information gained from these sources are supplemented by other references and then expanded upon to aid in the research of the study.

1.3.3 HVAC

Since there is this lack of information relating the telecommunications environment to HVAC, books, journals, articles, and reports focussing on air-conditioning with no connection to telecommunications are used e.g. [6], [23], [24], [25], [26], [27], [28]. In addition, *no references could be found that relate operating (energy) costs of HVAC equipment in telephone exchanges to tariff structuring* (it is precisely this which provides the primary motivation for conducting this study!).

There is a vast amount of information on HVAC and its role in energy management, providing valuable data and information. However, no other reference supplies more information relating to HVAC than ASHRAE (American Society for Heating, Refrigeration and Air-Conditioning Engineers) [24], [25], [26]. These books provide the bulk of the data needed for the development of the energy conversion models presented in chapter 4. However, because these references are strictly focussed on HVAC, the study builds upon this knowledge by combining the relevant theory contained in all the (and other) references mentioned above.

1.3.4 Modelling

From the above paragraph it can be reasoned that the primary objective of the study is to develop energy conversion models related to HVAC, but more specifically to the cooling of telephone exchanges. For the model development, a methodology that can be followed in order to relate the process inputs to outputs is needed. Such a methodology is used to derive at the energy conversion models presented in chapter 4.

Various methods of developing models have been designed. Different processes to be modelled may have a better methodology to follow than others. That is, one method of deriving at a set of models for a specific process may be more relevant, or easier to apply than another. Such methodologies were investigated and analysed from various references e.g. [29], [30]. Of these, the "building block" approach laid out by Delport [30] was found to be the most relevant (the reasoning will be discussed in chapter 3 when the modelling methodology is discussed).

1.3.5 Scheduling and Tariff Structures

Utilities have for a number of years imposed energy optimisation incentives to the customer in the form of billing tariffs. These tariffs are continuously being updated to provide maximum benefits to both the customer and utility. Each year, tables are published with the new rates and tariffs to be imposed, providing the necessary information for the study.

Energy management handbooks also give valuable information and data pertaining to tariff structures and their influence on scheduling e.g. [31], [32]. This literature enables the further development of the models by incorporating a cost analysis with reference to billing tariffs. However the references in themselves will not provide the necessary information to extend the models as they need to be used in conjunction with the other references discussed earlier.

1.3.6 Summary

This section provided an overview of the literature needed for this project. It presented the shortcomings of the applicable references, and in so doing provided the motivation to conduct the study. To summarize the findings from the studied literature, a flow diagram giving the 'reasoning' for the project is provided in figure 1.3. This illustrates the areas where information is lacking (hexagonal blocks) and hence where research development is needed (rectangular blocks).

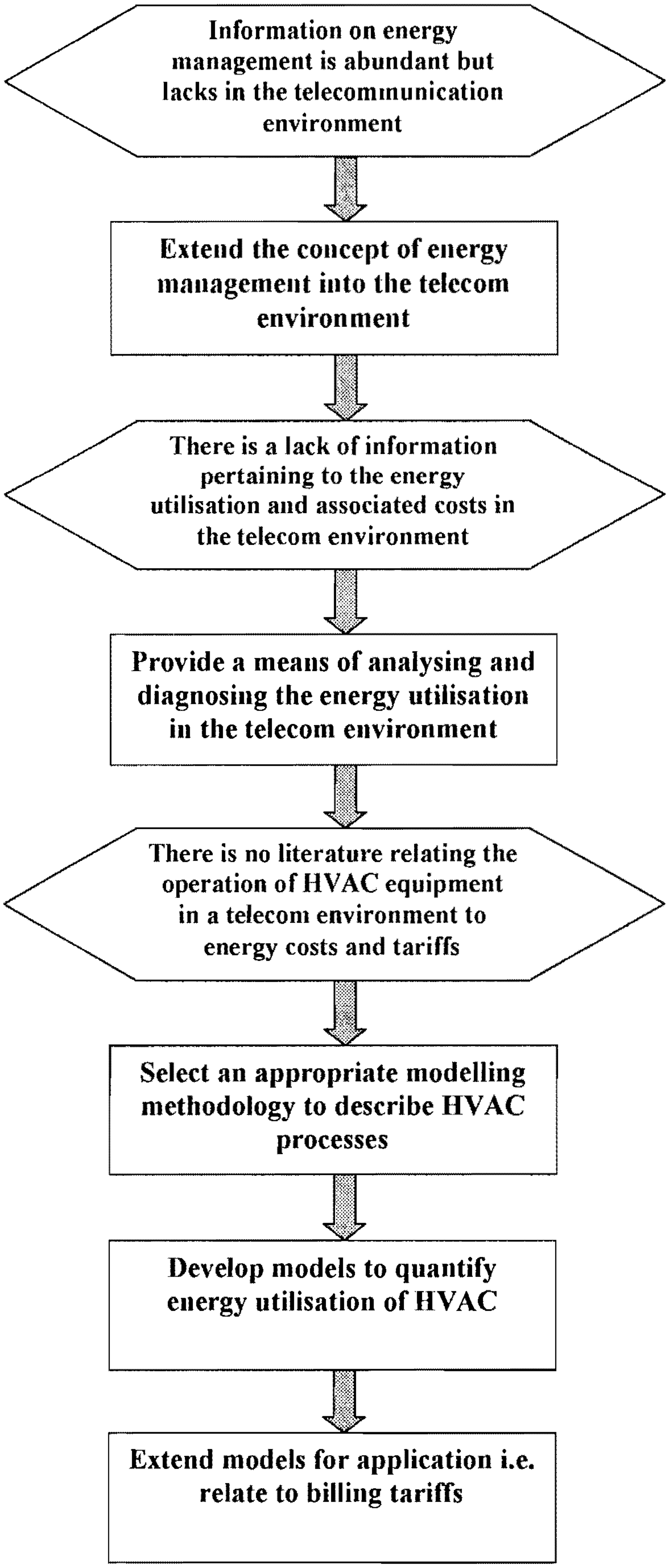

Figure 1.3 Summary of literature study – motivation for project

1.4 PROBLEM IDENTIFICATION

As in most industries, telecommunication centres require energy to perform their respective tasks. This is supplied in the form of electrical energy, which is generated and distributed via the Electrical Supply Chain of the utility (*Eskom*) at cost determined by the applicable tariff. Telkom (or the Post Office as it was previously known) have in the past been protected by the government which granted them exclusive rights to be the sole provider of fixed-line telecommunications.

Ironically though, this "protection" has forced Telkom into a desperate situation; the lack of competition has caused the company to "slack" allowing inefficiency to infiltrate into all aspects of the organization. With the period of "exclusivity" ending in 2002, the company is forced to streamline itself to such an extent that it is able to compete on the global market.

The acceptance of Telkom into the global economy will mean unprecedented challenges for the organization. Pressure from competition in the telecommunications sector is mounting; business customers are demanding faster, more modern and more efficient service. There is also a growing need for telephony among the millions of South Africans who lack access to even basic telecommunication services. This upgrading and streamlining will require large amounts of capital and financial backing. Fortunately however, streamlining certain process will in themselves provide financial rewards e.g. lowering operating expenses by optimising the energy utilisation (it is precisely this, that is the focus of the study).

Most telecommunication centres were designed and built many years ago; with the advancement of technology these buildings (and associated equipment) have become largely outdated, being over designed, under designed, and/or unreliable. These centres (still today) are being designed and built with outdated and inaccurate information. This has compounded inefficiencies in building type, power systems, equipment, and operating schedules.

As an illustration, many of the buildings were originally designed and built with the available technology – the HVAC systems were for example correctly designed and implemented. With the advancement of better software packages for modelling air-distribution patterns however, better ventilation of the exchanges could be implemented. This enabled the reduction of equipment size since less cooling capacity was needed. The installed HVAC systems were however never upgraded, resulting in them now being largely over-sized.

To rectify the situation, it will be the purpose of the study to provide a methodology for optimising the energy utilisation so as to reduce the costs involved. As such, to implement energy management in a telecommunications environment, in which methodologies for enhancing energy efficiencies in telephone exchanges are to be presented. These include assessing energy efficiency levels, classifying exchanges with respect to energy utilisation, and a financial analysis with respect to billing tariffs.

It will be shown in chapter 2 that a large problematic situation exists with HVAC, and because this end-user constitutes the largest of all energy consuming equipment, the study will primarily focus on optimising the energy utilisation of this process. In addition to this, Grobler [23, p. ii] mentions that HVAC systems generally tend to offer the widest range of energy conservation opportunities. As such, this provides an excellent opportunity to implement energy management in this environment.

1.4.1 Energy Policy

According to Delport [2] the aim of an energy policy is to "reduce the energy expenditure and thereby reduce the cost of a product so as to increase competitive performance". Telkom recognises that it has to be environmentally friendly and has imposed a regulatory policy enforcing this [33]; this states that:

"*Telkom is a proponent of preserving the environment. Telkom actively deploys technology with a low environmental impact, especially in ecologically sensitive areas such as Cape Point in the Western Cape and in the Kruger National Park. Telkom took its environmental* *commitment even further by implementing in 1998 an Environmental Management System (EMS) that spans the full spectrum of our operations. Telkom's environmental system, based on ISO 14001 standards, is aimed at ensuring that, in our drive to provide all South Africa's people with access to our telecommunications network, the environment is not negatively impacted. The system includes integrating environmental consideration into all of Telkom's planning activities and business decisions*".

This is the closest Telkom has got to implementing a program managing its energy resources. The company has at present no energy policy in place which has led to it being inefficient in its energy utilisation. Without an energy policy there can be no responsible management of energy resources and as such, no control measures to ensure that the energy is being used to its maximum potential.

1.4.2 Efficiency

At present there is no methodology to establish if an exchange, and its installed equipment is operating in an optimal manner. Clearly, in terms of energy management this constitutes a problem and needs to be address so that operational benchmarks can be defined. A set of norms pertaining to the operational performance needs to be developed to provide a tool for retrofitting, designing, redesigning and implementation of exchanges.

1.4.3 Modelling

The bulk of the study will focus on HVAC and the processes involved in cooling telephone exchanges. Since this is the largest energy consuming process, a means of evaluating the variables that affect the cooling process is needed. Energy Conversion Models that describe the processes involved need to be developed so that a tool for evaluating cost-effective energy configurations, schedules and tariffs is available.

These models will provide a means for calculating the correct size air-conditioning plant to install in a particular exchange. As such, they can be used to establish if the cooling systems are either over, or under designed. They will be useful in determining if the air-conditioning systems are operating in the way they were intended in terms of their energy utilisation, schedule, and load profile.

More importantly however, at present the HVAC systems are designed and implemented with no attention paid to operating costs. The models will thus be extended to provide a means of assessing the costs involved in operating the equipment.

A modelling methodology also needs to be generated and closely followed in order to develop models systematically and ensure that they remain completely compatible and within the system's context.

1.4.4 Cost Analysis

The most important consideration of energy management is that of reducing the energy costs. The overall purpose of this study is thus to provide a tool that can be used to evaluate cost-effective energy configurations, schedules and tariffs. Once the models have been satisfactorily developed, the relationship between the energy consumed and the maximum rate at which it was consumed will be determinable in respect of billing tariffs and the least-cost alternative.

1.5 OBJECTIVES

1.5.1 Main Objective

The main objective of the study is to implement energy management in a telecommunications environment and in so doing provide useful energy optimisation tools.

1.5.2 Specific Objectives

The specific objectives of the study are as follows:

- Set up a methodology for the implementation of energy management in a telecommunications environment. The basis for this is the development of an energy management program for Telkom i.e.
    - Set up an energy policy.
    - Draw up an energy policy strategy.
    - Conduct energy audits and provide an energy diagnosis.

- Devise a methodology for enhancing energy efficiency in telephone exchanges i.e.
    - Classify exchanges with respect to energy utilisation.
    - Develop energy norms for the energy consuming equipment and utilisation.
    - Evaluate manned and unmanned exchanges according to the norms.

- The bulk of the dissertation will focus on undertaking an in-depth investigation into HVAC in a telecommunications environment i.e.
    - Set up a modelling methodology that can be used to develop energy conversion models relating to HVAC.

- Develop a unique set of energy conversion models pertaining to the cooling process of exchanges i.e. the models should enable the:
    - Redesigning, retrofitting and implementation of air-conditioning equipment in telephone exchanges.
    - Setting up of cost-effective energy configurations, schedules and tariffs.
    - Understanding of the effects of manipulating the elements that contribute to the required cooling load.

- Implementation of the models into a package that can be used to simulate specified operating conditions, and that will provide a tool for implementing cost-effective energy configurations i.e. demonstrate the applicability of the models.

- Verification of the models using case studies.

1.6 DISSERTATION LAYOUT

Chapter 2 provides a methodology for the implementation of energy management in a telecommunications environment, thereby providing the basis for the remainder of the dissertation. The chapter begins by formulating an energy policy for a telecommunications environment and then provides a strategy for its implementation. A methodology for enhancing energy efficiencies in telephone exchanges, which includes assessing energy efficiency levels, classifying exchanges with respect to energy utilisation are also the focus of the chapter.

Chapter 3 addresses the methodology used to generate the energy conversion models for the processes involved in the cooling of exchanges. It defines the approach taken to relate the real world to an abstract mathematical world. In addition to this, assumptions, criteria, limitations and constrains are defined.

Chapter 4 deals with the actual mathematical development of the models, and includes mathematical tools used to generate them. The chapter also deals with the testing and verification of the models.

Chapter 5 provides simulations using case studies of actual telecommunication exchanges. This leads to a discussion on the benefits and applicability of the models for the telecommunications sector, as well as an explanation of the energy cost savings that can be obtained as a result.

Chapter 6 concludes the dissertation and also provides recommendations for further studies and implementation of the models.