ENERGY MANAGEMENT IN A TELECOMMUNICATIONS ENVIRONMENT WITH ASSOCIATED ENERGY AND COST MODELLING OF HVAC

by

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SUMMARY

Johansson [1] mentions that in past years, pressure from governments have forced organizations to become environmentally friendly, this, in addition to increased global competition and the deregulation of energy markets is forcing companies to introduce energy-saving measures.

Until recently, companies have paid their electricity accounts without giving it a second thought – it has been assumed that what has been printed on the electricity bill is what has to be paid, and that very little can be done about it. Fortunately this is not the case; there are many ways in which companies can lower their accounts ranging from merely changing light bulbs, to a complete operational restructuring. According to Delport [2, p. 4] this process of optimising the energy consumption to reduce the energy costs has paved the way for what is now known as "Energy Management".

This dissertation will investigate implementing energy management in a telecommunications environment (e.g. Telkom) in which methodologies for enhancing energy efficiencies in telephone exchanges are presented. These include assessing energy efficiency levels, classifying exchanges with respect to energy utilisation, and a financial analysis with respect to billing tariffs.

The bulk of the study will focus on HVAC (Heating Ventilation and Air Conditioning). According to Rabie [3, p. 6] HVAC constitutes the largest energy end-user in telephone exchanges; a large portion of the dissertation will thus be dedicated to this process. The study will comprise of developing energy conversion models that will enable cost-effective energy configurations, schedules and tariffs for the HVAC process.

KEYWORDS

Energy Management, Telephone Exchanges, HVAC, Energy Conversion Models

OPSOMMING

Volgens Johansson [1] is organisasies die afgelope paar jaar onder groot druk gesit, deur regerings (onder andere) om omgewingsvriendelik te word. Hierdie druk, tesame met toenemende wereld-wye kompetisie en die deregulering van energiemarkte, forseer maatskappye om energiebesparende beperkings daar te stel.

Tot hede het maatskappye kragrekenings betaal sonder om twee keer daaroor te besin. Daar was geglo dat nie veel gedoen kon word om die bedrag te verminder nie. Dit is nie die geval nie, daar is verskeie maniere waardeur maatskappye hulle kragrekeninge kan verminder, van maniere so eenvoudig as om gloeilampe te vervang, tot 'n volledige operasionele herstrukturering. Delport [2, p. 4] noem dat hierdie optimalisering van energieverbruik om koste te bespaar die weg gelê het vir wat bekend staan as "Energiebestuur"

Hierdie verhandeling ondersoek die implementering van energiebestuur in 'n telekommunikasie-omgewing (b.v. Telkom) waarin die metodiek vir die bevordering van energievaardighede in telefoonsentrales voorgestel word. Energievaardigheidsvlakke, die klassifikasie van telefoonsentrales ten opsigte van energie verbruik en 'n finansiële analiese ten opsigte van tariewe word ondersoek.

Die grootse gedeelte van hierdie studie sal op die HVAC (Heating, Ventilation and Air Conditioning) fokus. Volgens Rabie [3, p. 6] is HVAC die grootse eind-gebruiker van energie in telefoonsentrales, daarom sal 'n groot gedeelte van hierdie verhandeling daaraan aandag gee. Hierdie studie bestaan uit die ontwikkeling van energie-omskakelingsmodelle, wat tot koste-effektiewe energiekonfigurasies, skedules en tariewe sal lei.

SLEUTELWORDE

Energiebestuur, Telefoonsentrales, HVAC, Energie-omskakelingsmodelle

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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.

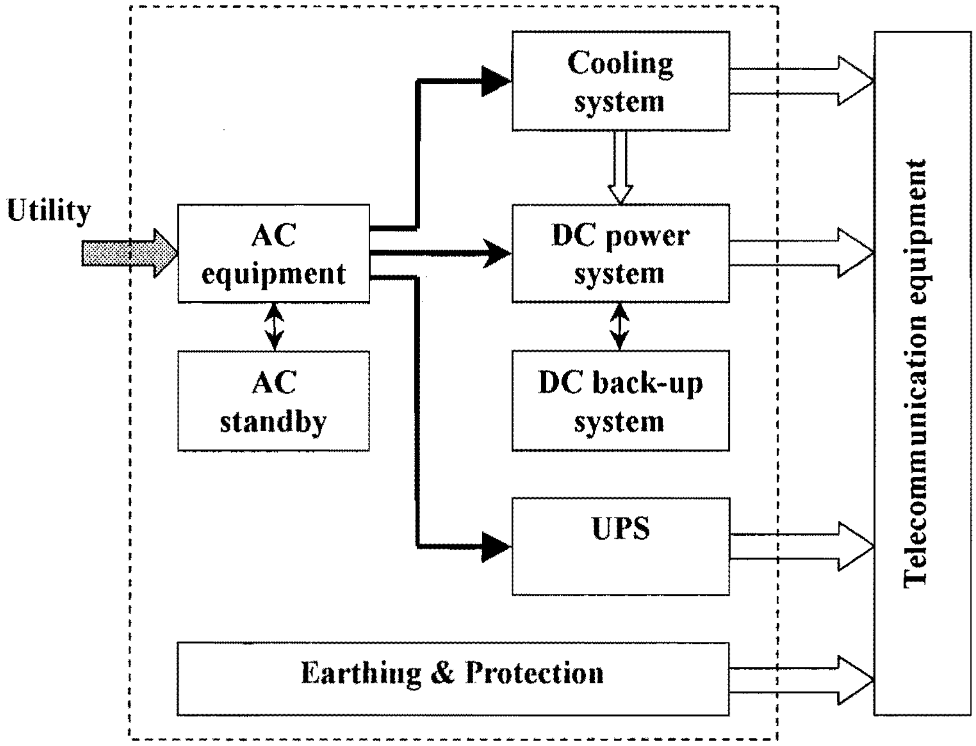


Figure 1.1 Electrical layout of a telecommunications exchange [15]

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.

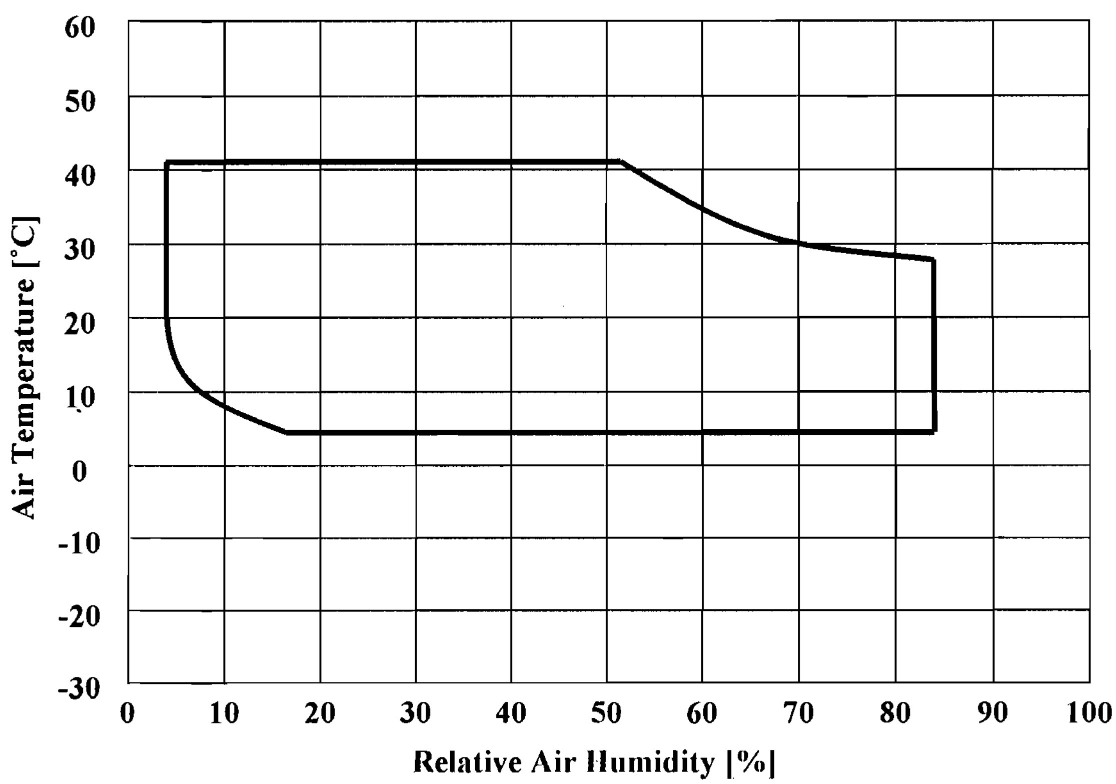


Figure 1.2 ETSI 300-019-1-3 CLASS 3.1 temperature control specifications

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).

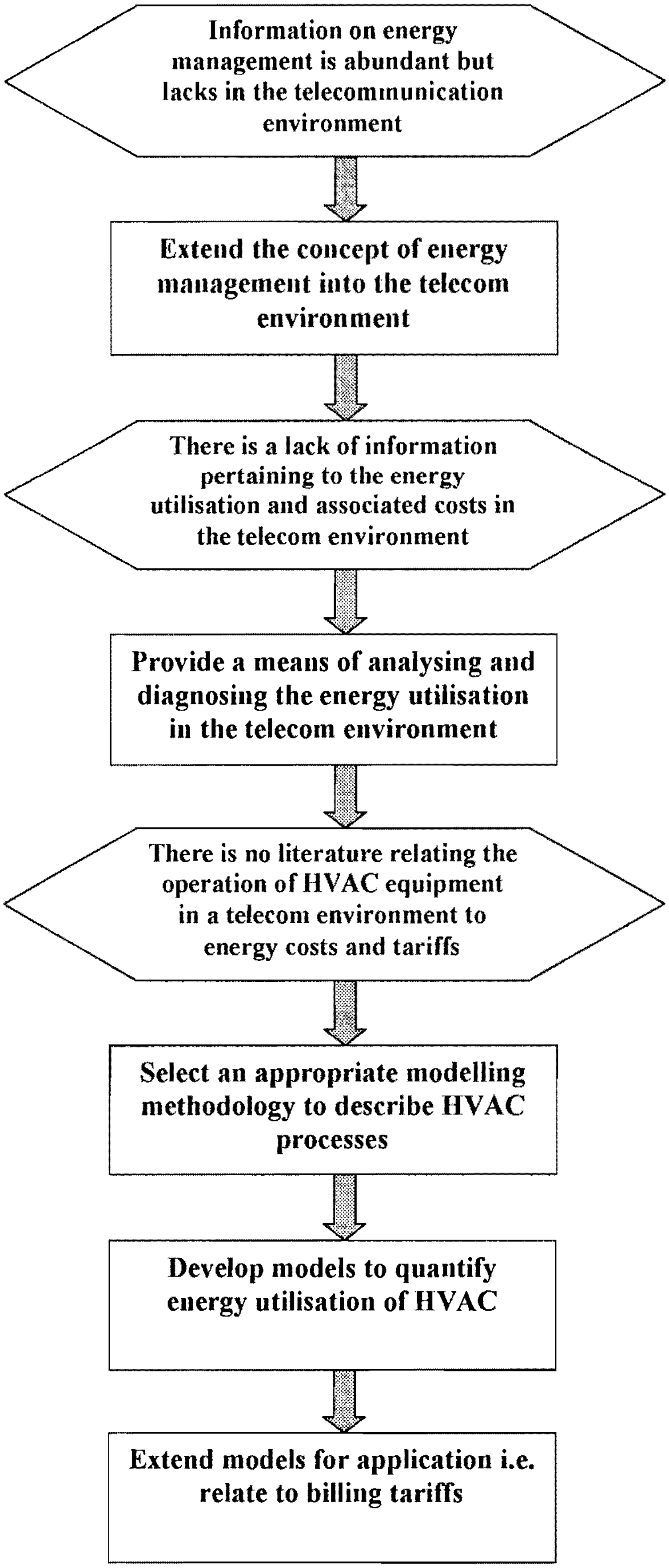


Figure 1.3 Summary of literature study – motivation for project

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.

2. ENERGY MANAGEMENT AND TELKOM

2.1 INTRODUCTION

It was mentioned that Telkom has no energy management programme in place and thus no formal energy policy implemented by top-management. Without such a policy there can be no responsible management of energy resources and as such, no control measures ensuring that the energy is being used to its maximum potential. This has been the major contributing factor to the high level of inefficiency in the organization's energy utilisation.

Calmeyer [31,p. 16] suggests that the goal of an energy management programme is to reduce energy costs within the context of environmental harmony so as to enhance competitiveness and maximise profits. It is thus clear that with the introduction of such a programme, Telkom will be closer to streamlining the organization and so be capable of competing with other international telecommunication companies destined to enter the South African market.

The chapter is thus focussed on presenting an energy management programme in a telecommunications environment, specifically for Telkom SA. It makes sense to first present a structured methodology for the implementation of energy management before techniques for optimising the energy utilisation are discussed (as those given in chapter 4 and 5). Following this format enables a holistic approach to be taken to optimise the available energy resources.

The chapter begins by presenting important energy management tools that are used in the context of the study. It continues by explaining what an energy management programme is and also the elements needed to implement it. Such a programme is then developed for Telkom that will provide the necessary means for ensuring the efficient usage of the energy resources. As part of the quantification process and hence motivation for the remainder of the study, the chapter ends off by providing a useful tool for establishing whether telephone exchanges (and installed equipment) are operating in the most efficient manner.

2.2 ENERGY MANAGEMENT TOOLBOX

It is the purpose of this section to provide the necessary energy management tools needed for the remainder of the study by explaining billing elements, tariff structures and DSM activities. It is intended to equip the reader with the necessary background needed to understand the applicability of the study. The *billing elements* will provide the necessary tools needed for analysing the electrical performance; *tariff structures* provide the means for analysing the costs associated with energy utilisation, and *DSM activities* are those tools that are used to optimise the energy utilisation. The meaning of each element will become clear as it is used in context of the study.

2.2.1 Billing Elements

Load Profile: The consumption graphically plotted on a time versus power axis (usually kW or kVA) and shows the profile (shape) of the power consumed during a specified period (typically a day, week or month) is known as a load profile. Two essential elements can be obtained from the profile (1) the maximum amount of power consumed (termed *maximum demand*) for the period under consideration and (2) the total amount of energy consumed during the period [31, p. 30]. As an example, consider figure 2.1 showing a typical load profile of the University of Pretoria for a period of one day [34].

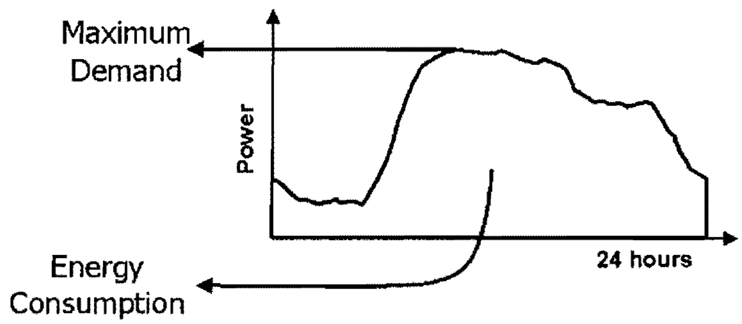


Figure 2.1 Typical load profile of the University of Pretoria

Load Factor: Is the ratio between the actual energy consumed and the energy that could have been consumed had the demand remained at the maximum demand for the particular period [32, p. 13] i.e.

$$\mathbf{L.F}_{\text{for period}} = \frac{\textbf{Actual kWh Consumed}_{\text{in period}}}{\textbf{Maximum Demand}_{\text{in period}} \times \textbf{Number of Hours}_{\text{in period}}} \qquad [2.1]$$

The factor provides an indication as to how cost effectively the energy is being utilised i.e. the greater the load factor the less it costs per unit of energy [c/kWh] if a two-part tariff is applied (see next paragraph).

Equivalent Cost Per Unit (c/kWh): This provides the average cost of using energy. It is defined as the ratio between the total costs incurred utilising electrical energy (as a result of a particular tariff structure) and the total energy [kWh] used i.e.

$$\textbf{Average Cost} = \frac{\textbf{Total Electrical Cost}}{\textbf{Total Energy Consumed}} \qquad [2.2]$$

2.2.2 Tariff Structures

Two-Part Tariff: Customers are charged for the maximum demand (MD) and the energy used during a billing period [35, p. 32] i.e. they are billed for the peak rate of consumption [kW or kVA] for that particular month as well as the total energy consumed [kWh]. There is a capacity charge [Rand/kVA] and a constant consumption charge [c/kWh] i.e.

$$\mathbf{R}_{\text{Tot}} = \mathbf{R}_{\text{MD}} + \mathbf{R}_{\text{Energy}} \qquad [2.3]$$

The MD charge [R/kVA] has been included to provide incentive to customers to lower peak consumption. The monetary benefit induced by this motive can be analysed using the load factor concept explained previously – a low load factor implies that the load profile has a large peak (MD) as compared to the rest of the profile. It is this peak that dictates the R/kVA charge in the tariff. This charge has a high prices attached to it, and as a result contributes a large portion to the total electricity bill causing a high average cost per unit of energy [c/kWh]. This provides a powerful incentive to customer to increase their load factors and hence decrease the average c/kWh.

Time Of Use (TOU) Tariff: This tariff applies different energy consumption charges during different periods of the day, and seasons of the year [31, p. 38]. The energy charges during each interval closely tracks the cost to supply the energy (from the utility side). There are usually three billing periods in a day: peak, off-peak and standard. TOU tariffs also usually incorporate demand charges for MD. As with the consumption charge, the demand rates are also differential with time.

2.2.3 DSM Activities

According to Gellings and Chamberlin [36], DSM are those activities which involve action on the demand- or customer-side of the electricity meter resulting in a reconfiguration and/or change in magnitude of the load inducing energy expenditure savings, such as:

Peak Clipping: This is the process of reducing the system peak load (MD) and has most applicability when considering tariff charges for maximum demand.

Valley Filling: Entails building load during off-peak periods so as to increase the system load factor and thus decrease average cost of energy [c/kWh].

Load Shifting: Involves shifting load from peak to off-peak and thus has major monetary benefits when use in conjunction with tariffs structures.

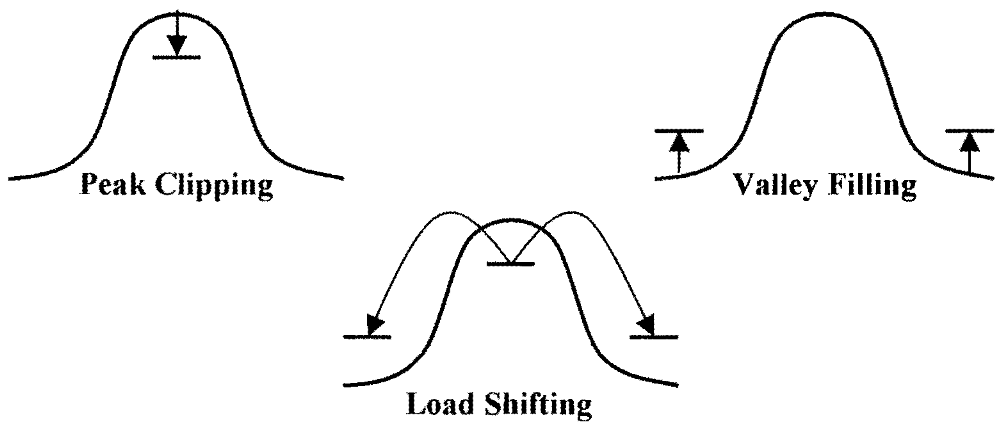


Figure 2.2 DSM activities

2.3 THE ENERGY MANAGEMENT PROGRAM

Delport [2, p. 2] suggests that the basic philosophy followed in generating an Energy Management Programme for an organization consists of 4 closely linked building blocks; they are (1) Energy Policy, (2) Energy Policy Strategy, (3) Energy Audit Policy, and (4) Energy Audit Strategy. The interaction of these with each other is depicted in figure 2.3 below.

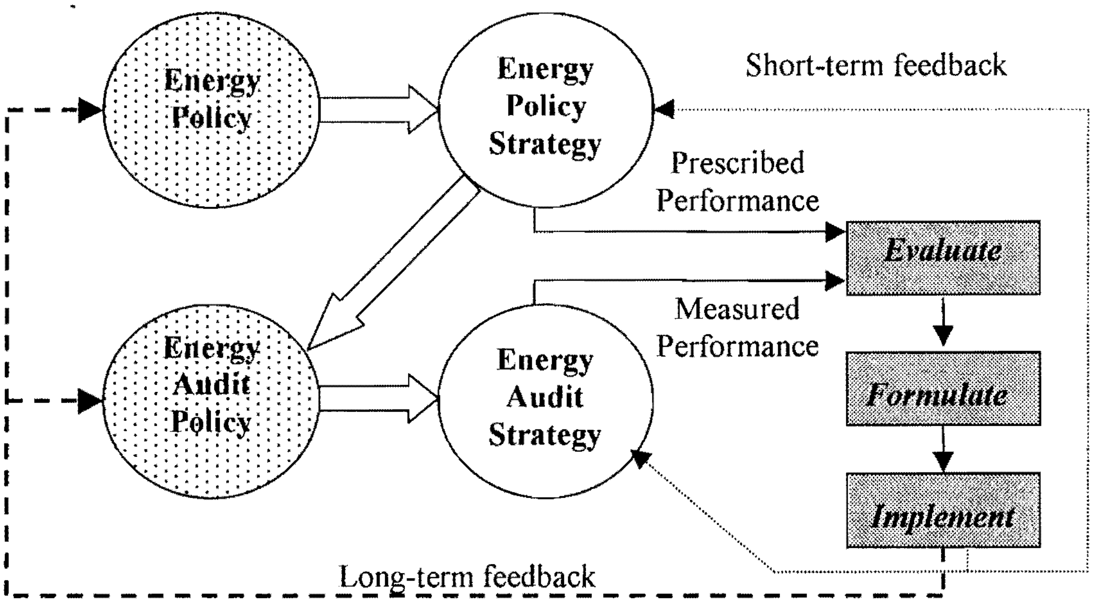


Figure 2.3 Interaction of the four elements needed for an energy management program

According to the Oxford Advanced Learners Dictionary [38] the following definitions apply:

- **Policy**: "A plan of action, statement of ideals, etc proposed or adopted by a government, political party, or business".
- **Strategy**: "A plan designed for a particular purpose; the process of planning or carrying out a plan in a skilful way".

2.3.1 The Energy Policy

From the definition above, an energy policy is the starting point for any government, party or person wishing to address the responsible management of their energy resources. It is the formal statement through which the course that is being adopted with respect to energy is defined. The policy provides vision, and directs the energy management programme in the right direction. Calmeyer [31, p. 18] states that "energy policies ensure the sustainability and transparency of the energy management programme, and are statements of corporate commitment towards environmental harmony through the activity of reducing energy costs per product or business process". He extends upon this by mentioning that there are three essential components needed to completely formulate an energy policy:

- **Declaration of commitment**: A written declaration from top management ensuring that the programme of managing energy will be sustained and has their full co-operation.
- **Mission Statement**: extends on the declaration by defining the focus of the energy management program.
- **Program Goals**: determine the specific objectives in order to achieve the mission statement.

Examples of energy policies are presented in addendum A which have been drawn up by:

1. the Centre for New Electricity Studies (CNES) for the University of Pretoria [39, pp. 1 to 4].
2. the American telecommunications provider, AT&T [40].

2.3.2 The Energy Policy Strategy

It is however not enough to merely generate yet another policy for an organization without formulating a method of implementing or achieving the objectives. An energy policy strategy, or a way in which the policy can be achieved needs to be generated [21]. According to Delport [2,p. 2] a strategy is dynamic in the sense that it is regularly adapted and updated in synergy with changes in the energy management of organizations. As such there needs to be short-term and long-term feedback.

Calmeyer [31,p. 21] suggests that there are four "areas of activities" that need to be followed in a systematic way so as to optimise the energy utilisation of available resources.

These, and the interrelationships are depicted in figure 2.4 and make up the energy policy strategy.

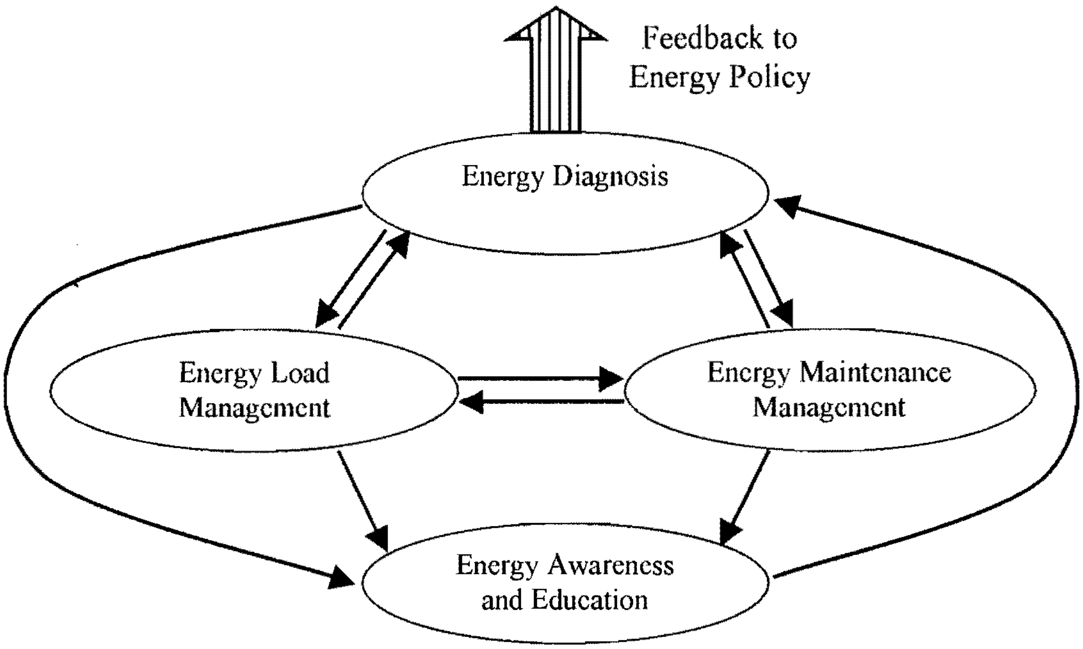


Figure 2.4 The interaction between the "areas of activities" for an energy policy strategy

- **Energy diagnosis**: Acquisition and analysis of the energy utilisation through the activities of auditing, load metering and measurement.
- **Energy load management**: This focuses on optimising the energy utilisation so as to reduce the energy cost per product or process through load control. Delport [32, p. 15 & 16] mentions that this can be done with a number of Demand-Side Management activities as those discussed in chapter 2.2.3.
- **Energy maintenance management**: This aims to improve system efficiency and ensure sustainability through proper maintenance of system components.
- **Energy awareness and education**: It is essential to promote energy awareness to all employees. Without the co-operation of these people the management of energy cannot be done in an effective manner.

See energy policy strategy examples presented in Addendum A.

2.4 ENERGY MANAGEMENT PROGRAMME FOR TELKOM

Using the energy policy examples of the University of Pretoria and AT&T presented in Addendum A, a policy for Telkom has been constructed. The policy of the University is used as a template, whereas the information provided in AT&T's policy is used for its content.

It is important to mention that the energy policy presented on the following pages is not an official policy of Telkom, but is rather a recommendation for the further development of energy management in the company. As such it provides the basis for the remainder of the study and presents a methodology for the implementation of energy management.

AN ENERGY POLICY FOR TELKOM

Mission Statement

Manage the energy resources available to Telkom with the purpose of optimising operation and hence provide the best possible services to its customers.

Primary Objectives

Manage the supply and demand of the energy resources available to the organization. Ensure the optimal usage of these resources so as to reduce the energy expenditure through promotion and energy awareness to all users. An accurate account of energy consumption is to be made with the purpose of reducing energy expenditure, while still enabling customers to telecommunicate when, where and how they want to.

Specific Objectives

Manage the supply and demand of energy resources

This involves the controlling and manipulation of all the electrical and/or energy sources, resources and consumables available to the organization through processes such as Demand-Side Management. In so doing optimise the energy consumption with the objective of minimising energy expenditure and thus maximise profits. Areas of primary importance are building design, standby equipment, HVAC, rectifiers and tariff selection, all of which have a significant effect on the energy utilisation.

Energy measurement

This involves the complete energy auditing of all energy sources, resources and consumables available to the organization. This includes all major energy consuming equipment installed and implemented in buildings and exchanges; and involves the buildings and exchanges themselves. A complete, and accurate account of all energy usage is to be made according to an audit plan.

Setting energy norms and benchmarking

This involves the setting of applicable norms and standards according to measurable benchmarks. Through the use of these norms, management of all major energy sources, *resources and consumables can be carried out in an optimal manner. The norms are to be set up in such a way as to provide guidance to present and future energy-users, technical personnel and would-be contractors.*

Promote energy awareness to all energy users

This is the transfer of information to all energy-users, technical personnel and would be contractors in the organization, in which a message of conserving and saving energy is conveyed and carried out. A direct consequence of energy awareness is the promotion of efficient usage of energy by all users.

ENERGY POLICY STRATEGY

Manage the Supply and Demand of Available Energy Resources

Long-term Strategies

- *Have the capabilities of controlling and manipulating the energy consumption of the buildings and exchanges through automated load control. Although the organization is a long way away from this it is important to include it here to present an optimal and aggressive energy management strategy.*
- *Set up clear and defined management procedures for the controlling and manipulation of energy sources, resources and consumables within the organization.*
- *Draw up strict procedures for the purchasing and implementation of energy consuming equipment.*
- *Review existing energy end-users and assess energy efficiency performances.*

Short-term Strategies

- *Appoint a dedicated Energy Manager to assess the energy "needs" and implement viable long-term solutions for the organization as a whole.*
- *Compile and implement an audit plan to investigate the supply and demand of electrical energy within buildings and exchanges.*
- *Investigate currently employed technologies such as HVAC, lighting and telecommunications equipment for inefficiencies.*
- *Investigate and implement alternative tariff structures to suit individual buildings and exchanges.*

- *Also investigate alternative technologies, and set guidelines and specifications (i.e. norms and benchmarks) for the purchasing of energy consuming equipment.*

Energy Measurement

Long-term Strategies

- *Install dedicated measuring equipment at all buildings and exchanges so that progressive and continual monitoring of the energy load can be conducted.*
- *Have a central control centre capable of controlling and monitoring the energy consumption of all buildings and exchanges within the organization. This concept is linked to the automated load control, and is added to present an aggressive and ambitious view of the future.*

Short-term Strategies

- *Develop an audit policy that will enable and authorise the complete load measurement of buildings and exchanges within the organization.*
- *Conduct an energy audit to assess the current state of energy utilisation.*
- *Install automated measuring equipment to measure the various energy end-users, such as HVAC, lighting and telecommunications equipment.*
- *Analyse acquired data to draw up conclusions and recommendations.*

Set Energy Norms and Benchmarks

Long-term Strategies

- *Implement managerial procedures for the utilisation and implementation of energy norms and benchmarks.*
- *Formulate benchmarks for buildings and exchanges, and installed equipment.*
- *Revise norms and benchmarks continually (feedback) to avoid stagnation.*

Short-term Strategies

- *Set up energy norms and standards compatible for all buildings and exchanges with reference to building dimension, HVAC, lighting and telecommunication equipment.*

Promote Energy Awareness to All Users

Long-term Strategies

- *Have a workforce that is energy efficient.*
- *Have clear and defined communication channels for feedback of energy users.*

Short-term Strategies

- *Educate management on the efficient use of energy.*
- *Educate employees on how to use energy efficiently and the benefits thereof.*
- *Set up a working procedure that describes the exact process for employees to provide feedback to management.*

2.5 AN ENERGY ACCOUNT OF TELKOM

Paragraph 2.4 provided a methodology for the implementation of energy management in the form of an energy policy. Included were the specific objectives needed to define the outcomes of the programme, and incorporated in the objectives was the complete energy measurement (auditing) of all energy sources, resources and consumables. By providing a detailed diagnosis of the energy utilisation, a reference point is established from which the remainder of the study can be conducted.

As such, extensive energy audits were conducted at various exchanges so that a comprehensive analysis of the energy utilisation could be compiled. The measurements were conducted on exchanges selected on the basis of their respective functions. That is, from the walk audits it was observed that exchanges could be classified into two broad categories: *manned* and *unmanned*. It was noticed that while some buildings were exclusively used for the purpose of telecommunicating, others were also used for office work and thus contained office space. This prompted an investigation into the effects thereof.

2.5.1 Electrical Layout of a Typical Exchange

Figure 1.1 illustrated the energy requirements for a typical telecommunication site; figure 2.5 on the next page on the other hand, presents a simplified one-line diagram of the electrical layout of a typical exchange. This provides a clear understanding of the energy requirements and interconnections, and as such forms the basis for the implementation of energy management.

An 11kV, 3-phase line supplied by the utility forms the primary energy source. This is then stepped down to the standard 380V by a transformer, usually the property of Telkom. In the event of a power failure or interruption, a backup diesel generator is on stand-by. In some cases the entire exchange can be supplied by the backup, while in others only the vital equipment such as the rectifiers, telecommunication equipment, HVAC, and control systems are connected.

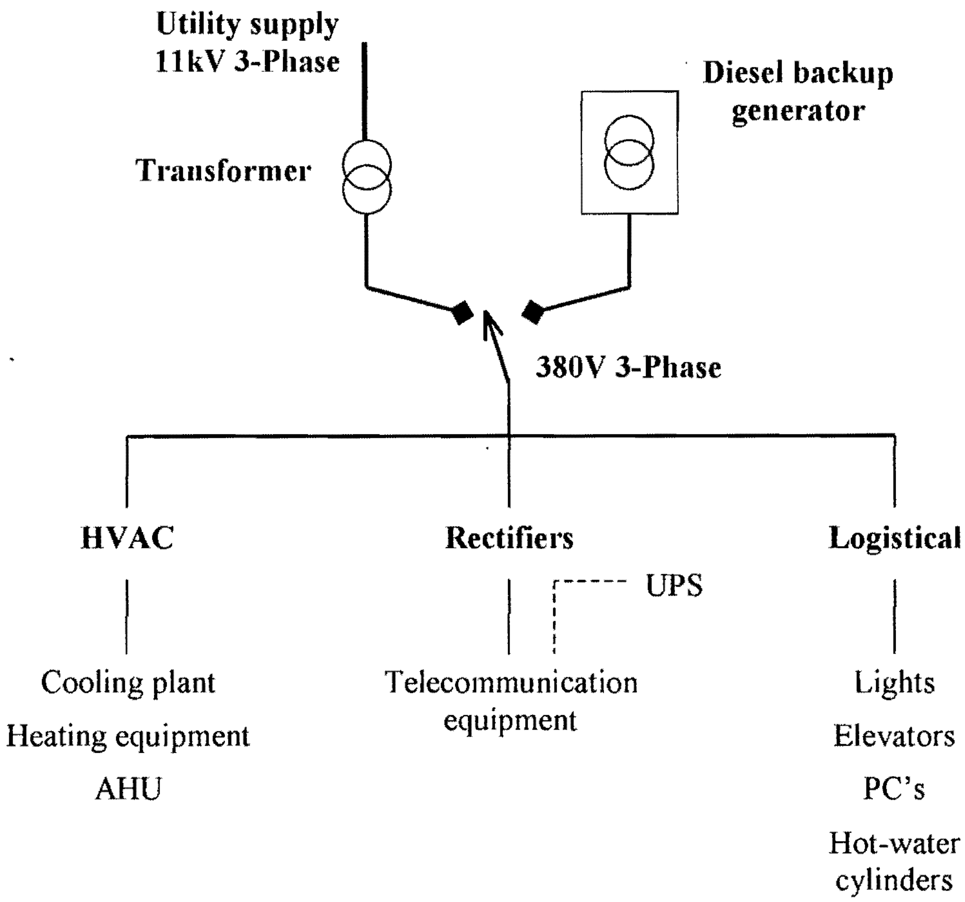


Figure 2.5 One-line diagram of a typical telecommunications exchange

A 380V, 3-phase bus supplies the necessary energy to the equipment (end-users), which can be divided into two broad categories: AC and DC. The DC end-users, which operate at a constant 48V, are the rectifiers, batteries, and telecommunication equipment. HVAC and logistical equipment (lights, elevators, alarms, Computers, hot-water cylinders etc.) make up the AC components which require the standard 380V (AC).

According to Parsons [17], exceeding the temperature specifications (specified by the ETSI 300-019 series mentioned in chapter 1) can affects the telecommunication equipment's reliability and even result is system failure. Most of the energy used by the telecommunication equipment is converted directly to heat [15], thus to avoid temperatures drifting beyond the specified limits, the indoor temperature has to be controlled using an appropriate HVAC system.

The telecommunication equipment requires a constant 48V supply, generated by the rectifiers. A UPS (Uninterruptible Power Supply) is present in case of power failures. Typically, exchanges also require logistical equipment, if not for the purpose of telecommunicating, then for human activity (maintenance, office work etc.).

2.5.2 Measurement Audit

Extensive measurement audits were conducted to analyse the energy utilisation and to establish efficiency levels. This paragraph summarises the results of the audits and draws conclusions from them, thereby providing the motivation for the continuation of the study.

Energy Consumptions

Table 2.1 below shows the various loads depicted in figure 2.5 as a percentage of the total building load. Confirming the differences between manned and unmanned exchanges, it is noted that manned exchanges consume more energy as a result of additional logistical equipment such as lights, personal computers, alarms, hot-water cylinders etc.

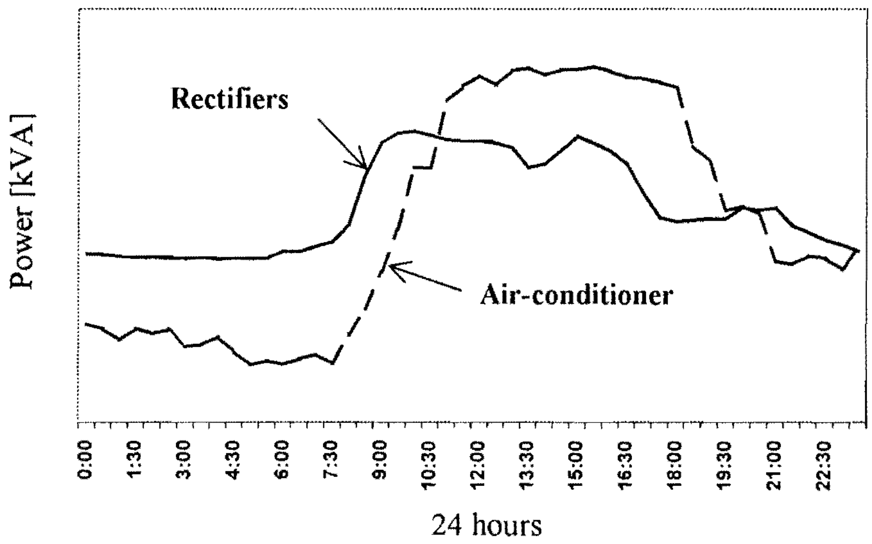
	% Of Total Building Load	
End-User	***Unmanned***	***Manned***
Rectifiers	44	33
HVAC	55	55
Logistical	1	12

Table 2.1 Percentage energy consumed by the various end-users in an exchange

Load Profiles

Typical load profiles of the rectifiers and HVAC equipment are plotted in figure 2.6 below. Knowledge of these profiles aid in the implementation of demand-side management and is therefore used in this context in chapter 5. For the moment however, the profiles are presented so that the processes involved can be visualised and understood.

At 07h30 the rectifier's power consumption starts to increase as a result of Telkom clients making use of telephonic services as they arrive at their place of work; consumption continuously increases as more customers make use of the services; at 09h30 the profile levels-off. As lunchtime approaches at approximately 13h00 the consumption decreases slightly, and then increases again as lunch ends. There is then a decrease in consumption as the clients end the day and go home. A base-load exists after office hours due to residential phone calls, and remembering the rectifiers also supply certain control equipment, also for system operation. Interestingly, it is noticed that after 19h00 the consumption rises slightly as a result of "call-more-time" when Telkom's tariff rates are lowered.



2.6 Typical load profiles of the cooling equipment and rectifiers for a period of one day

The profile describing the air-conditioning equipment can be explained as follows: many sources of heat exist in an exchange, of which the telecommunication equipment and outdoor conditions are the most prominent. Note that as the rectifier's consumption begins to increase, so does the air-conditioner's. At approximately the same time, the sun's radiation begins to take effect and the outdoor temperature rises; this has a pronounced effect on the cooling load and hence the air-conditioner's load increases. Similarly, as the rectifier's consumption decreases and the outdoor temperature drops, so does the air-conditioner's profile.

From the descriptions it is noted that the rectifier's profile is primarily dictated by the customers use of the telephonic services. Thus, in terms of demand-side management there is very little that can be done to improve efficiency of this end-user i.e. according to the energy policy, customers must still be able to "telecommunicate when, where and how they what to". On the other hand however, the cooling equipment's profile is strongly dependant on operational, and hence managerial constraints (operating times, set points, building design, installed equipment etc.) all of which allow DSM activities to be carried out. The importance of this becomes clear in the following paragraph.

2.6 AN ENERGY EFFICIENCY EVALUATION TOOL

The energy policy states that *energy norms* need to be developed in order to establish measurable benchmarks with which to compare performances, and thus provide reference points from which to analyse efficiencies. According to Delport [42, p. 1], an energy norm is a performance level that links elements of production to the energy consumption. As such it is an excellent tool for the management of energy.

The development of measurable benchmarks is an integral part of an energy policy. Referring to figure 2.3 it is noted that there needs to be controlled feedback (long-term and short-term) if there is to be successful management of energy; this however only has relevance if there are reference points with which to compare results i.e. if there are no set standards, how is it possible to determine if performance is optimal or not?

Table 2.2 presents the energy norms for the processes taking place in exchanges. In addition to streamlining, the norms also provide an efficient way of distinguishing between manned and unmanned exchanges. For the purpose of illustrating this, actual values obtained from energy audits are listed in the table – note the differences between the two types of exchanges!

Norm	Description	Units	Unmanned Exchanges	Manned Exchanges
$\frac{Q_{TOT}}{FloorArea}$	This is the most general of all the norms and determines the total energy consumed per month, per square meter of floor area. It is used to establish if a problem exists with the energy utilisation and also as a measure of efficiency, and hence if further investigation is necessary. *Many European companies define the benchmark to be 16 kWh/m²* [1].	[kWh/m²]	163.78	92.15
$\frac{Q_{HVAC}}{FloorArea}$	The norm is defined as the ratio of the energy consumed by HVAC for a period of one month to the total floor area. Once a problem with the energy utilisation has been detected, the cause of the problem can be narrowed down using this norm. That is, if it is determined that the value for this norm deviates far from a specified benchmark, the fault lies with HVAC, if not then further investigation is necessary. Since this norm provides a value for the amount of energy to be consumed per square meter of floor area, it is very useful when predicting HVAC energy consumptions (and hence tariff selection) for a particular building.	[kWh/m²]	89.63	51.32
$\frac{Q_{REC}}{FloorArea}$	This is very similar to the norm above, except that it determines if the problem lies with the rectifiers (which supply the telecommunication equipment)	[kWh/m²]	73.90	30.18
$\frac{MD_{TOT}}{FloorArea}$	Defined as the ratio of the maximum demand (MD) for a particular month to the total floor area, the norm has applicability when considering tariff structures (especially when a MD charge is incurred). It is thus used for DSM.	[kW/m²]	0.268	0.141
$\frac{MD_{HVAC}}{FloorArea}$	Normally, the installation of HVAC equipment is sized on the basis of the floor area e.g. the cooling capacity must be 0.2 kW/m². Thus finding the correct benchmark for this process is critical. In addition to this, the norm provides a tool for predicting power consumptions and thus aids in tariff selection and scheduling.	[kW/m²]	0.165	0.074

$\frac{Q_{HVAC}}{Q_{TOT}}$	This is one of the most important benchmarks to set; it defines how much of the total energy consumed by the exchange is due to HVAC. As such it determines if the air-conditioning plant is consuming too much or too little energy, and hence if it is optimal for that particular exchange.	[%]	55	55
$\frac{Q_{REC}}{Q_{TOT}}$	The norm is similar to the one above, except that it determines what percentage of the total energy utilisation is due to the rectifiers (and hence telecommunication equipment). If the value of a particular exchange is far from the benchmark, then either there is a problem with the rectifiers, or the other equipment (e.g. HVAC) is consuming too much or too little. *Many European companies define this benchmark to be 70%* [1].	[%]	44	33
$L.F_{TOT}$	The norm defines the load factor of the total energy utilisation of an exchange. This has applicability when considering tariff structures (especially when MD charges are applicable) and thus is used to optimise energy costs.	[%]	80	89
$L.F_{HVAC}$	Aids in setting operating schedules for the HVAC equipment e.g. a load factor of unity implies that the air-conditioner is operating 24 hours a day (never switching off) – for obvious reasons this is undesirable.	[%]	75	96
$L.F_{REC}$	The norm is very similar to the one above, except that it calculates the load factor of the rectifiers (and hence telecommunication equipment).	[%]	85	77

Table 2.2 Energy Norms for telephone exchanges

European standards stipulate that the energy consumed per floor area should not exceed 16 kWh/m^2 (see first norm), however with manned exchanges consuming 92 kWh/m^2 and unmanned exchanges consuming 164 kWh/m^2, it is clear that there is large scope for improvement in Telkom's energy utilisation. Granted, there are vast differences in weather conditions (i.e. temperature levels are typically a lot lower in Europe than they are locally), and in addition, the thermal quality of buildings are much higher in Europe (due to more stringent building codes) than in South Africa, enabling the European countries to use a lot less energy for space cooling. Nonetheless, it still illustrates the fact that Telkom is extremely inefficient with its energy.

Magnus [41] mentions that the process of HVAC in Bell Communications (USA) only constitutes 21% of the total energy consumption, and Bengtsson [19] stipulates that in Swedish based Telia this process only consumes 30%. Thus, it is clear that while Telkom consumes 55% for this process (see table 2.1) drastic improvements are necessary!

Fortunately, from the explanations presented in paragraph 2.5.2, it was mentioned that while little can be done in terms of DSM to optimise the energy utilisation of the rectifiers, the process of HVAC offers the widest selection of energy management opportunities. Confirming this, Grobler [23, p. ii] states that the "biggest energy-saving potential lies in the retrofitting of HVAC systems".

2.7 SUMMARY

The chapter formed the basis of the study by presenting a holistic methodology for the implementation of the management of energy. As such, an energy policy was formulated enabling the responsible management of energy sources, resources and consumables; in so doing setting up control measures ensuring that energy is being used to its maximum potential.

This then led to energy audits being conducted to establish efficiency in the organization. It was then concluded that a distinction between manned and unmanned exchanges could be made, prompting an investigation into the effects thereof. This resulted in development of an energy efficiency evaluation tool in the form of energy norms, which highlighted the differences between the two types of exchanges.

Typical load profiles of the rectifiers and HVAC equipment were also obtained from the audits. From these, it was concluded that not much in terms of demand-side management could be done to lower the energy expenses of the rectifiers, but that the process of HVAC offered a vast selection of DSM activities.

This fact was welcomed since it was determined that in both manned and unmanned exchanges 55% of the total load was as a result of HVAC, and because literature showed that European standards dictate this value to be less than 30%, it presented great incentive to investigate optimising this process through DSM. This has formed the basis for the remainder of the study i.e. to concentrate primarily on optimising the process of HVAC through demand-side management.

3. MODELLING METHODOLOGY

3.1 INTRODUCTION

Correctly predicting alterations to the process of HVAC (energy utilisation, operating schedules etc.) resulting in energy efficient solutions solely depends on an abstraction that completely describes the system and the processes involved. According to Rose [43, p. 1] such an abstraction of a real world process is called a mathematical model i.e. any process or system described in mathematical terms is called a mathematical model. Since the study focuses on energy related models, they will be of the energy conversion form, and are thus more aptly called *energy conversion models*.

Broadly speaking, the purpose of this chapter is to present a methodology for the development of energy conversion models relating the energy utilisation of the air-conditioning equipment to energy costs. In so doing provide a DSM tool that will enable cost effective energy configuration, schedules and tariffs. The methodology will ensure that the models are developed in such a manner that they represent the processes with acceptable accuracy without being too complicated.

3.2 CONTEXT OF MODEL DEVELOPMENT

According to Delport [30, p. 1], energy conversion models represent the energy engineer's view and understanding of the real world system. It is thus clear that the models that describe the processes or systems need to be as accurate as possible, so as to provide a realistic approximation of the actual real world. For this to be possible, the development of the models needs to be kept within the context of the real world, which they are to represent. For this purpose figure 3.1 on the next page graphically represents the operational hierarchy of the context of energy models.

In terms of this study, the *system* would be the HVAC plant installed in an exchange and the *processes* would be the activities needed to control the internal environment, more specifically temperature levels. The interaction and interdependence between these two elements of the hierarchy can be defined as *operational performance* (i.e. maintaining the environment within specifications). Energy usage values are outputs of the *system* and inputs to the *plant*, which in this case would collectively represent a telecommunications exchange. The uppermost element in the hierarchy is the *organization*, which is comprised of all the *plants* (exchanges) situated around the country. For the purpose of the study this element is concerned only with managerial considerations and for this reason the interdependence with the *plant* is primarily monetarily based i.e. *energy costs*, the reduction of which is the fundamental objective.

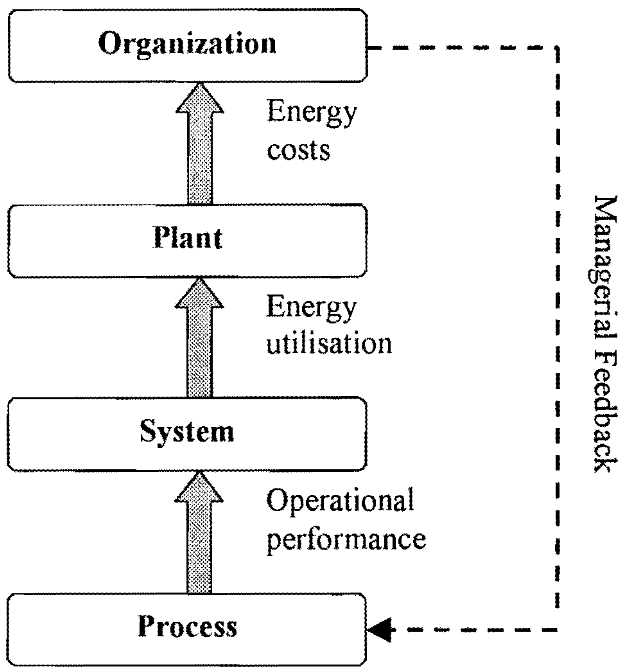


Figure 3.1 Modelling Context

The primary objective of any organization is to maximise profits, for this reason there needs to be continual feedback from the upper organisational hierarchy to the lower elements of operation. Thus, in terms of the organization's energy policy, decisions are based in terms of performance and profit margins. In this context, it is easy to understand that an evaluation tool is needed to aid this decision-making process. That is, a model that can completely describe the relationship between the respective processes and the organization as a whole is needed.

3.3 IMPACT OF OPERATIONAL PERFORMANCE ON ENERGY COSTS

3.3.1 Energy Costs Versus Operational Performance

Since the primary objective of the study is to lower the energy costs of HVAC through DSM, the models are to represent the operational performance relationship with economic aspects of the cooling process. From the modelling context, such a relationship will in fact form the pivotal point for the development of the models. The relationship between the operational performances of the *processes* and the energy costs of the *organization* can be collectively described by the energy conversion models as shown in figure 3.2.

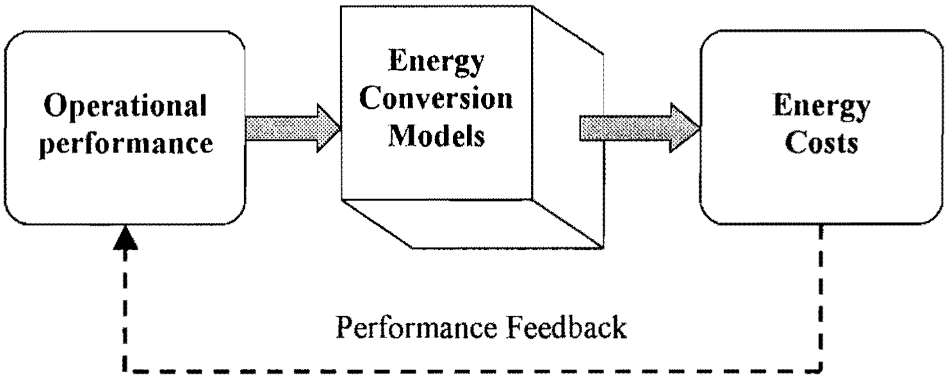


Figure 3.2 The interdependence between operational performance and energy costs

It is easy to understand that a strong relationship between operational performances and energy expenditure exists. Since there is this interdependence, a mathematical abstraction in the form of energy conversion models can be constructed to closely approximate this relationship. Changes in operational performances, such as altering temperature set points, have a direct influence on the air-conditioning equipment's energy consumption, and hence energy costs. These alterations can obviously have a negative or positive influence on the energy costs, and thus on the organization's profit margins. For this reason there needs to be continual feedback ensuring only positive influences are induced.

This relationship between the operational performance and energy cost can be modelled in a number of ways i.e. Murphy and Groncki [44, p. 91] suggest that because there is a definite relationship between energy and cost, such models can be modelled in one of the following two ways:

- *Capturing Energy-Economy Interactions*: this is the complete capturing of the full general equilibrium interactions between energy and economy in a single set of complex models.
- *Linking Energy Models*: this is the building of individual models for the energy and economic relationships separately. As such the outputs of the one set of models forms the input to the other.

For the purpose of this study the latter option was chosen for the sake of conforming to a modular approach, which will be discussed in detail in paragraph 3.5. Following this methodology also allows experts to focus on their field of expertise i.e. they are able to concentrate only on the models relevant to their specific needs.

3.3.2 Minimising Energy Costs

Figure 3.3 was drawn up to provide a visual understanding of how energy costs are to be minimised. For the sake of simplicity, the operational performances (which will be discussed during and after the development of the models in chapter 4) that are to influence the energy costs are merely represented as "*inputs*" for the moment. Of importance here, is the methodology followed ensuring energy cost savings are incurred. For the sake of clarity, note that the figure represents the interdependence of the *systems* level with the *organisational* level in figure 3.1; and as such it explains the relationship between the energy utilisation and energy costs.

The implementation of demand-side management requires that a complete understanding of the energy utilisation be known. This necessitates the understanding of energy consumption levels, rate of energy consumption (power levels), and load profiles. Hence, the outputs of the energy conversion models need to be energy and power values.

Dictating the energy costs at the end of every month is a specified billing tariff. Paragraph 2.2.2 discussed numerous such tariffs, each of which has its own billing structure. This provides a practical means of reducing the energy costs – by manipulating the energy utilisation (energy and power consumptions, and load profiles) through various demand-side management activities, and selecting the most appropriate tariff structure, maximum energy cost savings can be realised.

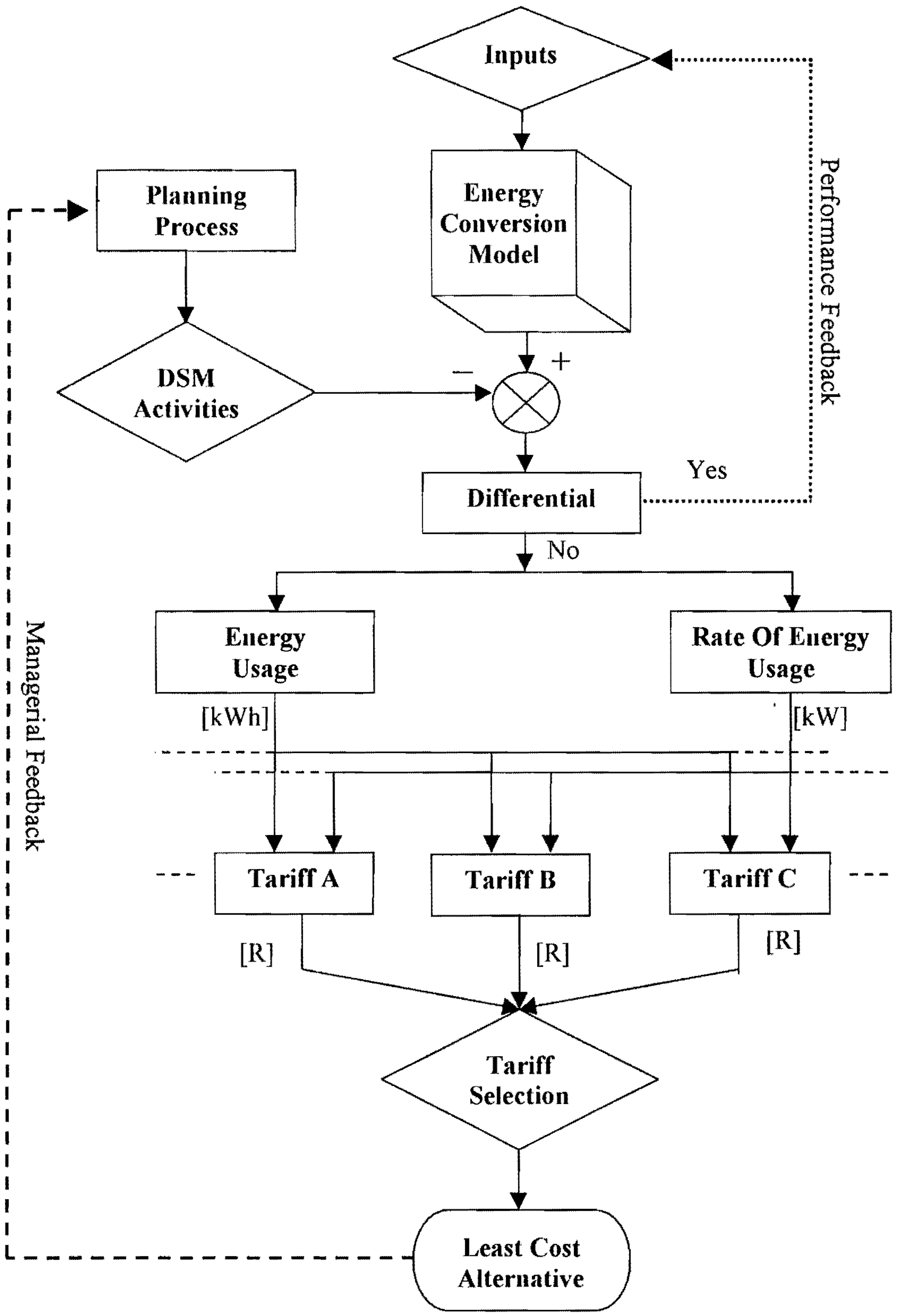


Figure 3.3 Finding the least cost alternative

The problem is, there needs to be a way of predicting if the applicable DSM activities will indeed result in savings. The function of the energy conversion models is precisely this – various variables (i.e. *operational performances*) can be used as inputs to the models and the outputs observed. If these theoretical outputs concur with what is required by the DSM activities, the appropriate tariff structure can be selected using these outputs to ensure maximum energy cost savings. However, if the outputs do not agree with the suggested DSM activities, the operational performances need to be reconsidered until they are in agreement; this explains the "*performance feedback*" illustrated in the figure (note this feedback is the same as that shown in figure 3.2).

3.4 SYSTEM BOUNDARIES AND CONSTRAINTS

According to Murray [45, p. 28], in order to keep a clear perspective of the system being modelled, finite system boundaries must be identified. Any system, which is being modelled has certain inputs, which are obviously part of or relevant to the system. He goes on to mention that these inputs are either internal to a direct system boundary, having a direct influence on the processes, or to an ultimate system boundary, which would mainly consist of environmental factors and indirect influences such as managerial constraints on the specific system.

3.4.1 Boundaries and Constraints

To clarify where these boundaries exist in context of the models it will be poignant to describe them in terms of figure 3.1. Figure 3.4 on the next page demonstrates the direct and indirect system boundaries, as well as the environmental influences for the modelling at hand in terms of system context. It is important to note that the boundaries may vary if different objectives are required, such as if the processes themselves rather than the system are modelled, in which case the direct system boundary would be at the *process-level* and the ultimate boundary would either be at the *plant* or *organization-level*. For the modelling at hand however, which requires the models to describe the system (e.g. air-conditioning system) rather than processes, the direct system boundary and ultimate system boundary are defined at the *system* and *organization-level* respectively.

3.4.2 Modelling Inputs and Outputs

The *direct inputs* are defined as those influences which are within the direct system boundary, and which have immediate effect on the model outputs i.e. they are essentially the 'operational performances' mentioned in paragraph 3.3. The *indirect inputs* are process and system limitations, and system specifications. *Environmental influences* are the "outside" influences affecting the model outputs, and which there is no control over. These are aspects such as managerial constraints and limitations.

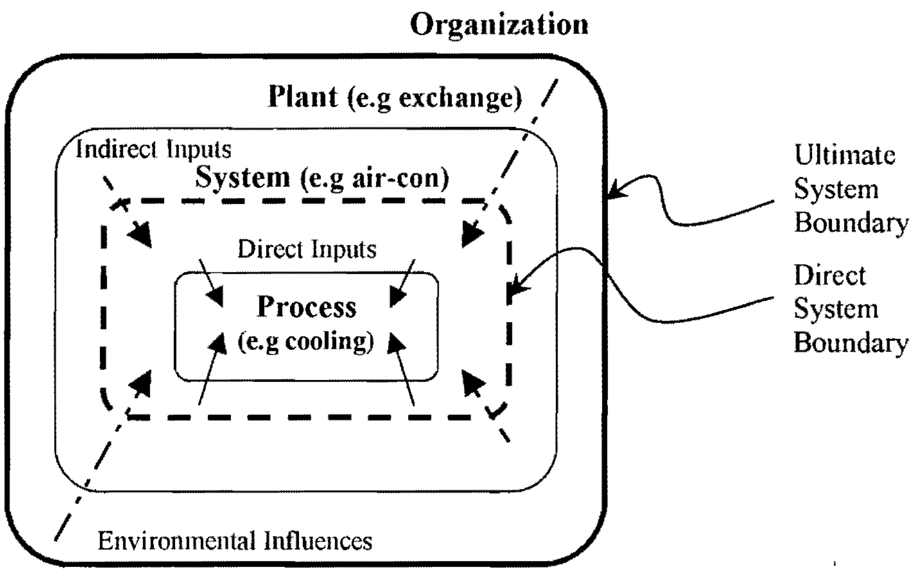


Figure 3.4 System boundaries and inputs

3.5 CONSTRUCTING ENERGY CONVERSION MODELS

3.5.1 Introduction

Hogan and Weyant [46, p. 4] suggest that the development of energy conversion models should posses the following set of criteria: (1) they should be based on a *consistent theory*, for the development and use thereof; (2) to simplify acquisition and application of the data, they should follow the *natural organization* of the data; (3) a very desirable quality, is that they should by *modular in form* to ensure system integrity when individual components are considered; (4) they should be *decentralised* enabling experts to concentrate on their own field of expertise; (5) they should *promote efficient* computation in both development and application.

3.5.2 The Building Block Approach

In keeping with these criteria, Delport [30, pp. 10 – 14] provides a holistic approach to developing energy conversion models using the "Building Block" approach. This methodology enables the development of the models to be modular in nature and thus have immense applicability when considering different systems with many processes – considering figure 3.1, it allows the *processes* to be modelled individually, yet at the same time enable them to be integrated with others to describe the *system*. Similarly, because of the modular nature, various *systems* can be integrated with each other to represent a *plant*, which can then also be used to describe the *organization*.

The approach states that each identifiable process of a particular system can be modelled as a building block consisting of a specified *storage buffer* and a *process*. As an example, consider figure 3.5 modelling a centralised water-cooled air-conditioner's ability to lower the temperature of an exchange. The storage buffer in this case would be the amount of cold water contained in the chiller's storage tanks; the process would be the actual process of lowering the exchanges temperature.

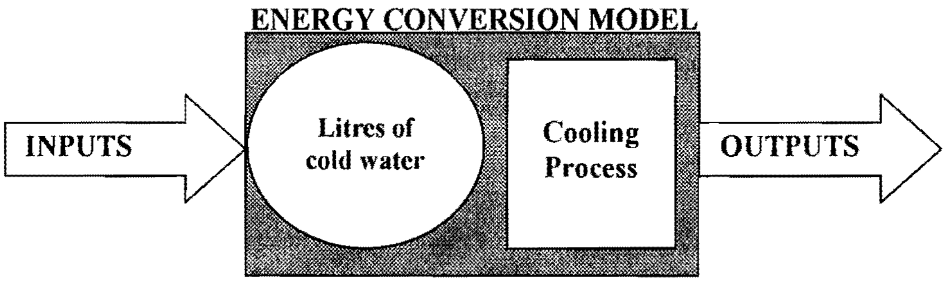


Figure 3.5 Example of modelling an air-conditioner's ability to cool an exchange using the Building Block approach [3, p. 8]

In the above example, if a DX (Direct Expansion) air-conditioner that uses CFC's is modelled instead of a water-cooled system, the buffer in figure 3.5 is equated to zero i.e. a *zero-buffer*. In a DX system there is no storage mechanism of any kind – once the air-conditioner is switched on, the process of cooling begins, there is no thermal storage of any kind. Thus in the 'building block' only a process would be included, and no buffer.

A crucial factor governing the development of any such modules (models) is that they need to be completely compatible with each other, in any configuration i.e. the inputs and outputs of each individual module must conform to a specified standard established for the entire system.

From the discussions above it is clear that using this methodology to develop energy conversion models adheres to all the criteria pointed out in paragraph 3.5.1. For this reason this approach will be followed in chapter 4 where the development of the required models are undertaken.

3.5.3 Acquisition and Processing of Data

Figure 3.6 on the next page presents a flow chart of how models are to be developed using this methodology [45, p. 24]. The graphical representation illustrates that the development stage of the model requires a number of inputs, namely theoretical knowledge, manipulated real world data, and a refining input from previous model trials. The output is of course the actual model.

In the development of the model, it is necessary to obtain theoretical knowledge as well as real world data for the processes involved. That is, all scientific information pertaining to existance, operation and limitations need to be gathered and interpreted in conjunction with real world data. This includes basic physics and applied theory for which ever process the model is being developed.

Models will in general be developed from a theoretical standpoint, but cannot be totally independent from the real world. Knowledge of permissible values such as limitations, efficiencies and managerial aspects all need to be taken into account. Once all information has been interpreted and related to the physical process, a relationship between input and output can be established from which an explicit model is developed.

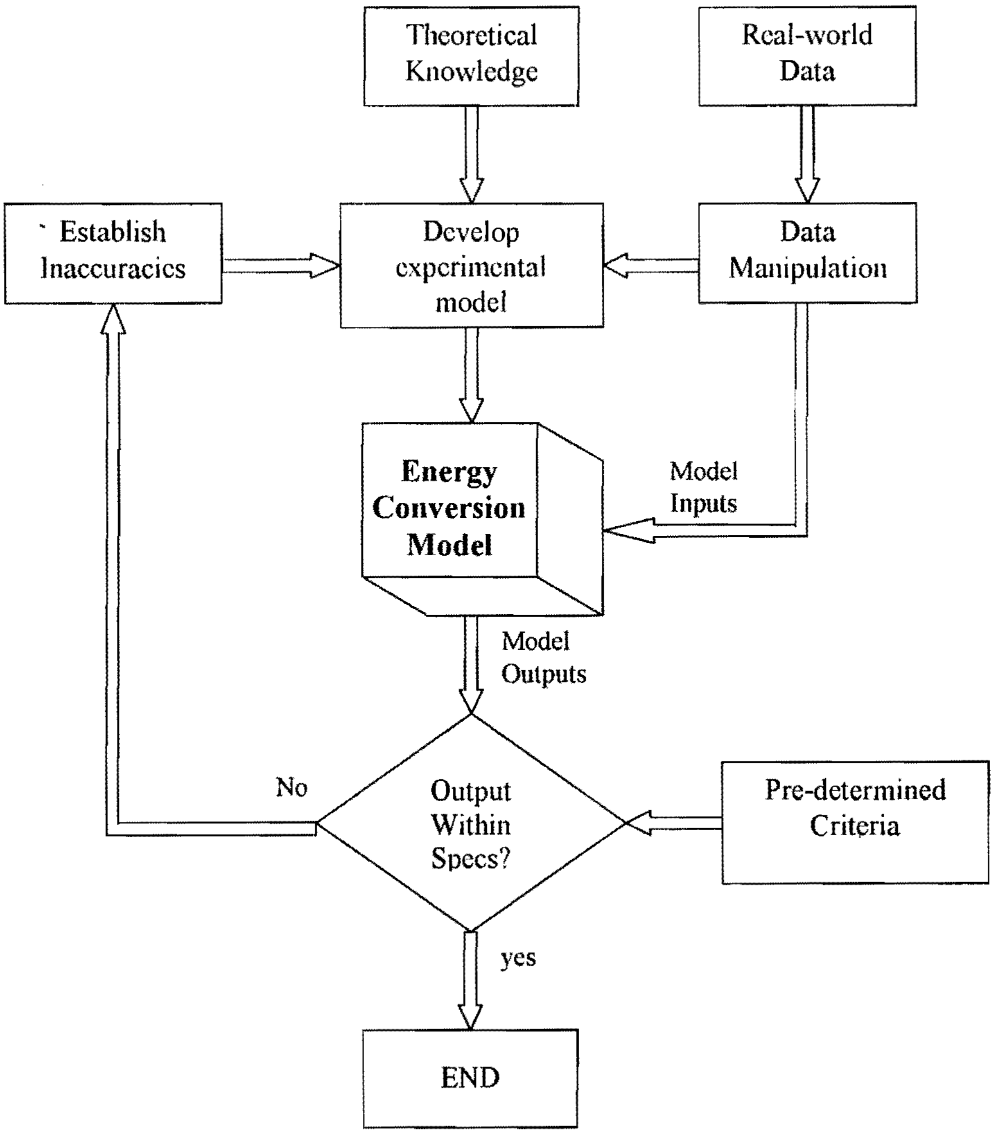


Figure 3.6 Model development flow chart [45, p. 24]

Once the model has been developed, it needs to be verified and tested. Since the model represents a relationship between input and output of a real-world process, it needs to be tested in the real world to confirm that the relationship is valid. Usually it is not possible to include each and every process in the model, it is either impossible to identify all the processes, or the model will be too complex. As a result, there will always be a slight discrepancy between the model outputs and the real world process.

3.6 SUMMARY

The chapter provided a detailed modelling methodology for the development of the energy conversion models pertaining to the cooling process of exchanges. It illustrated how the models fall into the context of the organisational hierarchy, and as such explained the relevance of the models to describe the operational performance/energy costs relationship. A flow diagram was presented that illustrated how maximum energy cost savings can be incurred as a result of DSM and correct tariff selection. In so doing it laid out the methodology to be followed to ensure the most cost effective manner to operate the air-conditioning equipment.

Thereafter the methodology for the development of the actual energy conversion models was presented. The "Building Block" approach, described by Delport [30], was selected for the development of the models. This approach ensures that the models conform to the criteria provided in paragraph 3.5.1.

Now that the methodologies have been completely described, the following chapter delves into the development of the models according to the method. As will be explained, the models consist of three modules that will completely describe the air-conditioning equipment and the processes involved; enabling the energy cost reduction of this end-user through DSM activities.

4. HVAC MODEL DEVELOPMENT AND VERIFICATION

4.1 INTRODUCTION

The previous chapter presented the methodology to be followed in developing the energy conversion models related to the air conditioning systems installed in exchanges. This chapter extends upon this by developing a set of models according to the modelling methodology for the process of cooling these buildings. The set of models will enable the complete management of the electrical energy utilised by the air-conditioners.

Conforming to the methodology, the set of models can be broken down into three concurrent *modules*, each describing a different process of the *operational performance* versus *energy cost* relationship described in chapter 3. These three modules are defined as:

- ***Total building heat load***: This is the total heat gained by an exchange building i.e. the total amount of heat energy added to an exchange due to various heat loads or elements e.g. solar radiation, equipment, lights etc.
- ***Required cooling capacity of the air-conditioning equipment***: This specifies the required "size" air-conditioner for an exchange i.e. the cooling capacity required by the air-conditioning equipment for a specific exchange.
- ***Air-conditioner's energy utilisation***: This is the amount of electrical power, and hence energy, consumed by the air-conditioning equipment for a specified exchange and air-conditioner.

4.2 BUILDING BLOCKS

To be consistent with the 'Building Block' concept, the outputs of one module are to form the input to the other. This is illustrated in figure 4.1 on the next page. Note that the outputs of the first two modules are thermal energy values (British Thermal Units), whereas those of the third module are electrical energy values (Kilo-watt-hours). From this it is easy to understand the term "energy conversion models".

For the sake of clarity, an additional two modules have been included to provide insight into how the models are to be used to minimise energy costs through DSM activities and tariff selection; it also explains the type of modelling that is to be done i.e. *Linking Energy Models* (discussed in paragraph 3.3.1).

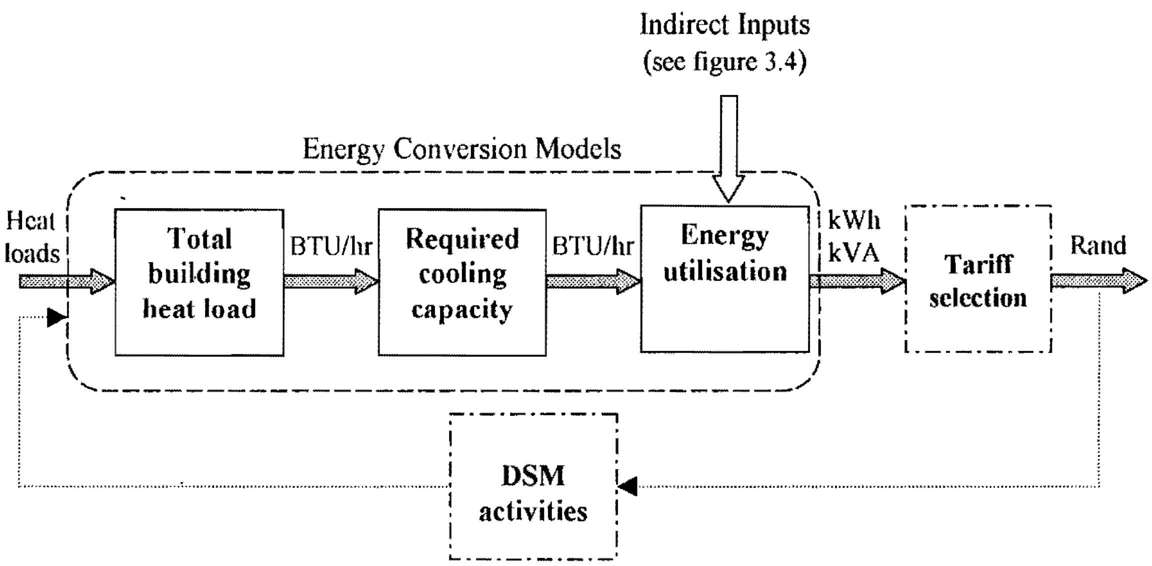


Figure 4.1 Modules forming the model set

Constructing the models in this manner allows experts to use the models relevant to their field of expertise. For example, if the focus were on improving the thermal quality of an exchange, the expert would only need to use the models defining the *total building heat load*. If the models were not constructed in this manner but were combined in a single equation for example, it would be a tedious task extracting the information for a particular field of interest, if even at all possible.

4.3 MODELLING ASSUMPTIONS

According to Delport [30, p. 1], when developing models it is usually necessary to make simplifying assumptions – to include all relevant real-world processes will make the model too complex, not only in the development but also in the utilisation of the models. At the same time, it is also important to ensure that an acceptable degree of accuracy is attained by the model outputs, and for this reason assumptions are to be made only if they can be justified. For the modelling at hand, the following assumptions will be made:

- ***There are no temperature gradients:*** it will be assumed that there is a homogeneous temperature throughout the building i.e. the temperature is the same at any region in the building (if one were to measure the temperature on the first floor, for example, and compare it with the temperature on the third floor, there will be no temperature difference). This includes temperatures in adjacent rooms. This assumption is valid as long as there is adequate ventilation throughout the building.
- ***Temperatures are taken at steady state:*** if a parameter that causes the temperature level to vary is changed (e.g. the temperature set point is changed), the interior temperature will undergo a transient and eventually stabilise at some point; the models are developed assuming the temperature is in this region of stability.
- ***Humidity levels remain unchanged:*** it is assumed that the humidity levels inside the exchanges remain constant, even if the dry-bulb temperature is changed. This is a valid assumption as most exchanges have control hardware installed for controlling this.
- ***Air-conditioning equipment is correctly sized:*** for the purpose of the 'energy consumption' module in figure 4.1, it is assumed that the air-conditioner is correctly sized (i.e. its cooling capacity) for the building it has been installed.
- ***Other:*** during the derivation of the models, further assumptions will be made that are more specific to each particular model.

4.4 UNITS

For the purpose of this study the following units will be used:

Length	**Feet**	**[ft]**
Area	**Feet^2**	**[ft^2]**
Mass	**Pounds**	**[lb]**
Temperature	**Fahrenheit**	**[F]**
Heat	**British thermal unit**	**[Btu]**

Making use of these units and not the standard SI units is simply to coincide with tables and charts set up by ASHRAE (American Society for Heat, Refrigeration and Air-conditioning Engineers). Expressing equations in these units simplifies matters considerably since conversions for each element in the tables is not necessary. If it is desired that the final result be in the standard SI unit, then the solution can simply be translated using the following conversions.

$$\mathbf{C = \frac{F - 32}{1.8}}$$

$$\mathbf{0.3\ m = 1\ ft}$$

$$\mathbf{1\ kW = 3410\ Btu/hr}$$

4.5 TOTAL BUILDING HEAT LOAD

Figure 4.2 on the next page shows the real-world processes (heat transfers) involved in developing this energy conversion model. Except for $\mathbf{Q_{capacity}}$, which is the cooling load supplied by the air conditioner, all the **Q**'s are either the internal or external heating loads (adding heat) to the exchange. Note that these heat gains can be categorised as being either *internal* (heat sources inside the exchange), or *external heat gains/elements* (occurring outside the building envelope).

Now, the problem at hand is to calculate the total building heat load which consists of all the internal and external heat elements. According to Sauer and Howell [26, pp. 6.1 – 6.4] this is accomplished by summing all the heat elements, internal and external. Thus, from figure 4.2 the total building heat load of a typical exchange is given by equation 4.1.

$$\mathbf{Q_{building} = Q_{solar} + Q_{glass} + Q_{infil} + Q_{wall} + Q_{ceiling} + Q_{part} + Q_{lights} + Q_{people} + Q_{telecom}} \quad [4.1]$$

Where each **Q** is defined as follows:

$\mathbf{Q_{building}}$	total building heat load.
$\mathbf{Q_{solar}}$	heat gain due to solar radiation through windows to the interior.
$\mathbf{Q_{glass}}$	heat gain due to conduction through glass (windows).
$\mathbf{Q_{infil}}$	heat gain due to air infiltrating through cracks (e.g. door edges).
$\mathbf{Q_{wall}}$	heat gain due to conduction through walls.
$\mathbf{Q_{ceiling}}$	heat gain due to conduction through the ceiling.
$\mathbf{Q_{part}}$	heat gain due to conduction through interior wall partitions.
$\mathbf{Q_{lights}}$	heat gain from lights.
$\mathbf{Q_{people}}$	heat gain from people.
$\mathbf{Q_{telecom}}$	heat gain from telecommunication equipment.

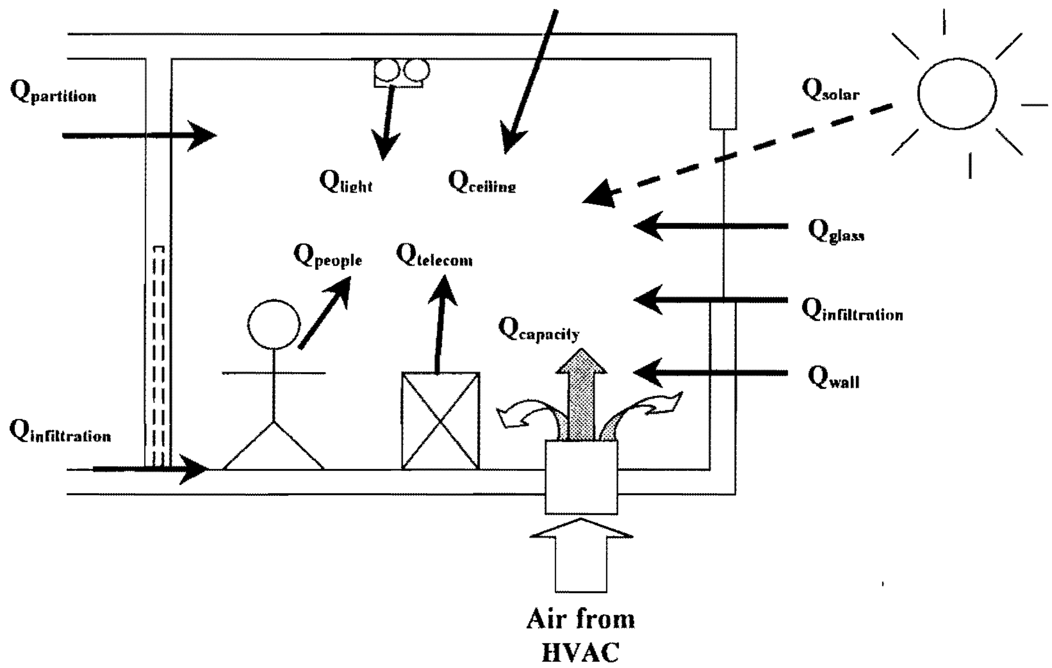


Figure 4.2 Typical heat transfers occurring in an exchange

The assumptions made in paragraph 4.3 enable equation 4.1 to be simplified considerably. That is, the assumption made that there is a homogeneous temperature throughout the building and that no heat transfer occurs through interior partitions (such as from room to room), means that $\mathbf{Q_{part}}$ can be ignored. Most exchanges in South Africa do not have windows in their envelopes, allowing the $\mathbf{Q_{solar}}$ and $\mathbf{Q_{glass}}$ terms to be negated. The equation can thus be rewritten as equation 4.2. All that remains now is to calculate the various heat elements in this equation.

$$\mathbf{Q}_{building} = \mathbf{Q}_{infil} + \mathbf{Q}_{wall} + \mathbf{Q}_{ceiling} + \mathbf{Q}_{lights} + \mathbf{Q}_{people} + \mathbf{Q}_{telecom} \qquad [4.2]$$

4.5.1 Heat Gain Through Walls and Ceilings

A building envelope that consists of walls, roofs, windows and doors is not perfectly heat insulated, as a result heat energy is able to transverse through these structures by means of one or more of the following processes: conduction, convection or radiation. Extrapolating from Young [47, p. 433], when considering the heat transfer through this envelope, a number of considerations have to be taken into account that affect the rate at which heat is added to, or removed from the building:

- *Building size* – The physical dimensions of the building have a direct influence on the rate at which the heat is transferred. The surface area of the walls, roofs, windows, and floors are of importance here. The larger the surface area, the faster the rate of heat transfer.
- *Type of materials used in the construction of the building* – various materials have different properties when it comes to the transfer of heat. The property of a material to resist the flow of heat (from a region of high temperature to a region of low temperature) is known as the *thermal resistance*. The higher the resistance, the slower the transfer of heat.
- *Temperature difference* – this is the change in temperature from one side of a structure (e.g. a wall) to the other side. The higher the temperature gradient, the greater the rate of transfer.

These three factors have a direct influence on the rate at which the heat energy is transferred through a material and can be related by the following equation [48, p. 45]:

$$\mathbf{Q} = \frac{\mathbf{1}}{\mathbf{R}} \times \mathbf{A} \times \Delta\mathbf{T} \qquad [4.3]$$

where **Q** is the heat transfer rate [Btu/hr], **R** is the thermal resistance [hr-ft^2-F/Btu], **A** is the surface area [ft^2], and $\Delta\mathbf{T}$ is the temperature difference [F].

In many cases the building envelope does not only consist of one type of material, but of many. The thermal resistance of this is a combination of the individual resistances. Take for example a brick wall consisting of bricks, plaster and paint.

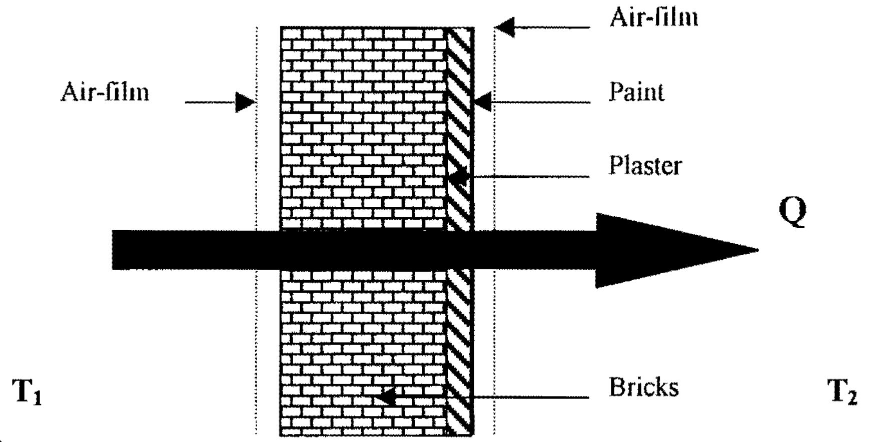


Figure 4.3 Cross-sectional view of a wall

According to Pita [48, p. 46] the total or *overall thermal resistance* is the sum of all the individual resistances of each material. The figure shows that if temperature T_1 is greater than T_2 the heat will flow through the wall in the direction indicated. Note that there is an air-film on both sides of the wall, the thermal resistance of which must also be taken into account. The overall thermal resistance for this example is therefore:

$$\mathbf{R_T = R_{AIRFILM1} + R_{BRICK} + R_{PLASTER} + R_{PAINT} + R_{AIRFILM2}} \quad [4.4]$$

ASHRAE have measured the thermal resistances for many building materials, however these values are not given in terms of **R** but rather in terms of the thermal conductance called the *overall heat transfer coefficient* [26, p. 5.7] (***see appendix B for heat transfer coefficients for different building materials – supplied by Pita [48, pp 445 - 449]**) i.e.

$$\mathbf{U = \frac{1}{R_T}} \quad [4.5]$$

where **U** is the overall heat transfer coefficient [Btu/hr-ft^2-F], and $\mathbf{R_T}$ is the total thermal resistance [hr-ft^2-F/Btu].

It was mentioned earlier that the rate at which heat is transferred across a material depends on three factors: surface area, thermal resistance and temperature difference. The heat transfer rate for the exchange's walls and ceiling are thus:

$$\mathbf{Q}_{\mathbf{wall}} = \mathbf{U}_{\mathbf{w}} \times \mathbf{A}_{\mathbf{w}} \times \Delta\mathbf{T} \quad [4.6]$$

$$\mathbf{Q}_{\mathbf{ceiling}} = \mathbf{U}_{\mathbf{c}} \times \mathbf{A}_{\mathbf{c}} \times \Delta\mathbf{T} \quad [4.7]$$

where **Q** is the heat transfer rate [Btu/hr], **U** is the overall heat transfer coefficient [Btu/hr-ft^2-F], **A** is the surface area [ft^2], and **ΔT** is the temperature difference on the opposite sides of the structure [F].

4.5.2 Heat Gains Due to Lights

According to Schweitzer and Ebeling [28, p. 2-6] each watt of electrical energy consumed in producing light from fluorescent lamps (used by Telkom) gives off 3.42 Btu/hr. Thus

$$\mathbf{Q}_{\mathbf{lights}} = \mathbf{3.42} \times \mathbf{P}_{\mathbf{L}} \quad [4.8]$$

Where $\mathbf{Q}_{\mathbf{lights}}$ is the heat given off due to lighting [Btu/hr], and $\mathbf{P}_{\mathbf{L}}$ is the electrical power consumed by the light sources [W].

4.5.3 Heat Gains Due to People

ASHRAE [25, p. 26-8] have devised a list of human activities and their respective heat emissions. For the modelling at hand, where telecommunication exchanges are of interest, it is assumed that the work force is predominantly male, and that the two primary activities carried out by the personnel are (1) "seated, very light work" such as office work, and (2) "light bench work" such as maintenance work done on the telecommunication equipment. These *degrees of activities* give off 444 Btu/hr (130W) and 800 Btu/hr (235W) per adult male respectfully. Therefore

$$Q_{peolpe} = N_p \times \Psi \qquad [4.9]$$

Where $\mathbf{Q_{people}}$ is the heat given off by humans [Btu/hr], $\mathbf{N_p}$ is the number of people, and Ψ is the degree of activity [Btu/hr].

4.5.4 Heat Gains Due to Infiltration

The infiltration of air through door and window edges obviously also causes an additional heat gain or loss to the exchange. According to ASHRAE [24, p. 25.4] this heat gain to the building can be expressed by the following equation:

$$Q_{infil} = 1.08 \times \beta \times \Delta T \qquad [4.10]$$

Where $\mathbf{Q_{infil}}$ is the heat gain due to infiltration [Btu/hr], $\Delta\mathbf{T}$ is the temperature difference [F], and β is the cubic feet per minute of infiltrating air [ft^3/min].

4.5.5 Heat Gains Due to Telecommunication Equipment

It was mentioned in the opening chapter that most of the energy utilised by the telecommunication equipment is converted into heat. More specifically, the average equipment heat load is 2 W/line, which translates into 6.826 Btu/hr/line [41]. Thus,

$$Q_{telecom} = 6.826 \times N_T \qquad [4.11]$$

Where $\mathbf{Q_{telecom}}$ is the heat gain due to the telecommunication equipment [Btu/hr], and $\mathbf{N_T}$ is the number of lines.

Now, substituting all these heat loads into equation 4.2 gives the following:

$$Q_{building} = \left[\Delta T \times \left(U_w A_w + U_c A_c + 1.08 \cdot \beta\right)\right] + \left[3.42 \cdot P_L\right] + \left[N_p \cdot \Psi\right] + \left[6.826 \cdot N_T\right] \qquad [4.12]$$

Equation 4.12 can be used to determine the building heat load to an unmanned exchange. However, because the cooling air supplied by the air-conditioners is only concentrated on the exchange rooms themselves and not offices areas, the equation does not completely describe the heat load to a manned exchange. This facet can be included into the model by observing that only the first term in the equation is dependant on temperature, and consequently is the only term that will have a different effect on the heat load. Equation 4.12 can be rewritten to include the effects of having office space in an exchange:

$$\begin{aligned} Q_{building} = & \left[(T_{Out} - T_{Ech}) \times (U_{w\,Out} A_{w\,Out} + U_c A_c)\right] \\ & + \left[(T_{Offic} - T_{Exh}) \times (U_{w\,Ech} A_{w\,Exh} + 1.08 \cdot \beta_{Exh})\right] \\ & + \left[3.42 \cdot P_L\right] + \left[N_p \cdot \Psi\right] + \left[6.826 \cdot N_T\right] \end{aligned} \quad [4.13]$$

where T_{Out} is the outdoor temperature, T_{Exh} is the exchange room temperature, $U_{w\,Out}$ and $A_{w\,Out}$ are the heat transfer coefficient and area of the non-office (exchange room) walls facing the outdoors, U_c and A_c are the heat transfer coefficient and ceiling area of the exchange rooms respectfully, β_{Exh} is the infiltration from the offices areas into the exchange room, T_{offic} is the office temperature, $U_{w\,Ech}$ and $A_{w\,Ech}$ are the heat transfer coefficient and areas of the partitioning walls between the office areas and the exchange rooms.

4.6 REQUIRED COOLING CAPACITY

According to Schweitzer and Ebeling [28, p. 2-3], the principle used to determine the cooling capacity required by an air conditioner is "*load*" determination i.e. the purpose of an air-conditioner to remove the heat supplied by the various heat loads (as those depicted in figure 4.2) so as to maintain a prescribed temperature. The problem is, how much of this heat must the air-conditioner remove – with too much removed the temperature will become too low; conversely, with too little heat removed the temperature will be too high.

The problem can be solved by observing the first law of thermodynamics that states: *The energy added to a system less the energy removed from the system equals the energy change in the system* [48, p. 31]. This can be expressed by the following:

$$\textbf{Energy Gained} - \textbf{Energy Lost} = \textbf{Change in Energy} \quad [4.14]$$

It was mentioned that the role of the air-conditioner is to maintain a constant temperature. This implies that the energy content of the air contained within the building remains unchanged. Hence, the 'Change in Energy' term in equation 4.14 can be equated to zero, implying:

$$\textbf{Energy Gained} = \textbf{Energy Lost} \quad [4.15]$$

For the modelling at hand, the 'Energy Gained' term in equation 4.15 is the sum of the heat gains (Q's) given in figure 4.2; and the 'Energy Lost' term is the energy that the air-conditioner is to remove. From this it is clear that the air-conditioner is to remove an amount of energy (heat) equal to that supplied by the various heat loads. Thus, noting that the total building heat load is calculated in equation 4.12 and 4.13 as $\mathbf{Q_{building}}$, the cooling capacity required by an air conditioner to maintain an energy balance is:

$$\boxed{\mathbf{Q_{capacity}} = \mathbf{Q_{building}}} \quad [4.16]$$

Where $\mathbf{Q_{capacity}}$ is the cooling capacity of an air-conditioner [Btu/hr].

4.7 ENERGY UTILISATION

The building heat load will determine how "hard" the air conditioner must operate in order to keep the exchange at a predetermined temperature. More specifically, the cooling capacity [Btu/hr] required to establish an energy balance is dependant upon the building heat load. Once the cooling capacity is known, the electrical input energy to the air conditioning system can be determined using its C.O.P (Coefficient Of Performance), which is defined as [3, p. 16]:

$$\mathbf{C.O.P} = \frac{\mathbf{Useable\ Output\ Energy}}{\mathbf{Electrical\ Input\ Energy}} \qquad [4.17]$$

Grobler [23, p. 80] applies this definition to an air conditioning system; however, the units of his definition have been manipulated to suit the content of this study i.e.

$$\mathbf{C.O.P} = 0.293 \times \frac{\mathbf{Q_{capacity}}}{\mathbf{P_{aircon}}} \qquad [4.18]$$

Where $\mathbf{Q_{capacity}}$ is the cooling capacity of the air conditioner [Btu/hr], $\mathbf{P_{aircon}}$ is the power consumed by the air conditioner [W], and the coefficient is as a result of balancing units.

Most air-conditioning systems installed in exchanges throughout South Africa are centralised HVAC systems. These systems consist of two or more air-conditioning units, of which each might have a different C.O.P. With this taken into account, equation 4.19 provides the energy conversion model enabling the calculation of the power consumed by an air-conditioning system.

$$\mathbf{C.O.P} = 0.293 \times \frac{\sum_{i=1}^{n} \mathbf{Q_{capacity_i}}}{\sum_{i=1}^{n} \mathbf{P_{aircon_i}}} \qquad [4.19]$$

Where **n** is the number of air-conditioning units contained in the HVAC system.

It has been established thus far that in order to maintain an energy balance, the cooling capacity of the air conditioner ($\mathbf{Q_{capacity}}$) must equal the building heat load ($\mathbf{Q_{building}}$). It has also been established that the C.O.P is the ratio of this cooling capacity, to the electrical input energy, in this case $\mathbf{P_{aircon}}$. Therefore, from equation 4.16 the C.O.P is also:

$$\mathbf{C.O.P} = 0.293 \times \frac{\mathbf{Q_{building}}}{\mathbf{P_{aircon}}} \qquad [4.20]$$

From this, and equation 4.19 the following useful formula is constructed:

$$P_{tot\ aircon} = 0.293 \times \frac{Q_{building}}{0.293 \times \frac{\sum_{i=1}^{n} Q_{capacity_i}}{\sum_{i=1}^{n} P_{aircon_i}}} \quad [4.21]$$

or

$$P_{totaircon} = Q_{building} \times \left(\frac{\sum_{i=1}^{n} P_{aircon_i}}{\sum_{i=1}^{n} Q_{capacity_i}} \right) \quad [4.22]$$

The "Electrical Input Energy" used in the equations 4.17 and 4.18 to describe the C.O.P was defined as being *real power* (Watts). However to be more accurate, the *apparent power* (VA's) should be used. Fortunately this feature can be included into equation 4.22 using the *power factor* (the ratio between real power and the apparent power) i.e.

$$P_{totaircon} = \left(Q_{building} \times \left(\frac{\sum_{i=1}^{n} P_{aircon_i}}{\sum_{i=1}^{n} Q_{capacity_i}} \right) \right) \times pf^{-1} \quad [4.23]$$

Where $\mathbf{P_{tot\ aircon}}$ is the total power consumed by the air conditioning system [VA], $\mathbf{Q_{building}}$ is the total building heat load as given by equations 4.12 or 4.13 [Btu/hr], $\mathbf{P_{aircon\ i}}$ is the power consumed by each air conditioning unit [W], $\mathbf{Q_{capacity\ i}}$ is the cooling capacity of each air conditioning units [Btu/hr], and **pf** is the power factor of the entire air-conditioning system.

The energy utilisation of an air-conditioning system installed in a telecommunication exchange can now be completely described by the models defined by equations 4.12, 4.13, 4.16, and 4.23. Since the output of model 4.23 is dependant on models 4.12 or 4.13, the energy utilisation can be described in terms of aspects such as outdoor weather conditions, building envelope, type of building materials, lights, people and telecommunication equipment.

4.8 MODEL VERIFICATION

For the purpose of verifying the proposed energy conversion models, input values gathered from typical exchanges under normal operating conditions were obtained. More specifically two exchanges were used for this purpose; namely *case study one* (CS1) and *case study two* (CS2). For explanatory reasons, CS1 and CS2 made use of an unmanned and manned exchange respectively.

4.8.1 Case Study Details

	Description	
Detail	**Case Study 1**	**Case Study 2**
Name	Hillcrest Exchange	Bronberg Exchange
Location	Hillcrest, Pretoria	Sunnyside, Pretoria
Type	Unmanned	Manned
Audit dates	5 Oct 2000 – 6 Nov 2000	23 Jan 2001 – 31 Jan 2001
Air-conditioner type	3 x 4.8kW stand-alone units.	6 x 18.5kW chillers.
C.O.P	1.49	1.62
Power Factor	1	0.71
Wall type	8 in. common brick walls with no insulation.	12 in. concrete + 8 in. common brick with no insulation.
Outer wall area [ft^2]	2 110	5920
Office Wall area [ft^2]	-	5850
Set point [F]	70	68
Power for lighting [W]	1 430	20 000
Number of people	1	20
Degree of activity	"Seated, very light work"	"Light bench work"
Install lines	5 750	122 000

Table 4.1 Case study details

4.8.2 Verification of Models: *Case Study One*

Figure 4.4 below presents a visual comparison between the measured and simulated (using models 4.12, 4.16, and 4.23) power consumptions of the air-conditioning system installed in Hillcrest exchange. The real world values tabulated in table 4.1 were used as the inputs to the models.

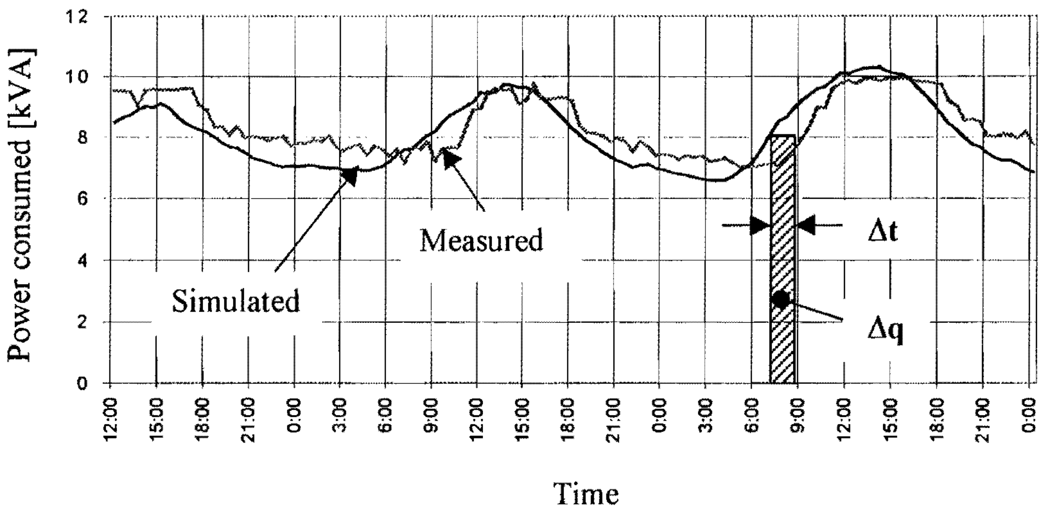


Figure 4.4 Comparison between measured and simulated air-conditioner power consumptions for two and one half days at Hillcrest

Note that the power consumed by the air-conditioners have a cycling period of one day. The reason for this is largely due to the outdoor temperature – at approximately midday the ambient temperature is usually the hottest, thereafter it gradually cools until the next morning when the temperature starts to increase again. Since the building heat load is strongly dependant on the temperature difference between the outdoor and indoor temperature (see ΔT in equation 4.12), and because the indoor temperature is to remain constant (at 70 °F), it is easy to understand that the building heat load, and hence 'power consumed' (see equation 4.23) tracks the profile of the outdoor temperature.

It is also noted in the figure that a phase-shift, which the models do not take into account exists between the simulated and measured readings because of time delays that occur in the transfer of heat through materials, such as through walls and air. Modifying an equation presented by Halliday and Resnick [49, p. 361] to suit this study, this phase-shift can be corrected by the inclusion of equation 4.24 (presented below) into the models; the formula is graphically explained in the figure.

$$\Delta t = \frac{\Delta q}{U \times A \times \Delta T} \qquad [4.24]$$

where Δt is the time delay [hours], Δq is the energy transferred during the period Δt [Btu], U is the heat transfer coefficient [Btu/hr-ft^2-F], A is the surface area [ft^2], and ΔT is the change in temperature [F].

A more detailed evaluation of the data obtained from the audit showed the results listed in table 4.2 below. Note that the percentage errors are marginal, and thus the simulated results generated by the models are a true representation of the actual, real-world process.

	Energy Consumption [kWh]	**Maximum Demand [kVA]**
Measured	6 074	9.95
Simulated	6 002	10.33
Difference [%]	1.2	3.8

Table 4.2 Comparison between measured and simulated results

4.8.3 Verification of Models: *Case Study Two*

Case study 2 was used to verify the models for a manned exchange. Bronberg exchange was used for this purpose. Once again, for verification purposes figure 4.5 is presented to provide visual confirmation that the models are a true representation of the real world. As with the case above, the values given in table 4.1 are used as the inputs to the models (in this case equations 4.13, 4.16, and 4.23). An evaluation of the data showed the results listed in table 4.3 below.

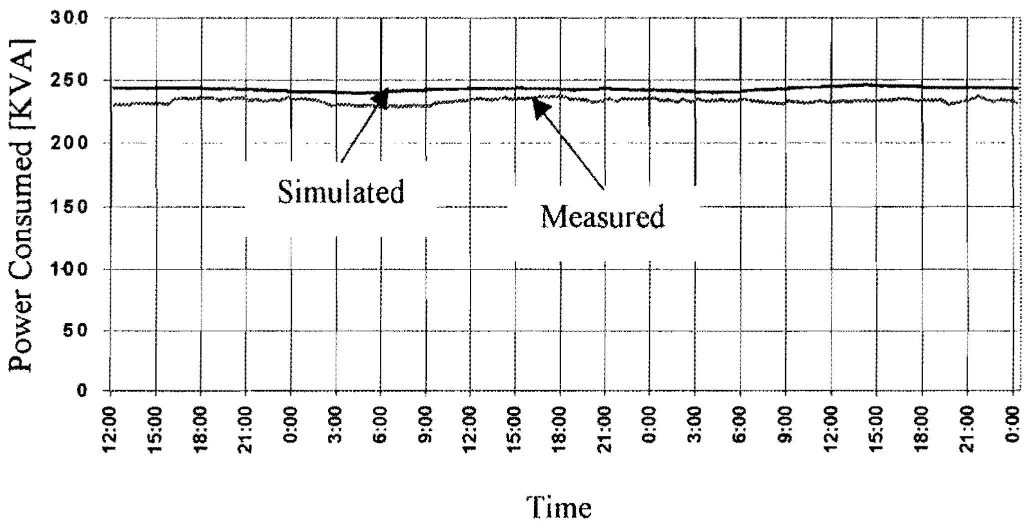


Figure 4.5 Comparison between measured and simulated air-conditioner power consumptions for two and one half days at Bronberg

	Energy Consumption [kWh]	**Maximum Demand [kVA]**
Measured	133 271	236.99
Simulated	140 837	247.96
Difference [%]	5.7	4.6

Table 4.3 Comparison between measured and simulated results

From the case studies it is clear that the proposed energy conversion models are feasible and are able to accurately predict the processes involved in cooling exchanges. It is noted that the load profiles of the simulated results are very similar to the actual (measured) profiles. However, more applicable to DSM is that the simulated results for the *energy consumption* and *maximum demand* are in the order of 5% of the actual values.

4.9 SUMMARY

The purpose of the chapter was to develop energy conversion models related to the air-conditioning equipment installed in telephone exchanges that could be used in DSM. Three areas (defined as modules at the beginning of the chapter) of the cooling process were modelled; these collectively described the relationship between *operational performances* and *energy utilisation* of the air-conditioning equipment. As such the models provide a useful tool in the implementation of Energy Management and hence DSM.

The models were verified using two typical exchanges under normal operating conditions. These two exchanges, of which one was a manned exchange and the other an unmanned exchange, formed the basis for two case studies. The results of these case studies showed that the models are extremely accurate at predicting the energy utilisation (consumption and maximum demand levels) of air-conditioning equipment.

Now that the models have been developed and verified, the next step is to illustrate the manner in which they can be used to aid the DSM process. The next chapter is focused on just this, and will clarify how the models can be used as a tool to lower the energy costs incurred as a result of the cooling process.

5. APPLICABILITY OF MODELS

5.1 INTRODUCTION

Now that models, relating the cooling process to the energy utilisation have been developed and verified, it is necessary to explain how they can be used to reduce the related energy costs i.e. what becomes important now, is to demonstrate the applicability of the models through the use of examples and illustrations.

Finon [50, p. 155] provides an explanation of the validity of models such as those developed in chapter 4: "an energy model can aid the planning activity by providing help at three stages of the energy system:

- *System behaviour*: predict system response to various inputs ('what happens if?').
- *System controllability*: manoeuvrability of the system with reference to decision-making variables ('what can be done?')
- *Policy alternatives*: generate different policy alternatives with respect to system outputs ('what shall be done?')"

To explain this, let's recap on the energy conversion models developed in chapter 4. For the purpose of simplifying matters, figure 5.1 on the next page shows the inputs and output of the complete set of models i.e. models 4.12, 4.16 and 4.23 combined. The inputs can be divided into two groups: *operational performance* and *equipment specific*. The operational performance inputs are those explained in paragraph 3.3, and specified in paragraph 4.5 as the elements affecting the building heat load (e.g. outdoor temperature, wall type, number of people etc.). The equipment specific inputs are those factors which influence the energy utilisation directly, such as C.O.P and power factor. The output of the model-set is the actual energy utilisation of the air-conditioning equipment.

From this it is clear that the energy utilisation can be determined if the operational performance and equipment specific inputs are known. Thus, by specifying one of the inputs as a variable and holding the other inputs constants, the effects of manipulating this input on the energy utilisation can be observed enabling system behaviour and controllability to be forecast, as well as alternatives to be sought.

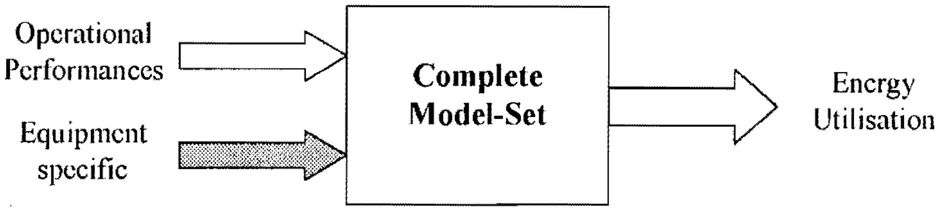


Figure 5.1 Inputs and output to the complete model-set

5.2 REQUIRED COOLING CAPACITY

Equations 4.12 and 4.16 provide the tool for calculating the cooling capacity required by an air-conditioning system to maintain a specified temperature set point. As such they enable the correct "size" air-conditioner to be calculated for a specific exchange. As an example consider Hillcrest exchange, with inputs as specified in table 4.1. The "total building heat load" (as specified by equation 4.12) is plotted in figure 5.2 below for a period of one day.

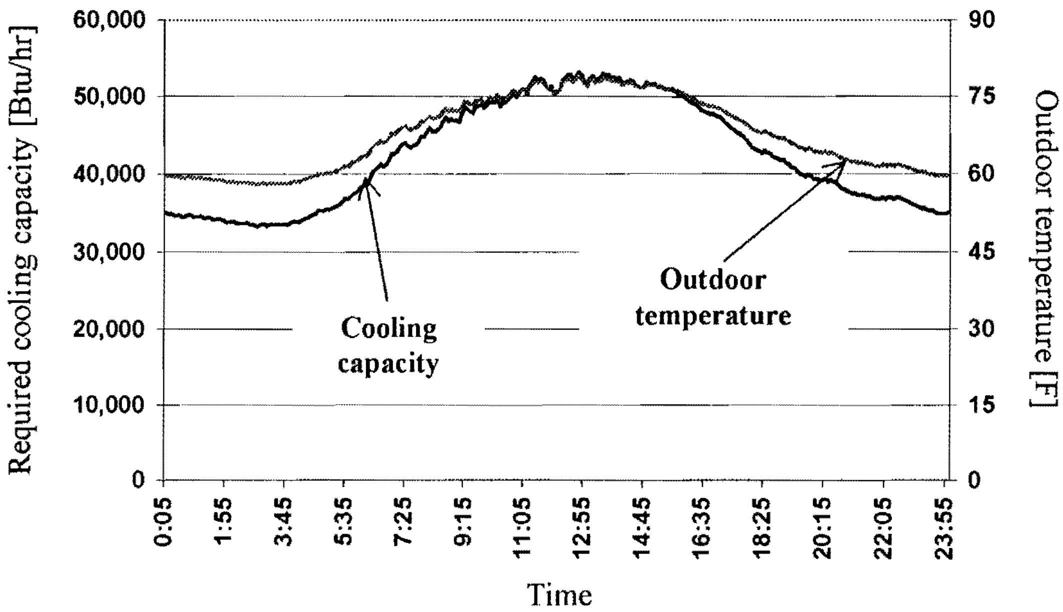


Figure 5.2 Required cooling capacity to maintain a constant temperature of 70 F (21 °C) at Hillcrest exchange for a period of one day

As a result of the ΔT term (which is the outdoor temperature (T_{Out}) minus the indoor temperature (T_{Exh})), the required cooling capacity follows the basic profile of the outdoor temperature. Since the indoor temperature is in fact the temperature set point (in this case 70 F) and is assumed to remain absolutely constant, and because the other terms in the equation are also fixed constants, it is clear that the cooling capacity will follow the outdoor temperature.

With the ability to plot graphs such as these, the applicability of the first two models becomes apparent – by specifying the required inputs to the models, the correct "size" air-conditioner can be determined by observing the maximum "required cooling capacity". That is, if an exchange is to be erected in a certain part of the country (with a particular climate), the required cooling capacity can be determined by specifying the appropriate inputs i.e. outdoor and set point temperature; number of installed telephone lines; number of lights; wall and ceiling type etc.

At this point it is important to qualify the phrase, "correct size air-conditioner", used above. That is, the air-conditioner's cooling capacity can be optimal for two very different objectives i.e. it can either be sized to meet operational specification, or to optimise energy costs. Finding the required cooling capacity for the former criteria is rather simple once graphs such as figure 5.2 can be plotted – by specifying the extreme conditions the exchange will be subject to, the peak "required cooling capacity" can be read off the graph, which in turn will be the required "size" to meet operational performance (i.e. temperature set point). In other words, this method calculates the absolute minimum "size" air-conditioner needed to maintain a specified temperature set point.

Calculating the cooling capacity for the latter criterion is not as simple. Sizing the equipment to optimise the energy costs involves a process known as TES (*Thermal Energy Storage*). This entails cooling the exchange below normal operating temperature during the cooler portions of the day (night and early morning). As a result, less cooling is need during the warms periods (daytime) since the air and equipment contained in the building, as well as the walls and floors, have "stored" this low temperature. This in turn enables reducing the air-conditioner's energy consumption during peak periods, and also lower maximum demand costs. Obviously, because lower temperatures are required, this type of cooling requires a larger cooling capacity than the previous scenario.

Thermal energy storage is however a large topic on its own and will not be focussed upon in this study, and as such will not form part of the literature to follow. It will be assumed that the air-conditioning equipment is "sized" to exactly meet operational specification.

5.3 INPUT MANIPULATION

Consider for the moment the effects of manipulating the exchange's temperature set point. If the set point is set as a variable and the other inputs to the models are held constant, the effects of altering the indoor temperature can be observed. This is accomplished by noting that the ΔT term in equation 4.12 is the outdoor temperature (T_{Out}) minus the indoor temperature (T_{Exh}), which is in fact the temperature set point.

Using equation 4.23, figure 5.3 on the next page shows load profiles of Hillcrest exchange's air-conditioning system for various set point values. Note that as the set point is increased, the power consumption decreases; this makes sense since the air-conditioners do not have to work as "hard". A value-added feature of these models is that they can also illustrate when heating instead of cooling is required – note that when the temperature set point is adjusted high enough, the power consumed becomes negative for certain times of the day (see before t_1 and after t_2). Although it is not possible for the air-conditioners to consume negative power, these "negative" regions do illustrate where heating instead of cooling is required.

This concept is easily conceptualised: if the temperature set point is set relatively low, the outdoor temperature is warm enough to enable ΔT to be positive for all times of the day. If the set point is now increased, there might be certain times of the day when the outdoor temperature is cooler than the indoor temperature; for these periods the ΔT term will be negative (implying heat is flowing out of the exchange). However, because of the additional terms in the equation (which are independent of temperature), this does not necessarily translate into a "negative power consumption". If the set point is now increased even further, the times when the outdoor temperature is cooler than the set point temperature will increase; this then carries more weight and as a result eventually causes the building heat load to be negative, which with the use of equation 4.23 translates into a "negative power consumption" for certain periods of the day.

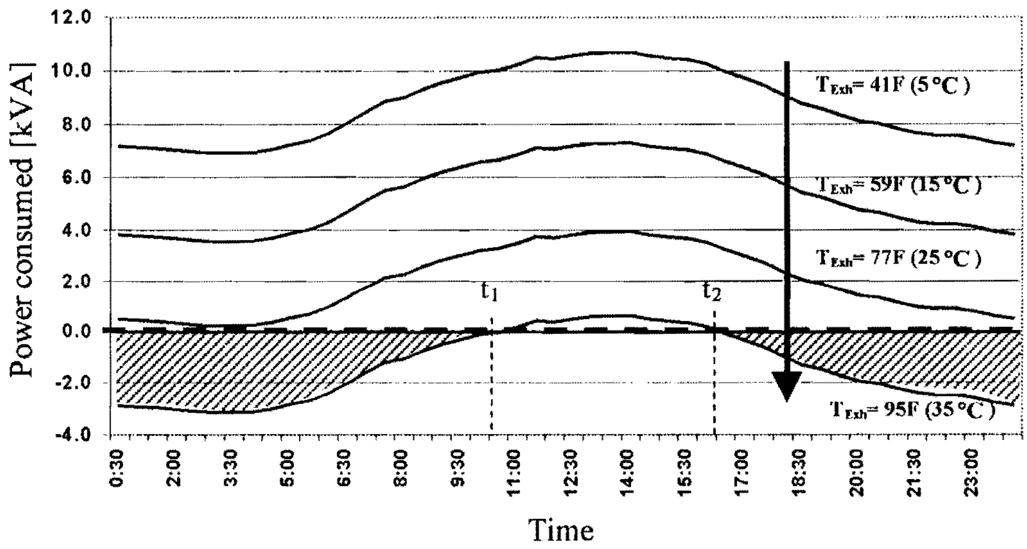


Figure 5.3 Load profile of the air-conditioning equipment versus temperature set point for a period of one day

By specifying other inputs (other than temperature set point) as variables, similar graphs as that shown above can be plotted. That is, load profiles for the air-conditioning equipment can be plotted as a function of inputs such as the number of people (personnel); power consumed for lighting; number of telephone lines; infiltration of air through doors and windows; wall and ceiling type, C.O.P, power factor etc.

It was mentioned in chapter 2 that two important quantities could be read from a load profile i.e. *energy consumption* and *maximum demand*. Thus from the load profiles that can be plotted using inputs as those mentioned above, the effects on the energy consumption can be observed. As an example consider figure 5.4 showing the air-conditioner's energy consumption versus the number of telephone lines installed in Hillcrest exchange. It was mentioned in the opening paragraphs and in the derivation of the models that most of the energy used by the telecommunication equipment is in fact converted directly into heat.

Hence, as the number of installed telephone lines is increased, so is the air-conditioner's energy consumption.

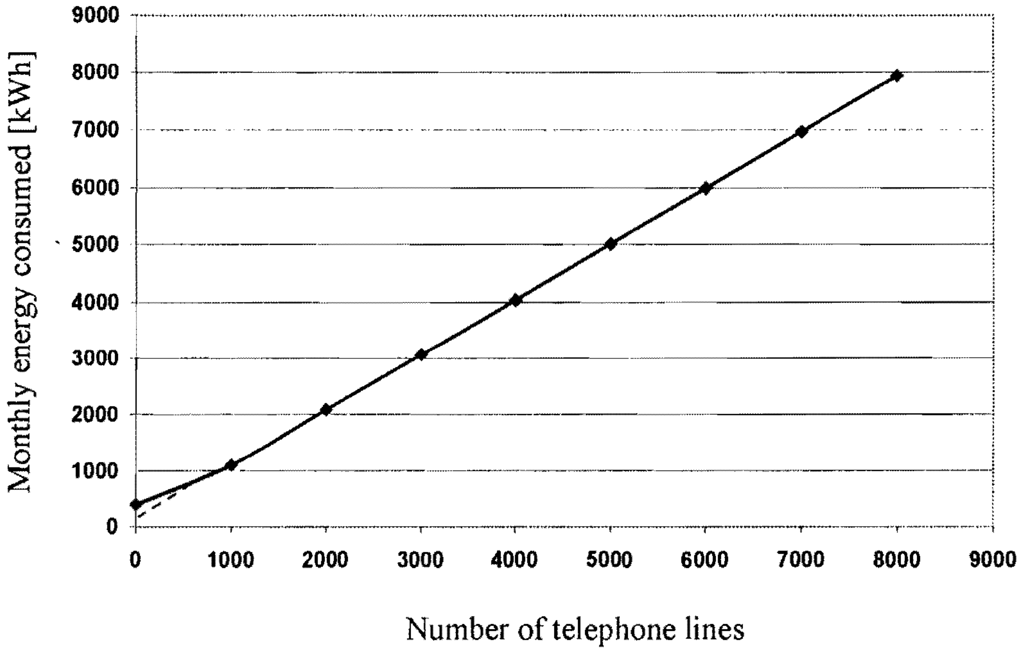


Figure 5.4 Monthly energy consumed by the air-conditioning equipment versus the number of installed telephone lines

Upon close inspection, it is noted that the gradient of the curve from 0 to 1000 lines, and 1000 to 8000 lines is different. The reason for this difference is that telephone lines contribute a large portion to the heat load; with less than 1000 installed lines a lot of heat is "lost" (as compared to 8000 lines) and when the outdoor temperature drops below the set point temperature at certain times of the day, insufficient heat is generated to maintain a constant indoor temperature. In this case additional heat needs to be generated by heating equipment. However the models do not take this equipment into account, and as a result the output of the models is equated to zero whenever there is a tendency for a "negative power consumption".

Graphs similar to figure 5.4 but with different input manipulations can be seen in addendum C. The reason for presenting them there is that there are far too many derivatives to be included in this study. Thus for the moment only the two examples provided above will suffice. None-the-less these do illustrate how the models can provide valuable information regarding the cooling of exchanges, but more importantly how manipulating certain key inputs can affect the air-conditioner's energy utilisation.

5.4 INTERACTION WITH TARIFFS

The most important aspect of having a tool such as the models presented in chapter 4 for energy management is that they can be used in economic analysis. With the aid of tariff structures the output of the model set (i.e. energy utilisation) can be translated into energy costs, and hence aid in the reduction of the electricity bill at the end of the month.

In paragraph 2.2.2 two tariffs structures were discussed, from these generic structures three derivatives have been implemented by Eskom (South Africa's utility supplier) i.e. *Nightsave*, *Miniflex*, and *Megaflex*. Due to specific criteria which have to be met, Telkom's exchanges can only be placed on either Nightsave or Miniflex. The costs associated with these tariffs are:

- Apart from a basic charge, monthly rental, voltage discount and transmission percentage surcharge, **Nightsave** charges customers for the total energy used per month, as well as a maximum demand charge for either kW or kVA integrated over a 30 minute period. The maximum demand charge for Nightsave is only applicable between 06:00 and 22:00 on weekdays.
- Customers using the **Miniflex** tariff are subject to a basic charge, monthly rental, reactive energy charge, voltage discount and transmission percentage surcharge. In addition they have to pay an active energy charge but no maximum demand (MD) charge. The main difference between Miniflex and Nightsave is that the energy cost varies on a daily time of use; these costs also vary according to two, yearly intervals i.e. *High Demand* (June – August) and *Low Demand* (September – May).

Using these tariffs it is possible to determine the air-conditioning system's monthly contribution towards the electricity bill by making use of the output of the model-set. That is, from the power versus time graphs (load profiles) that can be plotted (such as figure 5.3), it is possible to obtain the necessary information for the two tariffs i.e. active energy consumptions [kWh]; and the air-conditioner's contribution towards the maximum demand (MD) [kVA].

Consider for the moment the previous example explained in paragraph 5.3, where the number of telephone lines is adjusted. For this scenario, figure 5.5 below shows the air-conditioner's monthly contribution towards the electricity bill as a result of either Nightsave or Miniflex. **Note: all costs provided are exclusive of VAT, and are based on Eskom's 2001 tariff rates.*

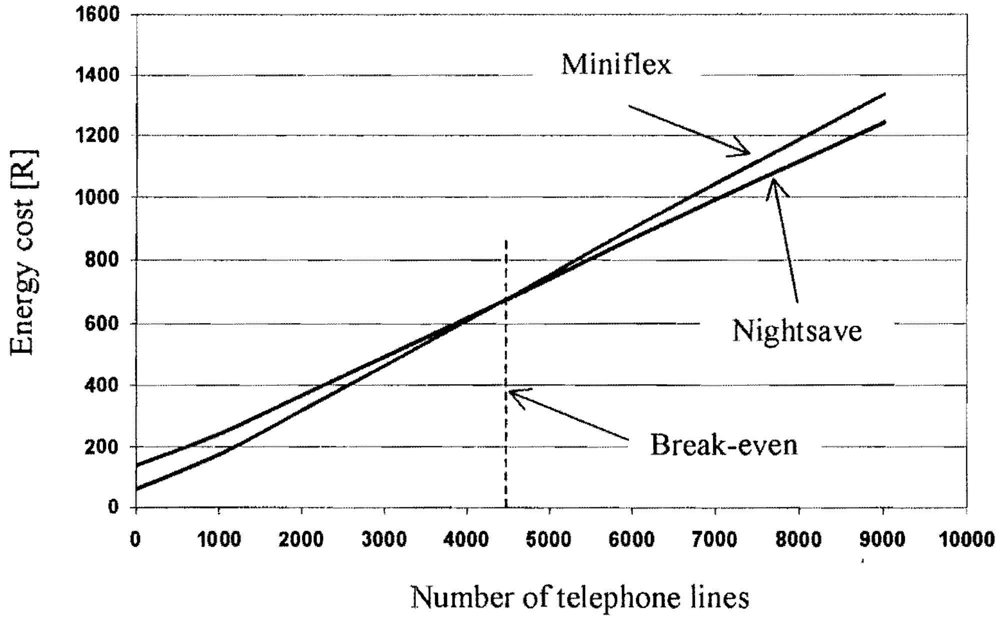


Figure 5.5 Air-conditioner's monthly energy cost contribution versus number of installed telephone lines

For illustrative purposes, a number of important aspects can be observed from a graph such as this. Firstly, it is clear that as more telephone lines are installed, the higher the energy cost will be as a result of the air-conditioner system having to work "harder". Secondly, the break-even point (if one exists) can be determined i.e. where the cost incurred as a result of Miniflex is the same as Nightsave. Thirdly, the rate at which the energy cost increases can be calculated for a specified billing tariff e.g. in this case it is R145 per additional one thousand lines per month on Miniflex, and R125 on Nightsave. Table 5.1 on the next page shows the rate at which energy cost increase as other operational performance inputs are increased.

	ENERGY COST RATE OF INCREASE PER MONTH							
	Hillcrest Exchange				Bronberg Exchange			
	Rand per Fahrenheit (T_{Exh})	Rand per 1000 Lines	Rand per person	Rand per 1000W for lighting	Rand per Fahrenheit (T_{Exh})	Rand per 1000 Lines	Rand per person	Rand per 1000W for lighting
Miniflex	-21	145	9	73	-75	135	12	67
Nightsave	-17	125	8	63	-76	136	12	68

Table 5.1 Energy cost rate of increase as a result of input manipulation

It is important to note that the '*Rand per person*' values are calculated assuming the exchanges are occupied 24 hours a day (this is the assumption used in the development of the models). Similarly, it is also assumed that the lights are on 24 hours a day. Note also that the '*Rand per Fahrenheit*' values have a negative sign because of the energy cost decreasing as the set point temperature is increased (see figure 5.3); all other values are positive because the cost increases as the variable is increased.

The above discussion was presented to explain the effects of manipulating the *operational performance* inputs, now for the first time the effects of manipulating the *equipment specific* inputs are discussed. Figure 5.6 on the next page illustrates how the monthly energy cost contribution is affected as the equipment's C.O.P is varied. In addition, figure 5.7 is presented to demonstrate how the system's power factor affects the energy cost.

Note that as the C.O.P of the air-conditioning equipment is decreased, the energy cost increases exponentially for both Miniflex and Nightsave. In terms of energy costs, it thus makes sense to have a system with a C.O.P as large as possible. Figure 5.7 illustrates that the energy cost is affected differently for Miniflex and Nightsave as the power factor is varied. This is because Nightsave, which has a MD charge, is strongly dependant on the apparent power (kVA's), and thus power factor i.e. as the power factor decreases, so the apparent power increases. Although Miniflex does not charge for MD, it still has a dependence on power factor in that the tariff imposes a *reactive energy charge*. This charges customers for the portion of the reactive energy (kvarh) consumed in excess of 30% of the active energy (kWh) consumed – this occurs at a power factor of 0.96. For both tariffs it is obvious that a power factor tending towards unity is desired.

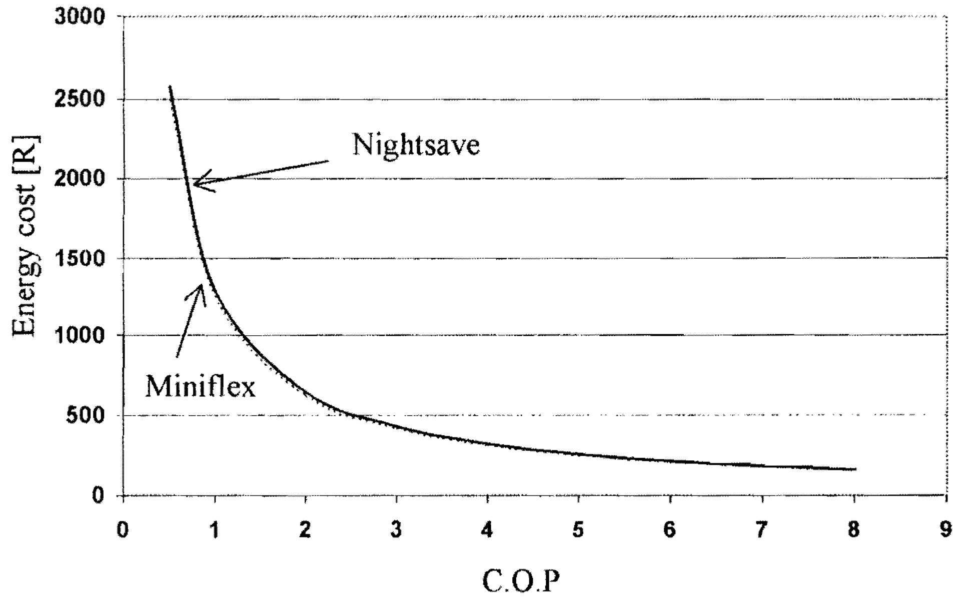


Figure 5.6 Energy cost versus C.O.P for Hillcrest exchange

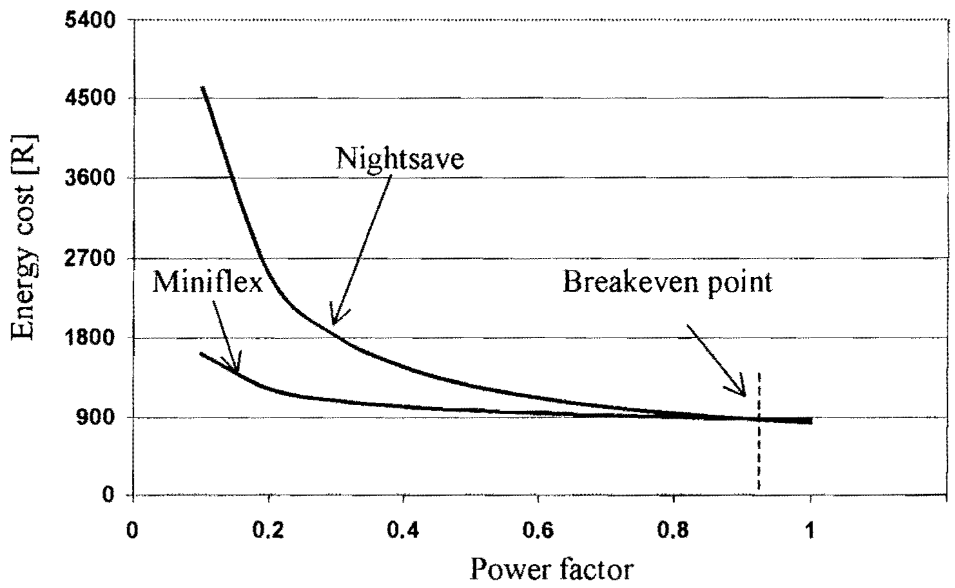


Figure 5.7 Energy cost versus power factor for Hillcrest exchange

5.5 ENERGY COST REDUCTION

The previous paragraphs explained how the energy utilisation and energy costs are affected by manipulating the operational performance and equipment specific inputs. However the discussions neglected to explicitly mention how energy cost savings could be implemented as a result. Cost savings can be realised in the following four ways: improved operational performance, improved equipment performance, correct tariff selection, and scheduling.

5.5.1 Operational Performance

From the examples presented previously, it is clear that energy costs savings can be forecasted by altering the operational performance inputs to the models. That is, by manipulating aspects such as temperature set point, wattage used for lighting, number of people, number of telephone lines, thermal insulation of walls and ceilings, and air infiltration through doors and windows, it is possible to arrive at a situation where maximum savings are realised.

As an example, consider the effects of personnel occupying Bronberg exchange. Assuming there are usually 40 employees working in the exchange, from table 5.1 it can be calculated that the air-conditioner's energy cost, as a result of people, is in the order of R480 per month. If a decision was made to relocate 20 of these employees out of the exchange, cost savings of approximately R240 could be realised. Although this does not seem much, if one considers that there are over 3600 exchanges situated countrywide, it is clear that this can translate into a rather large figure.

As another example, consider the temperature set point policy of the company – at present the guideline is to have the exchanges operate at 68 F (20°C). If however this is changed to say 95 F (35°C), which is still well within the ETSI 300-019-1-3 temperature specifications (see figure 1.2), Bronberg exchange can realise a cost saving of approximately R1 125 per month (which is approximately 3.2% of the electricity bill). Obviously, with the set point adjusted to this level, it would be impossible to have any personnel working in the exchange; meaning even more of a cost reduction can be realised (see previous example). If however mandatory work was needed (e.g. maintenance and/or repair), the set point could be lowered and thereafter raised again.

From the various operational performance inputs, it is clear that there are numerous ways of lowering the energy cost. Due to constraints however, only the above two examples will be discussed. These do however illustrate the applicability of the models for lowering the energy cost.

5.5.2 Equipment Specific

Large energy savings can also be achieved through improvement to the air-conditioning equipment itself. However, unlike the savings that can be realised through operational performance manipulation, this usually is accompanied by an initial capital outlay e.g. upgrading of equipment, improved maintenance etc. A financial decision thus has to be made as to the viability of the investment. Fortunately, a tool, in the form of the models presented in chapter 4 exists, which can provide great assistance in making a calculated decision.

For example, consider purchasing a new air-conditioning system for Bronberg exchange. The new system is to have an improved C.O.P of 2.00, as compared to the old system, which had a C.O.P of 1.62. An energy cost saving of R3,548 and R3,631 (roughly 10% of the electricity account) can be realised on Miniflex and Nightsave respectively. With this amount known, aspects such as payback period and cost budgeting can be calculated – providing valuable investment information. A similar discussion can be made when considering improving the system's power factor.

5.5.3 Tariff Selection

An additional way in which the models can be used to lower the energy cost is their ability to aid in the selection of an appropriate tariff structure. To completely understand this process recall figure 3.3 – once the operational performance and equipment specific inputs have been optimised through DSM activities, the tariff structure that will result in the least cost alternative can be selected.

To illustrate this concept, consider the effects of the number of installed telephone lines on the energy cost (figure 5.5). In the example a "break-even" point was illustrated – before and after this point the energy cost varied depending on the selected tariff. As a result, at certain points it would be more cost effective to be placed on a particular tariff i.e. in this example, at all points before the breakeven point it would be better be billed on Nightsave, all points after the breakeven point it would be financially more viable to be on Miniflex.

5.5.4 Scheduling

Massive energy cost savings can also be realised if TES (Thermal Energy Storage) is used. However, as mention in paragraph 5.2, because it is a new field and such a vast subject, an independent study needs to be conducted. None-the-less, a brief description of how this concept can be used to minimise energy costs is presented here.

For explanatory reasons a hypothetical time-line showing the various billing rates in a 24-hour day is presented in figure 5.8 on the next page. Included above this time-line is a diagram illustrating the process of TES and how the temperatures, and hence energy utilisation, are affected as a result. Note that, as mentioned before, TES requires that the building structure be cooled below "normal" operating temperature during the cooler periods of the day. Hence the air-conditioner is to operate (depending on its capacity) at full load. In terms of energy costs this does not matter because it is during the off-peak periods. Come peak periods (06h00 – 07h30 and 17h00 – 19h30), the air-conditioner can be completely switched off since the stored "cool energy" will keep the exchange within temperature specification (i.e. 41 F (5°C) to 113 F (45°C)). This then enables energy cost reductions to be realised through maximum demand (MD) reduction, and possible energy consumption reduction.

From this it is clear that there are two fundamental aspects that needed to determined in order to implement TES: (1) to what level should the temperature be dropped during the off-peak and standard periods, so as to prevent the temperature exceeding the upper bounds of the temperature specification when the air-conditioner is switched off during the peak periods, and (2) what will the optimal size air-conditioner be to implement TES successfully.

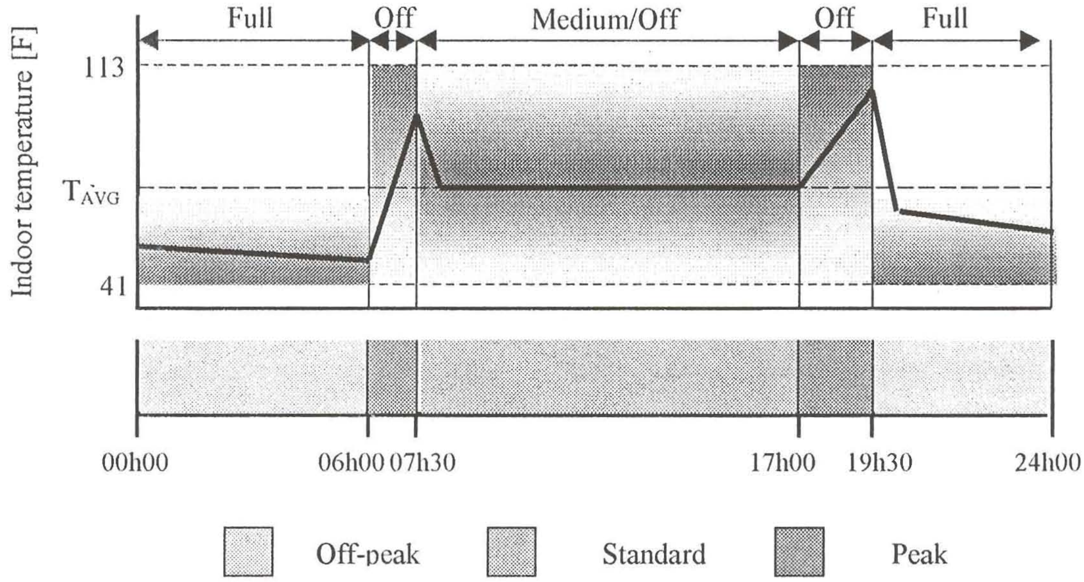


Figure 5.8 Reducing energy costs using TES

5.6 SUMMARY

The chapter was used for the purpose of illustrating the applicability of the energy conversion models developed in chapter 4. As such it described how the models could be used to (1) determine the required cooling capacity, and hence "size" air-conditioning equipment for a particular exchange, and (2) forecast energy requirements as well as the air-conditioner's monthly energy cost contributions towards the electricity bill.

In so doing, the chapter explained how energy cost reductions could be realised through manipulation of the operational performance and equipment specific inputs. For this to be explained it was necessary to discuss the two tariff structures available to Telkom i.e. Miniflex and Nightsave. These were then used in the energy cost savings analysis and hence quantified the effects of altering certain elements affecting the energy utilisation. Finally, specific target areas were discussed where energy costs savings could be realised i.e. operational performances, equipment specific, tariff selection, and scheduling.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS ON OBJECTIVES

6.1.1 Conducting This Study

From the studied literature it was determined that there is certainly large scope for the development of Energy Management in the telecommunication environment. It was observed that most telecom companies have implemented *energy conservation* with the objective of lowering energy costs, however it was noted the conservation techniques do not necessarily translate into savings. This study thus focused on implementing *energy management* in its truest form i.e. "the process of optimising the energy consumption to reduce the energy costs".

Further studies revealed that there was a lack of information relating telecommunications, HVAC, and energy costs. In addition, case studies presented supporting data to suggest that investigation into this relationship was necessary. As such, the technical portion of the dissertation concentrated on developing energy conversion models relating the cooling of telephone exchanges to energy costs. Due to the scope of the study, these models were developed with a strong emphasis placed on the "energy management" concept.

As a whole, the study was strongly motivated by the lack of necessary information, which is essential to Telkom if it wishes to streamline its operation and hopefully be strong competition to other prospective companies wishing to enter the country in the near future. As such, the study will have a substantial impact on the company's strive to become an efficient operator, and hence provide its customers with the best quality of service possible.

6.1.2 The Energy Management Programme

The foundation for the study was the construction of an *Energy Management Programme*. Although this programme is, as of yet, not an official policy of the company, it did provide the pivotal drive for the continuation of the study. The programme was developed using the energy policies of the University of Pretoria and AT&T, which provided the intricacy, and specification for the development of "Telkom's Energy Policy".

It was discovered that if such a programme were not presented, the study would have been ambiguous and unfocussed. As such, it formed the basis, providing direction and scope for the research. In addition to this, the programme (and hence the work conducted in this dissertation as a result) was not merely presented for the purpose of the study, but was, and is intended to be an official policy for the implementation of energy management in the company. That is, the research conducted here within is not merely yet another hypothetical and/or theoretical study, but has definite practical (real-world) applicability.

The programme was developed with a holistic view of the company taken into account i.e. in context of the organisational hierarchy, the primary objective of the policy was focussed on implementing energy management on an *organisational level* (see figure 3.1). From this, more specific, narrowed down objectives can be drawn up, from which more specialised implementation of energy management can be carried out. Thus, the programme presented is intended to be the starting point to the introduction of the management of energy in the company.

Concluding the specific objective: An *energy policy* was presented that will provide the structure needed to implement energy management in Telkom. An *energy policy strategy* was also presented to provide a method of fulfilling the objectives of the policy. To obtain a better understanding of the energy utilisation and hence implementation of the management of energy in the company, *energy audits* were conducted at selected exchanges, which enabled a *diagnosis* of the utilisation.

6.1.3 Energy Efficiency

Following the guidelines of the programme, an investigation into the energy efficiency of the company was conducted. The results showed that telephone exchanges were operating in an extremely inefficient manner, especially when compared to other telecommunication companies around the world. This prompted the development of an *Energy Efficiency Evaluation Tool* in the form of energy norms.

Although not explicitly stated, it was illustrated that the tool has four inherent functions: (1) it is used as an energy efficiency evaluator – indicating whether an exchange and/or the various energy end-users are operating in an efficient manner, (2) it enables inefficiency to be pinpointed i.e. equipment causing an energy wasteful environment can now be located, (3) benchmarks can be established form which standards for the equipment, and the exchanges themselves can be determined, and (4) exchanges can be classified according to energy utilisation e.g. manned or unmanned exchanges; small, medium or large installation etc.

The investigation into the energy efficiency also provided important information related to the energy distribution in an exchange i.e. it was discovered that three major electricity end-users could be identified: HVAC, rectifiers (supplying the telecommunication equipment), and logistical equipment. From measurement audits conducted, it was determined that the HVAC equipment tends to consume the bulk of the energy i.e. 55% of the total building load (see table 2.1). It was also reported that, as compared to other telecom companies, this is an exorbitant amount of energy to be used merely for space cooling. From this, and the fact that HVAC generally tends to present the most energy saving opportunities, it was deduced that the remainder of the study should focus on this process.

Concluding the specific objective: *Energy norms* related to the processes involved in telecommunication exchanges, and the exchanges themselves were presented in an evaluation tool. This then enabled exchanges to be classified as either *manned* or *unmanned* i.e. where the former contains telecommunication equipment and office space with human activity, and the latter only has telecommunication equipment and no office space.

6.1.4 HVAC Model Development Methodology

It was discovered that in order to explain the context in which the models, relating the process of HVAC to energy costs were to be developed, an appropriate modelling methodology had to be formulated. For this reason figure 3.1 was constructed to provide insight into the "global" framework for the development of the models. As such, it illustrated that the organisational hierarchy, and hence managerial aspects have a direct influence on the modelling to be done. This was then zoomed in on, and showed that *operational performances* (elements affecting the HVAC process) have a definite influence on the energy costs – see figure 3.2.

With the above in mind, a flow diagram (figure 3.3) was developed to incorporate all aspects affecting the energy utilisation, and hence energy cost of the air-conditioning equipment. From this, it can be concluded that both managerial and operational aspects have a direct influence on the minimisation of energy costs. That is, Demand-Side Management (DSM), tariff selection, as well as the operational performances all have an effect on the electricity bill at the end of the month.

An analysis of various modelling strategies revealed that the "Building Block" approach would be the most appropriate methodology for the development of the models. For the modelling at hand, it was discovered that using this methodology provided ease of construction but most importantly, retained model versatility, which is important when developing a tool that is to be used in energy management.

As the name suggests the models were to be developed using "building blocks", the output of one block being the input to another. Construction of the models in this manner proved to have a number of benefits: (1) it enables experts in a particular field to use a "block" (model) relevant to his/her field of study, (2) the models themselves are not complex, and enabled quick calculation, and (3) integrity of the models are maintained i.e. they can be integrated into other model sets and hence be used in conjunction with other studies.

Concluding the specific objective: Not only was a *modelling methodology* selected for the development of the energy conversion models, but the context in which they were to be developed was also explained. The "building block" approach, as mentioned above, proved to be very efficient for the purpose for which it was intended.

6.1.5 HVAC Model Development

Following the methodology, the construction of the models proved to be relatively simple. In all, three "building blocks" were constructed. Combined, these "blocks" enable the elements that affect the heat load (i.e. Btu/hr) to be translated into electrical energy utilised by the air-conditioning equipment (i.e. kWh and kVA); hence the term, "energy conversion model". The three models enable the calculation of (1) the *total building heat load*, which is the total heat gained by an exchange, (2) the *required cooling capacity* an air-conditioner needs when installed in a particular exchange, and (3) the *energy and power* utilised by the equipment (i.e. kWh and kVA) to maintain a constant temperature set point.

From the model set it is determined that the total heat load to a typical exchange is dependent on six *heat gain elements*: (1) temperature difference between outdoor (ambient) temperature and the indoor (set point) temperature, (2) conduction through walls and ceiling, and hence also thermal resistances of these structures, (3) heat gained due to infiltration of air, (4) heat gained due to lights, (5) heat gained due to people and their respective "degree of activity", and (6) heat gained due to the telecommunication equipment itself. Since there is direct proportional relationship between the total building heat load and the required cooling capacity (equation 4.16), it is also noted that the air-conditioning equipment's "size" is also dependent on these same six elements.

Being able to calculate the air-conditioner's required cooling capacity as a function of these elements, provides an extremely useful tool – it can be used for (1) checking if presently installed equipment is adequately sized for a particular exchange, (2) sizing equipment (for newly built exchange), (3) retrofitting, and (4) forecast equipment "size" (e.g. what capacity air-conditioner will be needed if an additional 5 000 lines are installed?)

The final " building block" (model) was developed using *equipment specific* information (i.e. C.O.P and power factor) to relate the required cooling capacity to the energy utilisation. The model was constructed in such a way that these could also be used as variables, and hence also occur as inputs to the model set. This enhances the applicability of the models since there is now greater versatility, and as such provides a very powerful tool for implementing energy management.

Concluding the specific objective: Energy conversion models were developed that enable redesigning, retrofitting and implementation of air-conditioning equipment in telephone exchanges. They also aid with understanding the effects of manipulating the elements that contribute to the heat load. In addition the models proved that they could be used to set up cost-effective energy configurations, schedules and tariffs.

6.1.6 Model Verification

In retrospect, the context in which the models were developed, as well as the construction of the models using the methodology, proved to be viable options. This conclusion is drawn from the fact that the data obtained from case studies compared closely to the theoretical results obtained from the models i.e. the simulated power and energy values (calculated by the models), for both manned and unmanned exchanges, was in the order of 5% of the actual measured values (95% accuracy). As such the models are a true representation of the real-world process and can be used to closely predict the energy and power utilised.

6.1.7 Applicability of Model Set

It was discovered that the models presented a number of useful functions – not only do they provide reliable information for which they were intended, they also offer insightful information into the process of cooling exchanges. As such, it is noted here that the models have immense applicability, not only for energy management (for which they were intended) but also for fields other than this. That is, the methodology used to construct the models, enables them to be used in applications such as management, financial analysis, building design, HVAC equipment design, and also in future research fields such as TES (Thermal Energy Storage).

As a reminder, it is noted that the models were intended for three specific objectives: to calculate (1) the *total building heat load* of a specific exchange, (2) the air-conditioning equipments' *required cooling capacity* to maintain a specified temperature set point, and (3) the *energy utilisation* (active, reactive and apparent power/energy) of the equipment.

Models 4.12 and 4.13 are used to calculate the total building heat load for a manned and unmanned exchange respectively. The results obtained using specifications of the two case studies (Hillcrest and Bronberg exchange) revealed that the building heat load has a cycling period of one day, and thus has a repetitive profile. From this and model 4.16, the cooling capacity required by the equipment to maintain a fixed temperature set point can be calculated (see figure 5.2). Being able to simulate graphs such as this has enormous implications – cooling capacities (and thus equipment size) can be anticipated for exchanges that already exist, and that still need to be built. This enables management to do forecasting, and can thus project budget costs, capital outlays and payback periods.

The last model, model 4.23, is the pivotal link between the cooling of exchanges and energy management. That is, it places an extra dimension to the context for which the models were intended – being able to calculate the energy utilisation as a function of the *total building heat load*, and hence elements that supply heat, the management of energy can be carried out rather effectively. It is now possible to determine the effects of manipulating aspects such as temperature differences, wall and ceiling types, lighting, personnel, and telephone lines on the energy utilisation. In addition the model incorporates two *equipment specific* elements, which also have a pronounced effect on the energy utilisation. In all, the models provide a complete package for projecting, forecasting and calculating energy usage of air-conditioning equipment as a function of the elements that necessitate the need for the equipment.

With energy and power values available, cost analysis of the equipment can be conducted through the introduction of tariffs. This completed the "energy management tool" that was a subsidiary of the primary objective of this study. The Rand amount it would costs to alter a particular element affecting the cooling of an exchange can now be calculated. As such it enables a diversity of energy cost reduction techniques in the form of (1) altering operational performances, (2) improving equipment specific performances, (3) selecting the correct tariff, and (4) imposing an optimal operating schedule.

It is noted that from the examples and illustrations presented in the previous chapter that definite energy cost savings can be realised if certain alterations to the operational performances are made, such as increasing the temperature set point or decreasing the number of lights. Energy costs can also be drastically lowered if the power factor and C.O.P are increased. In addition, it was also illustrated that different tariffs result in different energy costs; thus by selecting the appropriate tariff, energy costs can also be lowered.

In conclusion, the models developed do indeed provide a useful "energy management tool", and as such present an alternative method for lowering energy costs of air-conditioning equipment. In all, the model-set goes a long way to improving the efficiency of telephone exchanges and the company as a whole.

Concluding the specific objective: A simulation package implementing the models was constructed to illustrate the effects of altering certain operating conditions. As such this enables cost effective energy configurations to be set up for specific scenarios. The models proved to have great applicability in lowering energy costs of the air-conditioning equipment.

6.2 RECOMMENDATIONS ON SPECIFIC OBJECTIVES

6.2.1 The Energy Management Programme

First and foremost, for Telkom to manage its energy effectively it will be necessary for the company to draw up an official energy policy, in which the Energy Management

Programme is laid out. Only once this has been done, can the organization begin to make use of its energy sources and resources responsibly.

6.2.2 Energy Efficiency

Making use of the *Energy Efficiency Evaluation Tool*, it is recommended that every exchange (of which there are approximately 3600) be evaluated so that an overall picture can be obtained. Utilising the norms presented in the tool, statistical data can be retrieved, from which the energy efficiency of the various end-users and the exchanges themselves can be analysed. This will indicate, as a whole, where primary attention should be paid and where improvements are to be implemented. These could be managerial and/or operational amendments.

Further studies are to be made into calculating actual benchmarks for the norms presented in the tool. The statistical data obtained from a complete audit (as mentioned above) will provide valuable data with regards to this; however further more in-depth studies are required to come to an explicit solution. Once such benchmarks have been determined, currently utilised exchanges, and exchanges still to be built can be optimised using these figures, going a long way to improving the energy efficiency of exchanges as a whole.

6.2.3 HVAC Model Development

Although the models conclusively describe the relationship between the cooling of exchanges to energy costs, there is one concept that was not explicitly covered. Thermal Energy Storage is slowly starting to gain interest, promising to be a viable method of minimising the energy consumption and demand. Since this is a relatively new topic, there is certainly vast scope for research in the field.

There are essentially two variations of TES – thermal storage of the building, and thermal storage of the air-conditioning plant itself. The former method involves lowering the temperature of the building structures (e.g. walls, floors, doors, equipment etc.) below the usual operating temperature, so that at peak-demand times the air-conditioner can be switched off, and hence lower energy cost. The latter process involves utilising storage tanks (e.g. water tanks) to store energy – water is cooled during the low-demand periods of the day, which is then used to cool the building interior during peak-periods.

Combining this process to the models developed in chapter 4 has two aspects which have to be considered. Firstly, the air-conditioner's cooling capacity has to be revised – obviously to lower the building structures below normal operating temperature, a system with a larger cooling capacity is necessary. The question is, what is the optimal required cooling capacity? Secondly the correct operating schedule has to be determined i.e. with various billing periods, an optimal operating schedule exists.

6.2.4 Applicability Of Model Set

In the chapter covering the applicability of the model, a number of examples and illustrations were presented. These illustrated how the energy utilisation was affected as the operational performance and equipment specific inputs were manipulated. This was then combined with two tariff structures, namely Nightsave and Miniflex. The examples presented, showed that for different conditions, one of the tariffs resulted in a lower cost than the other. As such, it is recommended that the models be applied to all exchanges so that the most cost-effective tariff can be selected for a particular exchange.

In addition to this, the models are also to be applied to exchanges so that the best operational performance for a particular exchange can be achieved. For example, removing unnecessary lights, ensuring doors are left closed so as to reduce infiltration, place insulating material on walls to increase thermal resistances etc. The models are also to be used when designing new exchanges e.g. wall and ceiling area, wall and ceiling insulation, lighting etc.

The models are also to be used when drawing up policies and regulations e.g. they can be used to motivate a temperature set point change from the present 20 °C, to 35 °C or even higher, which will result in massive cost savings; or they can be used to motive the implementation of a policy stating that no office work is to be done in exchanges – separately built office blocks are to be constructed for this, which also drastically reduce energy costs.

6.3 SUMMARY

The study proved to be very successful in that it provides a practical means of improving energy efficiency in telecommunication exchanges. The work contained in this dissertation was laid out is such as manner that it provides information that can be adapted to other fields of study, and as such provides a versatile tool for any industry wishing to improve its efficiency.

In all, the study provides Telkom with an extremely useful tool for ensuring the efficient use of its energy. As such it truly fulfils its primary objective, "to implement energy management in a telecommunications environment and in so doing provide useful energy optimisation tools"

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ADDENDUM A

A.1 ENERGY POLICY FOR THE UNIVERSITY OF PRETORIA

Mission Statement

Manage the energy resources of the University of Pretoria to ensure maximum benefit to the university community with the minimum energy consumption and cost.

Primary Objective

Manage the consumption of the energy resources available to the University of Pretoria so as to ensure that all the energy consumed at the university can be accounted for, the awareness of all users is increased, the energy efficiency strives towards set performance levels, the energy reticulation systems are strategically developed in accordance with policy and financial accountability of the university, as a result of energy consumption, is minimised.

Specific Objectives

- *Energy measurement and control*
- *Energy consumption benchmarking*
- *Energy Education*
- *Energy economics*
- *Product supply and maintenance contracts*
- *Energy marketing and awareness*

ENERGY POLICY STRATEGY

Long-Term Strategies

1. Compile and implement an audit plan that highlights the regularity and detail with which the energy audits are conducted at the university.

2. Evaluate the effects of new technologies on the energy efficiency of the University in accordance with the recommendations in the audit plan.

3. Be able to measure the energy consumption of the various end-user groups of the entire University.

4. The implementation of "Smart" Lecture Halls whereby the halls are capable of automatically controlling the HVAC temperature and light levels dependant on whether a specific hall is in use or not.

5. ...

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Short-Term Strategies

1. Install measurement equipment to ensure data acquisition from the City Council of Pretoria (Lynnwood Sub-Station) of the following points:

- *The 3 feeders to the Main Campus.*
- *The 2 feeders to the Men's Hostels.*
- *The total consumption at the Lynnwood Sub-Station.*

2. Upgrade the existing measurement on Main Campus to include the following:

- *The measurement of the electricity of the newly built Post-Graduate School.*
- *Detailed measurements at the Woman's Hostels.*

3. ...

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A.2 ENERGY POLICY FOR AT&T

AT&T's Environmental, Health and Safety Vision

AT&T's vision is to be recognized by customers, employees, suppliers, shareowners, communities and other stakeholders worldwide as an environmentally responsible company which protects human health and the environment by fully integrating lifecycle environmental, health and safety considerations into our business decisions and activities.

AT&T's Environmental, Health and Safety Policy

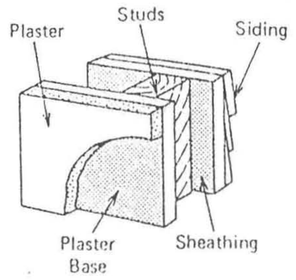
AT&T is committed to engaging its employees and leveraging its technology to protect human health and the environment in all operations, services and products, and to contribute to the achievement of a socially responsible environmentally efficient national and global economy. Implementation of this Policy is a primary management objective and the responsibility of every AT&T employee.

Goals and Guidelines

- *Comply with all applicable laws, regulations, and AT&T standards and practices governing environment, health and safety.*
- *Support the development of responsible, technically and scientifically valid, cost-effective environmental, health and safety laws, regulations and standards.*
- *Engage and educate employees to implement this Policy and encourage them to further contribute to the achievement of a socially responsible environmentally efficient national and global economy through volunteerism.*
- *Promote the conservation of raw materials and other natural resources, including energy, by eliminating or reducing waste and emissions, and by recycling and reusing materials, components, and products.*
- *Support environmental, health and safety efficiency by purchasing socially responsible environmentally preferable products and services.*

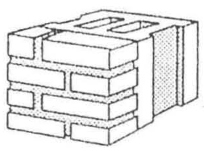
- *Continuously improve environmental and safety management systems to support the integration of applicable environmental, health and safety considerations into our business decisions and planning activities.*
- *Design new generations of processes, products and services to be environmentally preferable to the ones they replace, and enable our customers to increase their environmental and economic efficiency.*

ADDENDUM B



FRAME WALLS Construction

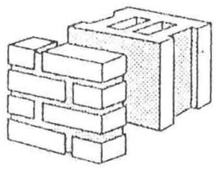
Exterior	Sheathing	Interior Finish (See Note 1)					
		A	B	C	Any Type		
		Insulation Resistance					
		None			R-4	R-7	R-11
wood siding or wood shingles	25/32 in. wood	.22	.23	.24	.13	.09	.08
	3/8 in. plywood	.26	.27	.27	.14	.10	.08
asbestos-cement or stucco	25/32 in. wood	.26	.27	.27	.13	.10	.08
	3/8 in. plywood	.31	.35	.32	.15	.11	.08
4 in. face brick veneer	25/32 in. wood	.24	.26	.24	.13	.10	.08
	3/8 in. plywood	.28	.31	.29	.14	.10	.08



MASONRY WALLS Construction

Construction	Interior finish (See Note 1)							
	None	A	B	C	D	Any Type		
	Insulation Resistance							
	None					R-4	R-7	R-11
8 in. common brick	.48	.29	.31	.30	.45	.13	.10	.07
8 in. stone or 8 in. conc. 140 lb/cu. ft	.67	.35	.39	.38	.63	.15	.11	.07
8 in. concrete 80 lb/cu. ft	.25	.18	.19	.19	.24	.11	.08	.06
8 in. concrete 30/lb cu. ft	.11	.10	.10	.10	.11	.07	.06	.05
8 in. cinder block or clay tile	.39	.25	.27	.26	.38	.13	.09	.07
12 in. cinder block or clay tile	.36	.24	.26	.25	.35	.13	.09	.07
4 in. face brick + 4 in. cinder block	.41	.26	.28	.27	.39	.13	.09	.07
4 in. face brick + 8 in. cinder block	.33	.22	.24	.23	.32	.13.	.09	.07

Table B.1 Overall heat transfer coefficient U [Btu/hr-ft^2-F]

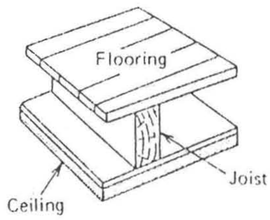


MASONRY CAVITY WALLS		Interior Finish (See Note 1)						
Construction		None	A	B	C	Any Type		
		Insulation Resistance						
Exterior	Inner Section	None				R-4	R-7	R-11
4 in. face brick	4 in. common brick	.33	.23	.25	.24	.13	.09	.07
or 4 in. stone	4 in. cinder block or clay tile	.41	.26	.28	.27	.13	.09	.07
4 in. common	4 in. common brick	.30	.21	.22	.21	.11	.08	.06
brick	4 in. cinder block or clay tile	.27	.20	.21	.20	.11	.08	.06
4 in. cinder	4 in. conc. block (gravel agg.)	.27	.20	.21	.20	.11	.08	.06
block	4 in. cinder block or clay tile	.25	.18	.19	.18	.11	.08	.06

FRAME PARTITIONS	No. Sides Finished		
Construction	One	Both	Both + R-4 Insul.
3/8 in. gypsum or wood lath and 1/2 in. plaster	.56	.32	.14
3/8 in. plywood	.55	.31	.14
metal lath and 3/4 in. plaster	.67	.39	.15
3/8 in. gypsum board	.60	.34	.14

MASONRY PARTITIONS	No. of Sides Finished							
	None	One				Both		
		Finish (See Note 1)						
Construction		A	B	C	D	A	B	C	D
4 in. cinder block or clay tile	.40	.26	.28	.36	.39	.22	.24	.29	.31
8 in. same	.32	.19	.21	.32	.37	.17	.19	.27	.30

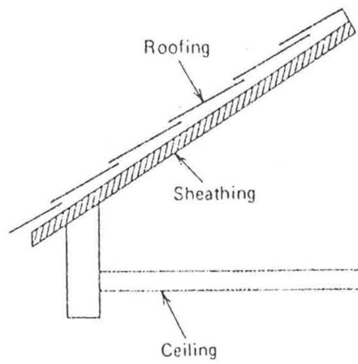
Table B.1 (continued)



FRAME FLOOR-CEILING (suspended ceiling) Floor	Direction of Heat Flow									
	Up					Down				
	Type of Ceiling (See Note 1)									
	None	A	B	C	E	None	A	B	C	E
none		.61	.74	.65	.41		.44	.51	.46	.33
$^{25}/_{32}$ in. wood subfloor	.45	.29	.31	.30	.24	.35	.24	.25	.24	.20
same + $^{3}/_{4}$ in. hardwood floor	.34	.24	.26	.24	.20	.28	.20	.21	.21	.17

CONCRETE FLOOR-CEILING (Suspended Ceiling) Floor		Direction of Heat Flow							
		Up				Down			
		Type of Ceiling (See Note 1)							
Slab	Finish	A	B	C	E	A	B	C	E
4 or 6 in.	none or tile	.35	.38	.36	.27	.27	.30	.28	.23
concrete,	$^{13}/_{16}$ in. wood block	.28	.30	.28	.23	.23	.24	.23	.19
sand agg.	tile + $^{3}/_{8}$ in. plywood + air space	.22	.23	.22	.19	.19	.20	.19	.16
	$^{3}/_{4}$ in. hardwood + $^{25}/_{32}$ in. wood + air space	.18	.19	.19	.16	.16	.17	.16	.14

Table B.1 (continued)



PITCHED ROOF-CEILING (Attic with Natural Ventilation)		Heat Flow Up or Down Ceiling Type A, B, C, or E		
		Insul. Resist.		
Roof	Sheathing	R-8	R-12	R-19
shingle or slate or tile	wood or plywood	.09	.06	0.04

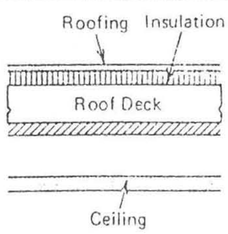
	FLAT ROOF	Heat Flow Up or Down Ceiling Type A, B, C, or E		
		Insul. Resist.		
	Slab	R-5	R-10	R-15
	4 in. concrete (gravel agg.)	.13	.08	.06
	8 in. same	.12	.08	.05
	2 in. concrete (light agg.)	.10	.07	.05
	4 in. same	.09	.06	.05
	2 in. gypsum on ½ in. board	.11	.07	.05
	4 in. same	.10	.07	.05
	2 in. wood	.10	.07	.05
	flat metal	.13	.08	.06

Table B.1 (continued)

WINDOWS & DOORS-glass (See Note 6)	Summer	Winter
single	1.04	1.10
single + storm	.50	.50
double, 1/4 in. air space	.61	.58

DOORS-wood or metal	Summer	Winter
1 1/2 in. wood	.47	.49
same + wood storm	-- --	.27
same + metal storm	-- --	.33
1 3/4 in. metal-urethane core	.18	.19

WALLS & FLOORS – below grade (See Note 2)	Wall	Floor
	.20	.10

CONCRETE FLOORS – at grade. Heat Loss Per Foot Edge (See Note 3)					
Outdoor design temperature, F	−20 to −30	−10 to −20	0 to −10	10 to 0	15 to 10
Heat loss, BTU/hr per ft edge	50	45	40	35	30

Notes for Table A.5.

1. Types of interior wall finish or ceilings are:
   - A. 3/8 in. gypsum lath or wood lath and 1/2 in. plaster
   - B. metal lath and 3/4 in. plaster
   - C. 3/8 in. gypsum board
   - D. 1/2 in. plaster on wall
   - E. 1/2 in. acoustic tile on furring strips
2. U values for below grade basements and walls are to be used with ground temperatures (range from 40 to 60 F in U.S.).
3. Heat losses for floors at grade are given per foot of exposed floor edge. These values apply when 2 in. of edge insulation is used, 24 in. wide.
4. All U values apply for winter or summer except as noted.
5. The U values for frame walls have been adjusted for effect of studs 16 in. on center.
6. For wood sash windows, multiply listed U value by 0.9.

Table B.1 (continued)

ADDENDUM C

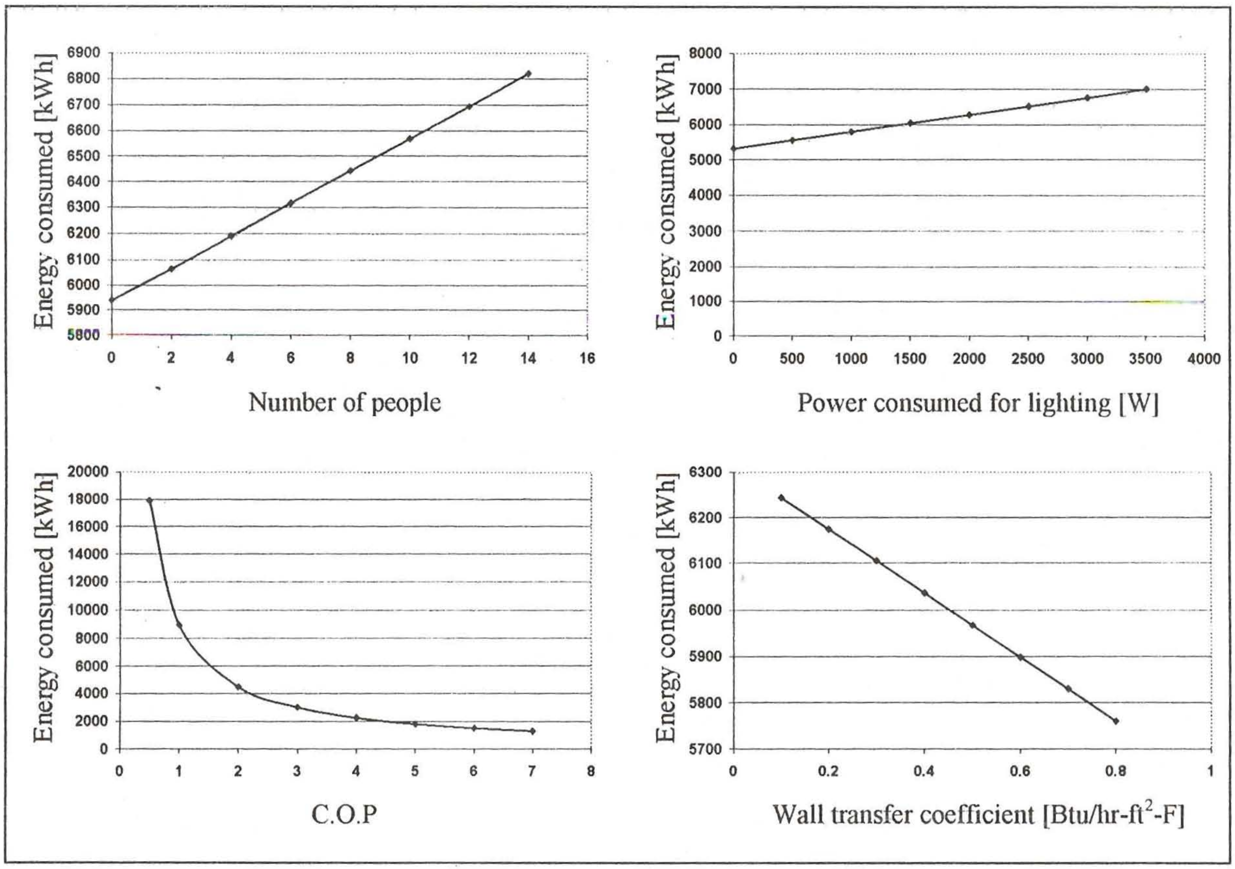


Figure C1. Energy consumptions versus input manipulations for Hillcrest exchange

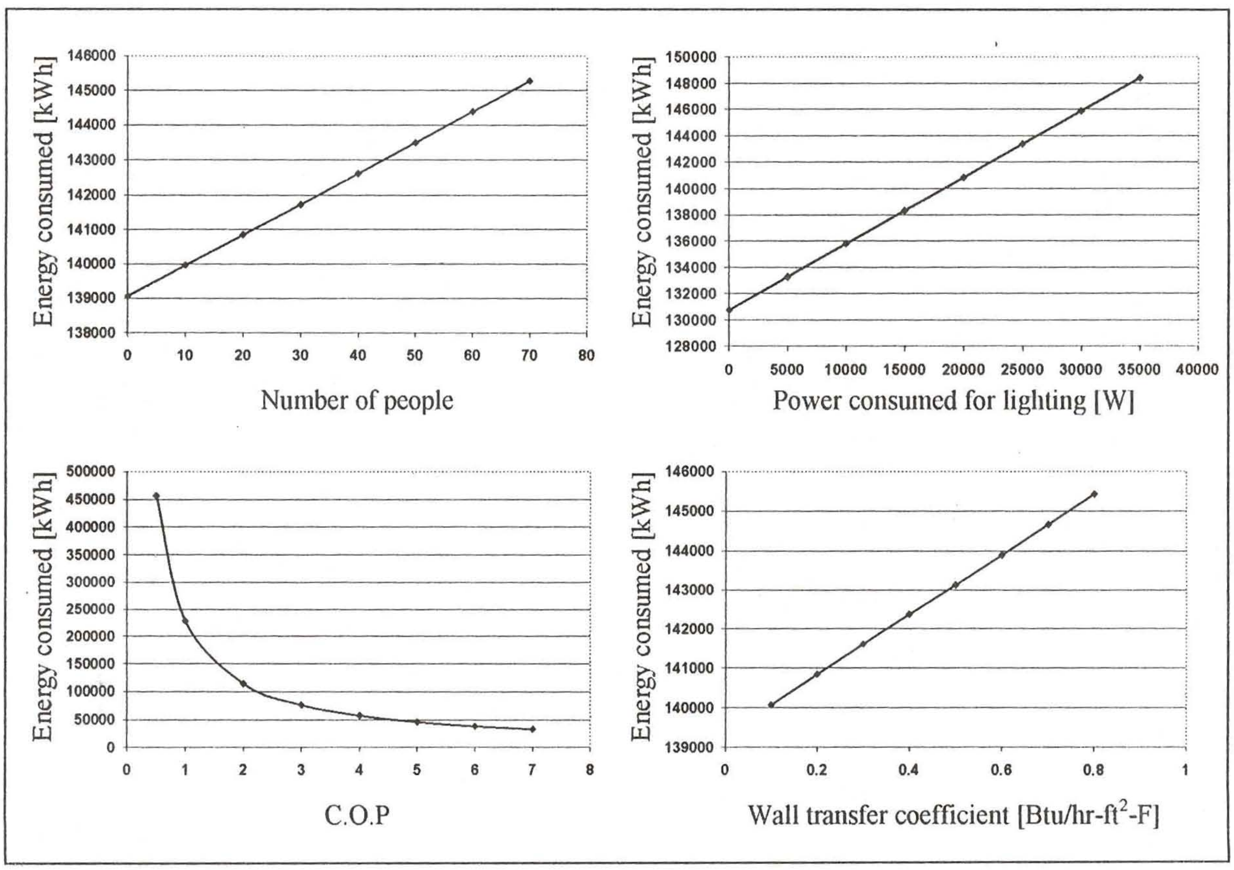


Figure C2. Energy consumptions versus input manipulations for Bronberg exchange