DEVELOPING ESCO PROCEDURES FOR LARGE TELECOMMUNICATION FACILITIES USING NOVEL SIMULATION TECHNIQUES

J.F. VAN RENSBURG

Thesis submitted in fulfilment of the requirements for the degree
PHD in Engineering at the North West University

PROMOTER: PROF. M KLEINGELD

JANUARY 2006

PRETORIA

Title:	Developing ESCO procedures for large telecommunication facilities using novel simulation techniques
Author:	Johann Francois van Rensburg
Promoter:	Prof. M Kleingeld
School:	Electrical and Electronic Engineering
Faculty:	Engineering
Degree:	Philosophiae Doctor
Search terms:	Energy Management, ESCO Procedures, Telecommunication Facilities, Demand-side Management, Simulation, Heating Ventilation and Air conditioning (HVAC), Building Retrofits.

Peak electricity demand in South Africa will exceed the available operational generation capacity in 2007. The state utility Eskom is addressing this challenge, inter alia, with the implementation of the Demand-side Management (DSM) initiative. The aim of DSM is to defer the building of additional power stations by modifying the end-user pattern to reduce electrical load during the morning and evening peaks. At the end of 2005 the DSM programme has only achieved 30% of its target. Some of the biggest problems are the lack of knowledge on how to perform ESCO audits and availability of tools and procedures to enable Energy Service Companies (ESCOs) to evaluate DSM potential.

Studies in South Africa have shown that 20% of the total municipal energy is utilised in commercial buildings. Additional investigations have shown that in the commercial sector approximately 50% of energy is used for air conditioning. Energy savings of around 30% can be realised through improved management procedures and retrofit projects of HVAC systems of existing buildings.

Telecommunication companies own and operate a large portfolio of diverse buildings. It was shown that these buildings are very inefficient in terms of energy usage. Performing ESCO analyses on these building portfolios present huge savings opportunities for the building owners as well as load reduction opportunities to help meet DSM targets.

ESCOs however face major problems in evaluating DSM projects on telecommunication facilities. Some of these problems are: time to perform the ESCO audits on such a large portfolio of buildings; skill levels of available personnel; lack of experience and structured audit process; availability of information; data capturing of information; determining the impact of the retrofits and calculating the savings and financial benefits of retrofits.

Obtaining approval for DSM projects is also a lengthy process. Smaller ESCOs cannot afford to commit resources to ESCO investigations only to recover their investment after project approval. Having an ESCO procedure that will speed up the audit process will help the ESCO to minimise resources that need to be committed to these investigations. Having a tested and reliable ESCO procedure will also help Eskom since they will receive more and better quality DSM proposals.

A new ESCO procedure for telecommunications facilities was developed. The primary requirements for the new ESCO procedure are that it should be simple, stable, fast and accurate. This procedure is evaluated against the known energy management opportunities in telecommunication facilities.

Some of the benefits of the new ESCO procedure are: time taken to perform ESCO analysis on all types of buildings is drastically reduced; lower qualified personnel can be used to perform the ESCO analysis; any type of HVAC system configuration can be accommodated; new data capturing procedures ensure that only essential data is captured; integrated simulation software is used that can easy and accurately simulate the building operations and retrofits on a building; retrofit options suitable for telecommunication facilities are identified; contribution to the DSM programme is evaluated; financial evaluation of the retrofits and feasibility for DSM funding and results are integrated into a standardised reporting format.

The new ESCO procedure was implemented on several case studies within the telecommunication infrastructure. Five different types of buildings were selected to implement the ESCO procedure. Each step of the procedure was evaluated and tested against the requirements of the new ESCO procedure.

It was proven through implementation that the new ESCO procedure is successful in solving the unique problems in performing ESCO analyses for telecommunications facilities. Valuable insight into the problems that can occur during the ESCO process was highlighted, and recommendation for future work was presented.

Titel:	Ontwikkeling van ESCO prosedures vir groot telekommunikasie fasiliteite deur gebruik te maak van unieke simulasie tegnieke
Outeur:	Johann Francois van Rensburg
Promotor:	Prof. M Kleingeld
Skool:	Skool vir Elektriese en Elektroniese Ingenieurswese
Fakulteit:	Ingenieurswese
Graad:	Philosophiae Doctor
Sleutelterme:	Energiebestuur, Energie diens verskaffings maatskappy (ESCO), Nuwe prosedures, Telekommunikasie Fasiliteite, Aanvraag bestuur, Simulasies, Lugversorging en verkoeling, Gebou veranderinge.

Piek elektrisiteits aanvraag sal die beskikbare opwekkingsvermoë oorskry teen 2007. Die staatsbeheerde elektrisiteits diensverskaffer, Eskom, poog om die probleem aan te spreek met, onder andere, die DSM (Demand-side Management) inisiatief. Die DSM program is ten doel is om die bou van addisionele kragstasies uit te stel deur die elektrisiteitsverbruik in die oggend en aand piektye te verlaag. Teen die einde van 2005 het Eskom egter slegs 30% van hul energie doelwitte bereik. Een van die grootse oorsake is die tekort aan kennis hoe om ESCO analises te doen, en die beskikbaarheid van stelsels en prosedures wat gebruik kan word om DSM potential te bepaal.

Studies in Suid Afrika het gewys dat 20% van kragverbuik in munisipale gebiede gebruik word in kommersiële geboue. Daar is verder bevind dat 50% van alle krag in geboue deur die lugversorgingstelsels in die geboue gebruik word en dat 30% daarvan bespaar kan word deur beter beheer en veranderinge aan die lugversorgingstelsel.

Telekommunikasie maatskappye besit groot diverse portefeuljes van geboue. Daar word ook aangetoon dat die geboue baie energie oneffiektief is. Hiedie geboue hou dus groot geleenthede in vir ESCO projekte wat die telekommunikasie maatskappye en ESKOM DSM sal bevoordeel.

Energie diens maatskappye (ESCO) ondervind egter groot probleme met die bepaling van DSM potensiaal binne telekommunikasie geboue. Sommige van die probleme is: lang tydsduur om ondersoeke te doen; kundigheid van beskikbare personeel; gebrek aan ondervinding en

stelsels wat kan help met die ondersoek; beskikbaarheid van data; bepaling van die impak en besparing van voorgestelde veranderinge.

Die goedkeuringsproses van DSM projekte is ook 'n tydsame proses. Kleiner ESCOs kan nie bekostig om hulpbronne aan te wend en eers maande later vergoeding te ontvang wanneer die projek goedgekeur is nie. As 'n ESCO prosedure en stelsel gebruik kon word wat die oudit proses kan bespoedig sal dit die risiko van die ESCO ook verlaag. Om 'n ESCO prosedure te hê wat betroubare resulate weergee, sal ook vir ESKOM DSM help om met vertroue projekte te kan goedkeur.

'n Nuwe ESCO prosedure vir toepassing in telekommunikasie geboue is ontwikkel. Die primêre vereistes van die prosedure is dat dit maklik, stabiel, vinnig en akkuraat moet wees. Die prosedure word ook ge-evalueer teen bestaande energiebestuur geleenthede in die telekommunikasie geboue.

Die voordele van die nuwe prosedure is onder andere: die tyd wat dit neem om gebou ondersoeke te doen word drasties verminder; laer kwalifikasie vlak van personeel word benodig vir die ondersoeke; die prosedure kan enige konfigurasie van lugversorgingstelsel simuleer; nuwe data versamelingstegnieke verseker dat slegs die nodige data ingesamel word; geintegreerde gebou simulasies word gebruik om die geboue en beoogde veranderinge te simuleer; spesifieke besparings geleenthede binne telekommunikasie geboue word geidentifiseer; bydrae van veranderinge tot die DSM program word bereken; finansïele analise word gedoen en resultate word in 'n standaard verslag formaat weergegee.

Die nuwe prosedure word in verskeie gevalle studies toegepas binne die telekommunikasie omgewing. Vyf verskillende tipes geboue is gekies om die prosedure te evalueer. Elke stap in die prosedure word ge-evalueer en getoets teen die vereistes van die nuwe prosedure.

Dit was bewys dat die nuwe prosedure die behoeftes bevredig vir 'n ESCO prosedure wat suksesvol gebruik kan word in telekommunikasie geboue. Waardevolle lesse is ook geleer uit die toepassing van die nuwe prosedure in gevalle studies, en word omskryf. Tekortkominge van die prosedure en voorstelle vir opvolgwerk word bespreek.

There are several people I would like to thank for their help and support during this study:

- To God, for giving me the capabilities and opportunity to complete this study. Thank you Lord for always being there, and for all the things you bless me with.
- To Marike, my wife. Your support and love has always motivated me. I love you, and thank you for always caring and being there for me. Your technical writing skills were truly valuable to me.
- Thank you to my son Rian, and daughter Mieke for putting up with their dad while he worked each night.
- To my parents for their love, support and encouragement.
- To my mentors, Prof. Eddie Mathews and Prof. Marius Kleingeld for their guidance. Special thanks to my study leader Prof. Marius Kleingeld for his motivation and continued support.
- To Dr. Frikkie Geyser for his contributions and guidance in doing the building simulations and for his base documents on which this work is built.
- To Dr. Werner Bouwer for his assistance with the Data Building simulations and base documents.
- To Mr. Derek van Rhyn for his help on the data capturing procedures.
- To Mr. Gareth McNaugton for his assistance with gathering of information during work done for the case studies.
- To everyone else who also made a contribution, and was not mentioned.

To Marike...

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AC POWER	Alternating-current Power
AHU	Air Handling Unit
BMS	Building Management System
CAV	Constant Air Volume
DC POWER	Direct-current Power
DSM	Demand-side Management
EE	Energy Efficiency
ESCO	Energy Service Company
ETSI	European Telecommunication Standards Institute
FAR	Fresh Air Ratio
FCU	Fan Coil Unit
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
KVA	Kilovolt-ampere (Standard Unit for Peak Demand)
KVAH	Kilovolt-ampere Hours
KVAR	Kilovolt-ampere Reactive (Reactive Power)
KW	Kilowatt (Standard Unit for Power Consumption)
KWH	Kilowatt-hour (Standard Unit for Electricity Consumption)
LR	Load Reduction
M&V	Measurement and Verification
MD	Maximum Demand
MW	Megawatt
MWH	Megawatt-hour
NER	National Electricity Regulator
PC	Personal Computer
PDA	Personal Digital Assistant
RH	Relative Humidity
SLA	Service Level Agreement
TFMC	Telecommunication Facility Management Company
TTE	Telkom Towers East
TTN	Telkom Towers North
TTS	Telkom Towers South
UPS	Uninterruptible Power Supply
VAV	Variable Air Volume
VSD	Variable Speed Drive

1. INTRODUCTION

1.1 NEED FOR ENERGY MANAGEMENT IN SOUTH AFRICA

In recent years the term *energy management* has become a very popular phrase for the simple reason that it relates to cost savings. Companies are forced to become more economically competitive and to cut running costs wherever possible. Energy management can be defined as the judicious and effective use of energy to minimising costs, thus maximise profits, and enhance competitive positions [1].

Electrical energy is an essential ingredient of a modern economy and its industrial production, and therefore of the all-round development of any country. Electrical energy today constitutes about 30% of the total annual energy consumption on a worldwide basis [2]. This figure is expected to rise as oil supply for industrial uses becomes more stringent and expensive. The International Energy Agency estimates that the South African economy is between two to five times more energy intensive than the Organisation of Economic Corporation Development (OECD) nations. It was also found that South Africa is one of the most energy intensive countries in the world, consuming more energy per unit of economic output than all but ten countries in the world [3].

With the increase in electrical energy use comes a concurrent increase in the maximum demand level that needs to be supplied during peak demand periods. A typical daily demand profile is dominated by a morning and afternoon peak (as shown in Figure 1-2). These peaks can mainly be attributed to the energy usage of the residential sector but with the commercial and industrial sectors also contributing to these peaks. The main reason for these peaks is the electrification of 3.5 million homes since 1993, which added 750 MW to the national grid [4].

Approximately 40% of all homes in South Africa, as well as numerous schools and clinics are currently still without ready access to electricity supply [5]. Eskom, which is by far the largest supplier of electricity in South Africa (95%) [6], plans to electrify an additional 1 750 000 homes in the near future [7]. This will place additional strain on the electricity utility and is one of the main reasons why the peak demand is expected to increase within the next five years [8].

Electricity demand in South Africa is currently estimated as growing at approximately 1 000MW per annum. Operational generation capacity in South Africa currently (2005) totals 37 GW [9], [10].

Unless drastic steps are taken before 2007, peak demand will exceed Eskom`s ability to supply electricity during these high demand periods. The predicted demand growth is shown in Figure 1-1 [11]:

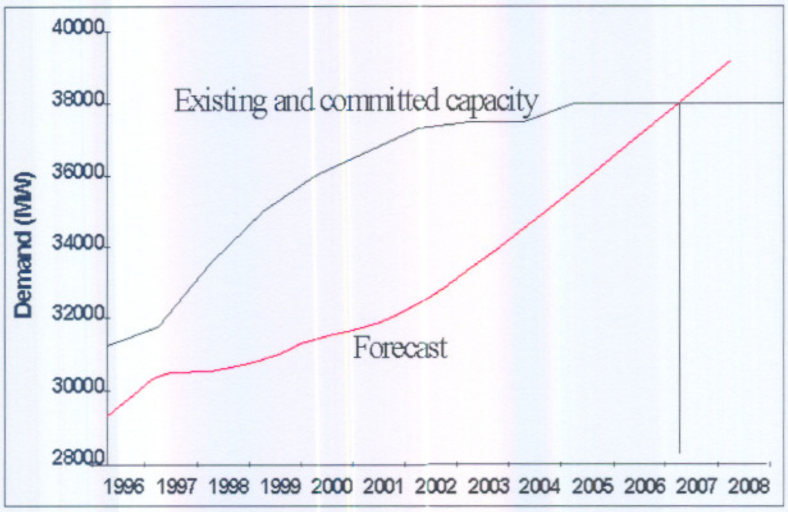


Figure 1-1: Eskom capacity status and forecasted maximum demand

The maximum electrical power capacity of Eskom is governed by the maximum demand of their clients. At the moment Eskom`s off-peak capacity is well within demand, it is only during the peak periods that a problem is foreseen. The demand profile for South Africa for 2005 is illustrated in Figure 1-2 [12].

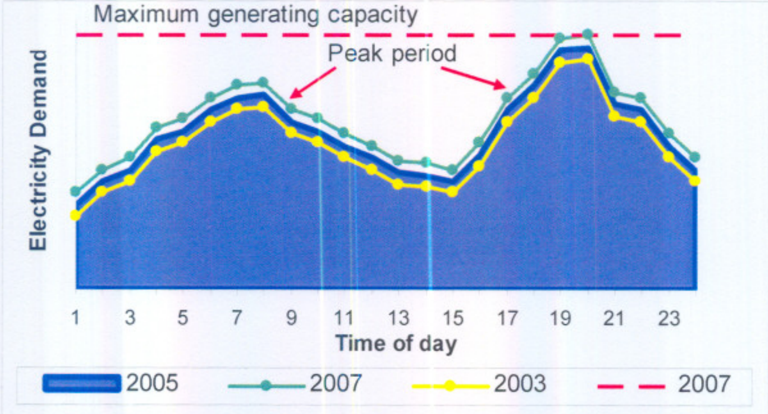


Figure 1-2: Electrical demand profile for South Africa

The green line shown in Figure 1-2 indicates the electrical demand profile for 2007, while the red line indicates the maximum generating capacity Eskom currently (2005) can supply. As illustrated in Figure 1-2, the electricity consumption during peak periods for 2007 touches the red line, which means that Eskom cannot supply any more electricity during the evening peak period.

Various supply and demand technologies have been identified to address the growing demand of electricity in South Africa. Eskom is addressing this challenge by the expansion of supply options, Return to Services programme of mothballed power stations as well as the Demand-side Management (DSM) initiative.

In accordance with Eskom's latest planning, building a new peaking load power station can take up to seven years to build [13] at a cost of around R16 billion [14]. It can take up to three years to return mothballed and gas-fired plants to service. It is therefore clear that there will be a potential peak demand supply shortage if no corrective actions are taken soon. At the very least the price for electricity, especially in the peak periods, will become much higher due to higher long run marginal costs resulting from the investment in new plants.

As growing power shortages in South Africa threaten its continued economic growth, it becomes more important than ever to find ways to use energy more efficiently! One of the main initiatives to try and curb the demand shortage and improve energy efficiency is the Demand-side Management programme.

1.2 DEMAND-SIDE MANAGEMENT PROGRAMME IN SOUTH AFRICA

1.2.1 Introduction

One tool that has proven effective in many countries for delivering energy efficiency and load management but has not yet been widely adopted in South Africa, is Demand-side Management (DSM). DSM is a mechanism in which a utility or some other designated entity (Energy Service Company – ESCO) uses funds derived from the electrical system to modify patterns of electricity usage, including the timing and level of electricity demand.

Demand-side Management aims to i) reduce electricity demand during peak periods, and ii) promote energy efficiency when Eskom's supply capability is limited. The greater the cooperation between Eskom and customers in reducing demand during peak periods, the longer Eskom will be able to delay investment in new power stations and the accompanying price impact for energy users [15].

The prime objective of DSM is providing constant, efficient use of electricity thus managing the demand effectively. If electricity is managed in this way, the demand is more consistent and consequently electricity suppliers are more able to meet the requirements of all of its consumers. The key benefit of DSM is efficient use of electricity, without influencing the customer production and satisfaction levels, resulting in significant cost savings to the consumer.

The rise in energy usage would not have been so much a problem if the country had a constant energy profile throughout the day. Unfortunately, South Africa suffers from dominant morning and evening peaks that are increasing in magnitude over time. The two main areas of focus in this regard are Load Reduction (LR) and Energy Efficiency (EE). In so doing, it assists the utility to reduce or shift the electricity peaks, usually from 07h00 to 10h00 in the morning and from 18h00 to 20h00 in the evening, to other low demand periods of the day. A graphical explanation of these concepts is given in Figure 1-3 below:

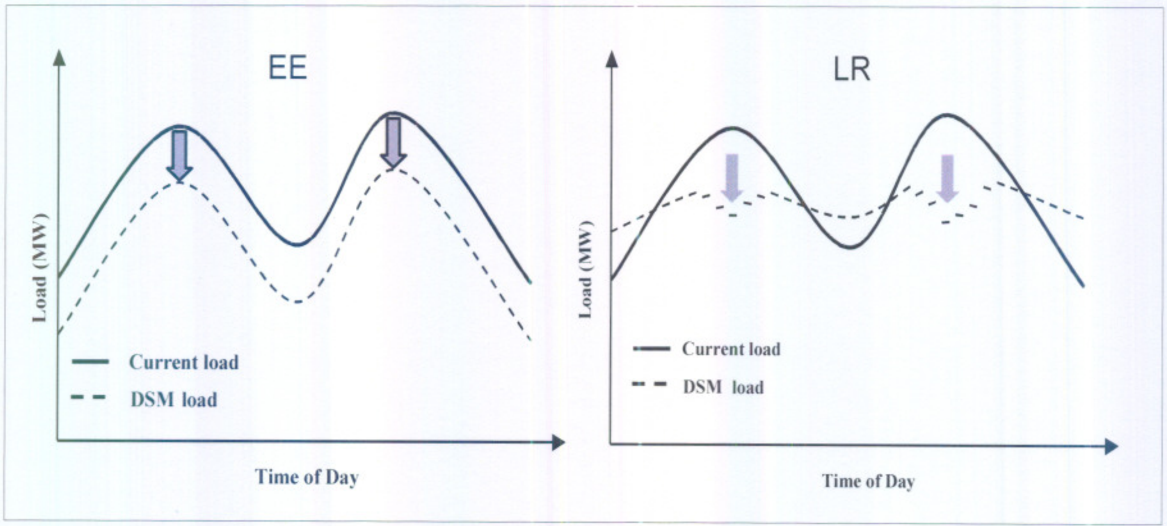


Figure 1-3: DSM through energy efficiency (EE) and load reduction (LR)

There are also environmental advantages in reducing demand, in that reduced power station operations will lead to reduced green house gas emissions into the atmosphere. Eskom, the National Electricity Regulator (NER) and other government organisations support DSM, and it is clear that the benefits to South Africa and its people are significant.

Based on the Integrated Strategic Electricity Planning (ISEP) guidelines, Eskom's DSM's objectives are to [13]:

- *Add value to the South African economy by initiating DSM programmes that comply with sound business principles.*
- *Concentrate on DSM programmes that provide win-win situations for the customer and Eskom.*
- *Create the opportunity for Eskom to improve supply-side planning, which results in lowered risks in implementing supply-side solutions.*
- *Achieve market transformation and ensure DSM sustainability. This should ensure that the market does not regress to lower levels of efficiency after active participation of the utility has ceased.*
- *Reduce the energy consumption and maximum demand by changing the configuration or magnitude of the load shape.*
- *The DSM initiative over the next 10-year rollout period will be more cost-effective than the supply-side alternatives (Building a new generation plant).*

1.2.2 DSM targets and results

The National Energy Regulator has set an annual target to Eskom of a 153 MW load reduction out of the evening peak period since 2003 [16]. Thus, at the end of 2005 the accumulated target load to be shifted should be 612 MW. The aim over the next 20 years is to save an accumulative total of 4 255 MW, representing the capacity of one six-unit, coal-fired power station [17]. Additional goals include awareness building, community building, establishing a new skills base, black empowerment and benefits to the environment.

The DSM provision in Eskom's planning includes a 7 300 MW of peak load reduction by 2015 as broadly classified in Table 1.1 below. The general view is that the targets outlined are extremely conservative. Recent work shows that over 11 000 MW could be achieved within the same time period [18]. This could also be done at costs significantly below the equivalent of expanding the supply-side costs for additional production capacity.

Options	Impact 2015(MW)
Interruptible load	3 200
Load shifting	1 600
Energy efficiency	2 500
Total	7 300

Table 1-1: Eskom DSM load reduction targets

The capital costs associated with these deferrals are R1.6 million per MW for Energy Efficiency programmes and R1.45 million per MW for LR programmes. These values are estimated costs [18].

Measurement and Verification (M&V), the independent monitoring and evaluation team for Eskom DSM projects, has indicated that an accumulated total of 181 MW load will be shifted at the end of 2005. This means that since 2003 the Eskom DSM programme only achieved 30% of the targeted 612 MW. These results can be seen in Figure 1-4, extracted from M&V's quarterly report for 2005 [19].

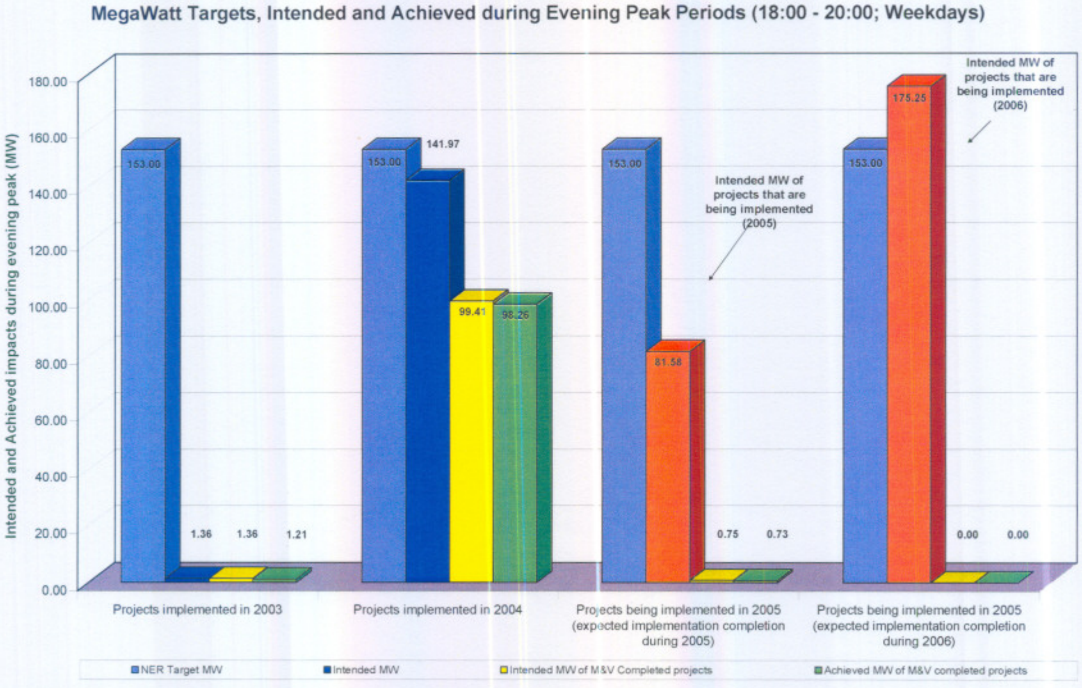


Figure 1-4: Eskom DSM target and results since 2003

One could also expect the area of energy conservation and energy efficiency to become an issue increasingly driven by Government. The Reconstruction and Development Program of the South African government states that: "Energy efficiency and conservation must be a cornerstone of energy policies" [20].

In the foreword to the March 2005 Energy Efficiency Strategy of the Republic of South Africa, former Minister of Mineral and Energy, Phumzile Mlanbo-Ngcuka states [21]:

"In South Africa we take energy for granted, with the consequence that our energy consumption is higher than it should be. Whilst our historically low electricity price has contributed towards a competitive position, it has also meant that there has been little incentive to save electricity. "

One could expect that policies from Government could make it worthwhile for end users to be more energy conscious. It is also expected that deregulation will take place in the electricity sector as it has in many parts of the world [22]. Some of the other benefits energy management and DSM may hold to households, enterprises, utilities, and society in general are listed below [22]:

- Reduces customer energy bills
- Reduces the need for power plant, transmission, and distribution construction
- Stimulates economic development
- Creates long-term jobs that benefit the economy
- Increases the competitiveness of local enterprises
- Can reduce maintenance and equipment replacement costs
- Reduces local air pollution
- Reduces emissions that contribute to national and international environmental problems, such as acid rain and global warming
- Enhances national security by easing dependence on foreign energy sources
- Can increase the comfort and quality of workspaces, which in turn can increase worker productivity
- Can create market transformations with long-term results

The influence of DSM in the reduction of peak growth is critical to Eskom, and is crucial to prevent the installation of further generation capacity.

1.2.3 Role of ESCOs

The World Energy Council, a global organisation that promotes sustainable energy use, defines an ESCO as: "... an organisation that provides a wide range of services related to the implementation of energy-efficient products, technologies and equipment to owners of industrial, commercial, institutional, agricultural and/or domestic facilities" [23]. Typically, they offer the following services [24]:

- Develop and design energy efficiency and load management projects
- Install and maintain the energy efficient equipment involved
- Measure, monitor, and verify the project's energy savings
- Assume the risk that the project will save the amount of energy guaranteed

ESCOs are private companies that help to achieve DSM goals. They make use of DSM programs, technologies and optimisation packages to determine and realise DSM results at the electricity consumer. The ESCO is the party responsible for implementing and maintaining the project in order not to burden the client with committing additional resources to the initiative. It is the client's prerogative to decide if he wants to act as the ESCO, or to appoint an ESCO [13].

Normally the ESCOs operate in a three-way partnership between themselves, the electricity supplier or regulatory body responsible for DSM and the electricity consumer. The parties must be contractually bound to define the roles and responsibilities of each in order to avoid any confusion and penalties if one party does not perform as required. The actual energy and financial savings will be measured by an independent Monitoring and Verification (M&V) body and distributed to all parties concerned.

In the following section the opportunities for ESCOs to implement DSM projects in commercial facilities will be investigated.

1.3 ENERGY USAGE AND DSM OPPORTUNITIES IN COMMERCIAL BUILDINGS

1.3.1 Energy usage in commercial buildings

International studies have shown that building operations account for approximately one-third of the total energy consumption of most countries [25]. Already in 1989, 37% of the world primary energy consumption was used in building operation [26]. In developed countries, 57% of all the electricity generated is utilised in commercial buildings. In developing countries, commercial buildings account for 38% [27].

Eskom research has shown a number of saving opportunities in South Africa [15] in different sectors that can help reduce the growing peak demand. The research has identified opportunities for both *energy efficiency* and *load management* interventions in the residential, commercial and industrial sectors. The contribution of the different energy consumers for 2003 is illustrated in Figure 1-5. Commercial buildings make up the majority of the commercial load.

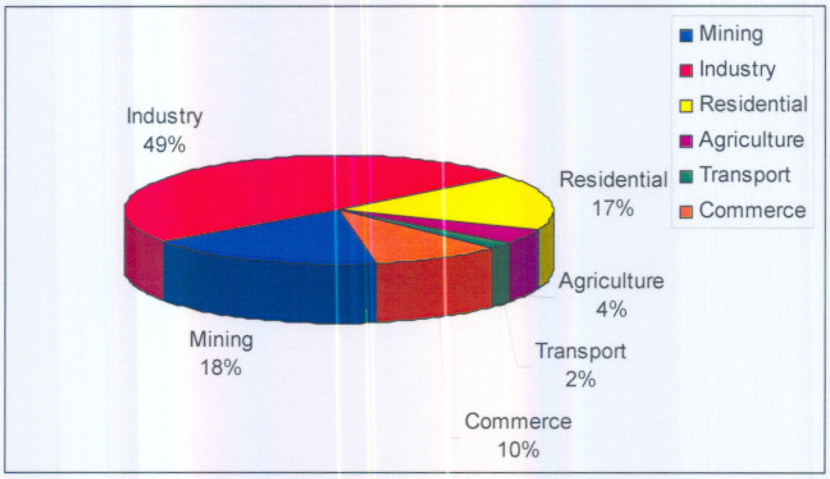


Figure 1-5: Energy consumption per sector in South Africa

Further studies have shown that 20% of the total municipal energy is utilised in commercial buildings [28] as shown in Figure 1-6.

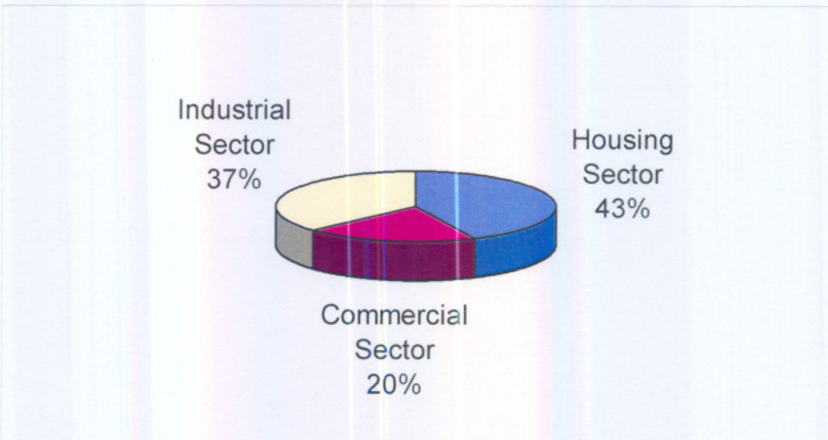


Figure 1-6: Energy consumption per sector in South African buildings

Rousseau and Mathews also concluded that 10% of all energy consumed in the world is expended by building air conditioning systems [29]. Studies done by TEMM International (Pty) Ltd. in South Africa have shown that in the commercial sector approximately 50% of energy is used for air conditioning [30]. According to the South African Department of Minerals and Energy, this figure can be as high as 74% in summer for temperate climates [31].

1.3.2 DSM opportunities in commercial buildings

Audits in India suggest that 33% of the annual electricity use in a typical building could be saved through management and technological changes [32]. Similarly, estimates from the former Soviet Union suggest that 25% of the energy used in existing building could be saved [33]. A study done in the USA of over 1 700 building-energy retrofits, reports annual savings of 18% of whole building energy usage with a medium payback period of 3.1 years [34]. In some instances very large savings have been achieved, large individual projects have saved in excess of $800 000 in a single year [35].

Optimistic sources estimate savings of as high as 70%, with the use of improved design and management, as well as through retrofit projects of existing commercial buildings [36]. However, it is more generally agreed that energy savings of around 30% might be realised through improved design management procedures and retrofit projects of existing buildings [37], [38]. If a 30% penetration in the industry with a 30% saving per building could be realised in South Africa, it would result in a substantial reduction in electricity demand [39].

Optimising building HVAC control provides the best return on investment, the easiest approach to promote savings to building owners and is also the easiest way to implement. Based on conservative assumptions, the total potential impact of optimising building HVAC control in South Africa could result in a cost saving of R280 million per year [40].

Such retrofit studies would in most cases be of more value in older buildings than in new ones. However, one must remember that a building can be considered outdated even after 15 years of use [41]. Depending on the system, the maintenance history and implementation, newer buildings may also have potential for energy saving.

Heating, ventilation, and air conditioning (HVAC) system energy efficiency in buildings means reduced electricity consumption, monetary savings for the owner and less greenhouse gases being released into the atmosphere. Although very important, energy saving measures must never compromise indoor air quality (IAQ). The reason is that IAQ has a direct effect on the health and productivity of the occupants [40][42]. The cost associated with poor IAQ far outweighs savings due to reduced energy consumption [43].

The popular belief in the past was that good IAQ and energy efficiency were in direct conflict [44]. A cost-effective way to improve the energy efficiency of an HVAC system, without compromising indoor comfort, is by implementing better control [45]. The most effective way to predict the impact of the system changes on the energy efficiency and indoor comfort is with the use of computer simulations [46].

Additional to the energy savings of a building retrofit study, there are various other improvements. For a lighting retrofit it could include improved light colour quality, and improved lighting levels. From HVAC improvements one may find reduced running hours, improved temperature control, faster equipment failure notification, more reliable preventative maintenance, additional safety and security and improved information on the system [47]. Some of these will also lead to additional savings over and above the energy cost reductions.

1.4 ENERGY USAGE IN TELECOMMUNICATION FACILITIES

1.4.1 Introduction

This study focuses on the development of new ESCO procedures for large telecommunication facilities. For the purpose of this study Telkom SA was used as a case study for the development and testing of the new procedure.

Until the end of 2005 Telkom SA was the sole fixed-line telecommunication service provider in South Africa. Their operation includes 6 500 properties, 14 000 telecommunication towers and all ancillary telecommunication infrastructure, totalling in excess of 3 million m^2 [48]. The period of exclusivity however ended in 2005 and the appointment of the second line operator was announced December 2005 [49].

To understand the energy usage in Telkom the annual resource consumption for Telkom SA for the 2004 financial year is shown in Table 1.2 below [50]:

Resource consumption

	Year ended March 31, 2004
Water (R million)	12.2
Water consumption (kilolitre million)	2.8
Electricity (R million)	196.8
Electricity (kilowatt hour million)	296
Electricity (kilovolt Ampere)	475,782
Sanitation (R million)	11.2

Table 1-2: Annual resource consumption of Telkom SA

From the table above it can be seen that R196 million is spent annually on electricity costs. This excludes rates and taxes and only covers the costs paid towards the use of kWh and KVA demand of buildings.

There are different types of buildings in the Telkom infrastructure. The buildings can be broadly classified as:

- Exchanges – Only used for telecommunication equipment, and often unmanned sites or limited people in the building.
- Commercial buildings – These buildings are similar to most office buildings and used for commercial purposes.
- Combined buildings – Buildings that have a mix of equipment and commercial activities.

1.4.2 Exchange buildings

A typical exchange building has the following energy end users:

- Switchgear – Supplies power to the building
- HVAC equipment – Ensures the correct environmental conditions
- Logistical equipment like computers, lights, elevators etc.
- Telecommunications equipment

For exchange buildings the typical electrical layout of the building is shown in Figure 1-7 below [51]:

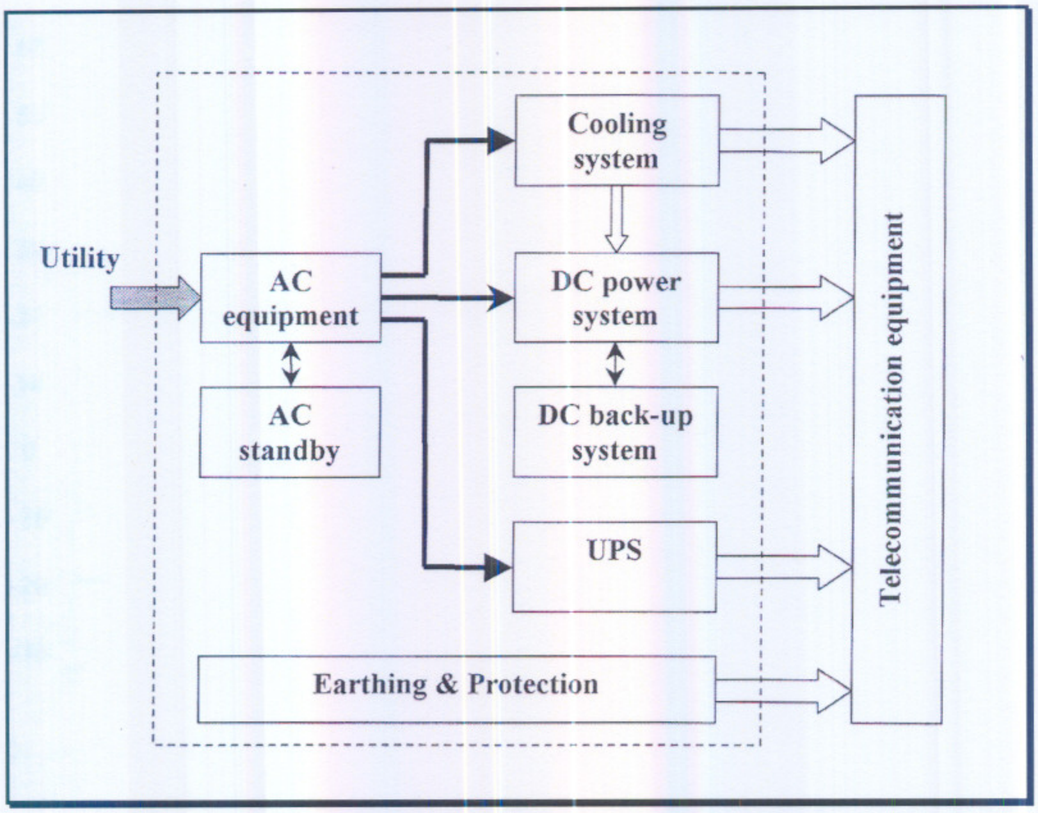


Figure 1-7: Energy end-users in exchange buildings

The main source of power to the telecommunication equipment is supplied in the form of DC power generated by rectifiers. In the event of the rectifiers failing to supply, battery banks are on standby. An uninterruptible power supply (UPS) provides power to the computers and other control equipment. Most of the energy supplied is converted to heat that needs to be removed by the cooling equipment. The entire cooling plant is powered from the utility in the form of AC power. A backup generator is always on standby in the event of a power failure [51].

The purpose of the cooling plant, which forms part of the HVAC system, is to maintain the interior environment within specific temperature and humidity limits. Rabie [52] mentions that of these end-users, the HVAC (Heating, Ventilation and Air Conditioning) system represent 55% of the total building load. This is even higher than the 50% found in typical commercial buildings due the constant heat load in these buildings. The environmental specification mostly used by Telkom to govern the conditions within the building is the ETSI 300-019 specification. Typically most of the telephone exchanges are designed to operate within narrow limits around nominal temperature and humidity values. The operating range in exchanges is 20°C ± 2°C for the under-floor supply air temperature and a humidity range of between 30% and 70% relative humidity (RH) [53].

Most telecommunications companies in the world design their telephone exchanges to operate within these limits [54]. According to Parsons [55] exceeding these temperature specifications can affect the telecommunication equipments reliability and even result in system failure.

One efficiency norm often used is the ratio between the energy used per month to the floor area of the building. The European norm is 16 kWh/m^2 for exchange buildings [56]. Rabie has shown that manned exchanges consume 92 kWh/m^2 and unmanned exchanges consume 164 kWh/m^2 [57]. Granted there are vast differences in weather conditions. The thermal quality of European buildings is of a much higher standard, enabling European buildings to use much less energy for space cooling. Nonetheless it still illustrates the fact that Telkom presents huge opportunities for energy saving.

Magnus [58] mentions that HVAC in Bell Communications (USA) only constitutes 21% of the total energy consumption, and Bengtsston [59] stipulates that Swedish based Telia this process consumes 30%. Thus, it is clear that while Telkom SA consumes 55% for this process big opportunity for improvement exist.

1.4.3 Commercial buildings

The purely commercial buildings are used for administrative purposes, and the power is mainly used for HVAC, computer, lights, elevators etc. It was shown by Mathews [30] that HVAC systems contribute typically 50% of the energy usage in commercial buildings and this is also the case in most of the commercial buildings in Telkom SA [52].

The commercial buildings also have special requirements such as minimum percentage of fresh air intake as required by law [53]. It is also very difficult to achieve the ideal indoor climate that will satisfy all people occupying the building. Figure 1-8 shows the total building power usage versus outdoor temperature for a typical commercial building.

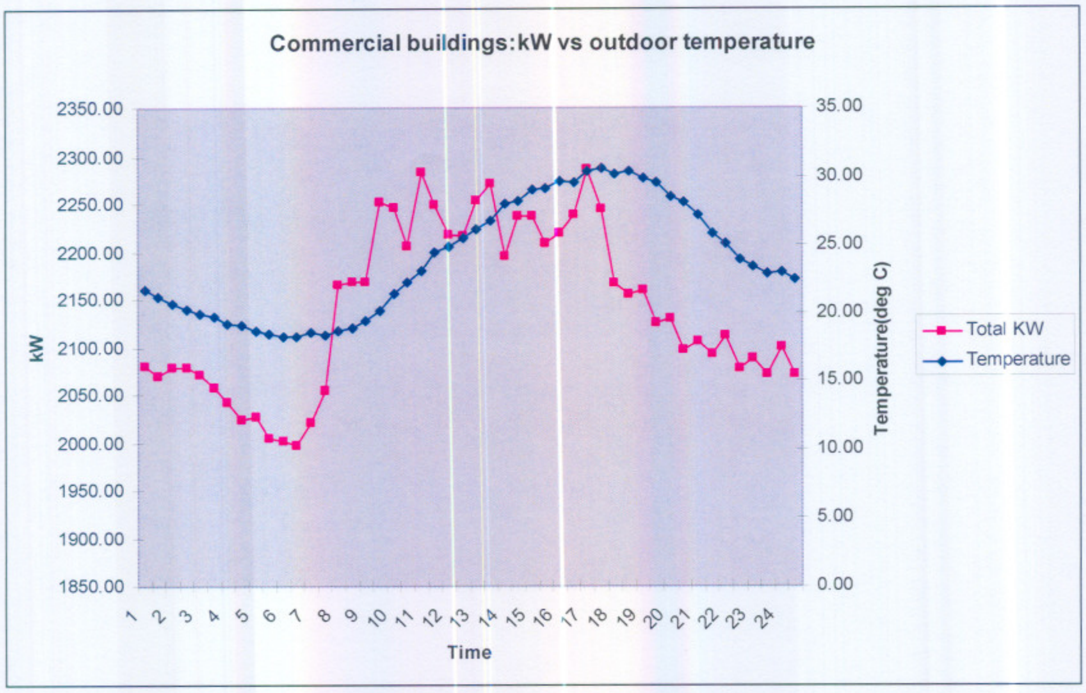


Figure 1-8: Commercial building: daily power profile versus temperature

It can be seen that the building load is influenced by the changing outdoor temperature as can be expected for commercial buildings. The building load also increases during office hours due to increased activity in the building.

1.4.4 Combined buildings

Combined buildings are used for commercial purposes and also contain telecommunication systems. This scenario presents a problem to the HVAC system of the building since the equipment needs to operate at a much lower temperature than that which is comfortable for humans (20ºC ± 2ºC). Office areas are thus often cooled by standalone air conditioning systems where centralised HVAC plants are used for cooling equipment areas.

A common problem in many of the buildings is that the equipment and building infrastructure is very old. This leads to inefficiencies in the HVAC plants and creates a problem for the facility managers to maintain these buildings, and also ensure minimum energy usage. Through the DSM funding mechanism the opportunity exists to upgrade infrastructure in the building that will improve environmental conditions, but also reduce maintenance costs.

1.4.5 Facility management of Telkom SA facilities

It is often the case that the facility management is conducted by a specialised group in the telecommunications company or outsourced to external facility managers. In the case of Telkom SA the facility management is outsourced to TFMC.

TFMC, a member of Mvelaphanda Services Ltd., was established in July 2000 through a strategic partnership aimed at providing facilities management services to Telkom South Africa through a ten-year contract valued at R15 billion [48].

TFMC is responsible for all maintenance of non-core equipment. Within Telkom the support equipment or the so-called environmental equipment is defined as the equipment which provides the correct operating environment for the telecommunications equipment.

Telkom had decided to outsource the maintenance of the environmental equipment as it is not part of their core business. TFMC won the contract and has been responsible since 1999 for the maintenance of Telkom facilities and infrastructure, which cover a wide variety of properties, installations and equipment throughout South Africa.

Part of the services offered by TFMC to Telkom SA is property management. This includes the payment and management of all electrical accounts on behalf of Telkom SA. Telkom SA is also constantly reducing the budget available to TFMC for paying these accounts and therefore forces TFMC to continuously aim to drive down energy costs within the Telkom infrastructure.

Part of the cost-reduction effort will obviously be energy management. Apart from the financial benefits some other benefits are listed below:

- Optimised performance of equipment and better reliability
- Reduced client running cost and thus increased profitability
- Energy reduction contributes to reduction in gas emissions caused by power generation
- Cost of power will be increasing, and need to be effectively managed

The fact that the telecommunication facilities are very energy inefficient and the need to be more profitable makes the telecommunication facilities an ideal platform to implement Demand-side Management projects.

1.5 PROBLEMS WITH ESCO IMPLEMENTATIONS IN BUILDINGS

Most ESCOs do not have the skills, nor the tools, to conduct energy studies in buildings cost effectively. A study by Stein [60] identified the common mistakes that are frequently repeated during energy efficiency projects. Some of these mistakes include the selection of inappropriate analysis tools, poor data collection, inadequate definition of baseline, inadequate reporting, inappropriate solutions and neglect of interaction between building systems [60].

Following is a list of problems ESCOs face implementing DSM projects on commercial buildings.

1.5.1 Time to perform ESCO analysis

Energy audits done by Geyser [61] have shown that a full building audit took up to four months to analyse and retrofit. One of the biggest problems was the lack of auditing software that specifically catered for their needs. The time taken to complete an audit has a big effect on the number of buildings that can be completed, and the resources required by the ESCO.

1.5.2 Skills levels of personnel

Performing building audits and quantifying retrofit suggestions is not a trivial exercise. As seen above it may take months to perform a full audit on a large building. If qualified engineers are used for this, the manpower costs will be a significant part of the project costs and might even have an impact on the feasibility of the project. Considering that the analysis part of an ESCO project is usually financed by the ESCO itself and that the cost of the analysis could be in the order of R10 000 per week it is clear that this part of the project needs to be done in as short a time as possible. It is thus important to try and simplify the process as much as possible. This will allow for lower qualified personnel to be able to perform the audit, and to reduce the amount of information that needs to be collected.

1.5.3 Lack of experience

Qualified personnel may have the ability to perform ESCO analysis, but may lack the necessary experience to perform a detailed audit. Learning by experience may not always be the best teaching tools, as this could be a costly exercise. It would be better if the "experience" needed to perform ESCO analysis could be made part of the ESCO procedure, in the form of tools and predefined procedures.

1.5.4 Lack of structured energy audit procedures

Different auditors may have different procedures for completing the audits which means that data captured and methods used will differ from building to building. A structured audit will ensure that minimum amount of time is spent and that all possible savings opportunities are investigated.

1.5.5 Availability of information and data capturing

One of the biggest problems with building audits is the availability of data. It is thus imperative that only essential data, as specified in the audit procedure, be collected during the audit. Current HVAC simulation software requires many detailed inputs, and is more geared towards HVAC design, and not optimising existing HVAC systems. These programs are not geared to produce good estimates of retrofit savings potential in a short time.

The data capture procedure should also be automated to prevent data loss or uncertainty due to ad hoc capturing on pieces of paper, and possibly neglecting to collect all the required data.

1.5.6 Lack of software tools to perform ESCO analysis

Most building simulation tools can be grouped into two types, namely system simulation programs and energy analysis programs [62]. The main aim of system simulation programs is to predict the dynamic response of the HVAC system and building, including the indoor air conditions, system operation points and energy consumption.

Energy analysis programs endeavour to calculate the system energy consumption. There is plenty of building energy tools available in the world today. A website sponsored by the United States Department of Energy hosts an online directory with a listing of over 200 programs [63]. None of these could be found that contains a procedure (not just simulation software) that provides a integrated audit and retrofit procedure. The procedure developed by Geyser [61] attempts to address many of the problems found in commercial buildings. Some limitations of this procedure is that it does not identify all the possible savings opportunities, the auditor needs to be skilled, focuses only on retrofits simulations and excludes practical steps involved in performing energy studies. This procedure was developed as a generic tool and has not been applied or proven to solve the unique audit requirements of telecommunications facilities.

1.5.7 Simulation of proposed retrofits and savings

It is important to be able to simulate the impact of the proposed retrofits. This limits the risks to the ESCO, the client and Eskom DSM. It is also important not to simulate the different systems in isolation but rather in an integrated fashion. An example would be a lighting upgrade in an office block. The savings would not only be the reduced energy consumption of the lights, but also a saving on the HVAC system, due to the reduced heat load in the building.

1.5.8 Consequential reporting

When doing several audits for a single client (for example: Eskom DSM), it is important to have a standard reporting format, and to understand what the client expects in the report. Issues like financial evaluation criteria are important since different criteria may be used for evaluating project viability. The data gathered from the audit should be easily reused when compiling the report, in order to shorten the time taken to compile the report.

It is clear from the above problems that an ESCO procedure is needed that would enable the ESCO to accomplish a building energy audit and retrofit study in the shortest possible time.

1.6 THE NEED FOR NEW ESCO PROCEDURES IN TELECOMMUNICATION FACILITIES

As shown previously the maintenance of the telecommunication facilities are often outsourced to facility managers, and include energy management. Even if the telecommunications company performs its own in-house energy management programme they are still faced with a few unique problems in the telecommunications environment which add to the problems already mentioned in the previous section.

1.6.1 Large number of buildings

As mentioned before telecommunication companies have large number of buildings due to the distributed nature of their services. Telkom SA for instance has approximately 6 500 facilities distributed over the country. Some of these buildings are small single-room buildings but there are also large multi-story buildings. This large number of buildings produces several problems and needs to be addressed with the new ESCO procedure:

- Since there are buildings in all provinces of the country several audit teams will be required in different areas to minimise travel time and time to do the audits. The procedure should thus be implemented by different teams, but by following the same procedures, and produce the same results.
- All the buildings will not be worthwhile to include in an audit. Making the correct selection of which buildings to include from the start will provide the biggest energy savings potential.
- There are several diverse types of buildings in the telecommunications portfolio. The buildings will range from pure telecommunication facilities to commercial buildings, and combinations thereof. The fact that telecommunications equipment requires different environmental conditions than normal office environments means that conventional ESCO procedures are difficult to implement.
- The buildings will have different climates types. It will range from hot, cold, humid, dry or all of these conditions in a single year. The climate conditions have a big impact on the HVAC system performance and possible retrofit options.
- Building location and layout: auditors need to be accompanied by local maintenance personnel to explain the layout of the building and equipment, but also to gain access to the buildings. The availability of these staff presents problems.

1.6.2 Low qualification levels of personnel

The required skill levels present problems if the ESCO analysis is performed by the telecommunication company or outsourced to an external party. Energy management is a specific skill and ESCO analysis requires experience and training. The focus in the most of the telecommunication facilities is on normal routine maintenance and not on the energy efficient operation of equipment. The majority of personnel are thus not trained, nor have the experience to perform energy audits. An audit procedure should thus take into account that auditor will probably not have the necessary experience or qualifications to perform the audit!

1.6.3 Various system configurations

There is a multitude of different HVAC systems and other electrical loads in the buildings. The auditor will thus need to understand the system layout and be able to identify and characterise the different loads. The audit procedure should be able accommodate all the different types of loads and system configurations. The effect of the different loads on the other will need to be characterised in the new ESCO procedure. An integrated building simulation model needs to be developed that will simulate the effect of retrofits on the building.

1.6.4 Planned maintenance does not support DSM

The planned maintenance done by the party responsible for the facility management does not necessarily include ensuring that the equipment is running within energy efficient levels. It is thus important to influence the maintenance philosophy to ensure equipment is not only performing within Service Level Agreement (SLA) with Telkom, but also energy efficiently. This will determine the long-term impact and sustainability of the energy management measures. The new ESCO procedure should make it easy to redo the ESCO analysis if required after retrofits have been implemented to evaluate the efficiency of the system.

1.6.5 Limited cooperation of the building owner/manager

In the telecommunication company structure there is a responsible person for each building. This person is referred to as the building owner/manager. Although energy savings are very important to the telecommunication company, it might not seem to be in the best interest of the site manager. In Telkom SA the company has a formal Energy Management Policy (See Appendix A) that stipulates the need for energy management. The maintenance company also has a similar policy, and agreed to by Telkom SA (See Appendix B).

One example of where the building manager can jeopardise the energy management efforts is where the temperature in the exchange buildings is adjusted upwards to comply with the ETSI specifications. The site manager is used to an under-floor supply temperature of 18°C in the exchange area. Sometimes the auditor would set the temperature back to the 22°C design temperature (ETSI specifications), to reduce the loading of the HVAC system, and thus reduce the energy consumption. In such an event it frequently happens that the auditors would either be ordered off-site or the building manager would simply set the temperature back to 18°C.

The ESCO must therefore get the buy-in from the building manager to support the saving incentives. The new, improved ESCO procedure should therefore be able to prove to the building owner that the proposed retrofits will not have any negative effect on the telecommunication equipment.

1.6.6 Different funding mechanisms

Apart from the Eskom DSM funding mechanism, the telecommunications company might decide to fund retrofits themselves, due to the fast payback periods. The telecommunication company will, however, need to have faith in the ESCO procedure that the estimated retrofit savings are accurate. The financial benefits, and the feasibility of obtaining DSM funding for retrofits, should also be determined in the new procedure.

1.6.7 Critical buildings with high service level agreements

Often the maintenance company is kept to a very strict Service Level Agreement (SLA) with penalties payable for poor service delivery. Optimising the building in terms of energy should never negatively impact on the SLA, since certain buildings are critical to the national telecommunications grid.

Obtaining permission to perform ESCO audits is difficult and it is often impossible to perform physical tests on a system. That is why being able to accurately simulate the proposed retrofits is vital on critical buildings.

1.7 NEED FOR THE STUDY

From the information provided in this chapter, the need for this study can be summarised as follows:

- The peak power demand in South Africa will exceed the available generation capacity by 2007. Eskom is addressing this problem by the implementation of the DSM programme. The DSM programme has, however, only reached 30 % of its targets by the end of 2005.
- One of the main reasons for the low DSM performance is the lack of knowledge and structured processes to perform ESCO analysis.
- Existing procedures are difficult, very time consuming and a costly exercise, especially since the ESCO performs these audits at its own risk.
- Buildings in South Africa present big opportunities for energy improvement, especially by retrofits and better control of HVAC systems.
- It was shown that telecommunication companies own and operate large portfolios of buildings. This presents a big opportunity to optimise the energy usage (saving costs) and contribute to DSM targets.
- Performing an ESCO analyses in the telecommunication environment presents the ESCO with unique problems, which make it difficult to evaluate ESCO opportunities by using conventional audit procedures.
- A new ESCO procedure is required that will address the problems experienced in the telecommunications environment and which will enable the ESCO to evaluate retrofit opportunities *fast*, *reliably* and in a *structured manner*.

1.8 CONTRIBUTIONS

The unique contributions of this study are the following:

- A *list of problems* facing ESCOs when doing ESCO analysis in telecommunications facilities was identified.

- A *new ESCO procedure was developed* specifically for telecommunication facilities. No existing ESCO procedure could be found that has been developed for, applied to, or that meets the specific requirements of, telecommunication facilities. The procedure also reduces the audit times significantly.

- The *new ESCO procedure was implemented and verified* in three different case studies and evaluated against the requirements of ESCO analyses on large telecommunication facilities.
- The procedure incorporates *novel simulation techniques* that were used to create an integrated building simulation model that can accurately simulate building operations.

- *New energy saving opportunities* that are specifically applicable to telecommunication facilities was compiled and incorporated into the new ESCO procedure.

- *Retrofit simulations techniques,* using the simulated building model, were used to evaluate savings potential in the telecommunication facilities. The retrofit simulation also ensures that the proposed retrofits do not negatively affect indoor air quality, by providing simulated zone temperatures.

- *New data capturing procedures, software and tools* were introduced that simplify the data capturing process, by reducing the amount of data required and integrating the data into the rest of the ESCO procedure.

- The procedure provides a *contribution to the DSM programme* since an ESCO procedure is now available that will speed up the ESCO process and provide reliable results that will help Eskom DSM to reach their DSM targets.

- The *feasibility of the facility management company acting as ESCO* was evaluated. The potential other benefits of the new ESCO procedures to the facility management company were also investigated.

- The *reporting of results* is automated by integrating the results and information from the study into a word processing environment.

- The *financial evaluation is an integrated part* of the procedure and automatically uses the results and information from the study to calculate the financial analysis.

- The *"experience" and procedures* required to be able to perform an ESCO analysis on telecommunication facility is embodied in the new procedure. Lower qualified personnel can thus be trained to implement ESCO audits. The ESCO procedure is easy enough to be implemented by the facility management company that is responsible for maintaining the building infrastructure.

1.9 OVERVIEW OF THE THESIS

In *Chapter 1 – Introduction,* the need for energy management in South Africa is introduced. Specific emphasis is placed on the growing demand in South Africa and the problem that Eskom has to supply this increasing demand. The contribution of commercial buildings to this demand problem is introduced. It was shown that HVAC systems contribute more than 50% of the total demand in the buildings, and presents an obvious opportunity for energy management.

Since this study focussed on telecommunication facilities the reader is introduced to Telkom SA and the diverse infrastructure of buildings in its portfolio. The majority of the Telkom portfolio are buildings and thus provide a big opportunity to optimise the HVAC and other systems within these buildings. It was shown that HVAC systems in telecommunication facilities huge opportunities for savings since it represents 55% of the total building load.

The problems with ESCO implementations in commercial buildings are discussed. The specific problems facing ESCO implementations in telecommunication facilities are introduced and form the background to the need for the new procedure.

In *Chapter 2 – New Data Acquisition Procedures*, the reader is introduced to a new data capturing procedure. In this chapter the needs and problems with audit procedures are elaborated and the new automated procedure described. The procedure automates the audit process, limits the amount of data required and shortens the time taken for the audit.

In Chapter *3 – New ESCO Procedure for Telecommunication Facilities,* the new ESCO procedure is introduced. It takes the reader through the whole process and explains the impact of each step. The procedure is evaluated against known energy management opportunities within Telkom SA, to analyse the value add of the new procedure.

In Chapter 4-6 the new ESCO procedure is implemented and verified on five different types of telecommunication buildings. Retrofit changes are suggested for each building. The first building (Chapter 4 – Telkom Towers South) is a typical commercial building with limited telecommunication equipment, and with a large centralised HVAC system. The second group of buildings that is analysed (Chapter 5 – Telkom Towers North complex) comprises of 3 different buildings serviced by a common HVAC system and includes and ice plant. In Chapter 6 (Data building) the new ESCO procedure was implemented on a building that consists mainly of telecommunication equipment and some commercial activity. The purpose of the case studies is to evaluate the application of the new ESCO procedure and to provide recommendation on how the process can be enhanced.

In Chapter 7 the results and contributions are summarised and the need for further work discussed.

1.10 REFERENCES

[1] Capehart, B.L., Turner, W.C., Kennedy, W.J., "Guide to Energy Management", 2nd edition, Lilburn: Fairmont Press, p.1, 1997.

[2] Ashok, S., Banerjee, R., "Load-management Applications for the Industrial Sector", Applied Energy, Vol. 66, pp. 105-111, 2000.

[3] Den Heijer, W., "The Development of a Methodology to Benchmark the Energy Consumption of Commercial Building", Thesis presented in partial fulfilment of the requirements for the degree Master of Engineering, Potchefstroomse Universiteit vir Christelike Hoër Onderwys, Potchefstroom, 1998.

[4] Philip, B., "Framework for improving energy efficiency in South Africa – the case of low-income household", SEPCO Workshop, National Electricity Regulator, November 2001.

[5] Department of Minerals and Energy, "White Paper on Energy Policy for Republic of South Africa", Private Bag X 59, Pretoria, 0001, December 1998.

[6] National Electricity Regulator, "Electricity supply statistics for South Africa 1999", PO Box 40343, Arcadia, 0007, Republic of South Africa, 4600, p.4, 1999.

[7] Eskom Online, Frequently asked questions, Available: http://www.Eskom.co.za/main.asp?curl=faq%2Ftopicindex%2Easp%3Fcatid%3D1, 26 September 2001.

[8] National Electricity Regulator, "An Integrated Electricity Outlook for South Africa", PO Box 40343, Arcadia, 0007, Republic of South Africa, 4600, 2002. (*Document was only available for a few months until April 2002 for public discussion and planning*).

[9] Gcabashe, T.S., "Connecting for Growth", Eskom News, Eskom, PO Box 1091, Johannesburg, p.2, May 2003.

[10] Department of Minerals and Energy, "Integrated energy plan for the Republic of South Africa", Private Bag X 59, Pretoria, 0001, p 9, March 2003.

[11] Surtees, R.M., "Electricity Demand Growth in South Africa and the role of Demand-side Management", In: Proceedings of Domestic Use of Energy 1998, Cape Town: Cape Technikon, 1998.

[12] De Kock, N.C.J.M., "Optimising the load shift potential of the clear water pumping system on a South African Gold Mine", Final project report presented in partial fulfilment of the requirements for the degree Bachelor of Engineering, Electrical & Electronic Engineering, North West University, Potchefstroom, 2005.

[13] Eskom, "Demand-side Management's Information Guide for Energy Services Companies", http://www.eskomdsm.co.za/download.php, Eskom, PO Box 1091, Johannesburg, 2002.

[14] Kok, S., "The impact of domestic solar water heaters on South Africa", TEMM International (Pty) Ltd, PO Box 55577, Arcadia, 007, p.44, 1994.

[15] Eskom, "Eskom Supports Energy Efficiency with DSM Programme", In: Proceedings of Industrial and Commercial Use of Energy 2005, Cape Town: V&A Waterfront, 25-27 May 2005 (*paper available at http://www.eskomdsm.co.za/news8.php*).

[16] Eskom, "Eskom Holdings Annual Report 2005", Available: http://www.eskom.co.za/annreport05/, Eskom, PO Box 1091, Johannesburg, p.106, 2005.

[17] Nortje, T., "South Africa's DSM Program: A savings opportunity", Eskom DSM, International Pump User Conference 2005, Johannesburg, 8 June 2005.

[18] Eskom, "Research and Development: DSM, In-line water heating concept", Available: http://www.eskomdsm.co.za/res_dev/res_dev.php, Eskom, PO Box 1091, Johannesburg, pp.106, 2002.

[19] Measurement & Verification, "CTAD Quarterly Report", Eskom, PO Box 1091, Johannesburg, August 2005.

[20] African National Congress, "The Reconstruction and Development Program: A policy framework", PO Box 61884, Marshalltown, 2107, p.28, 1994.

[21] Department of Minerals and Energy, "Capacity Building in Energy Efficiency and Renewable Energy", Private Bag X 59, Pretoria, 0001, Report No. 2.3.4 – 31, September 2005.

[22] Nadel, S., Zhirong, Y., Yingyi, S., "Integrated Resources Planning and Demand-Side Management Manual for China and Other Developing Countries", Available: http://www.aceee.org/pubs/i953.htm, 16 July 2002.

[23] Limaye, D.R., Balakrishnan, S., Lyons, C., "The Role of ESCOs in Promoting Energy Efficiency and Environmental Protection in Developing Countries", Regional Energy Forum for Southern & East African Countries, http://www.worldenergy.org, 5th Floor, Regency House, 1- 4 Warwick Street, London W1B5LT, United Kingdom.

[24] National Association of Energy Services Companies, "What is an ESCO?", Available: http://www.naesco.org/about/esco.htm, 1615 M Street, NW, Suite 800, Washington DC, 20036, USA, June 2000.

[25] Janada, K.B., Busch, J.F., "World-wide status of energy standards for buildings", Energy, Vol.19, No.1, pp.27-44, 1994.

[26] Drozdov, V.A., Matrosov, Y.A., Tabunschikoc, Y.A., "The main trends in energy savings in buildings – Theory and practice in U.S.S.R", Energy and buildings, 1989.

[27] Organisation for Economic Cooperation and Development (OECD), "Energy and Statistics of OECD countries", OECD Publications, 2 Rue André-Pascal, 75775, Paris Cedex 16, 1993.

[28] Andersen, J.J., "Cape Town Electricity Load Study and End-Use Segmentation", Proceedings of the seminal and main steering committee meeting demand-side management and related projects, DMEA, Private Bag X59, Pretoria, 0001, April 1993.

[29] Rousseau, P.G., Mathews, E.H., "Needs and trends in integrated building and HVAC thermal design tools", Building and Environment, Vol. 28, No.4, pp.439-452, 1993.

[30] TEMM International (Pty) Ltd., "Energy savings potential and guidelines for effective energy use in buildings", Project report compiled for the Department of Mineral and Energy Affairs: Energy Branch, Pretoria, 0002, March 1997.

[31] Department of Mineral and Energy, Available: http://www.dme.gov.za, Private Bag X 59, Pretoria, 0001, 25 October 2001.

[32] Deringer, J.J., Busch, J., "Energy standards", Final Report, ASEAN Building Energy Conservation project, Vol.1, Lawrence Berkeley Laboratory report LBL-32380, Berkeley, CA, June 1992.

[33] Wilson, D., Schipper, L., Tyler, S., Bartlett, S., "Policies and programs for promoting energy conservation in the residential sector: Lessons from five OECD countries", Lawrence Berkley Laboratory report LBL-27289, Berkeley, CA, June 1989.

[34] Kissock, J.K., Clardige, D.E., Haberl, J.S., Reddy, T.A., "Measuring retrofit savings for the Texas LoanSTAR Program: Preliminary methodology and results", Solar Engineering, Vol.1, ASME, 1992.

[35] "Performance contracting pays off", Air Conditioning Heating & Refrigeration News, Vol.209, Issue 14, p.41, April 2000.

[36] Aires-Barros, L., "The energy efficiency revolution: formula for success", Global Energy Issues, pp.111-116, 1990.

[37] Bevington, R., Rosenfield, A.H., "Energy for buildings and homes", Scientific American, pp.207-215, September 1990.

[38] Mozzo, M.A., "The state of the energy service company today", Energy Engineering, Vol.95, No.4, pp.67-69, 1998.

[39] Botha, C.P., "Simulation of a building heating, ventilation and air conditioning system," Thesis presented in partial fulfilment of the requirements for the degree Master of Engineering, Faculty of Engineering, University of Pretoria, Pretoria, 2000.

[40] TEMM International (Pty) Ltd, "Development of an integrated tool for the quick auditing of commercial buildings by energy service companies", Document proposed to the Support Programme for Industrial Innovation, 26 April 2001.

[41] Spoormaker, H.J., "Energy conservation during refurbishment", Presented on Energy Management Day Conference, Eskom, PO Box 223, Witbank, 1035, August 1995.

[42] Woods, J.E., "Cost avoidance and productivity in owning and operating buildings", Occupational Medicine, State of the art reviews, Vol.4, No.4, January 1989.

[43] Sterling, E., Collett, C., Turner, S., Downing C., "Commissioning to avoid indoor air quality problems", Proc. ASHRAE Transactions: Symposia, p.867, January 1994.

[44] Mathews, E.H., Piani, C.B., "Establishing the energy savings potential in South African office buildings", Refrigeration and Air conditioning, Vol.12, No.4, pp.59-65, July 1996.

[45] "Performance contracting", American School & University, Vol.70, Issue 4, p.18, December 1997.

[46] Lebrun, J., "Simulation of HVAC systems", Renewable Energy, Vol.5, Part 2, pp.1151-1158, 1994.

[47] "The heat is on...manage energy wisely", Hotel and Motel Management, Vol.211, Issue 21, p.24, December 1996.

[48] TFMC, "Introduction to TFMC", Available : http://www.TFMC.co.za, TFMC, Meersig Building, Cnr West and Lenchen Avenue, Centurion, 2005.

[49] Eskom, "Telecommunications sector review", Available: http://www.eskom.co.za/live/content.php?Item_ID=953, Eskom, PO Box 1091, Johannesburg, pp.106, 15 December 2005.

[50] Telkom, "Telkom SA Annual report: 2004", Available: http://www.telkom.co.za/pls/portal/docs/page/contents/minisites/ir/docs/Final.pdf, Telkom SA, Telkom Towers North Building, Pretoria, p43, 2004.

[51] Rycroft, M., "Energy Management in Telecommunications Networks", Electron Journal, SAIEE, Vol 17 No. 6, South Africa, pp.34-55, 2000.

[52] Rabie, N., "Investigation into various methods of climate control in a telecommunications environment with reference to energy management", EIX 788 Final Report, CNES, Department of Electrical, Electronic and Computer Engineering, University of Pretoria, p.3, 2000.

[53] Havenga, J.H., "Personal consultation throughout 2003 and 2004", TFMC: HVAC Design Engineer, TFMC (Pty) Ltd, Tel +2712 643 8000.

[54] Hannon, K., "Personal consultation throughout 2003 and 2004", TFMC Senior HVAC Maintenance Specialist, TFMC (Pty) Ltd, Tel +2712 643 8000.

[55] Parsons, J., "Reducing the Costs of Network Power & Cooling", IEEE, 0-7803-3996-7/97, pp.277-284, 1997.

[56] Johansson, A., "Are telephone Exchanges Energy Efficient?", Proc. INTELEC, Paris, pp. 100-105, 1993.

[57] Rabie, N., "Energy Management in a Telecommunications environment with associated energy and cost modelling of HVAC", Thesis presented in partial fulfilment of the requirements for the degree Master of Engineering, Faculty of Engineering, University of Pretoria, September 2001.

[58] Magnus, K.H., "Economic Benefits of Energy Savings Associated with: (1) Energy Efficient Telecommunications Equipment; and (2) Appropriate Environmental Controls", IEEE, 0-7803-3507-4/96, pp.731-736, 1996.

[59] Bengtsson, A., Ahnmarker, L., Akerlund, J., "A Three-Year Campaign for Saving Energy at Telia", IEEE, 0-7803-2750-0/95, pp.191-195, 1995.

[60] Stein, J., "How to Avoid Common Mistakes in Energy Efficiency Projects", Energy Engineering, Vol.93, No.4, pp.41-50, 1996.

[61] Geyser, M.F., "A New Integrated Procedure for Energy Audits and Analyses of Buildings", Thesis presented in partial fulfilment of the requirements for the degree PhD of Engineering, Mechanical Engineering, Potchefstroomse Universiteit vir Christelike Hoër Onderwys, p76, 2003.

[62] Lebrun, J., "Simulation of HVAC systems", Renewable Energy, Vol.5, Part 2, pp.1151-1158, 1994.

[63] Building Energy Software Tools Directory, Available: http://www.eere.energy.gov/buildings/tools_directory, United States Department of Energy, Washington DC, 2003.

2. NEW DATA ACQUISITION PROCEDURE FOR TELECOMMUNICATION FACILITIES

2.1 INTRODUCTION

It was shown in Chapter 1 that the need exists for a new ESCO procedure in telecommunication facilities. A new integrated ESCO procedure needs to be developed and evaluated for ESCO analysis of large telecommunication facilities.

The new procedure incorporates novel simulation techniques and data capturing methods into a structured procedure to perform a building retrofit audits in an integrated fashion.

In this chapter the new data capturing procedure is introduced. The need exists for a new data capturing and handling procedure that will form part of the new ESCO procedure and will address the following problems:

- The new data capturing procedure should identify and lead the ESCO to capture only the minimum amount of data required for the ESCO analysis, and thus reduce the time taken for data capturing, and thus the whole ESCO process.
- The data capturing procedure should be a paperless system in order to automatically integrate the captured data into the rest of the ESCO process.
- The data capturing procedure should be easy and user friendly enough for less skilled users to understand and use the system. This will mean that less skilled or less experienced personnel can be used for the data capturing process.
- The data capturing procedure should include templates for the different equipment types found in the telecommunication environment. The templates for similar building types should be reused or edited, to reduce the audit time on similar buildings.

The procedure should support the ESCO to perform ESCO analysis on a large number of diverse building types. This chapter will focus on these new solutions and form the procedure for data handling in the new ESCO procedure. The proposed solutions to these requirements are defined in Table 2-1 below:

Requirement	Solution
Identify and lead the ESCO to capture only the minimum amount of data.	Create customised software that suggest, collect and store all relevant data.
The data capturing procedure should be a paperless system.	Use a personal digital assistant (PDA) device.
Collected data needs to be automatically transferred to the integrated simulation program to save time and minimise errors.	The PDA will download and synchronise data with the rest of the software used in the ESCO procedure.
The procedure should be easy to use and be user friendly: less skilled or experienced users need to use it.	Program flow should be grouped according to the logical zone, and equipment structures. Create life-like systems and make use of pictures.
The data capturing procedure should include templates for the different equipment types, and should be customisable to be re-used on other buildings.	HVAC systems are created by customising templates, and drag-and-drop components. Projects can be saved and reused for similar buildings.

Table 2-1: Requirements of the new building data acquisition system

2.2 DATA GATHERING PROBLEMS UNIQUE TO TELECOMMUNICATION FACILITIES

Some of the challenges that makes data capturing unique for telecommunication facilities are discussed below:

2.2.1 Distribution of buildings

One of the biggest challenges in performing ESCO work in telecommunication facilities is the distribution and large number of buildings. Telecommunication companies usually have a national footprint and are spread over the whole country. These buildings, unlike normal commercial facilities, are located wherever telephone coverage is required. They might be in a city centre or on a mountain due to the transmission requirements. The nearest maintenance office could be as far as 400km from the building (as is the case with Telkom SA), and often 4x4 vehicles are required to reach these buildings. The point has to be made that when doing the analysis the ESCO will often not be able to visit the building more than once or twice. The ESCO should therefore know exactly what information to obtain and what measurements are required.

It also might be the first time the ESCO visits the building and they will have no prior knowledge of the layout. The correct maintenance personnel should be arranged to be on-site to aid the ESCO in obtaining the correct information.

2.2.2 Lack of information on building HVAC systems

The age of the buildings and infrastructure will range from new buildings to buildings that are more than 20 years old [1].

It also happens, as is the case with Telkom SA, that the facility management was outsourced to an external company, for example TFMC. During the outsourcing personnel was transferred to TFMC and it is difficult to maintain the necessary skills and knowledge base. The new maintenance personnel might not fully understand the functionality of the HVAC systems.

Typical information like equipment specifications, set points, floor layouts, current performance etc. might be available, but will most likely be outdated for older buildings. Since the HVAC system is by far the biggest energy user in telecommunication facilities, it is essential that the correct HVAC system information be obtained.

2.2.3 Operational changes in buildings

Telecommunication equipment has evolved from big electromechanical switches to small digital switches. This reduced the floor space required for equipment by up to 60%, and also the heat load on the HVAC systems [2]. The design condition of most buildings would thus have changed and current information will not be available.

Due to this change in telecommunications equipment more floor space has become available. This presents the opportunity to reuse some of the telephone exchange areas that are unoccupied. This space is either converted to office space, or rented out to other companies.

Updating the building designs on such a large scale, becomes an enormous task and unfortunately means that the information available from the building owners might not be updated.

The conclusion can be made that accurate building information might not be available from the building owner's archives or building maintenance personnel. The new data capturing process should not rely on the availability of such information. The auditor should be equipped to measure and derive all the necessary information from visits to the site. Since time is critical in the ESCO process, it is often much easier to measure the required data than to wait for external parties to provide the auditor with information.

The detailed information that is required for the new ESCO procedure in telecommunication facilities is described in Appendix C. The information is derived from identified energy management opportunities in Telecommunication facilities [3], [4].

2.3 DATA CAPTURING DEVICES AND MEASUREMENT EQUIPMENT

The new data gathering procedure was developed to be used with a Personal Digital Assistant (PDA). A PDA is a handheld electronic device used mainly as a diary and phonebook, but can also operate programs. A picture of a typical PDA is shown in Figure 2-1:

Figure 2-1: Personal digital assistant

The data that needs to be collected for a building audit can be categorised as building, equipment and zone data. Equipment data is further divided into air-circuit and water-circuit data. The auditor usually visits the plant room and rooftop of the building to gather this information. The zone data are collected by means of a walkthrough audit. Studying "as-built" drawings is also useful to obtain equipment specifications.

The user will need the following measuring equipment to obtain all the simulation component input data if not documented or measured by the BMS system:

- ***Measuring tape:*** To measure zone dimensions
- ***Anemometer:*** To measure air flows
- ***Thermometer with probe:*** To measure water temperatures
- ***Hygro-thermometer with probe:*** To measure air temperatures and relative humidities
- ***Three phase power logger:*** To log three phase electrical power over time
- ***Temperature and RH logger:*** To log climate temperatures and humidity over time
- ***Manometer:*** To measure air pressure differences

The new integrated way of data acquisition addresses the need to guide the auditor in the collection of the required data, in the most productive way possible. The data collection tool forces the user to collect only essential data that saves a lot of time that would have been wasted on unnecessary data gathering. The data acquisition software is also designed in the most user friendly way. This enables the auditor to reduce the amount of time spent on data collection. Data is keyed in an easy fashion and it is downloaded in a few seconds into the simulation program [5].

The initialisation screen of the data capturing software interface on the PDA is shown in Figure 2-2. A new project can be created, zone and equipment specified.

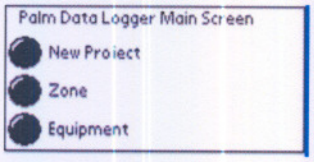


Figure 2-2: Initialisation screen of data capturing interface

2.4 DEFINING ZONE INFORMATION

The amount of zone data required for the new ESCO procedure has been reduced significantly. The zone model is constructed in a very fast and easy way. No complex technical data is required for the building. Instead, the user is given a set of choices, for example orientation, dimensions, surface structure, ventilation, etc. This prevents the input of unnecessary data that will have a negligible effect on the building thermal characteristics [6],[7].

Zones are defined by the auditor. Recommendations on how to select and define zones are discussed in more detail in Chapter 3. The zone program functionality consists of an interface that displays the underlying zone information in a list format. Individual records can be added, edited, copied and deleted.

The zone attributes that need to be defined are displayed in Figure 2-3. Zone records are made up of five different data groups: description, dimensions, structure data, internal heat generation information, and control information.

Figure 2-3: Zone data capturing interface

2.4.1 Zone description

The **description** interface allows ESCO auditors to enter a unique description for the specific zone being configured and shown in Figure 2-4.

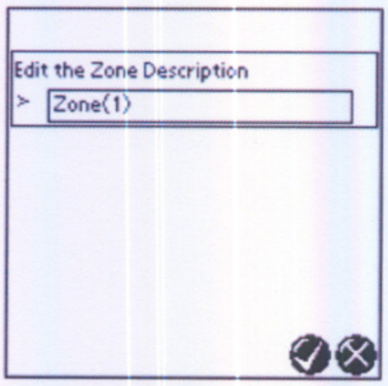


Figure 2-4: Zone description interface

2.4.2 Zone dimensions

Zone **dimensions** are recorded to characterise the physical layout of zones. North wall length, ground floor area, number of stories, total internal wall length and building orientation are recorded in the interface of Figure 2-5.

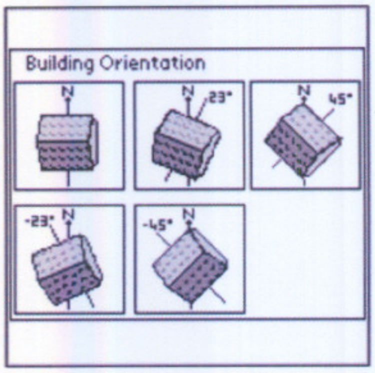


Figure 2-5: Zone dimensions and orientation interface

2.4.3 Zone structure

The zone **structure** describes zone surface properties and can be selected as shown in Figure 2-6.

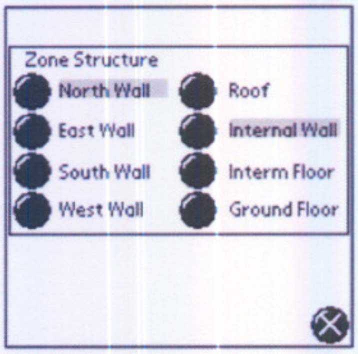


Figure 2-6: Zone structure interface

Thermal characteristics of the building structure determine how the building behaves at different thermal conditions and seasonal changes. The north wall characteristics (most thermal exposure) should be entered as shown in Figure 2-7.

Figure 2-7: North wall interface

2.4.4 Zone internal heat loads

Internal heat loads of each zone also need to be identified. The internal zone loads can be categorised by occupancy, lighting and other loads in the PDA software.

The first selection is the human **occupancy** of this zone. The peak occupancy of the zone is entered with a choice of leisure, office work or extensive physical activity. This will characterise how heat radiation from people will be added to zone.

The next selection is to quantify the **lighting** within the zone. The lighting type, number of units and power consumption must be entered.

The **other loads** selection is used to describe all the remaining load in the building. For exchanges the biggest loads would be the rectifiers that supply DC power to the telecommunications equipment.

Although the operating hours of equipment are not yet entered the information will be used later on in the simulation model. Figure 2-8 shows the inputs screens for capturing the internal load information.

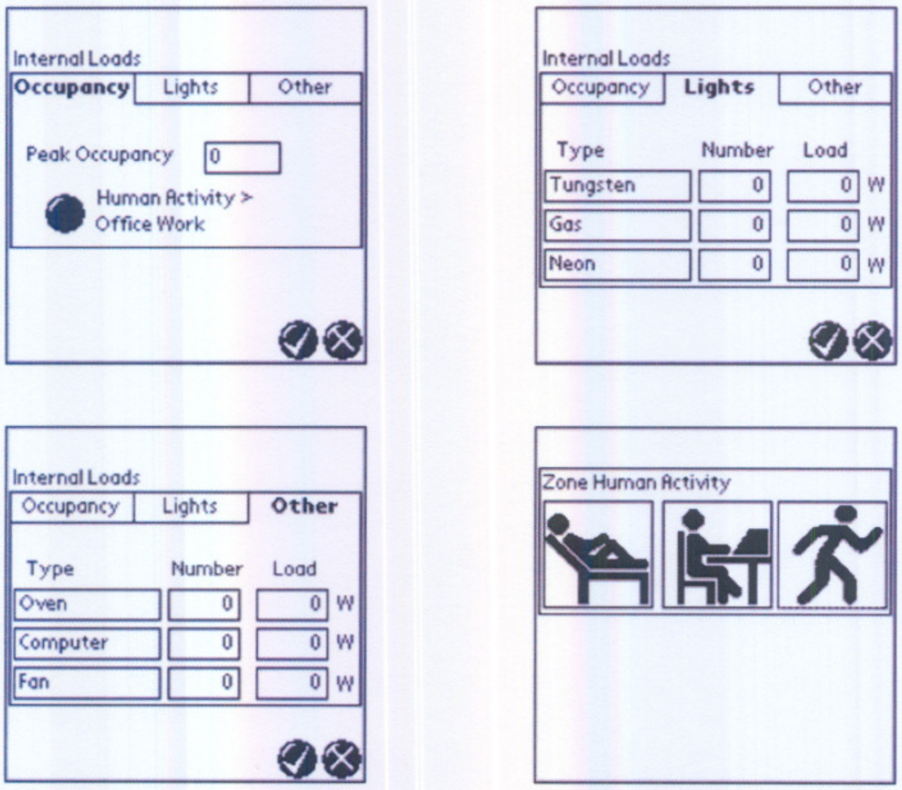


Figure 2-8: Zone internal loads interface

2.4.5 Zone control

The Zone control interface specifies the control strategies for the specific zone. This is important information to ensure that the HVAC system simulation controls the HVAC components correctly. An explanation of the zone control attributes is provided:

- The **temperature control** of a zone is specified in a control range. When the air conditioning schedule is active the system will control the zone temperature between the entered minimum and maximum temperature inputs.
- **Relative humidity** (RH) of zones is also controlled within a range. When the air conditioning schedule is active the system will control the zone RH between the entered minimum and maximum RH inputs.
- With the **volume flow** the auditor can either select constant air volume or variable air volume. Variable air volume means that the indoor temperature is controlled by supply air dampers in the building zone. The user will have to specify the minimum and maximum air flow into the building zone. The user can either obtain these flow values from the design specifications or measure it on-site. Variable air volume control is popular within office environment whereas the majority of equipment cooling is done with constant air volume due to the constant heat load in the building.

The Zone control interface is shown in Figure 2-9:

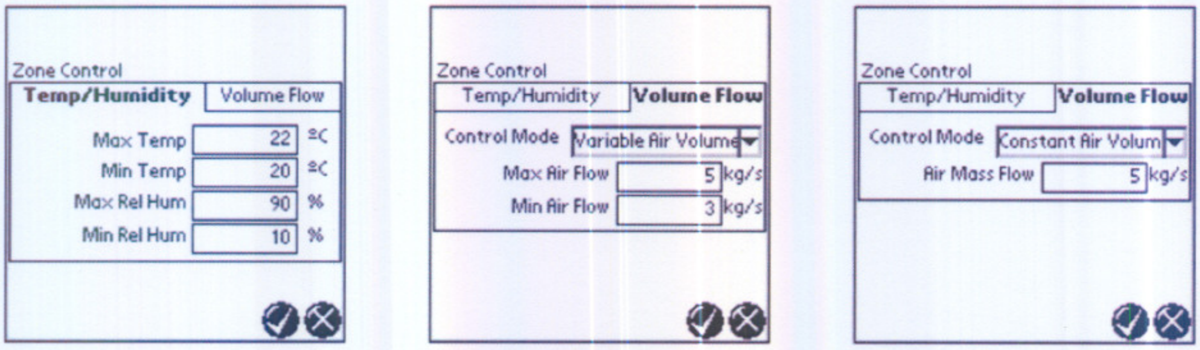


Figure 2-9: Zone control interface

A special equipment combination function helps the ESCO auditor to combine data of different cooling coil, heating coil and fan records. The user selects two or more record entries that he or she would like to combine as shown in Figure 2-10. Once the selection is made, the "Combine" function automatically creates a new entry in the structure. This is used to further simplify the HVAC system layout.

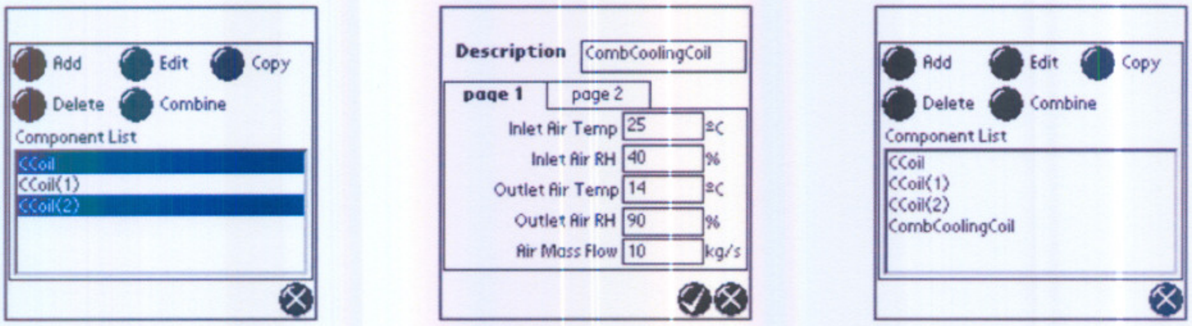


Figure 2-10: The combine function of the cooling coil component

2.5 DEFINING THE HVAC SYSTEM EQUIPMENT

Any type of HVAC system found in the telecommunications buildings can be configured in the PDA software (or on PC software and downloaded to the PDA). Each component in the software represents the respective component of the actual HVAC system. To accomplish this, the program makes use of a graphical representation of the different types of HVAC equipment. The HVAC system is constructed by graphically building a water- and air-circuit in the software and is discussed below.

2.5.1 Air-circuit

Table 2-2 provides an overview of the air-circuit components that are used to build up the air-circuit model in the PDA data acquisition software. For every component a brief functional purpose, example picture and an example PDA data logger program interface layout are provided [8].

More detailed information on the configuration and functionality of the air-circuit components are shown in Appendix D.

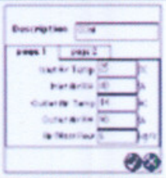
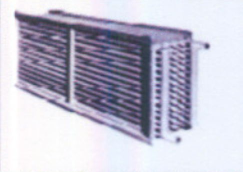
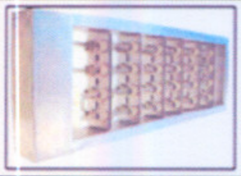
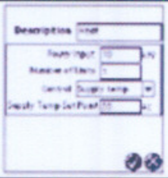
Description of the relevant components.	The purpose of the component in the HVAC system.	Example picture of the equipment.	*Palm data logger interface.*
		AIR CIRCUIT	
Cooling coil	This unit transfer the heat from the air- to the water circuit, thus reducing the temperature of the air. It is usually situated in an AHU.		
Heating coil	This unit transfer the heat from the water- to the air circuit, thus increasing the temperature of the air. It is usually situated in an AHU.		
Evaporative cooler	The temperature of an moving air is cooled down by an evaporation process. The humidity of the air is also adjusted inside this unit		
Fan	A fan creates air-mass-flow in the duct systems of HVAC installations.		
Fresh air ratio	Usually this is a mixing room complex, where return zone air is mixed with fresh air. Air also passes through an initial filter system before it is returned to the AHU.		
Heater	Electrical heating units heat air before it flows back to the zone		

Table 2-2: Air-circuit components

Figure 2-11 shows the model-building environment for the air-circuit. The air-circuit interface consists of eight components that can be manipulated by the auditor to represent the actual air-circuit of the HVAC system being constructed. The components include the cooling coil, heating coil, evaporative cooler, fan, fresh-air-ratio, heater, zone, and environment input components.

More detailed information on the model-building environment for the air-circuit components are shown in Appendix E.

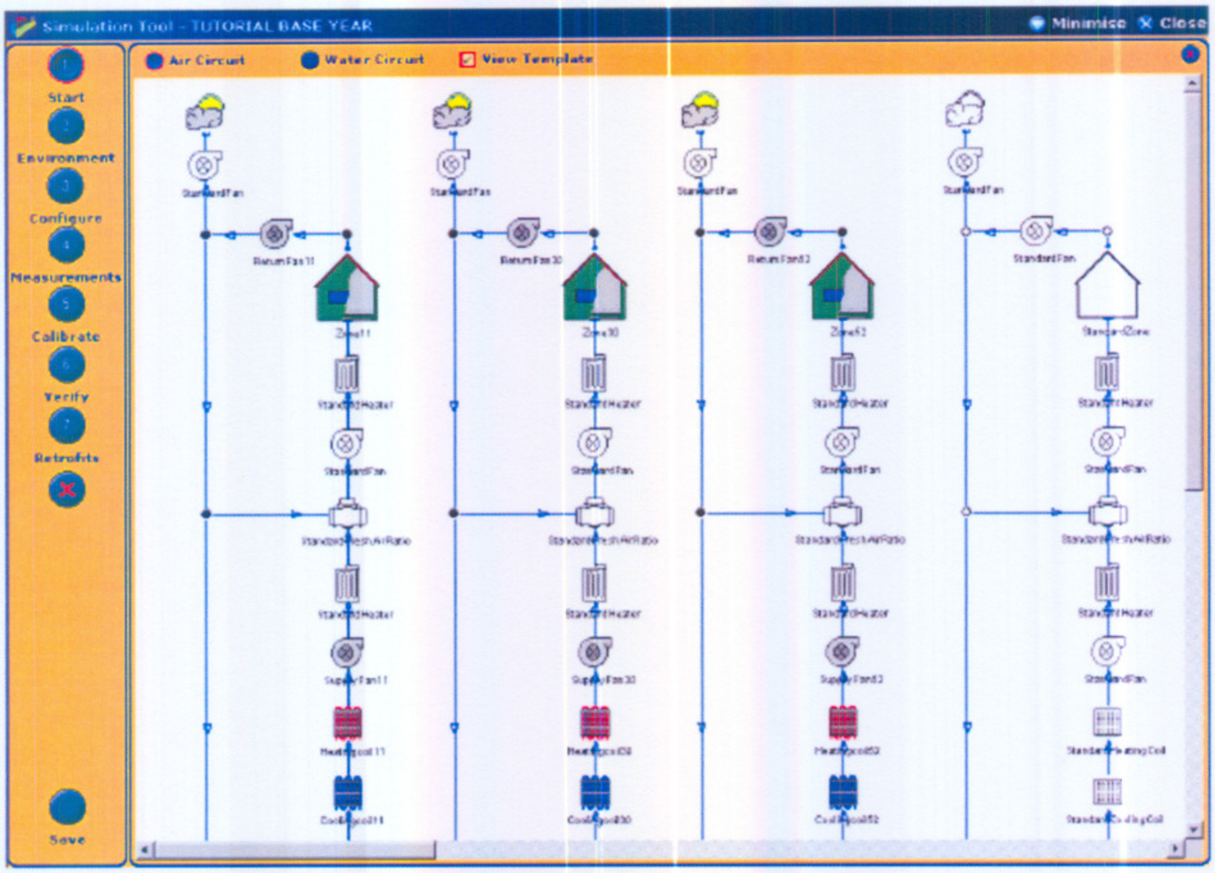


Figure 2-11: The model building environment: air-circuit

2.5.2 Water-circuit

Table 2-3 provides an overview of the water-circuit components that are used to build up the water-circuit model in the PDA data acquisition software. For every component a brief functional purpose, example picture and an example PDA data logger program interface layout are provided [8].

More detailed information on the configuration of the air-circuit components are shown in Appendix D.

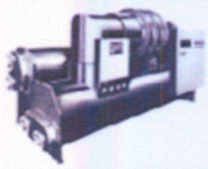
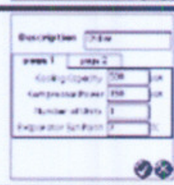
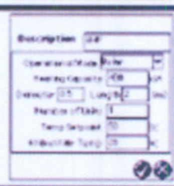
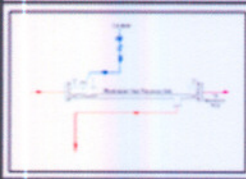
Description of the relevant components.	The purpose of the component in the HVAC system.	Example picture of the equipment.	*Palm data logger* interface.
WATER CIRCUIT			
Cooling tower	Heat is removed from the water-cooled condensers of air-conditioning systems by contact with the atmosphere. This is accomplished by natural draft or mechanical draft cooling towers.		
Pump	The water-pump creates water-mass-flow in the pipe systems of HVAC equipment.		
Chiller	Chillers cool water or other fluid that is circulated to a remote location where it is used to cool air with a cooling coil in an AHU.		
Heat pump	The heat pump is a system where refrigeration equipment is used such that heat is taken from a heat source and given up to the conditioned space, where heating service is needed.		
Boiler	Boilers heat water. The heated water is used by the HVAC equipment for heating air purposes.		
Water heat recovery	Heat energy is recovered from waste water. Redistribution of heat energy within a building structure can be accomplished through the use of heat pumps		

Table 2-3: Water-circuit components

Figure 2-12 shows the model-building environment for the water-circuit. The water-circuit interface consists of six components that can be manipulated by the auditor to represent the actual air-circuit of the HVAC system being constructed. The components include the cooling tower, pump, chiller, heat pump, boiler and water heat recovery units.

More detailed information on the model-building environment for the water-circuit components are shown in Appendix E.

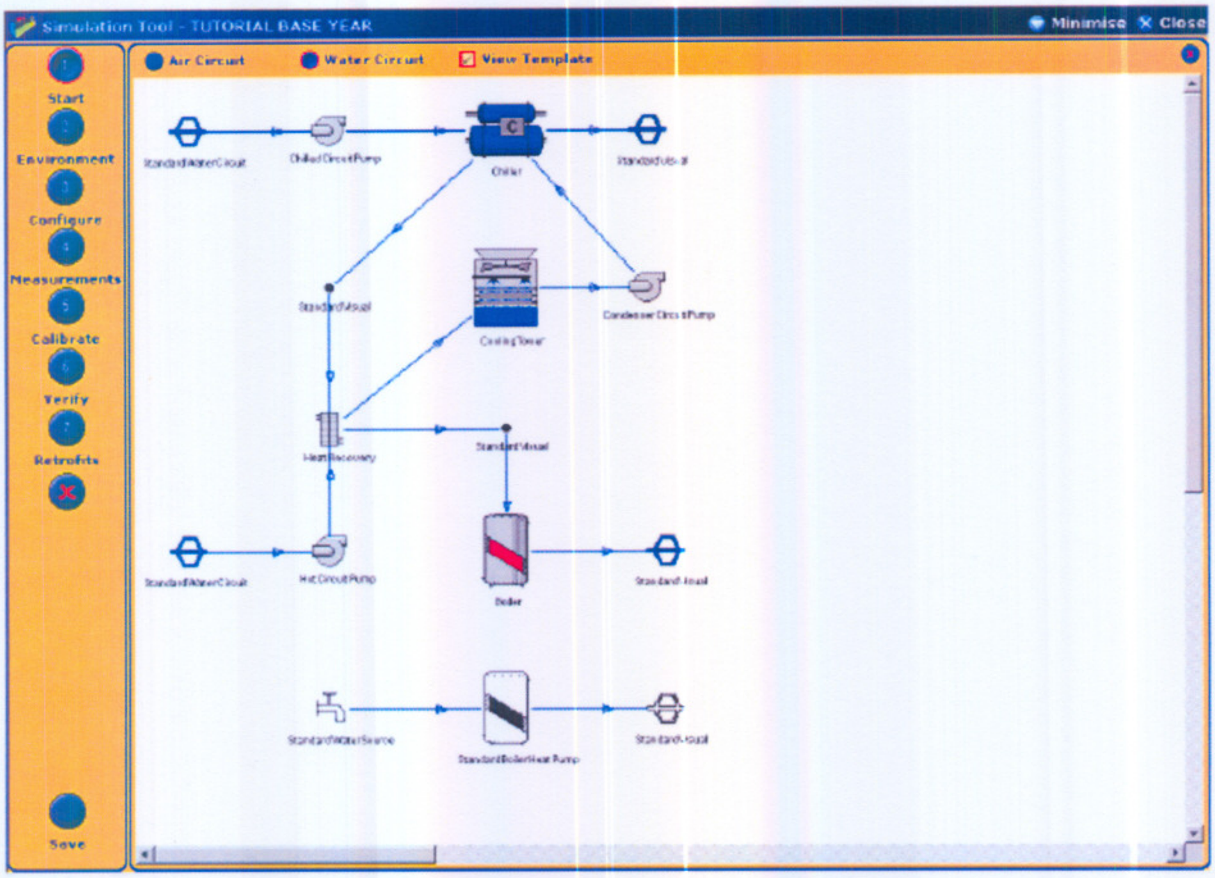


Figure 2-12: The model building environment: water-circuit

2.6 ADVANTAGES OF NEW DATA CAPTURE METHODS

The advantages of the new data capturing procedure are defined below:

- The data capturing procedure shortens the time required to perform data acquisition and thus also the whole ESCO analysis.
- The new procedure ensures that all required data is captured, and that no essential data is missed during the audit.
- The new procedure leads inexperienced auditors in following the correct audit procedure.
- It also ensures that no unnecessary data is captured wasting time on measurements that will not have a big effect on the results.
- Since data is captured on a PDA the data can be used in the next steps of the ESCO process.

- The layout of the HVAC system (water- and air-circuits) is configured in the building model and can be reused for similar buildings.
- The data is stored in a database and can be used with other information systems.
- The data is automatically available for inclusion when writing the final report.

2.7 CONCLUSION

In this chapter the data capturing procedure and data requirements for the new ESCO procedure was discussed. The fact that auditors use different processes to perform building audits meant that a standardised process and predefined data inputs needed to be defined.

The data capturing procedure has been automated by using software specifically developed for a PDA that will upload information from the device to a PC and therefore ensuring a paperless system.

The new data capturing procedure uses a graphical representation of the HVAC system components to recreate the HVAC system. The critical measurements/inputs for each component have been predefined, guiding the ESCO to only capture the relevant data.

The data capturing software uses pictures as much as possible to guide the less skilled/less experienced auditor in making the correct selection. It is however necessary for the auditor to have a basic understanding of the HVAC system, or be able to consult with maintenance personnel.

With the use of the software on the PDA, projects can be saved, and reused when similar buildings are encountered. This will reduce the audit times when similar buildings or HVAC system is encountered.

In the next chapter the full ESCO procedure is discussed, incorporating the data capturing procedure described in this chapter.

2.8 REFERENCES

[1] Hannon, K., "Personal consultation throughout 2003 and 2004", TFMC Senior HVAC Maintenance Specialist, TFMC (Pty) Ltd, Tel +2712 643 8000.

[2] Debbo, G., " Why New Generation Networks in Africa?", In: Proceedings of SATNAC 2004, Spier Wine Estate, Capetown, 2004.

[3] Van Rensburg, J.F., "Project NEON Energy Savings Initiatives", TFMC: Maintenance Engineering, Document Number: None, Meersig Building, Cnr Lenchen & West avenue, Centurion, June 2004.

[4] De Villiers, A., "Proposed Energy Management Plan/Process", TFMC: Professional Services, Document Number: TFMC-PS-0300, Meersig Building, Cnr Lenchen & West avenue, Centurion, July 2002.

[5] Geyser, M.F., "Personal consultation throughout 2004 and 2005", HVAC International (Pty) Ltd., Tel +2712 991 5110.

[6] Ellis, M.W., "New simplified thermal and HVAC design tools", Thesis presented in partial fulfilment of the requirements for the degree Philosophiae Doctor, Faculty of Engineering, University of Pretoria, Pretoria, 1999.

[7] Mathews, E.H., "Personal consultation during 2003 to 2004", CRCED, Pretoria, Tel +2712 991 3181.

[8] Van Rhyn, D., "The Design and Implementation of Information Systems for ESCO Energy Savings Software", Thesis presented in partial fulfilment of the requirements for the degree Master of Engineering, Mechanical Engineering, Potchefstroomse Universiteit vir Christelike Hoër Onderwys, Potchefstroom, 2003.

3. NOVEL ESCO PROCEDURE FOR TELECOMMUNICATION FACILITIES

3.1 INTRODUCTION

In the previous chapter new data capturing methods and procedures were introduced. It was shown that these new processes assist in drastically shortening the time to perform data collection, lead inexperienced auditors to capture only essential information, automate the process to ensure a paperless system and allow the data to be used in the rest of the ESCO process. These data capturing procedures form part of the new ESCO procedure. In this chapter the new ESCO procedure will be introduced.

The general energy audit procedure can be described as follows [1]:

- Identify the types and costs of energy use
- Understand how this energy is being used, and possibly wasted
- Identify and analyse alternatives such as improved operational techniques and/or new equipment that could reduce the energy costs
- Perform an economic analysis on the alternatives and determine which ones are cost effective for the business

When reading through this general procedure it makes a lot sense and sounds simple. Why the need for a new procedure for telecommunication facilities?

In previous chapters a lot has been said about the problems experienced while performing ESCO analyses in telecommunication facilities. Some of these problems are highlighted below to provide further background to the need for the new procedure:

- Telecommunication companies have large portfolios of facilities and electricity is a large expense. To generate cost savings it means that energy management needs to be implemented on a large amount of different building types.
- Before energy management can be implemented an energy audit is required on these buildings that will identify the energy management opportunities. Energy savings of

around 30% may be realised through retrofit projects and better control of HVAC systems [2], [3]. However, the only way to accurately predict the result and effectiveness of such measures is with the use of dynamic, integrated simulation software [4].

- The audit should provide the financial evaluation of the proposed energy savings opportunity and its potential DSM impact. The telecommunication company can then decide if DSM funding will be applied for, or if the project will be self-funded.
- The costs of these audits should be kept as low as possible to ensure projects are economically viable. It was found by Geyser that an experienced and highly trained engineering team takes approximately 45 days to complete a full investigation for a large building (10 000m^2) [5], [6]. Such long audit times on such a big scale will not be commercially viable. Considering that the analysis part of an ESCO project is usually financed by the ESCO itself and that the cost of the analysis is in the order of R10 000 per week it is clear that this part of the project needs to be done in as short a time as possible.
- The potential savings opportunity should not have any negative impact on the operational conditions of the buildings. Many of the buildings are critical to the communications infrastructure and damage to equipment and loss of income can be incurred if something goes wrong.
- The ideal scenario would be if the facility management company/personnel could perform these energy audits to save on audit costs. They already have a presence in the buildings, and know the detailed workings of the equipment in the building. The majority of maintenance personnel have good technical skills, but will lack the experience and tools to perform energy audits in the buildings, and evaluate energy savings opportunities. The new procedure should thus be simple enough and provide the necessary tools to perform the audit.
- Eskom DSM has only reached 30% of their DSM targets at the end of 2005. They need more and technically correct DSM project proposals to help them reach their targets. It was shown that the telecommunication facilities provide good opportunities for DSM projects.

This new ESCO procedure was developed and integrated with simulation software to solve the needs of ESCOs when evaluating DSM projects in telecommunication facilities.

3.2 BACKGROUND TO SOFTWARE USED IN THE PROCEDURE

It was shown in previous chapters that in the commercial building sector of South Africa, approximately 50% of the energy consumption is due to HVAC systems [7]. Rabie [8] has shown that in telecommunications facilities the HVAC (Heating, Ventilation and Air Conditioning) system consumes 55% of the total building load. Although the new ESCO procedure simulates the total building power consumption, the biggest opportunities will be to optimise the HVAC system.

Existing integrated simulation software was too complex and not easy to use. The software also required a large amount of input data. Models of these software programs often do not converge and are not geared to produce good estimates of retrofit savings potential in a short time. Verification of the HVAC system characterisation also takes many weeks. Many days are spent on retrofit investigations and writing the final report. The report is also often written in non-business language that is poorly understood by the decision maker.

HVAC control needs to be optimised with a comprehensive, integrated and dynamic simulation. Any building type, HVAC system and control strategy needs to be accounted for in such a procedure.

The new ESCO procedure was designed so that it provides an easy-to-use and effective toolkit for semi-skilled technicians to be able to conduct a building energy. It was shown before that implementation of the ESCO procedure in Telkom SA suggests that the user might have valuable practical experience, but have low qualification levels. The user must build the simulation model simply and intuitively. No intricate simulation, or mathematical options, should be set. All the standard retrofit options must be very easy to set up and analyse. This will reduce the overhead cost of the project, as fewer personnel would be required for the audit.

Given the background of the telecommunication environment and the ESCO work in South Africa it can be stated that the primary requirements for a new ESCO procedure are that it should be simple, stable, and fast. The following software tools are introduced for specific use for ESCO analyses in telecommunication facilities:

3.2.1 Data gathering software

A large percentage of the building audit time is normally taken up by the gathering of data. It also requires various loggers, notepads, calculators, and the like. Typically, it is a very uncomfortable experience for the ESCO. By using a PDA for the data gathering only the required data is obtained, all the required data is gathered and the procedure is made more manageable for the ESCO. The data capturing software and procedure was discussed in Chapter 2. The captured data and equipment layout is exported to the simulation software.

3.2.2 Simulation model software

The simulation model software is stable, fast, and reasonably accurate. To achieve this the mathematical models of all the HVAC components were simplified and verified in detail. A year-simulation is completed in less than three minutes on a regular personal computer (PC).

The software predicts the energy consumption and maximum demand figures of the last year within 15% of the actual figures. It must be remembered that the user is more interested in the potential savings figure (a relative figure) than the total cost. Fluid conditions are only required on an hourly basis. The dynamics of the control of HVAC equipment on a short time scale is not needed.

3.2.3 Retrofit analysis software

The retrofit analysis software uses the verified building simulation model, and allows the user to simulate retrofits on the building. This allows the auditor to establish what the potential savings will be, but also what the effect will be on the operating conditions of the building. These retrofits can now be evaluated without testing on-site, thus further reducing the time for the energy audit. It also means less risk for the telecommunication company and Eskom DSM since the retrofit has been verified through simulation.

Combinations of different retrofits can be simulated to evaluate the true effect of the combined retrofits (it is not always just the sum of the different retrofits). This can only be done using an integrated building simulation model.

3.2.4 Financial analysis software

Since all these software modules are integrated, the simulated saving from the retrofits are automatically imported into this modules and the financial analysis done. Calculations such as direct payback, discounted payback and net present value are calculated.

3.2.5 Report writing software

A template is generated to which all of the simulation and financial results are exported into a word processor format. This allows the ESCO to document the findings of the audit in much less time and in understandable format.

Detail interfaces and screen captures for the different software modules are described in Appendix E.

3.3 THE NEW ESCO PROCEDURE FOR TELECOMMUNICATION BUILDINGS

The different steps and the logical flow of the new ESCO procedure are shown in Figure 3-1. The steps in the new ESCO audit procedure will be discussed in detail in this section. Refer to Appendix E for detail screen captures of the software interfaces used during each step in the procedure.

3.3.1 Step 1: Determine which building to audit

This step is usually not a problem when performing ESCO analysis on single or small group of buildings. However, when working with a large portfolio of buildings, it is not a trivial exercise to decide on which building the ESCO procedure should be implemented. The best guideline would be to get a summary of the annual electricity costs, and to start with the highest consumer. The higher the energy costs, the more savings are possible. Obviously the location of the buildings and the number of audit teams available to do the ESCO analysis will also play a role in this decision.

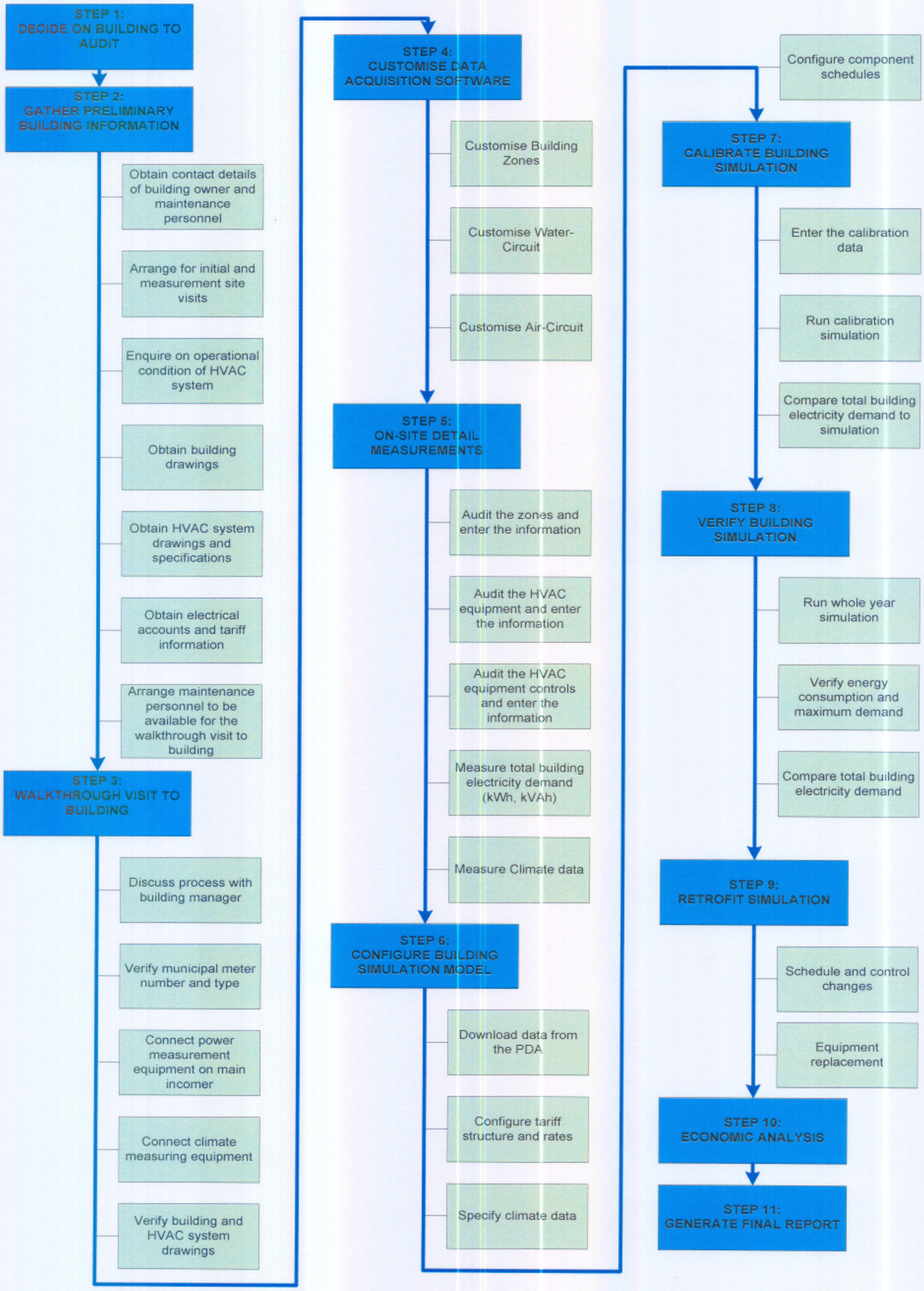


Figure 3-1: The new ESCO audit procedure for telecommunication facilities

3.3.2 Step 2: Gather preliminary building information

This step is used to gather background information on the building and the HVAC system. In this section, the ESCO should become familiar with the building, HVAC system and components, the personnel involved and obtain some of the data required for the simulation.

Obtain information from building manager and maintenance personnel

The ESCO will save a lot of time with the cooperation of the building manager and maintenance personnel. It is important that the HVAC and electrical maintenance personnel will be involved since both will be required for the detailed measurements that are needed in the building.

Arrange for initial and data capturing visits

In telecommunication facilities (as is the case with Telkom SA) permission to visit an exchange building should be arranged well in advance. The building manager will then issue the ESCO with a work reference number which will allow the ESCO access to the building.

Special permission will be needed when visiting the building to take measurements and to install measurement equipment. This task is mentioned early in the procedure, since these arrangements could seriously delay the whole procedure.

Enquire on operational condition of HVAC system

When planning the ESCO procedure and visits to sites, the ESCO should explain to the maintenance personnel what procedure will be followed and measurements required. It often happens that the some of the systems in the building are undergoing maintenance and that the measurements taken will not be true reflection of the building operations. The audit should preferable be done when the building is working under normal operating circumstances.

Obtain building drawings

Certain building dimensions are required to configure the building zones in the simulation tool. Building drawings will therefore assist the ESCO in obtaining these dimensions. Without any building drawings, the user will have to measure all the dimensions required for input. Floor plan drawings will further assist the user to divide the building into realistic simulation zones. Care should be taken to verify actual site conditions to drawings to ensure that drawings are up to date.

HVAC design and operating specifications

The HVAC system design specifications and drawings (service and maintenance manuals) will supply the ESCO with all the original design data such as flows, capacities, set points, control strategies, and operating schedules required to perform simulations. Without these specifications, each component will have to be measured to obtain the required input data.

Unfortunately it is very possible that the telecommunication exchange buildings and environmental equipment are very old (20+ years). The original design specifications will definitely be outdated, and actual on-site measurements will be required.

Electricity accounts

Detailed electricity accounts of the past 12 months will be required as input to verify the simulation models' energy consumption.

The accounts for all of the buildings in Telkom SA are paid and processed centrally by the facility management company (TFMC) Head Office. Since they are responsible for the payment of more than 10 000 accounts, problems are often experienced to link the correct account with the correct building [9]. The municipal meter number on the account should thus be verified with the actual meter number on-site. Care should be taken to request these accounts well in advance, in order for the data to be supplied in time to the auditor. It was also found that with municipal accounts the tariff structure is not always shown on the account, only the rates. The tariffs and rates charged also vary between municipalities and should be requested and checked with the local municipality.

Arrange for maintenance personnel and access to building

Ensure that access to the building has been arranged and that the maintenance personnel (electrical and mechanical) will be available on-site for the walkthrough visit and detailed measurements.

3.3.3 Step 3: Walkthrough visit to building

A comprehensive walkthrough investigation on-site will give the ESCO a better feel and understanding of the building. This will also help when planning the calibration measurements and PDA acquisition phases. After the completion of the walkthrough audit the ESCO must have gathered enough information to customise the building simulation circuit templates.

In the telecommunication environment it would be wise to discuss the building operation with the maintenance personnel responsible for the maintenance in the building. They will most likely be able to immediately identify problems areas and energy wastage. It is unfortunately a reality that minimum energy usage is not necessarily a focus of maintenance practices but rather maintaining the service level agreement (SLA).

Verify municipal meter number and type

As mentioned in the previous step it is important to verify the municipal meter number on-site with that on the accounts received in the previous step. It is very possible that wrong account information could have been supplied, and the ESCO will not be able to do the verification of the building simulation model.

The meter type should also be noted. The meter can be a thermal demand meter or an electronic demand meter. The type of meter is important since one of the savings opportunities will be on replacing the thermal demand meters with electronic meters due to the better accuracy of the digital meters.

Discuss ESCO procedure with building manager

It was mentioned in Chapter 1 that one of the challenges in doing ESCO work in the telecommunication facility is the cooperation of the building manager. It is thus very important to immediately report to the building manager, and explain the aim of the visit and subsequent visits.

In the case of Telkom SA the building owners do not know how much energy is consumed in their buildings, due to the fact that the payment of accounts is outsourced to the facility management company and not directly paid by Telkom SA. It will be very valuable if the ESCO could show the building owner a summary of the accounts obtained during the previous step.

Connect power measurement equipment on the main incomer

As part of the calibration measurements the power profile of the whole building is required. The power meter should be connected to the main incoming supply of the building as close to the municipal supply as possible. The meter can be left to record information until the next visit when the ESCO will do the detail measurements.

Connect climate measuring equipment

The equipment used for measuring outdoor temperatures and humidity should be placed on the outside of the building to record environmental conditions. In some cases the data can be obtained from the building management system (BMS).

Verify information from drawings

It is important to verify the information and drawings received during the previous step in the ESCO procedure. The drawings will be needed in next steps and the ESCO should ensure that all the information for building the zone, water and air-models are available and accurate.

3.3.4 Step 4: Customise data acquisition software

In this step the building simulation model is set up in the data acquisition PDA software. This can only be done if the user has a good understanding of the operation of the system.

It was verified by Geyser [4] that the generic model components are sufficient to build up any air conditioning system. In the Telkom SA group of buildings there are several standard HVAC designs that can be reused and customised. This means that projects created can be reused when similar buildings are encountered. Refer to Appendix D for detailed screen captures of the procedure.

Customise building zones

The first step is to divide the building in the least possible number of simulation zones. The number of zones in the simulation model has a direct influence on the simulation time. More zones in the model result in more elements in the model and an increased number of equations that must be solved. This increases the simulation time. Building spaces with similar load schedules, thermal characteristics and similar AHUs can be grouped as a zone. Zones can further be characterised into two main groups: air conditioned zones and non-air conditioning.

Air conditioned zones: Most of the time, the rooms in a building that are served by the same AHU, can be simulated as one building zone. For further simplification, building zones with the same cooling load and heat requirements, AHU characteristics and control strategies, can form one building zone.

Zones with no air conditioning: All the building zones (rooms) without air conditioning can form one building zone. The construction of this zone is not very important since the thermal performance can be ignored and only the internal electrical loads are required. This zone will be used to calculate all the electricity loads such as lights, extraction fans, lifts, etc. of all the zones without air conditioning.

Customise Water- and Air-Circuit

Here the user must setup the building air- and water-circuits matching it to one of the previously defined circuit templates available in the simulation tool. HVAC equipment with the same characteristics can be simulated as one template component. To do this their ESCO should have a good understanding of HVAC system layout and operation.

3.3.5 Step 5: On-site detail measurements

Measurement equipment is used to perform the required measurements. The ESCO is guided and information captured on the PDA. This includes the building zones and HVAC components.

By supplying the user with a standard set of inputs it is ensured that only the required data for the simulation model is taken. Also, the PDA makes it more manageable, because it replaces the typical clipboard, notepad and pen, which the ESCO must normally use to retrieve the data.

The required data includes parameters for the simulation and building model, as well as information regarding the air-and-water states (as discussed in Appendix D).

Audit the zones and enter the information

When the user has decided on the zone layout and background on the use of the building, the PDA is used to enter the relevant data as discussed in Chapter 2.

Audit the HVAC equipment and enter the information

When the user has configured the zone layout, the information of the accompanying HVAC components can be gathered.

The PDA will be used to collect all the information obtainable from the building site that is required to simulate the HVAC equipment. In a similar fashion to the zones, the equipments models are configured as it was decided upon and selected in the simulation circuit template.

By using the measured data (versus design specifications) the "current, real" building is simulated. Also, when the measurements are compared against the designed operating points it will help to determine any faults or inefficient operation of the equipment. This could give a good indication of possible areas of energy wastage.

Audit the HVAC equipment controls and enter the information

The control logic of the HVAC components must be entered. Once again the cooperation of the maintenance personnel will be required. Note of warning: the perception of how the equipment is operating and actual operation might differ. The auditor should always have checks and balances in place to verify the control philosophy.

Collect total building electricity demand (kWh, kVAh)

The power measurement logger was connected on the main incomer of the building during Step 3 of the ESCO procedure. The data can now be downloaded. Average hourly measurements of the total building energy demand (kWh, kW, kVA, kVARh, power factor) for a typical Friday (weekday), Saturday, and Sunday are required to calibrate the simulation model for realistic retrofit results.

Collect climate data

Average hourly climate measurements of the temperature and relative humidity (RH) for a typical weekday are required to calibrate the simulation model for realistic results. These measurements can either be captured by the BMS system or by standalone data loggers. It is very important that the climate data be measured during the same time as the electricity demand measurements.

Climate data for the major cities are available in the simulation software. This data can be automatically imported when inputting the climate data.

3.3.6 Step 6: Configure building simulation model

Download data from the PDA

The components that were recorded can be downloaded automatically from the PDA into the simulation software. After this is done, the components and captured data are available for use in the simulation software.

The first step to configure and complete the simulation model is to download all the PDA components onto the PC. Drag and drop all the downloaded components to their respective locations on the air- and water-circuits of the simulation program.

Configure tariff structure and rates

The information required by the simulations software includes electricity tariff structure, tariff rates and power factor of the building. The tariff information will be available on the accounts obtained in Step 2, or from the local municipal authority. The option exists to add new tariffs and to store in the database for buildings on the same tariff.

The electricity tariff includes the average hourly values for active energy charge, reactive energy charge, and maximum demand (MD) charge, for each of the three-day types for summer and winter seasons. It also requires the reactive energy supply percentage and the MD charge type.

The power factor can be determined from the measurements taken on the main incomer of the building.

Specify climate data

The environmental options required include the climate data and the number of summer months of the year. The option exists to add new climates to the database for use in similar buildings. The data required for the climate includes the location in terms of latitude, longitude, and elevation, as well as the average hourly temperature, relative humidity, global and diffuse radiation for every month.

The simulation is equipped with climate data for all the major cities. Once the information has been entered it can be saved to be reused for buildings in the same vicinity.

Configure component schedules

The schedules can typically not be measured on-site with the walkthrough audit due to the short period on-site. This information must be obtained from a person that has current knowledge of the building operation or from the building management systems. All the components in the project component list should be edited to set-up the building and system schedules for all the seasons and day types.

For zones with telecommunication equipment the HVAC system usually works 24-hours a day due to the constant heat load in the zone.

3.3.7 Step 7: Calibrate building simulation model

Enter the calibration data

The calibration data is required to calibrate the building model to measured values. The data required is average hourly temperatures and relative humidity for the calibration day, as well as the total building load for a weekday, Saturday and Sunday during the calibration period. The dates for the measured electrical and climate data must correspond. The data is obtained from the power and climate loggers that were placed on-site during the audit.

Run calibration simulation

The simulation model is calibrated in this step. The base for calibration is the percentage of time that the results of the simulation model are within 10 % of the measured values. This figure is given for the three day types (weekday, Saturday and Sunday). Additionally, the program also displays (for each day type) the supply and return-air temperatures for each zone, as well as the simulated and measured building load. This gives additional verification of the response of the system.

Compare total building electricity demand

The simulated total building electricity demand should fit (80% of time within 10%) the measured load. However, this figure is only a guideline. The calibration and verification simulations form a unit. A bad calibration figure does not necessarily translate into a building model error. The period simulated in the calibration simulation period is short and compared to the measurements from a similar time. Any events out of "character" in the building during the calibration measurement may reflect negatively on the calibration figure. Therefore, the final decision if the model is accurate rests with the ESCO.

3.3.8 Step 8: Verify building simulation model

Run whole year simulation

The verification simulation verifies the yearly energy consumption and MD values of the simulation model with the actual values. The simulation output is the total seasonal energy consumption, as well as the average seasonal MD for the building.

Verify energy consumption and maximum demand

This is a year verification, where the summer- and winter-simulated energy consumption and MD of the total building are compared to the respective measured data of the previous 12 months (electricity accounts). This result will give a good indication of the accuracy of all the assumptions made during the project. The result should be within 10% of the measured values 80% of the time to ensure realistic retrofit cost savings during the retrofit analysis.

In this step it is obvious that the auditor should have made sure that the correct account information has been obtained and that the meter number obtained during the site visit corresponds with meter number given on the account.

3.3.9 Step 9: Retrofit simulation

A number of retrofit simulations can be performed within the simulation environment. These retrofits are divided into three groups:

- Schedule changes
- Control changes
- Replacement or repair of old equipment

The simulation software presents the user with a typical set of schedule change retrofits and control change retrofits. The required retrofit can be chosen from a list and simulated. To simulate hardware changes, one must change the specifications of the relevant component in the simulation model. The detail of these retrofits is discussed later in this chapter.

3.3.10 Step 10: Financial analysis

After the various retrofit options have been simulated, these need to be financially evaluated to determine the best option. Normally this can only be done through time-consuming data manipulation and calculations. The financial analysis module calculates the most important indices regarding retrofits and energy consumption in buildings. The values calculated are the cost, cost saving, percentage saving and energy saving of each retrofit, the direct and discounted payback period of each retrofit, given the capital loan rate it calculates the net present value of each retrofit over a specified timeframe. It is then left to the user to interpret the data and choose the best options.

3.3.11 Step 11: Generate final report

The writing of the project report is normally time-consuming work, also not very much liked by most ESCOs. The tools in ESCO procedure comes with a complete word processing tool to summarise the findings of the project in report format. A report-writing wizard is available for systematic guidance. The user is led to answer certain questions regarding the building and HVAC system. These include general questions such as the building location, air conditioned area, HVAC system type etc. The user is also presented with generic report portions, for sections like the introduction, certain report paragraphs, executive summary etc. These portions are written specifically for the South African situation.

Relevant simulation and financial data are automatically imported into the report. The report is for the benefit of the building owner. It summarises the vital information of the analysis part of the ESCO project. It should allow Eskom DSM or the building owner to make an informed decision regarding investment in the proposed retrofit.

3.4 RECOMMENDED IMPLEMENTATION TIMES FOR NEW PROCEDURES

The recommended audit times for the new ESCO procedure on different building sizes are discussed below.

3.4.1 Small buildings

Small buildings are buildings less than 1000m^2. These building are typically small unmanned exchange buildings. The suggested implementation time for the new ESCO procedure on small buildings are shown in Table 3-1 below and allow for one calendar week:

Step in ESCO Procedure	Calendar days
Step 1: Determine which building to audit	Predetermined
Step 2: Gather preliminary building information	Monday 1- Monday 1
Step 3: Walkthrough visit to building	Tuesday 1- Tuesday 1
Step 4: Customise data acquisition software	Tuesday 1- Tuesday 1
Step 5: On-site detail measurements	Wednesday 1- Wednesday 1
Step 6: Configure building simulation model	Thursday 1- Thursday 1
Step 7: Calibrate building simulation	Thursday 1- Thursday 1
Step 8: Verify building simulation	Thursday 1- Thursday 1
Step 9: Retrofit simulations	Friday 1- Friday 1
Step 10: Financial analysis	Friday 1- Friday 1
Step 11: Generate final report	Friday 1- Friday 1

Table 3-1: ESCO audit times for small buildings

Although the procedure starts on a Monday it would be advisable to schedule Step 3 before a weekend (connection of data loggers) and Step 5 (Data collection) after the weekend, since the simulation requires measured data from a weekday, Saturday and Sunday.

3.4.2 Medium-sized buildings

Medium-sized buildings are buildings between 1000 m^2 and 5000 m^2. These buildings are typically bigger exchange buildings with personnel that do work on the exchange. The suggested implementation times for the new ESCO procedure on medium-sized buildings are shown in Table 3.2 below and allow for two calendar weeks:

Step in ESCO Procedure	Calendar days
Step 1: Determine which building to audit	Predetermined
Step 2: Gather preliminary building information	Monday 1- Tuesday 1
Step 3: Walkthrough visit to building	Wednesday 1- Wednesday 1
Step 4: Customise data acquisition software	Thursday 1- Thursday 1
Step 5: On-site detail measurements	Friday 1- Monday 2
Step 6: Configure building simulation model	Tuesday 2- Tuesday 2
Step 7: Calibrate building simulation	Tuesday 2- Tuesday 2
Step 8: Verify building simulation	Tuesday 2- Tuesday 2
Step 9: Retrofit simulations	Wednesday 2- Thursday 2
Step 10: Financial analysis	Friday 2- Friday 2
Step 11: Generate final report	Friday 2- Friday 2

Table 3-2: ESCO audit times for medium-sized buildings

3.4.3 Large buildings

Large buildings are buildings with floor space of more than 5000 m2. These buildings are typically commercial buildings, but there are however a few telecommunication facilities that might also fall within this classification.

The suggested implementation times for the new ESCO procedure on large buildings are shown in Table 3-3 below and shows suggested times for a 10000 m^2 and 20000 m^2 building.

Step in ESCO Procedure	Calendar days (10 000 m^2)	Calendar days (20 000m^2)
Step 1: Determine which building to audit	Predetermined	Predetermined
Step 2: Gather preliminary building Information	Monday 1- Wednesday 1	Monday 1- Thursday 1
Step 3: Walkthrough visit to building	Thursday 1- Friday 1	Friday 1- Tuesday 2
Step 4: Customise data acquisition software	Monday 1	Wednesday 2- Thursday 2
Step 5: On-site detail measurements	Tuesday 2- Thursday 2	Friday 2- Wednesday 3
Step 6: Configure building simulation model	Friday 2- Monday 3	Thursday 3- Friday 3
Step 7: Calibrate building simulation	Friday 2- Monday 3	Thursday 3- Friday 3
Step 8: Verify building simulation	Friday 2- Monday 3	Thursday 3- Friday 3
Step 9: Retrofit simulations	Tuesday 3- Friday 3	Monday 4- Wednesday 4
Step 10: Financial analysis	Friday 2- Friday 2	Thursday 4
Step 11: Generate final report	Friday 2- Friday 2	Thursday 4- Friday 4

Table 3-3: ESCO audit times for large buildings

The difference in the implementation periods is mainly caused by the increased time required for data collection and detail measurements in larger buildings.

3.5 RETROFIT SIMULATION TECHNIQUES TO EVALUATE ENERGY SAVINGS

In this section the simulation and retrofit software in the new ESCO procedure will be used to illustrate how simulation techniques can be used to evaluate energy management opportunities in the telecommunication environment. The list of the energy savings opportunities in Telkom SA has been compiled by practical investigation at several of the telecommunication buildings in Telkom SA [10], [11].

3.5.1 Retrofitting the building envelope

Energy can be saved if the building envelope can be made more energy efficient. The typical methods used in South Africa are insulation inside the ceiling void, increased shading on the outside windows with overhangs, and reflective glazing on the windows.

When constructing the zones with the simulation model the user is given several choices on the shading, construction and roof type of the zone. These settings can be modified at any time to re-simulate the annual total electricity costs (simulation automatically takes into account the seasonal effects). This can be compared to the base-year simulation of the current design to determine the savings. From this the project feasibility can be done using the financial analysis module.

3.5.2 Verification of municipal meter calibration and meter type

The accuracy of the municipal meter should be verified. During Step 5 (On-site Detail Measurements: Total building electricity demand) the total kWh, kW and KVA should be measured. These measurements (snapshots) can be compared to the municipal meter readings. An easy method to verify the meter calibration is to log the kWh's used during walkthrough audit and compare it with amount of kWh accumulated over the same time period.

The meter readings should be within 5%. Note that municipalities often consider a 5% inaccuracy as acceptable. Obviously a 5% fault on 10 000 buildings' energy accounts can have a major impact on electricity costs!

It is also true that many of the exchange buildings still have thermal demand meters installed. These meters make use of thermal properties of the meter to calculate the demand (kVA) used per month. It is perceived that these meters are more than 10% inaccurate compared to modern digital meters. If the building is still equipped with a thermal demand meter, it should be replaced with a new electronic meter.

During the walkthrough investigation of Step 3 (Walkthrough visit to building) the auditor should capture the make and model of the meter installed on the municipal side of power to the building. The meter number should also be captured to be able to compare this to the electricity accounts for the building.

3.5.3 Tariff structure

In several municipal districts the building owners have the choice of converting a building to a time-of-use tariff structure. It is a complicated process for the ESCO to determine what the benefit will be (if any), by switching tariffs.

In the simulation software the tariff rates and structure can be changed to represent the new proposed tariff. The total building simulation can be used to compare the annual electricity costs of the new tariff to the current electricity costs.

Although by simply switching the current building to a time-of-use tariff might not have a savings impact, by applying retrofits that reduces the energy consumption in peak periods, might have a bigger saving than on the current tariff structure.

By redoing the retrofit simulation on the new tariff structure the impact of the retrofits can be reinvestigated in a very short time. If this evaluation had to be redone without the simulation model it would have been a very lengthy process.

3.5.4 Power factor correction

The demand costs are usually calculated by the maximum kVA demand (integrated demand over a 30-minute window). A low power factor will mean higher demand costs.

During the walkthrough investigation of Step 3 (Walkthrough visit to the building) the auditor should investigate if power factor correction is installed. If power factor correction is installed, the power factor should preferably be higher than 0.95. There will normally be warning indicators on the panel to indicate if problems exist. Repairing the power factor equipment will have a immediate financial benefit.

If power factor correction is not installed the total kWh, kW and KVA should be measured as required in Step 5 (On-site Detail Measurements). The power factor readings are normally available on the meters that measure kW and kVA. If not, the power factor can be calculated from the following formula:

$$Powerfacor = \frac{Active\ Power(kW)}{Apparent\ Power(kVA)}$$

The repair or installation of new power factor equipment can be simulated as a retrofit to determine the expected demand cost reduction.

3.5.5 Lighting upgrade

Many of the old buildings are still equipped with old fluorescent tubes that use much more energy than the newer lamps that are available. The newer fluorescent tubes not only use less energy but have a better lighting effect.

During the walkthrough investigation of Step 5 (On-site detail measurements) the auditor records the number of lights, type and power rating on the PDA when customising the zone information.

The replacement of old fluorescent lamps with newer more energy efficient lamps will have a big saving. In Step 8 (Retrofit analysis) replacement of these lamps can be simulated and savings quantified.

3.5.6 Lighting control

Control of lighting to be switched off automatically during unoccupied periods can have huge energy cost savings. When switching the lights off more during the day, based on occupancy, the heat load on the HVAC system is also reduced, and a further savings is obtained.

During Step 6 (Configure the Building Simulation Model) the auditor captured the operating schedule of the lighting in the specific zone. The operating schedule can be changed to the new proposed operating schedule. The simulation can be rerun to calculate the saving of the new schedule. Obviously the lighting upgrade and scheduled changes can be combined to form a new retrofit.

3.5.7 Fan scheduling and control

At times when the building is not in use, no air conditioning is needed. If the fans operate during these periods, energy is wasted. A reduction in power consumption could be achieved if the fans are scheduled to operate only during certain times of the day.

These times would typically be when the building is unoccupied, unless heating or cooling is required at other times. Possible examples of this would be the application of night ventilation, or if the building is required to be at a specified temperature when the occupants arrive.

During Step 6 (Configure the Building Simulation Model) the auditor captured the operating schedule of the fans in the specific zone. The operating schedule can be changed to the new proposed operating schedule. The simulation can be rerun to calculate the saving of the new schedule. It is important to view zone temperature output graph to ensure that the required zone conditions are still met during occupied periods.

The scheduling of fans will only be possible in zones with commercial activities, and not in telecommunication equipment rooms due to the constant heat load in the zone.

Another control philosophy that can be implemented works on the assumption that the supply fan of a venue is not required to operate if the cooling and heating coil valves are closed during unoccupied times. Figure 3-2 shows the fan control strategy [4]:

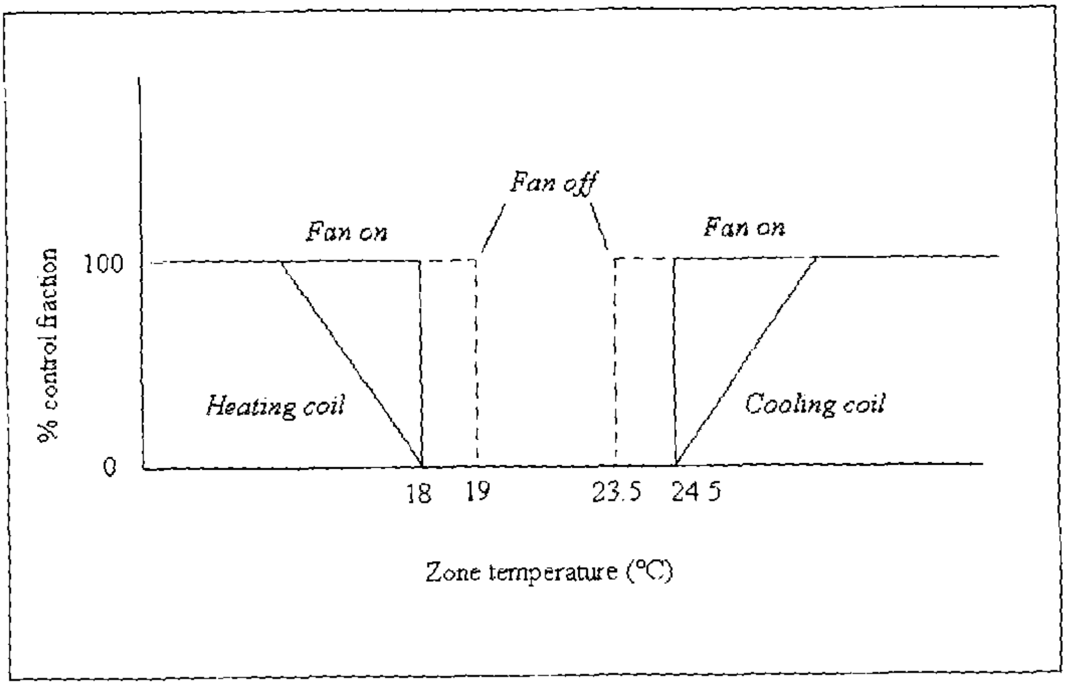


Figure 3-2: Fan control strategy

This control strategy can therefore only be used during unoccupied zone times. This control has a strategy for both cooling and heating sides. For the cooling side, the fan is switched on when the cooling valve opens at 24.5°C. The fan will then stay on until the temperature drops 1°C below the opening temperature before it switches off. For the heating side the fan will switch on at 18°C. It will then switch off 1°C above the valve opening temperature.

If the venue is occupied the supply fans must run at all times for ventilation purposes. The return fans will operate in tandem with their correlating supply fans.

3.5.8 Changing temperature set points back to design conditions

In some telecommunication exchange buildings a supply air temperature of 14°C is supplied when the supply temperature was designed to be 22°C± 2°C for equipment rooms in exchange buildings. Ensuring equipment is operating according to initial design conditions, ensures that the HVAC system is operating as efficient as possible.

During Step 5 (On-site detail measurements) the zone supply temperatures are recorded. By changing the supply air temperatures to the initial design set points the reduction in energy costs and the effect on the zone temperatures can be simulated. The output of the simulation is daily profiles of the temperatures in each zone of the building that can be used to ensure that the temperatures are still within the SLA agreements.

3.5.9 Temperature set point setback

This option allows set point drift if the venues are unoccupied. It operates on the assumption that a zone does not need to be kept on set point if it is not in use.

If a venue is unoccupied, the control will let both the cooling and heating coil set points to drift to hotter and colder temperatures respectively. The zones will then require less cooling and heating from the HVAC system. The following figure gives a graphical representation of this control logic [4]:

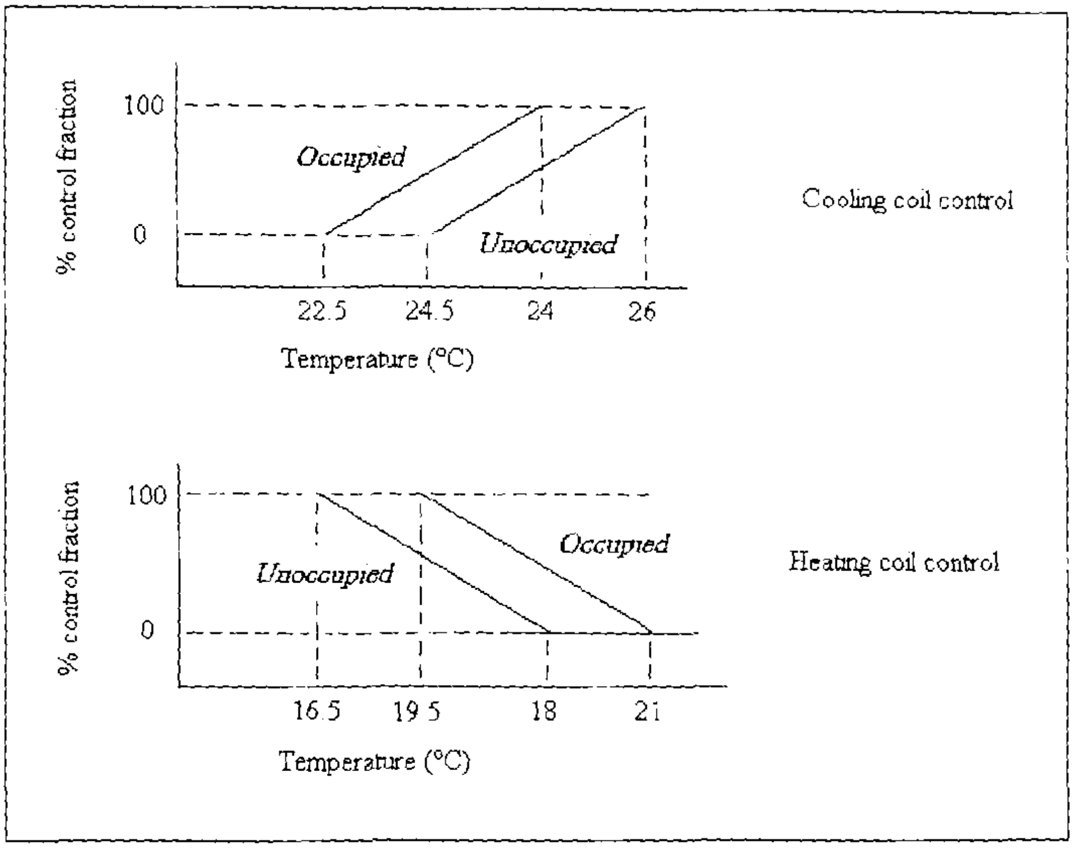


Figure 3-3: Set point setback control strategy

The occupied and unoccupied times are determined in a similar fashion as for the economiser logic. For the unoccupied condition, the cooling coil will be fully open at 26°C and fully closed at 24.5°C. The heating coil will be fully open at 16.5°C and fully closed at 18°C.

3.5.10 Economiser control

Many of the HVAC systems were designed to use outside air for cooling when the outside air temperature is low enough. This is commonly referred to as **"free cooling"**. The use of outside air instead of mechanical cooling is accomplished by economiser control.

The economiser control manages the fresh air intake into the building. With this control the air intake can be controlled to let in any amount, from a specified minimum up to 100% during occupied times, and 0% during unoccupied times.

The outside air can be used for cooling if required, when the outdoor temperature is lower than the return-air temperature. If the outside air is at a higher temperature than the return-air, the outside airflow will be reduced as much as possible. Care should be taken that the humidity values should also be within the allowed ranges for telecommunication equipment. For zones that have commercial activity the economiser strategy can be divided in two parts, an occupied strategy, and an unoccupied strategy [4].

The **occupied strategy** will generally operate in the following manner. If the return-air temperature is higher than the outdoor air temperature, the following strategy will be implemented:

- If the return-air temperature exceeds 22°C (the typical lower cooling set point), the fresh air damper will open proportionally from its minimum setting (40% fresh air of total supply) until fully open at 23°C (the typical upper cooling set point).
- The return-air damper will, for the same conditions, start to close proportionally from its maximum setting (60% return-air) to fully closed.
- If no cooling is required, the fresh air damper will be at its minimum setting (40% fresh air) and the return-air damper at its maximum setting (60% return-air).
- If the outdoor air temperature is higher than the return-air temperature the fresh air damper will close to its minimum setting (40% fresh air) and the return-air to its maximum (60% return-air). This strategy is graphically presented in the figure below.

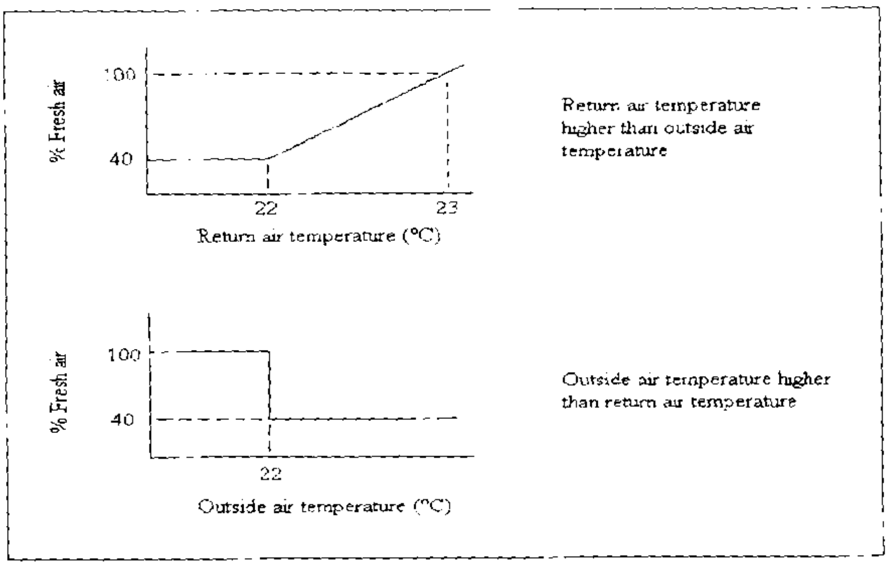


Figure 3-4: Occupied economiser control

The **unoccupied strategy** will operate as follows. If the return-air temperature is higher than the outdoor air temperature, the following strategy must be implemented:

- If the return-air temperature exceeds 22°C, the fresh air damper will open proportionally from its closed position (0% fresh air of total supply) until fully open at 23°C.
- The return-air damper will, for the same conditions, start to close proportionally from its fully open position (100% return-air) to fully closed.
- If no cooling is required, the fresh air damper will be closed and the return-air damper fully will be open.

If the outdoor air temperature exceeds the return-air temperature, the fresh air damper will close completely and the return-air damper will be fully open. The strategy is graphically presented in the following figure.

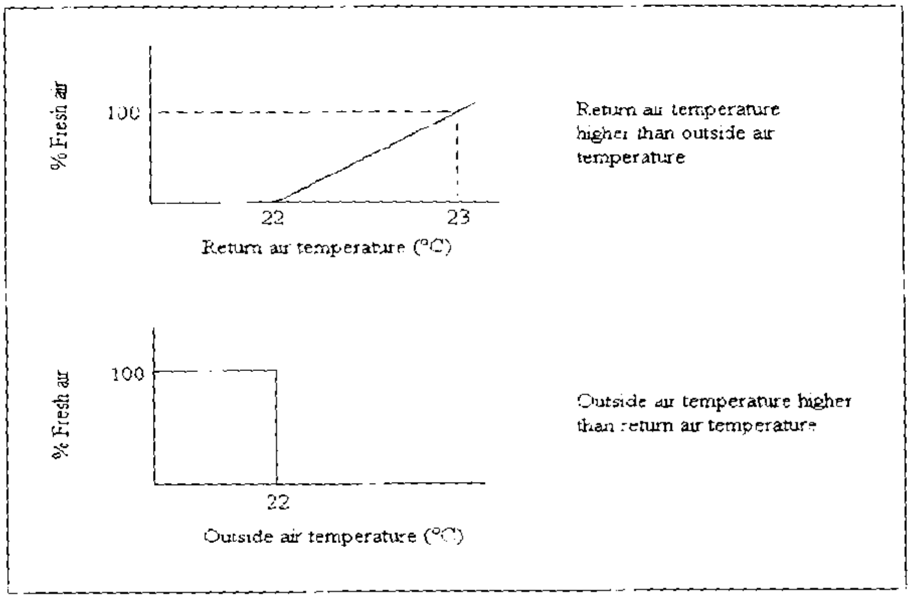


Figure 3-5: Unoccupied economiser control

The benefits and effect of these control changes can automatically be simulated as a retrofit in the retrofit analysis.

3.5.11 Verify control system operation

Ensuring that control systems on the HVAC system operates correctly ensures that only the minimum cooling requirements are met and therefore prevents wastage.

During Step 5 (On-site detail measurements) the control philosophy of the HVAC system is investigated. Actual measurements were taken during the audit to assist in identifying problem areas. Differences in the simulated response and the actual response of the HVAC system may indicate that problems exist.

3.5.12 Replacement of HVAC systems

A major saving can be obtained when replacing the large centralised HVAC systems with smaller more efficient types of units. It was shown previously that telecommunication switches has changed from analogue switches to digital switches that require much less floor space and cooling. The area in which the equipment is now located can be partitioned off in order to limit the space that needs to be cooled. Smaller HVAC units can replace old centralised HVAC systems. Future planning should be taken into account to calculate the growth expected in a facility. Some of the benefits are:

- Older centralised systems have often exceeded its financial life, and are expensive to maintain.
- Smaller units are more efficient and use less energy.
- Maintenance is much less on new generation HVAC systems.

As shown before, the building HVAC templates in the simulation are modular systems that can be used to build up the simulation model of any HVAC system configuration. When a building has been simulated, and the auditor is satisfied that it represents the actual building operation, the HVAC system components can be removed and the new design included. New zones can be generated for the newly partitioned part of the building.

This new simulation will give the building energy consumption due to the installation of the smaller HVAC system. The difference between the previous simulation and the new design will provide the savings by installing the smaller system. It can also be used to validate that the room temperatures will be kept within limits by the new system.

3.5.13 Identifying inefficiency in the HVAC system

In HVAC systems there are several components that can cause an overall lower system performance. A typical system will be built up of chiller units, condenser circuit, cooling towers, heating- and cooling coils and fans. Problems with any of any of these components can cause the system to have lower system efficiency (for example blocked cooling coils).

When taking measurements on the HVAC system as described in Step 5 (On-site detail measurements) efficiency problems are often identified. The current conditions can be simulated against the repaired conditions. The maintenance personnel should be informed as soon as possible of these problems since they can be corrected by performing proper maintenance.

3.5.14 Heating plant control

In many cases, the boiler of a building operates constantly throughout the entire year. The corresponding pump also operates continually right through the year. This wastes energy, as no heating is necessary during the hot months of the year.

A boiler control strategy that is included in the simulation software is discussed below [4]. The boiler set point is a second order function of the average outdoor air temperature of a previous timeframe, typically 24-hours (see Figure 3-6). The outdoor air temperature will therefore be monitored and logged at half hour intervals. A new average outdoor air temperature will be calculated for each new half hour by taking the previous 48 recorded temperature points. A new set point will then be calculated for each half hour of the day using the following function (for a timeframe period of 24-hours):

$$setp = 0.162t^2 - 8.857t + 139.18$$

Where *setp* is the boiler set point in °C and *t* is the average outdoor air temperature also measured in °C.

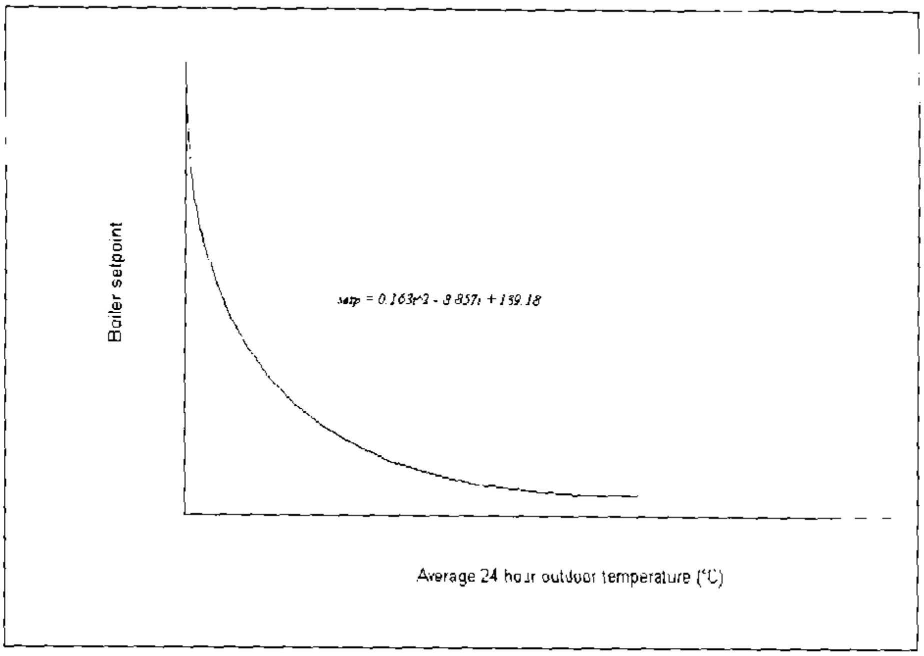


Figure 3-6: Boiler control strategy

This improved boiler control can be simulated to establish the benefits of the installing improved control on the boiler system.

3.6 ROLL-OUT SCENARIO OF THE NEW ESCO PROCEDURE ON TELKOM SA FACILITIES

To show the potential value that can be achieved by implementing the new ESCO procedure in telecommunication facilities, Telkom SA and TFMC are used as a case study:

As show in Step 1 of the audit procedure it is important to decide which building to include in the ESCO analysis. Since time is money, it is important to include buildings that will have the highest savings potential.

For the purpose of this case study a list of the highest energy consumers was requested from TFMC property services. Since there are more than 10 000 properties in the portfolio, a cut-off of buildings with electricity costs higher than R100 000 per annum was selected. The list was therefore reduced to only 250 buildings that represent 60% of the energy costs for Telkom SA.

The regional distribution within Telkom SA of the different sites is shown in Table 3-4 below:

Region	Buildings
Campus	2
Central	25
Eastern	42
Gauteng	59
North Eastern	40
Southern	27
Western	55
Grand Total	**250**

Table 3-4: Regional distribution of top 250 energy users in Telkom SA

The assumption was made that the energy costs are directly proportional to the building size. The different building sizes were classified according to their annual electrical costs and the suggested audit times shown earlier in this chapter was used:

- Very large site (20 000m^2):
  - Annual costs: >R1 000 000 per annum
  - Audit time: 20 working days

- Large site (10 000m^2):
  - Annual costs: R500 000 – R1 000 000 per annum
  - Audit time: 15 working days

- Medium site (5 000m^2):
  - Annual costs: R200 000 - R500 000 per annum
  - Audit time: 10 working days

- Small site (1000 m^2):
  - Annual costs: R100 000 - R200 000 per annum
  - Audit time: 5 working days

The total calendar period (months) for performing the audits on all of the buildings in each region is shown in Figure 3-7 below:

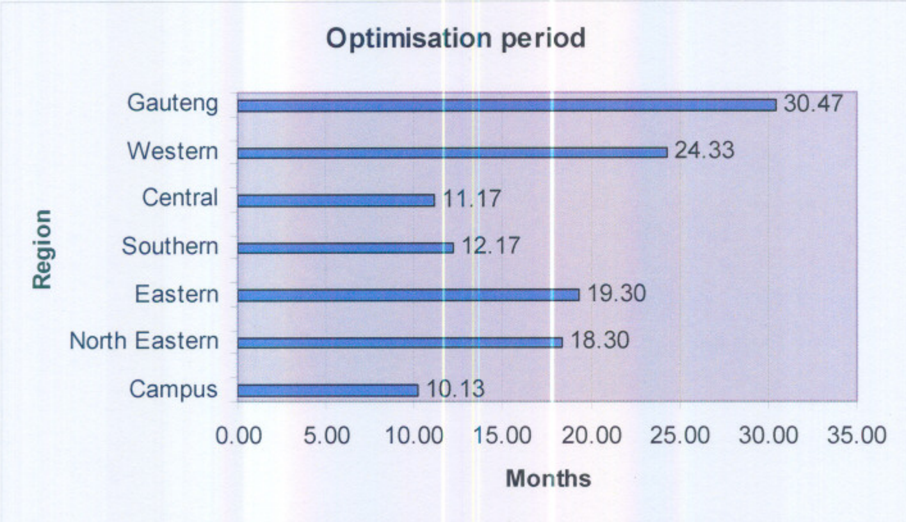


Figure 3-7: Audit periods per region

It can be seen that some regions the audits can be completed in less than a year, and a maximum of 30 months in the region with the largest and most buildings (ideal scenario).

To be conservative in the savings calculation, it is assumed that the audit and retrofits will accomplish a 10% saving (this has been proven in the case studies to be a conservative figure). Since the project roll-out is sequential the savings will be smaller during the first year, the full 12 months of saving can only be achieved in the next full year.

The 10% savings calculation was determined from the account data that was used to compile the site list. If the savings were to be obtained during the period of investigation, and limited capital funding were required (operational changes implemented), the savings potential can be calculated and is shown in Table 3.5. The purpose of this table is not to provide accurate saving but mere to show that even with a conservative figure of 10% savings per building a saving of R45 million is possible over a 5-year period.

Region	*Year One*	*Year Two*	*Year Three*	*Year Four*	*Year Five*	*Total Savings*
Campus	R 409,261	R 1,790,928	R 1,790,928	R 1,790,928	R 1,790,928	R 7,572,973
Central	R 490,114	R 770,767	R 780,384	R 780,384	R 780,384	R 3,602,034
Eastern	R 602,234	R 1,288,465	R 1,394,018	R 1,394,018	R 1,394,018	R 6,072,753
Gauteng	R 907,798	R 1,955,073	R 2,567,771	R 2,666,234	R 2,666,234	R 10,763,111
North Eastern	R 541,866	R 1,197,813	R 1,273,371	R 1,273,371	R 1,273,371	R 5,559,790
Southern	R 479,501	R 812,177	R 812,177	R 812,177	R 812,177	R 3,728,210
Western	R 901,583	R 1,667,663	R 1,964,799	R 1,965,453	R 1,965,453	R 8,464,950
	R 4,332,357	**R 9,482,885**	**R 10,583,448**	**R 10,682,564**	**R 10,682,564**	**R 45,763,820**

Table 3-5: Five year savings forecast

The above scenario is to prove the need to perform the ESCO analysis in the shortest time possible. The quicker the audit report can be published, the quicker funding can be obtained and the retrofits implemented. Obtaining funding and retrofitting the building will be a time consuming processes, but cannot start before the audit report has been published.

3.7 CONCLUSION

In this chapter the new ESCO procedure was introduced. The new procedure uses simulation software to build up a simulation model, capture equipment data, simulate the building operations, perform retrofits simulations, do the financial analysis and generate the final report.

The eleven implementation steps of the new ESCO procedure are discussed in detail. The new procedure is evaluated against known energy management opportunities in the telecommunication facilities. It was shown that the new procedure allows the ESCO to evaluate all the listed savings opportunities.

It was also shown that the modular configuration of the simulation software allows for most types of HVAC systems and building types to be simulated. If a building configuration is not available in the simulation software it can be added onto the software as a new template.

Several retrofits are suggested for implementation in the telecommunication environment. The retrofit analysis allows the user to simulate the savings and the effect of retrofits on the building in an integrated fashion.

The ESCO procedure also allows for financial evaluation of the proposed energy savings opportunity and its potential DSM impact. The procedure also helps the auditor to write the final report.

The new ESCO procedure significantly reduces the time to perform a retrofit audit and automates the process for inexperienced auditors to be able to conduct the audit.

In the next three chapters the new ESCO procedure will be applied to three different case studies. The purpose of the three case studies is to demonstrate the application of the new procedure on different sizes of buildings with different HVAC system configurations. The case studies also serve as an example to possible problems that may be encountered during the procedure, but proves that the new procedure can be successfully implemented in telecommunication facilities.

3.8 REFERENCES

[1] Capehart, B.L., Turner, W.C., Kennedy, W.J., "Guide to Energy Management", 2nd edition, Lilburn: Fairmont Press, p.1, 1997.

[2] Bevington, R., Rosenfield, A.H., "Energy for buildings and homes", Scientific American, pp.207-215, September 1990.

[3] Mozzo, M.A., "The state of the energy service company today", Energy Engineering, Vol.95, No.4, pp.67-69, 1998.

[4] Geyser, M.F., "A New Integrated Procedure for Energy Audits and Analyses of Buildings", Thesis presented in partial fulfilment of the requirements for the degree PhD of Engineering, Mechanical Engineering, Potchefstroomse Universiteit vir Christelike Hoër Onderwys, 2003.

[5] Arndt, D.C., "Personal consultation on numerous occasions throughout 2004", PO Box 1943, Faerie Glen, 0043, Tel +2782 256 0907.

[6] Temm International (Pty) Ltd, "QUICKcontrol", PO Box 2156, Faerie Glen 4, Pretoria, 0043.

[7] Andersen, J.J., "Cape Town Electricity Load Study and End-Use Segmentation", Proceedings of the seminal and main steering committee meeting demand-side management and related projects, DMEA, Private Bag X59, Pretoria, 0001, April 1993.

[8] Rabie, N., "Investigation into various methods of climate control in a telecommunications environment with reference to energy management", EIX 788 Final Report, CNES, Department of Electrical, Electronic and Computer Engineering, University of Pretoria, p.3, 2000.

[9] Van Aswegen, B., "Personal consultation on numerous occasions throughout 2004-2005", TFMC, Meersig Building, Cnr Lenchen and West Avenue, Centurion, Tel +2783 294 3731.

[10] Van Rensburg, J.F., "Project NEON Energy Savings Initiatives", TFMC: Maintenance Engineering, Document Number: None, Meersig Building, Cnr Lenchen & West avenue, Centurion, June 2004.

[11] De Villiers, A., "Proposed Energy Management Plan/Process", TFMC: Professional Services, Document Number: TFMC-PS-0300, Meersig Building, Cnr Lenchen & West avenue, Centurion, July 2002.

4. CASE STUDY 1: LARGE COMMERCIAL FACILITY WITH A CENTRALISED HVAC SYSTEM

4.1 INTRODUCTION

In the previous chapter the new ESCO procedure was introduced. During this, and the following chapters the new ESCO procedure will be implemented in a number of different case studies. The aim of the case studies will be to evaluate the application of the new ESCO procedure on different types of buildings and HVAC systems in the telecommunication environment. The first building on which the new ESCO procedure was applied was Telkom Towers South (TTS).

TTS forms part of the Head Office complex of buildings owned and operated by Telkom SA. The Head Office complex was chosen for this audit since the Head Office group of buildings has an annual electricity cost of R14 million per annum. The TTS building was chosen because it represents a typical large commercial building in the telecommunications portfolio.

The building also has a single centralised HVAC system. If the application of the new ESCO procedure were to be successful on such a big building, it will definitely be feasible on smaller commercial buildings.

The ESCO procedure developed in Chapter 3 is once again shown in Table 4-1. The recommended audit times shown previously was 20 days for a building of 20 000m^2. The audit times was scaled accordingly for the 24 000m^2 of floor space in TTS to allow 23 calendar days for the whole ESCO procedure. The rest of the chapter will follow the logical steps as defined in the ESCO procedure.

Step in ESCO Procedure	Calendar days (24 000m^2)
Step 1: Determine which building to audit	Predetermined
Step 2: Gather preliminary building information	Monday 1- Friday 1 (5 days)
Step 3: Walkthrough visit to building	Monday 2- Thursday 2 (4 days)
Step 4: Customise data acquisition software	Friday 2-Monday 3 (2 days)
Step 5: On-site detail measurements	Tuesday 3- Monday 4 (5 days)
Step 6: Configure building simulation model	Tuesday 4- Wednesday 4 (2 days)
Step 7: Calibrate building simulation	Tuesday 4- Wednesday 4 (2 days)
Step 8: Verify building simulation	Tuesday 4- Wednesday 4 (2 days)
Step 9: Retrofit simulations	Thursday 4- Monday 5 (3 days)
Step 10: Financial analysis	Tuesday 5 (1 day)
Step 11: Generate final report	Tuesday 5- Wednesday 5 (2 days)

Table 4-1: TTS building ESCO procedure audit times

4.2 GATHER PRELIMINARY BUILDING INFORMATION

Time suggested (5 days), Time spent (8 days)

Gathering building information for TTS took a few days longer than planned. The reason for this is that a lot of the information that was required had to obtained via the facility management company. This task had to be scheduled between their normal maintenance tasks, and thus delayed the process. The HVAC system design drawings and building layout was also obtained from maintenance personnel [1].

The most important building and HVAC system information that was gathered are summarised in Table 4-2:

BUILDING DESCRIPTION	
Building name	Telkom Towers South (TTS)
Building description	Commercial building
Building location	Pretoria CBD
Number of floors	27
Total floor area	24 000m^2
HVAC system	Multi-zone
Cooling plant	Water cooled, screw
Cooling capacity	4530kW
Heating plant	Electrical boiler
Heating capacity	0
Air distribution	VAV and CAV
Control System	BMS

Table 4-2: TTS building description

The building is situated in the Central Business District (CBD) of Pretoria, South Africa and forms part of the Telkom campus group. It has 27 floors above ground and is mostly used as office space. Although some areas are used to accommodate equipment such as an exchange, file server rooms, and a cafeteria.

The building is equipped with a central cooling plant that supplies the building with chilled water. There are four Trane chillers in the chilled plant. Four cooling towers on the roof of the building cool the condenser water of the chillers. Hot water used to be supplied by electric boilers situated in the basement of the building but these are no longer in use. No hot water is required by the HVAC system during winter as a result of the high heat gain in the building due to equipment such as PCs.

The primary air conditioning of the building is done by AHUs located in plantrooms on the 15th and 27th floors. The air conditioning of the air in the air handlers is mainly done through a cooling coil, with a fan providing airflow to the conditioned space. Heating coils are installed but not currently used. From an air conditioning point of view the building can be divided into a northern internal area, a southern internal area, as well as four perimeter areas. There are three air handlers in the main plant room supply an internal section as well as two perimeter sections respectively.

The two perimeter units are of the CAV (Constant Air Volume) type, and they feed the building through induction units situated in the perimeter of the building. The internal AHU is larger and of the VAV (Variable Air Volume) type. Each plantroom is equipped with a constant speed return-air fan located in a common return-air duct. Outside and return-air dampers regulate fresh airflow to the zones. In addition to the 12 air handlers in the four main plantrooms, there are a number of smaller AHUs and fan coil units throughout the building. Some of these are discussed below.

The 14th floor is supplied by four small AHUs located in plantrooms on the 15th floor. There are two small air handlers on the ground floor, which serves the lobby, cafeteria and law offices. The 15th floor itself is served by above-mentioned ceiling units. The conference rooms on the 27th, 25th, 21st and 19th floor are respectively served by a small AHU located in the floor above. Fan coil units supply the three lift motor rooms, as is the small server rooms on each floor. An AHU, and fan coil units supply the library on the lower ground level, and the archive is supplied by an AHU. Fan coil units serve the central exchange on the 16th floor. All of these units are supplied with chilled water from the chillers, but the load and energy consumption is small compared to the rest of the main system.

The chilled water-circuit is divided into a primary and a secondary circuit. The primary circuit circulates the chilled water through the air handlers and fan coil units throughout the building, while the secondary circuit pumps the water through the induction units in the perimeter of the building. Two pumps per circuit are installed to provide water flow, although only one pump is adequate.

The building is equipped with an extensive BMS system. This system is capable of logging and controlling numerous equipment and states in the building and HVAC system.

The description above provides an overview on the complexity of the system but also provides the necessary background information to be able to understand the simulation models that will be discussed later in this chapter. The HVAC system undergoes regular maintenance. The maintenance personnel were informed when the detail measurement tests were to be conducted and to ensure that system can be tested at full capacity as required by the ESCO procedure.

Another problem that was encountered was obtaining the account information. TTS building is grouped with other buildings on a single municipal meter. The accounts for this meter were available, but obviously not for the TTS building on its own. Fortunately power meters are installed on each transformer of the building and connected to the BMS.

The walkthrough visit and detailed site measurements were arranged well in advance to ensure that no delays were encountered.

4.3 WALKTHROUGH VISIT TO BUILDING

Time suggested (4 days), Time spent (4 days)

During this visit the purpose of the ESCO analysis was communicated to the building and maintenance managers. They were very cooperative and assigned one of the maintenance personnel to be the single point of contact (spoc) for the audits. This saved a lot of time since you can request information via a single person.

It was also made clear that if any work were to be performed without the written permission of the building managers, the ESCO personnel would be banned from the premises. This is quite different from other office type buildings, since this building is seen as part of the telecommunication infrastructure with very high service level agreements.

The municipal meter number and type is also verified during this step of the procedure but as discussed above TTS does not have its own municipal meter. No electrical measurement equipment had to be connected to obtain the total building profile, since this data was already available on the BMS. The environmental information was also available on the BMS.

The walkthrough audit is a very valuable part of the audit procedure, since the auditor gets a "feel" for the building layout and equipment operation. The design information was compared to the actual system configuration.

4.4 CUSTOMISE DATA ACQUISITION SOFTWARE

Time suggested (2 days), Time spent (2 days)

The simulation program has a maximum of 12 zones that can be used in the simulation model. This forces the user to simplify the simulation model if the building has a more complex HVAC system. This was also the case for TTS.

The focus of the TTS simulation was on the main AHUs on the 15^{th} and 27^{th} floors. These units, together with the chilled plant, are the main energy consumers of the HVAC system.

The other installed fans in the building are small compared to the main units, and the various fan coil units are additional load on the chilled plant. Therefore the building was divided into seven zones comprising of the following areas:

- North perimeter units
- East perimeter units
- South perimeter units
- West perimeter units
- North internal units
- South internal units
- Other loads

The corresponding units on the 15th and 27th floor plantrooms were simulated together. All other additional loads were added into one zone to simulate the remaining electrical load in the building and its effect on the chilled plant. Figure 4-1 and Figure 4-2 shows a schematic drawing of the simulation model water-circuit and the schematic air-circuit.

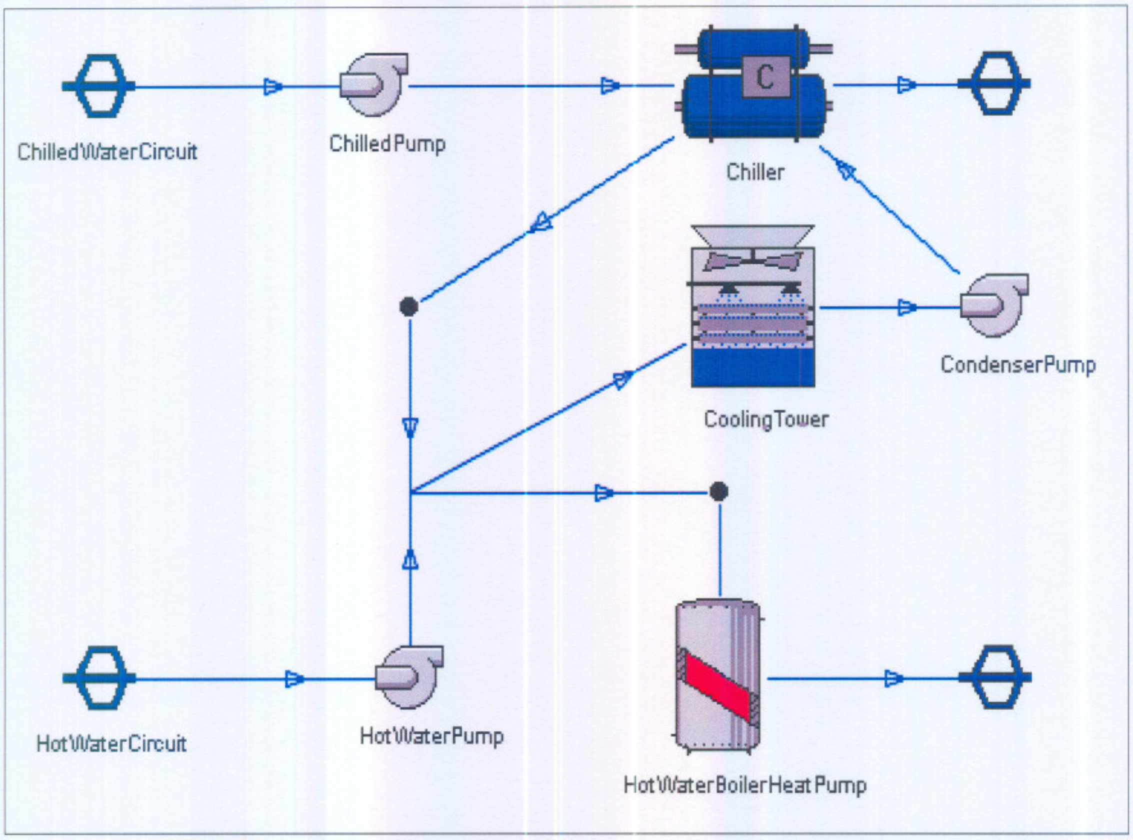


Figure 4-1: Simulation model: water-circuit

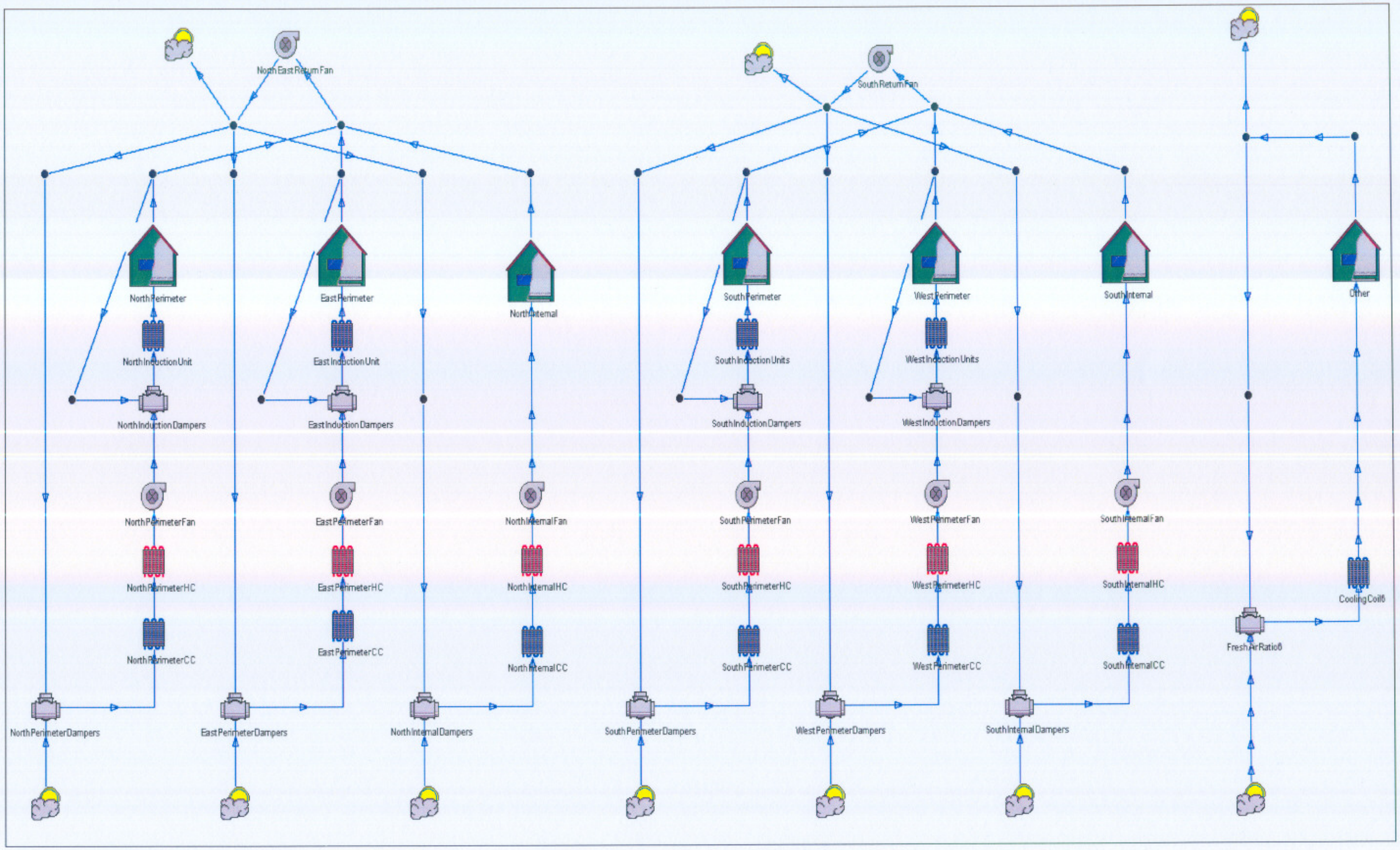


Figure 4-2: Simulation model: air-circuit

The zones and equipment of the corresponding 15th and 27th floors were combined to obtain the seven zones for the simulation model.

Figure 4-3 and Figure 4-4 below show a graphical representation of the air conditioning on the floor, as well as the simulation zone.

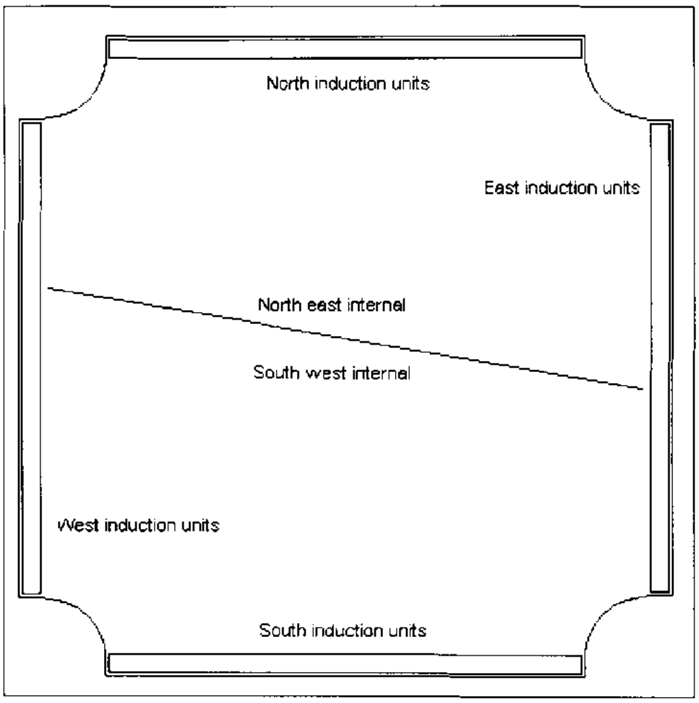


Figure 4-3: Supply areas of the main air handling units

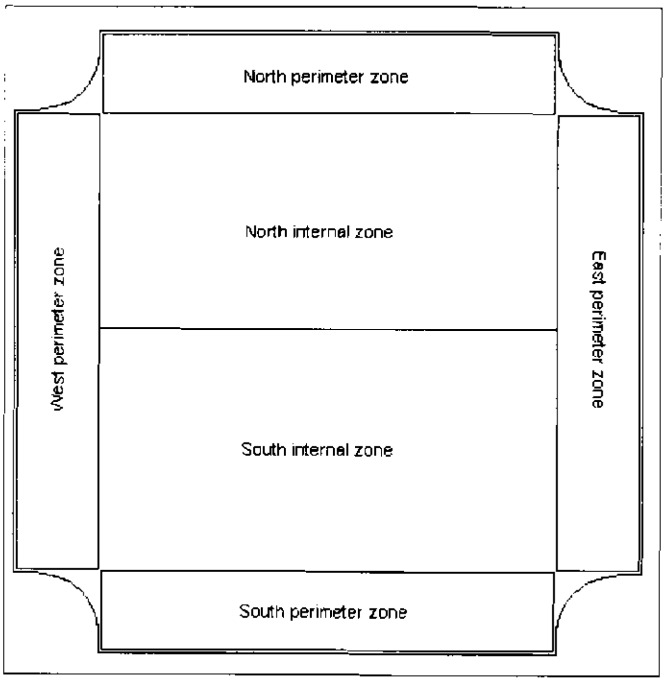


Figure 4-4: Zone supply areas

4.5 ON-SITE DETAIL MEASUREMENTS

Time suggested (5 days), Time spent (5 days)

The PDA was used to capture the information required for each component defined in the simulation model. The maintenance personnel were required to accompany the auditor through the building. This was normally arranged through several short visits to the building.

The following information was used to customise the zone data:

- Each of the simulation zones serves 24 floors. The main units serve floors 1 to 26, excluding the 14^{th} and 15^{th} floors.
- Each of the simulation zones serves a single, separate area. This differs from the actual building in that the areas on the floor served by the main air handlers are not physically divided.
- For the lights, 8 000 units at 90W per unit, was used for the building. This resulted in a load of $22W/m^2$, which is realistic compared to the design values.
- From the access control system, it was determined that approximately 1 500 persons were working in the building.
- It was assumed that 80% of the occupants operate PCs.

Although much of the water- and air-circuit information was available on the BMS, the data needed to be extracted from the BMS, which could only be done by certain personnel. Some of the detailed measurements on the HVAC system was not available on the BMS and had to be measured. Measurements were taken for a weekday, Saturday and Sunday.

During the measurement audit it is not unusual to find that the HVAC system does not operate according to specification. Various operational and maintenance problems were found and these are discussed in Appendix F.

The faults that were found were mostly on the main energy consumers of the building, which formed the main part of the project. The repair of the faults identified in the audit, will already result in energy savings and better indoor air quality.

Table 4-3 and Figure 4-5 shows the climate data used in the energy simulation. It is calculated from yearly data for Pretoria, South Africa over the past 20 years. The temperature and relative humidity (RH) are shown.

Hour	Summer Temperature	Summer RH	Winter Temperature	Winter RH
0	18.4	73.3	10.0	71.1
1	18.0	75.4	9.4	72.8
2	17.5	77.3	8.8	74.9
3	17.1	78.8	8.3	76.6
4	16.7	80.4	7.8	78.9
5	16.4	82.1	7.2	80.8
6	16.3	82.9	7.0	81.8
7	17.0	80.7	7.1	82.0
8	18.9	74.3	9.0	76.0
9	20.6	68.6	13.1	62.8
10	22.2	62.7	16.1	53.5
11	23.6	57.8	18.3	45.8
12	24.6	53.7	19.9	39.9
13	25.4	50.3	20.8	36.0
14	26.0	48.1	21.4	33.0
15	26.1	46.8	21.3	32.3
16	25.8	47.4	20.9	32.5
17	25.0	49.2	19.6	35.1
18	23.8	52.7	17.2	42.3
19	22.3	57.7	15.3	48.8
20	21.1	62.8	13.6	56.1
21	20.2	66.4	12.3	61.4
22	19.5	69.3	11.5	64.8
23	18.9	71.8	10.6	68.1

Table 4-3: Simulation temperatures

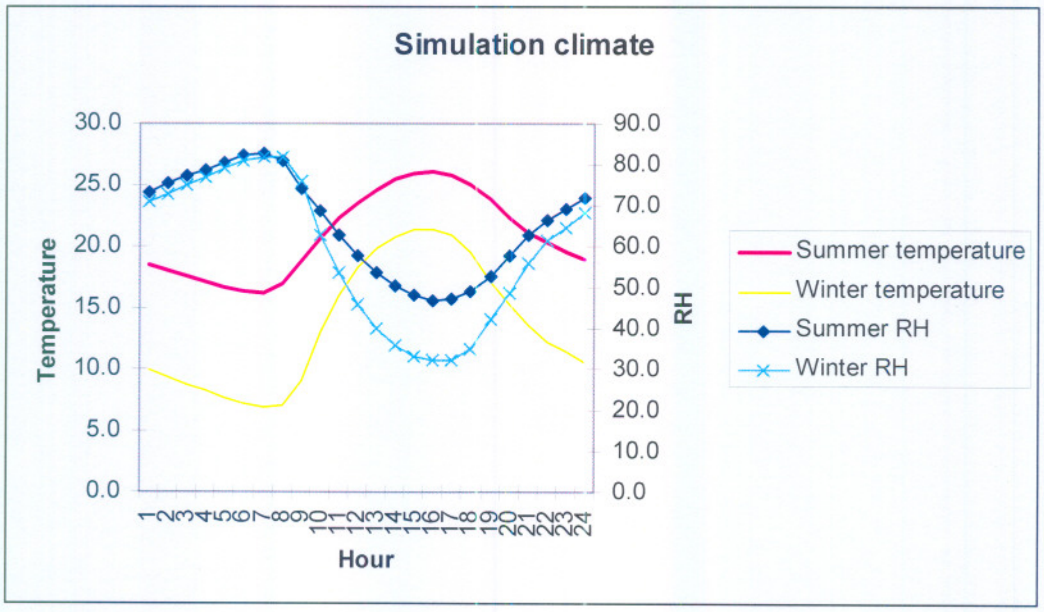


Figure 4-5: Climate data used for simulation

4.6 CONFIGURE BUILDING SIMULATION MODEL

Time suggested (2 days), Time spent (2 days)

The data captured during the building data acquisition phase was uploaded from the PDA device to the simulation software.

The tariff rates applied for the Head Office group of buildings were applied to the TTS building. The climate data for Pretoria is one of the preloaded climate databases that is part of the simulation software and was used.

The operating schedules of the different equipment were configured from information obtained from the BMS and discussions with maintenance personnel. Interesting observation was that lighting in the building is never switched off. This results in a 24-hour heat load on the HVAC system.

4.7 CALIBRATE BUILDING SIMULATION MODEL

Time suggested (2 days), Time spent (2 days)

The "calibration" simulation ensures that the current status of the building will be simulated correctly, so that cost savings predictions are realistic. The model is considered calibrated when the predicted daily demand load is within 10% of the measured value 80% of the time.

The calibration simulation compares the total building energy consumption over a weekday, Saturday and Sunday, to measured energy values. The total actual building energy consumption for these day types was measured during on-site detail measurements. One calibration climate input is used for the three simulated days.

Figure 4-6, Figure 4-7 and Figure 4-8 show the simulation results for a weekday, Saturday and Sunday:

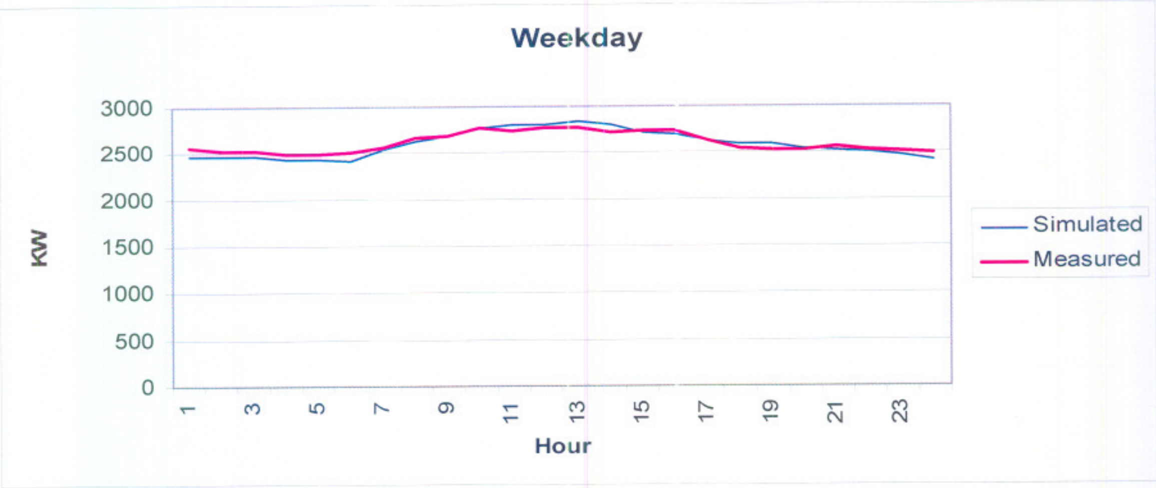


Figure 4-6: TTS: Weekday calibration simulation results

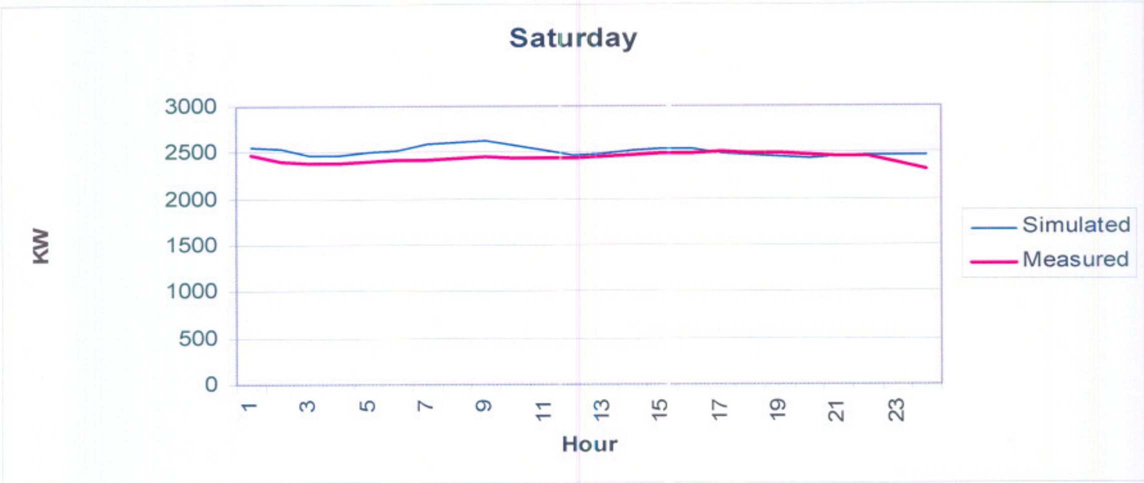


Figure 4-7: TTS: Saturday calibration simulation results

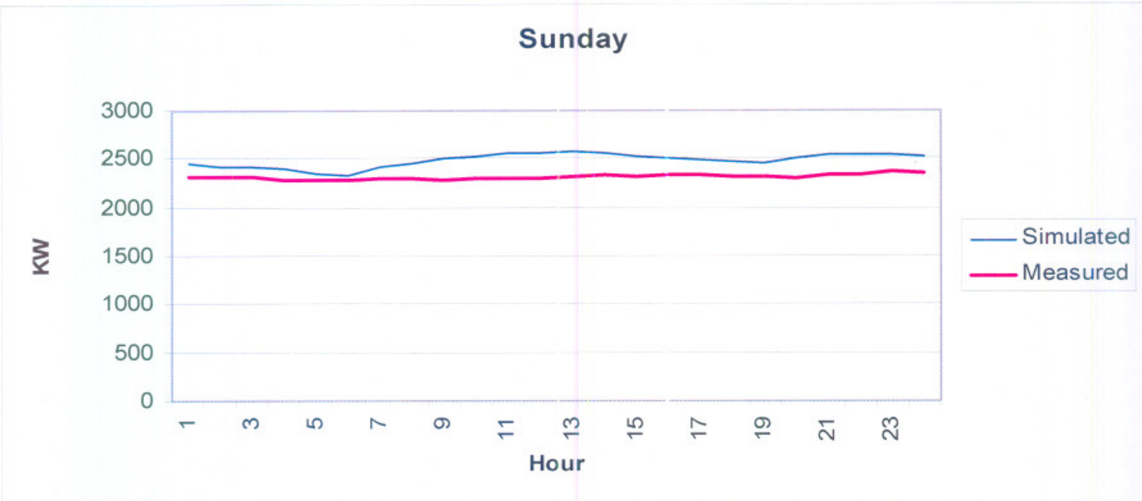


Figure 4-8: TTS: Sunday calibration simulation results

From the figures it can be seen that very accurate results have been obtained. For all three day types the simulated results was the benchmark value of being within 10% of the measured values for 80% of the time.

4.8 VERIFY BUILDING SIMULATION MODEL

Time suggested (2 days), Time spent (2 days)

The verification study is performed in order to verify the accuracy of the simulation model's energy consumption over a typical year. The verification simulation compares the simulated average seasonal energy consumption and maximum demand to the actual building data. The measured data was obtained from trended measurements on the BMS. The verification table is shown in Table 4-4 below:

Total Seasonal Energy Consumption [MWh]

	Summer	Winter
Simulated	14150	5870
Measured	14353	6010
Error [%]	1	2

Average Seasonal Maximum Demand [kW]

	Summer	Winter
Simulated	2632	2254
Measured	2560	2234
Error [%]	3	1

Table 4-4: Verification study outputs

It can be seen that the annual simulated values are very close to the actual measured values. This can be expected due to the good calibration results obtained in the previous step. This shows that the simulation model, weather and other seasonal data used in the simulations are accurate enough to proceed with the retrofit analysis.

4.9 RETROFIT SIMULATION

Time suggested (3 days), Time spent (3 days)

Although the retrofits are easy to implement in the new audit software, the outputs of the retrofits need to verified to ensure that the results are realistic. The output graphs from the simulation and resulting kWh values were used to confirm the results.

To determine the largest energy users in the building an end-user energy cost breakdown is simulated and shown in Table 4-5. Since the biggest savings opportunity exists on the HVAC system, the contribution of the different HVAC components is also calculated and shown in Table 4-6. The highest energy consumers will have the biggest potential for energy cost savings. If the contribution of each energy user had to be measured this would have been a very lengthy process. Because of the accurate building simulation model the end-user contribution could be simulated.

Building Energy Cost Breakdown				
Description	**Energy (MWh)**	**Cost (R)**	**R/kWh**	**% Of total**
HVAC system	8170	1612464	0.1201	46
Lights	7288	1438463	0.1201	41
Other	2391	471996	0.1201	13
Total	**17850**	**3522923**	**0.1201**	**100.00**

Table 4-5: TTS building energy cost breakdown

HVAC System Energy Cost Breakdown				
Description	**Energy (MWh)**	**Cost (R)**	**R/kWh**	**% Of total**
Cooling	4143	817717	0.1201	51
Heating	0	0	0.1201	0
Ventilation	2143	423029	0.1201	26
Pumping	1883	371719	0.1201	23
Total	**8170**	**1612464**	**0.1201**	**100.00**

Table 4-6: TTS HVAC system energy cost breakdown

From the tables it is obvious that the HVAC and lighting systems are the biggest consumers, and thus present the biggest opportunity for savings. The different retrofit options are described in more detail below.

4.9.1 Verification of tariff structure and metering

The building group is currently on a standard two-part tariff. This means that the user is billed for total kWh used during the month, the maximum demand recorded and service charges. There is no time-of-use periods and thus energy is charged at a flat rate.

With big users such as Telkom the local municipality allows you to convert to a time-of-use tariff structure. The building simulation model was used to simulate the electricity costs and retrofits should the building be changed to the time-of-use tariff. The results are discussed in Appendix F. The study resulted in a 3% **increase** in the electricity costs should the tariff be changed. This could be expected since the time-of-use tariff is designed to encourage the user to use less energy in peak periods. The building load profile does not change much during the peak periods, and thus the energy costs increases. The results of the simulated retrofits on the time-of-use tariff are shown in Appendix F.

4.9.2 Power factor correction

The current power factor of the building is approximately 0.8. This is a low power factor, but, as mentioned before, the municipal meter measures several buildings of which TTS is only one of the buildings. At this municipal supply point the power factor is 0.94, and thus rather good.

The only benefit that there would be from installing power factor on TTS itself, would be to reduce the losses in the reticulation network, due to the higher current that flows because of the low power factor. The savings will be small and not worth including as a retrofit. Also not that the DSM program does not fund power factor correction projects since the DSM targets are to reduce the kW load.

4.9.3 Verify temperature set points

In commercial buildings the zone temperature set points are seldom a problem, or something that cannot be changed much. The buildings tenants complain on a daily basis about too warm or too cold conditions, and the optimum set point that suits everybody is difficult to find. It can be stated that the set points in commercial buildings are self regulatory due to the human comfort element.

4.9.4 Verify control system operation

During the investigations, several problems were found with the HVAC control system. These problems were immediately corrected, which meant better IAQ and lowered power consumption. Since these problems were corrected as part of the normal responsibility of the maintenance company (TFMC) these changes were not shown as separate retrofits.

4.9.5 Fan scheduling night

For this retrofit, the fans were turned off at night when the building is unoccupied. The assumption was made that these times are from 18:00 to 04:00. The working hours of the occupants of the building are from 07:00 to 16:00. It was therefore assumed that turning the fans of at 18:00 would be safe. Also, turning the fans on at 04:00 should have the zones at the correct temperature when the occupants arrive. The scheduling times used are shown in Table 4-7:

Weekday	Saturday	Sunday
00:00 – 04:59: OFF 05:00 - 17:59: ON 18:00 – 23:59: OFF	00:00 – 05:59: OFF 06:00 - 13:59: ON 14:00 – 23:59: OFF	00:00 – 23:59: OFF

Table 4-7: Fan scheduling times

The simulation program showed that all zones were on set point temperature in the morning at the start of office hours. The simulation also showed that the temperatures in some of the zones become high during the night when the fans were switched off. Figure 4-9 gives the simulation temperature output for a summer weekday (worst case scenario).

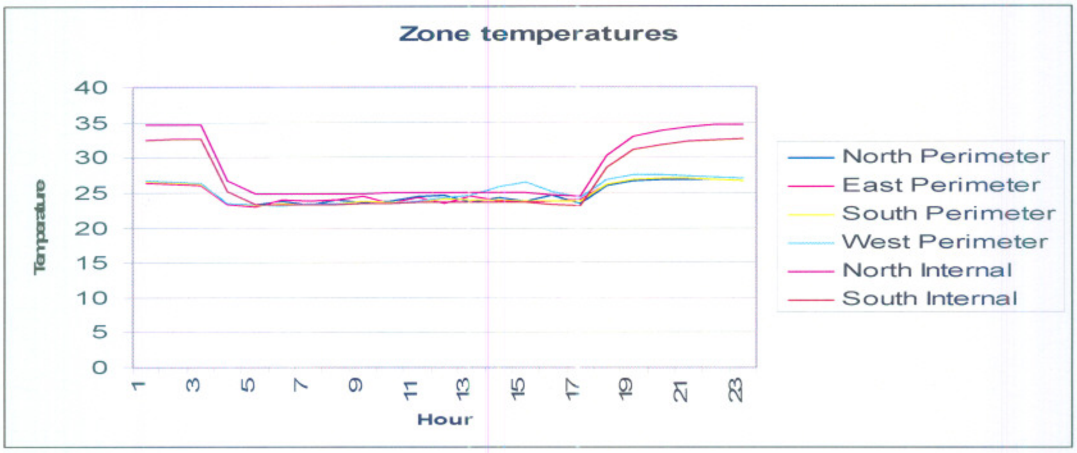


Figure 4-9: Fan scheduling at night: Simulated zone temperatures

The total seasonal reduction due to the fan scheduling at night is shown in Table 4-8. It is interesting to note that this retrofit will have no effect on the MD of the building, since the MD always occurs during the day when the building is occupied and maximum energy usage.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	1522106	11%	278809	5%	9%
MAXIMUM DEMAND REDUCTION	0.00	0.00%	0.00	0.00%	0.00%

Table 4-8: Results: Fan scheduling at night

4.9.6 Fan scheduling night & weekends

During the day the fans were turned off for similar times as for the previous retrofit, but the assumption was made that on Saturdays the fans could be turned on again at 05:00 and switched off at 14:00. On Sundays the fans were turned off for the whole day. The total seasonal reduction due to the fan scheduling at night and on weekends is shown in Table 4-9.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	2009650	14%	399875	7%	12%
MAXIMUM DEMAND REDUCTION	0.00	0.00%	0.00	0.00%	0.00%

Table 4-9: Results: Fan scheduling at night & weekends

This and the previous retrofit will be subject to approval of the building owner. The off-periods of the fans can easily be changed and re-simulated should the building owner not agree with the time periods.

4.9.7 Economiser enthalpy control

The building is currently operating economisers with temperature control logic. However, the study showed that many of the dampers appeared to be out of order. Economisers operating on enthalpy control could save more energy, because it also takes into account the latent heat of the air. For this retrofit the economisers were simulated on enthalpy control. The total seasonal reduction due to the economiser enthalpy control is shown in Table 4-9.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	94063	1%	50	0.00%	0.5%
MAXIMUM DEMAND REDUCTION	794	4%	0.00	0.00%	3%

Table 4-10: Results: Economiser enthalpy control

It can be seen that the majority of savings will be achieved in the summer since the cooling load is more than in winter months.

4.9.8 Installation of evaporative coolers

Evaporative coolers cool the air by evaporating water into the air. The advantage of this is that it uses very little energy, and removes some of the cooling load from the chillers. Figure 4-10 shows the temperature of the zones predicted by the simulation program with the installation of evaporative coolers.

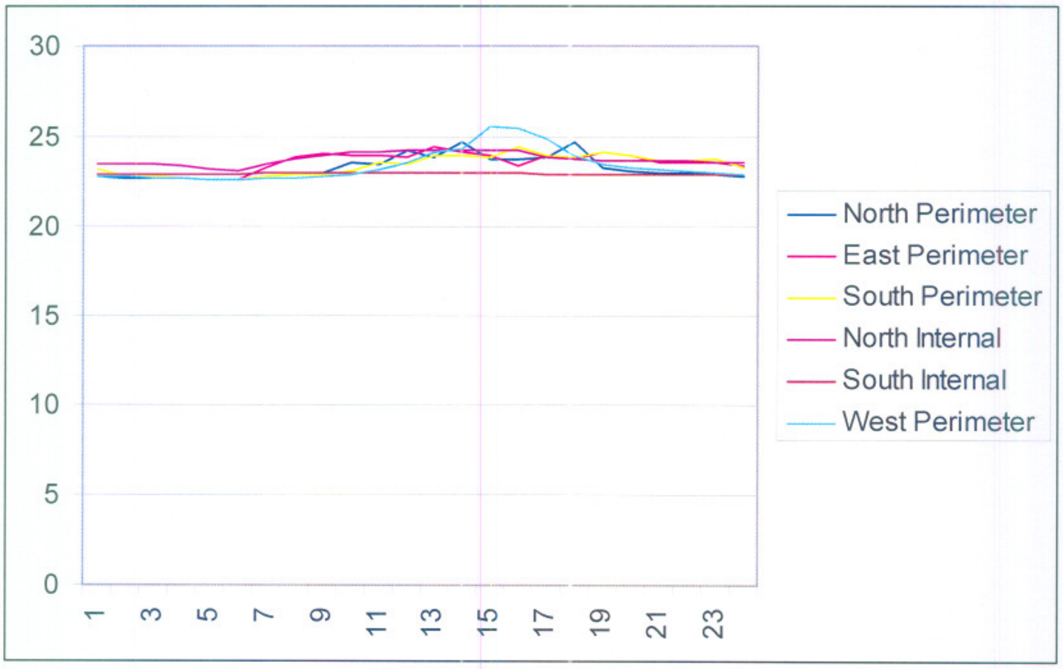


Figure 4-10: Installation of evaporative coolers: Simulated zone temperatures

It can be seen that the zone temperatures are kept between at 23ºC and 25ºC as required. The total seasonal reduction due to the evaporative coolers is shown in Table 4-10.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	793106	6%	266437	5%	5%
MAXIMUM DEMAND REDUCTION	1127	5%	835.64	9%	7%

Table 4-11: Results: Installation of evaporative cooler

4.9.9 Scheduling of lights at night

For this retrofit the lights are switched off at night, for the same period as for the fan scheduling. This retrofit does *not* assess the influence of energy efficient lighting, but uses the current lighting system in the building. The total seasonal reduction due to the scheduling of lights at night is shown in Table 4-12.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	2713714	19%	904263	15%	18%
MAXIMUM DEMAND REDUCTION	0.00	0.00%	0.00	0.00%	0.00%

Table 4-12: Results: Light scheduling at night

It is important to note that this retrofit will have no effect on the MD used by the building, since the MD always occurs during the day when the building is occupied. It is important to note that since the building model is an integrated simulation model the effect on other building systems is also calculated. Heating load in the zones was reduced by scheduling the lights and the savings will include kWh savings due to the reduced load on the HVAC system.

4.9.10 Lights scheduling nights & weekends

For this retrofit the lights are switched off for the same time during weekdays, Saturdays and Sundays as for the fan scheduling retrofit. This retrofit also does *not* assess the influence of energy efficient lighting, but uses the current lighting system in the building.

The total seasonal reduction due to the scheduling of lights at night & weekends is shown in Table 4-13.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	3619758	26%	1257285	21%	24%
MAXIMUM DEMAND REDUCTION	0.00	0.00%	0.00	0.00%	0.00%

Table 4-13: Results: Light scheduling night & weekends

4.9.11 Combined retrofits

The combination of all the retrofits will provide the biggest saving. The integrated simulation results of the combined savings of all the retrofits are shown in Table 4-14.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	4574097	32%	1657493	28%	31%
MAXIMUM DEMAND REDUCTION	1008	5%	734	8%	6%

Table 4-14: Results: Combined retrofits

The potential savings are impressive but do not say much until converted in monetary value, and compared to the implementation costs. The financial analysis will be discussed in the next section.

4.10 FINANCIAL ANALYSIS

Time suggested (1 days), Time spent (3 days)

Numerous retrofit options and combinations thereof were investigated through simulation. In the previous section the kWh and demand reduction percentages were calculated. The combined percentage reduction in kWh and demand does not directly relate to the total percentage cost savings. The actual percentage cost savings is shown in Table 4-15. The cost calculations are based on an active energy cost of 12.01c/kWh, and an MD cost of R51.51.

Annual Electricity Cost Savings			
Description	**Simulated Annual Cost**	**Annual Cost Savings**	**% Savings**
Base-year	R 3,956,038	-	-
Economiser Enthalpy control	R 3,903,903	R 52,135	1%
Fan schedule night	R 3,762,713	R 193,325	5%
Fan schedule night & Weekend	R 3,692,258	R 263,780	7%
Light schedule night	R 3,536,268	R 419,770	11%
Light schedule night & Weekend	R 3,371,383	R 584,655	15%
Evaporative cooler	R 3,727,703	R 228,335	6%
Combined	**R 3,117,916**	**R 838,121**	**21%**

Table 4-15: TTS electrical cost saving

It can be seen that the combined retrofits will have a 21% reduction in annual electricity costs. The financial analysis of the suggest retrofits are shown in Table 4-16.

Financial Analysis						
Description	**Savings**	**Project cost**	**Direct Payback Period (months)**	**Discounted Payback Period (Months)**	**Loan rate (%/year)**	**Net Present Value (R): Year 3**
Economiser Enthalpy control	R 52,135	R 14,500	3.3	4	12.00%	R 110,719
Fan schedule night	R 193,325	R 0	0.0	0	12.00%	R 464,334
Fan schedule night & Weekend	R 263,780	R 0	0.0	0	12.00%	R 633,555
Light schedule night	R 419,770	R 0	0.0	0	12.00%	R 1,008,216
Light schedule night & Weekend	R 584,655	R 0	0.0	0	12.00%	R 1,404,242
Evaporative cooler	R 228,335	R 600,000	31.5	38	12.00%	R -51,577
Combined	**R 838,121**	**R 614,500**	**8.8**	**10**	**12.00%**	**R 1,398,525**

Table 4-16: TTS financial analysis

The only user inputs required for the financial analysis is the project cost. It is assumed that the scheduling of the equipment will have zero capital input, as an existing maintenance contract on the BMS will be able to implement these retrofits. For practical purposes it was assumed that capital costs would be covered by a loan with an interest rate of 12% per annum.

In Table 4-14 the annual kWh reduction for the combined retrofits were shown. The DSM effect of the combined retrofits is calculated in Table 4-17 below:

	TOTAL SUMMER SEASON	TOTAL WINTER SEASON	ANNUAL REDUCTION	DAILY AVERAGE KW REDUCTION
kWh REDUCTION	4,574,097	1,657,494	6,231,590	721 KW

Table 4-17: DSM effect on TTS

In Chapter 1 it was shown that a guideline price for funding of energy efficiency projects is R1.6 million/MW. It can be seen from Table 4-17 that the average daily KW reduction is calculated as approximately 0.72 MW, and thus a maximum of R1,15 million would be funded from Eskom DSM (R1.6 million*0.72). For energy efficiency projects only 50% of the capital is funded, and thus only R577 000 will be available. This is more than the 50% of the required project costs and will thus be a viable DSM project. These results are shown Table 4-18.

Maximum DSM Funding R / MW	**R 1,600,000**
MW reduction due to retrofits	**0.72 MW**
Effective DSM funding	**R 1,154,000**
50% of DSM funding available because EE project	**R 577,000**
Combined retrofits project costs	**R 614,500**
50% of combined retrofit cost	**R 307,250**
Excess/shortage	**R 269,750**

Table 4-18: DSM financial analysis

4.11 REPORT GENERATION

Time suggested (2 days), Time spent (1 days)

Generating the final report is made easy with the new simulation software. All the results, projects steps and detail about each step were exported into the word processor environment. The auditor can simply edit the report to ensure that all information expected by the client, is included in the report. The other advantage is that the reporting format will be consistent between different auditors and different buildings.

4.12 CONCLUSION

The purpose of this case study was to evaluate the new ESCO analysis procedure on a commercial building with a centralised HVAC system.

The ESCO analysis procedure took longer than initially anticipated. The first delay was caused by the gathering of information required to build up the simulation model. The information needed to be supplied by external parties that do not necessarily have the same urgency to perform the ESCO analysis. The next delay was caused in obtaining the project costs of the proposed retrofits.

The total project time was 27 days compared with the 23 days initially planned for the 24 000m^2 building. It was shown by Arndt that typical ESCO audits took 45 days for a building of 10 000m^2 [1]. The audit time for the new ESCO procedure is thus significantly less than previous ESCO procedures.

It was seen during the verification phase that the building simulation was very accurate, even with the reduced data requirements of the new procedure. The simulation software accurately represented the HVAC system operation and was successful in simulating the centralised HVAC system.

The successful implementation of the ESCO procedure is greatly dependant on the cooperation of the building owners and maintenance personnel. Proper planning is also required to prevent delays in obtaining approval to perform the required measurements.

The TFMC maintenance person that assisted with the project would have been able to perform the ESCO procedure if properly trained. The procedure would probably be completed in a shorter time period since he already had a thorough knowledge of the building and HVAC system and would not have to explain the detail HVAC layout and operation to the ESCO.

4.13 REFERENCES

[1] McNaughton, G., "Personal consultation on numerous occasions throughout 2004-2005", TFMC, Meersig Building, Cnr Lenchen and West Avenue, Centurion, Tel +2712 643 8000.

[2] Arndt, D.C., "Personal consultation on numerous occasions throughout 2004", PO Box 1943, Faerie Glen, 0043, Tel +2782 256 0907.

5. CASE STUDY 2: MULTI-FUNCTION BUILDINGS WITH A SHARED CHILLED WATER SYSTEM

5.1 INTRODUCTION

The next buildings on which the new ESCO analysis procedure was applied to was the Telkom Tower North (TTN) Complex. The Telkom Towers North Complex consists of three independent buildings namely Telkom Towers North (TTN), Telkom Tower East (TTE) and Annex buildings. These buildings also form part of the Head Office complex of buildings owned and operated by Telkom SA.

Although buildings are normally simulated separately, these buildings were investigated together because of the similarity of the installed HVAC systems, as well as the shared chilled water plant. These buildings were chosen to evaluate if the building simulation model could be simplified even further by grouping the three buildings into a single building simulation.

The buildings have mainly commercial activities, with some telecommunication equipment on some of the floors. Telkom SA executives are located on the top floors in the TTN building. This makes the building a crucial building due to the importance of its occupants.

The other unique aspect of the TTN complex is that an ice storage system is installed in TTN building. Ice storage is an excellent way to store energy and to use this energy by melting ice in high demand periods.

The recommended audit times shown previously was 20 days for a building of 20 000m^2. The audit times was scaled accordingly to the 40 000m^2 of floor space in the TTN Complex to allow 40 calendar days for the whole ESCO procedure and is shown in Table 5-1. The rest of the chapter will discuss the logical implementation of these steps.

Step in ESCO Procedure	Calendar days (40 000m²)
Step 1: Determine which building to audit	Predetermined
Step 2: Gather preliminary building information	Monday 1- Tuesday 3 (12 days)
Step 3: Walkthrough visit to building	Wednesday 3- Tuesday 4 (5 days)
Step 4: Customise data acquisition software	Wednesday 4-Friday 4 (3 days)
Step 5: On-site detail measurements	Monday 5- Friday 6 (10 days)
Step 6: Configure building simulation model	Monday 7- Wednesday 7 (3 days)
Step 7: Calibrate building simulation	Monday 7- Wednesday 7 (3 days)
Step 8: Verify building simulation	Monday 7- Wednesday 7 (3 days)
Step 9: Retrofit simulations	Thursday 7- Tuesday 8 (4 days)
Step 10: Financial analysis	Wednesday 8-Friday 8 (3 day)
Step 11: Generate final report	Wednesday 8-Friday 8 (3 day)

Table 5-1: TTN complex ESCO procedure audit times

5.2 GATHER PRELIMINARY BUILDING INFORMATION

Time suggested (12 days), Time spent (15 days)

Gathering building information for the TTN complex took longer than planned. The design documentation was difficult to locate and the working of the HVAC system was complex. During the audit there were severe breakdowns on the BMS and some of the chillers [1]. These breakdowns kept the maintenance personnel very busy and it was very difficult to obtain information. As mentioned in the introduction that all the buildings in this group is serviced by a common chilled water system and will be discussed next.

5.2.1 Common chilled water plant

The chilled water plant is located in the basement of TTN building. The plant supplies TTN, TTE and Annex buildings with chilled water. The equipment in the plant includes two York water cooled chillers, one RC water cooled chiller, four sets of Grenco compressors that feed four ice tanks, two heat exchangers, and the accompanying pumps. The plant operates as follows:

Pumps draw 85% of the return water from the buildings and discharge it to the chillers where the water is cooled. This pre-cooled water then mixes with the remaining 15% of the return water. This mixture is then directed to the heat exchangers or bypass valve to maintain a constant temperature out of the heat exchangers. From the heat exchangers the water is then directed back to the buildings where it is used in the cooling coils of the air handling units (AHUs).

Additional to the chillers, there is a thermal storage facility in the form of an ice storage system. The system is made up of four sets of Grenco compressors that serve four ice tanks, where the ice is made. The build up of the ice occurs during the evening, and the ice is burned off again during the day. During the burn-off period, the resulting melted water from the ice tanks are fed to the heat exchangers where it supplies additional cooling to the chilled water that is directed to the buildings. Figure 5-1 below shows a graphical representation of the chilled water plant.

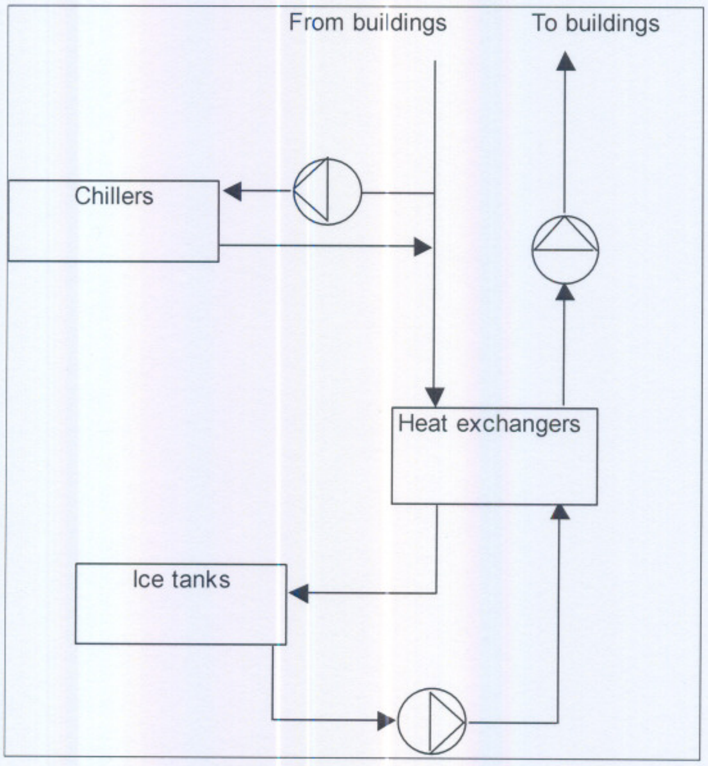


Figure 5-1: TTN complex: Common chilled water system

The Grenco compressors are supplied by four evaporative condensers, the York chillers by two evaporative condensers, and the RC chiller by its own evaporative condenser on the roof of the first floor of the TTN building.

The system was originally designed for an eight-hour operation period during the day. For this the ice plant was installed. The design purpose was that the ice plant would make ice during the evenings, which would be burned off during the day, and thus reduce the energy usage during the day. With increased occupation of the building and the large amount of computers being used in the building, the need arose for additional cooling. For this reason the York chillers and the RC chiller were installed.

5.2.2 Telkom Towers North building

The most important building and HVAC system details are summarised in Table 5-2:

BUILDING DESCRIPTION	
Building name	TTN
Building description	Commercial building
Building location	Pretoria CBD
Number of floors	26
Total floor area	21 000m^2
HVAC system	Multi-zone
Air distribution	VAV
Control System	BMS

Table 5-2: TTN building description

The building is situated in the CBD of Pretoria and forms part of the Telkom campus group. It has 26 floors above ground and is mostly used as office space, although some areas are used for other purposes, like a gym, a restaurant, and three conference venues located on the first floor.

The primary air conditioning of the building is done by AHUs located in plantrooms on the 13th floor. There are two plantrooms, with two air handlers in each plantroom. Each AHU consists of air filters, two pre-cooling coils, two cooling coils, a spray washer, two supply air fans, and electric heaters. Return-air use is enabled through two return-air fans, and return and fresh air dampers. The supply air fans, and the return-air fans, are supplied by variable speed drives (VSD's). The system operates on the variable air volume (VAV) principal.

The water for the pre-cooling coil is supplied by six cooling towers, located on the 26th floor of the building. The chilled water plant located in the basement of the building supplies the water for the other cooling coils. Figure 5-2 below shows the typical floor layout of the building.

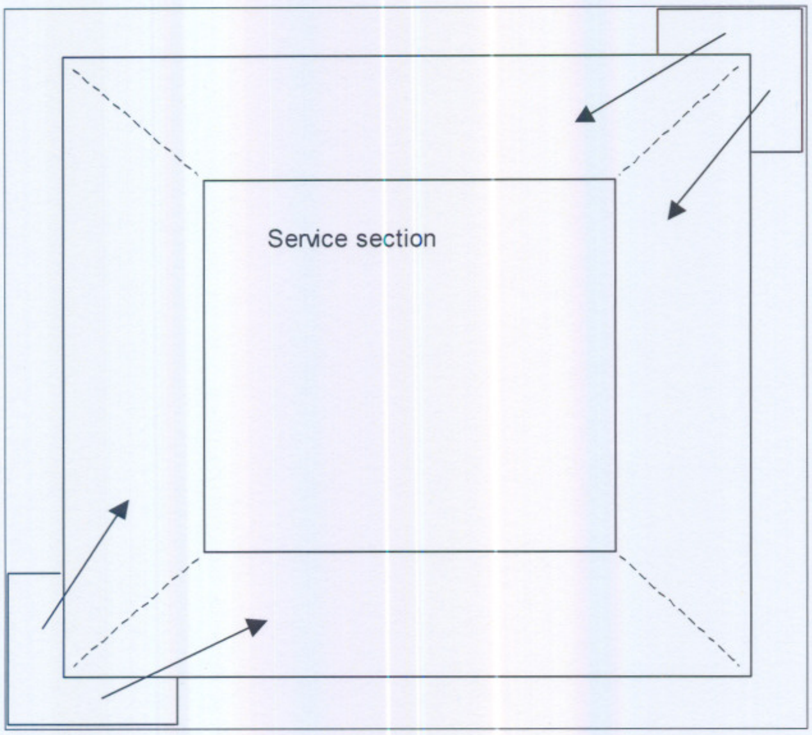


Figure 5-2: TTN building floor layout

The typical floor of TTN is divided into an office section, and a service section. The service section contains the elevator shafts, and stairs. This area is not air conditioned. From the plantrooms, the air is distributed to each floor by means of ducting located in the two air conditioning shafts. From an air conditioning viewpoint, each floor is then divided into four quarters, each section served by a separate air handler. However, there are no physical separations between these sections.

The first floor conference venues have a separate chiller and AHU system. The building is equipped with an extensive BMS system. This system is capable of logging and control of numerous equipment and states in the building and HVAC system.

5.2.3 Telkom Towers East building

The most important building and HVAC system details are summarised in Table 5-3:

BUILDING DESCRIPTION	
Building name	TTE
Building description	Commercial building
Building location	Pretoria CBD
Number of floors	16
Total floor area	12 100m^2
HVAC system	Multi-zone
Air distribution	VAV
Control System	BMS

Table 5-3: TTE building description

The building is situated in the CBD of Pretoria and forms part of the Telkom campus group. It has 16 floors above ground and is mostly used as office space.

The primary air conditioning of the building is done by AHUs located in plantrooms on the 16th floor. There are two plantrooms, with two air handlers in each plantroom. Each AHU consists of air filters, two pre-cooling coils, two cooling coils, a spray washer, supply air fans, and electric heaters. Return-air use is enabled through the return-air fan. This building differs from TTN in the manner that the fresh and return-air dampers are replaced by relief fans. This building is also supplied by a VAV system.

When the system operates at full return-air, the return-air fans draw most of the supplied air from the zone and return it to the AHUs. When more fresh air is required, the return-air speed is reduced. The relief-air fan is then used to maintain static pressure inside the zone. The supply air fans, return-air fans, and relief-air fans are supplied by variable speed drives (VSD's).

The water for the pre-cooling coil is supplied by eight cooling towers, located on the 16th floor of the building. The cooling towers are divided into two sets of four each, each set located next to the plantroom that it serves. The chilled water plant located in the basement of TTN supplies the water for the other cooling coils. Figure 5-3 below shows the typical floor layout of the building.

A typical floor of TTE is divided into an office section, and a service section. The service section contains the elevator shafts and stairs. This area is not air conditioned. From the plantrooms, the air is distributed to each floor by means of ducting located in the two air conditioning shafts. From an air conditioning viewpoint, each floor is then divided into four quarters, each section served by a separate air handler. However, there are no physical separations between these sections. This is similar to the layout of TTN.

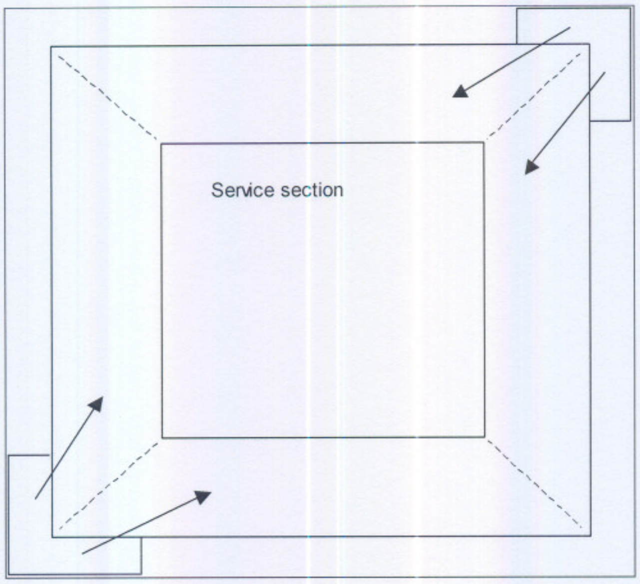


Figure 5-3: TTE building floor layout.

The building is equipped with an extensive BMS system. This system is capable of logging and control of numerous equipment and states in the building and HVAC system.

5.2.4 Annex building

The most important building and HVAC system details are summarised in Table 5-4:

BUILDING DESCRIPTION	
Building name	ANNEX
Building description	Commercial building
Building location	Pretoria CBD
Number of floors	4
Total floor area	6 500m^2
HVAC system	Multi-zone
Air distribution	VAV
Control System	BMS

Table 5-4: ANNEX building description

The building is situated next to the other two buildings, and forms part of the Telkom campus group. It has four floors above ground and is mostly used as office space and a Telkom call centre.

The primary air conditioning of the building is done by AHUs located in plantrooms on the 1st floor. There is only one plantroom with one air handler. The AHU is similar to the TTE air handlers, and consists of air filters, two pre-cooling coils, two cooling coils, a spray washer, two supply air fans, and electric heaters. Return-air use is enabled through the return-air fan. This building is also equipped with relief-air fans that regulate the fresh air intake into the building. There are two relief-air fans installed in the building.

When the system operates at full return-air, the return-air fans draw most of the supplied air from the zone and return it to the AHUs. When more fresh air is required, the return-air speed is reduced. The relief-air fan is then used to maintain static pressure inside the zone. The supply air fans, return-air fan, and relief-air fans are supplied by variable speed drives (VSDs).

The water for the pre-cooling coil is supplied by four cooling towers, located on the roof of the building. The chilled water plant located in the basement of TTN supplies the water for the other cooling coils.

The building is equipped with an extensive BMS system. This system is capable of logging and control of numerous equipment and states in the building and HVAC system.

5.3 WALKTHROUGH VISIT TO BUILDING

Time suggested (5 days), Time spent (4 days)

The same managers of Telkom SA and TFMC were involved in the TTN Complex audit. A meeting was once again held with these role-players to discuss the requirements of the project. During the meeting it became apparent that there were severe breakdowns in the BMS and the ice plant equipment. No commitments on when the problems were to be corrected could be provided.

The municipal meter for the whole campus group of buildings is located in the basement of the TTN building. The municipal meter number and type was verified with the account data. No electrical measurement equipment had to be connected to obtain the total building profile, since meters were already installed on all the transformers in the building. The climate data was however not available due to the breakdown of the BMS. A nearby building's BMS data was used for the climate data.

The walkthrough audit was very important for these buildings due to the complexity of the system. It is very difficult to have an understanding of the design information without fully understanding the physical layout of the building.

5.4 CUSTOMISE DATA ACQUISITION SOFTWARE

Time suggested (3 days), Time spent (3 days)

The simulation program has a maximum of 12 zones that can be used in a simulation model. This forces the user to simplify the simulation model if the building has a more complex HVAC system.

The simulation model includes the three buildings, namely TTN, TTE and Annex. The zone layout was simplified and each building was taken as a single zone. In TTN and TTE, only the main air handling system was simulated. This includes the AHUs in the two main plantrooms, in each building. The gym and restaurants were not simulated since they have a very small contribution to the total power consumption. Annex has one AHU, which was simulated. Figure 5-4 below show the water-circuit and Figure 5-5 the air-circuit of the simulation model.

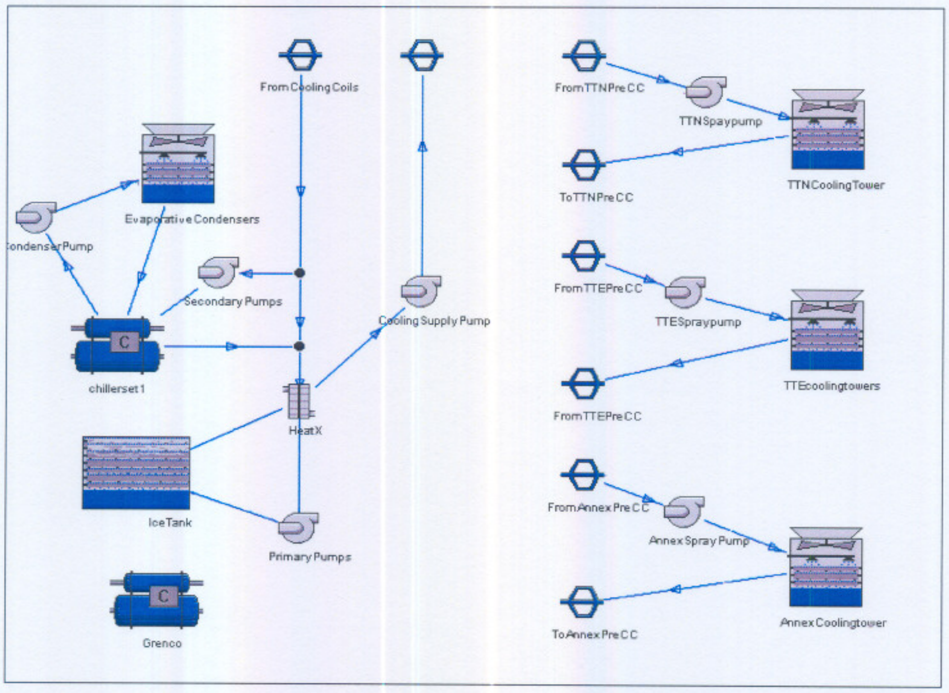


Figure 5-4: Simulation model: water-circuit

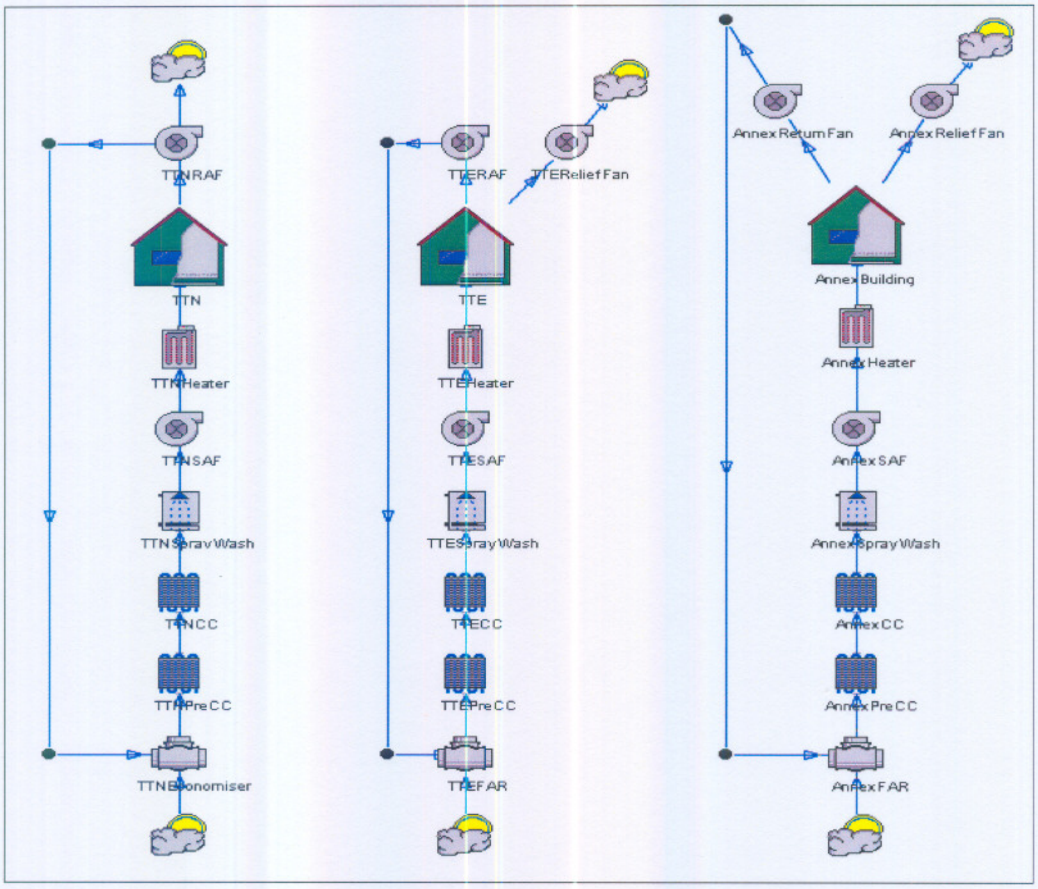


Figure 5-5: Simulation model: air-circuit

5.5 ON-SITE DETAIL MEASUREMENTS

Time suggested (10 days), Time spent (15 days)

Certain information is required to accurately simulate the integrated working of a building with the HVAC system. Firstly, the ESCO must have a good understanding of the operation of the building under normal conditions. Secondly, detailed measurements of the HVAC equipment are required to calibrate the simulation model.

During the study of TTN, TTE and Annex, various maintenance and operational problems were encountered, which resulted in some of the information not being available. Therefore, assumptions had to be made. A detailed list of problems encountered is listed in Appendix G.

The BMS components for TTE and Annex were out of service, and not repaired within the duration of the audit. The result of this was that the BMS had no control over the HVAC system during this period. The system was therefore running on the command last issued by the BMS. This could potentially lead to uncomfortable conditions in the building, and inefficient operation. The BMS is also required for the detailed measurements of the equipment. The equipment must be measured at maximum capacity, and the BMS is required to set the components to the maximum condition. The loss of BMS control made this impossible.

Therefore, the equipment was modelled according to the original commissioning data of the building. Changes in efficiency were taken into account to try and replicate the current building operations. These inefficiencies were calculated by comparing the current running of TTN to the commissioning reports of TTN (TTN could be measured for calibration). This was done by using the airflow through the cooling coils.

During the study, the chilled water plant was not running at capacity because of maintenance issues. These issues involved the ice plant, as well as all three chillers. Neither the chillers, nor the Grenco compressors were operating at full capacity during any part of the study.

During the detailed measurements, no Grenco compressors were online. Only three of the four York compressors were available, and one of three of the RC chiller compressors were operating. Firstly, it was not possible to ascertain the normal operation of the chilled plant. Secondly, the supply temperature of the chilled water system was very high. This made the temperature measurements taken on-site irrelevant for the calibration model. Therefore, the commissioning data was used for the calibration of the simulation model.

In the set-up of the building model, the following assumptions were made to obtain the relevant area, occupancy and load inputs:

- Campus operates on a typical load lighting load of 22 W/m^2. This value is realistic compared to typical design values.
- Assume 900 persons working in TTN. This was obtained from building telephone lists.
- Assume 700 persons in TTE.
- Assume 500 persons in Annex.
- Assume that 80% of the occupants operate PCs.

Table 5-5 and Figure 5-6 give the climate data used in the energy simulation. It is calculated from yearly data for Pretoria, South Africa over the past 20 years. The temperature and relative humidity (RH) are shown.

Hour	Summer Temperature	Summer RH	Winter Temperature	Winter RH
0	18.4	73.3	10.0	71.1
1	18.0	75.4	9.4	72.8
2	17.5	77.3	8.8	74.9
3	17.1	78.8	8.3	76.6
4	16.7	80.4	7.8	78.9
5	16.4	82.1	7.2	80.8
6	16.3	82.9	7.0	81.8
7	17.0	80.7	7.1	82.0
8	18.9	74.3	9.0	76.0
9	20.6	68.6	13.1	62.8
10	22.2	62.7	16.1	53.5
11	23.6	57.8	18.3	45.8
12	24.6	53.7	19.9	39.9
13	25.4	50.3	20.8	36.0
14	26.0	48.1	21.4	33.0
15	26.1	46.8	21.3	32.3
16	25.8	47.4	20.9	32.5
17	25.0	49.2	19.6	35.1
18	23.8	52.7	17.2	42.3
19	22.3	57.7	15.3	48.8
20	21.1	62.8	13.6	56.1
21	20.2	66.4	12.3	61.4
22	19.5	69.3	11.5	64.8
23	18.9	71.8	10.6	68.1

Table 5-5: Climate data used for simulation

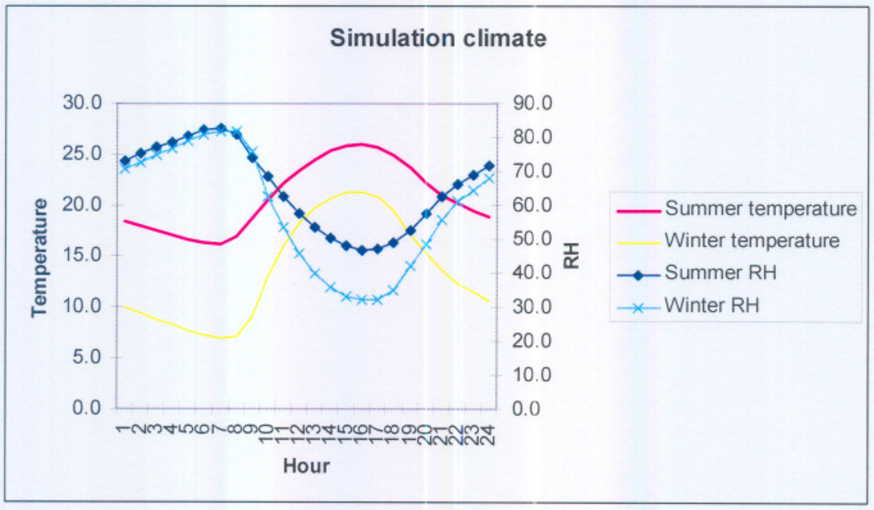


Figure 5-6: Climate data used for simulation

5.6 CONFIGURE BUILDING SIMULATION MODEL

Time suggested (3 days), Time spent (2 days)

The data captured during the building data acquisition phase was uploaded from the PDA device to the simulation software. The tariff rates that were applied to the Head Office group of buildings were applied to the TTN Complex. The climate data for Pretoria is one of the preloaded climate databases that is part of the simulation software and was used.

The operating schedules of the different equipment were configured from information obtained from the design information and discussions with maintenance personnel. An interesting observation was that the lighting is also never switched off in the building. This results in a 24-hour heat load on the HVAC system.

5.7 CALIBRATE SIMULATION MODEL

Time suggested (3 days), Time spent (3 days)

The calibration simulation ensures that the current status of the building will be simulated correctly so that cost savings predictions are realistic. The model is considered calibrated when the predicted daily demand load is within 10% of the measured value 80% of the time.

The calibration simulation compares the total building energy consumption over a weekday, Saturday and Sunday, to measured energy values. One calibration climate input is used for the three simulated days. Figure 5-7, Figure 5-8 and Figure 5-9 show the simulation and calibration data results:

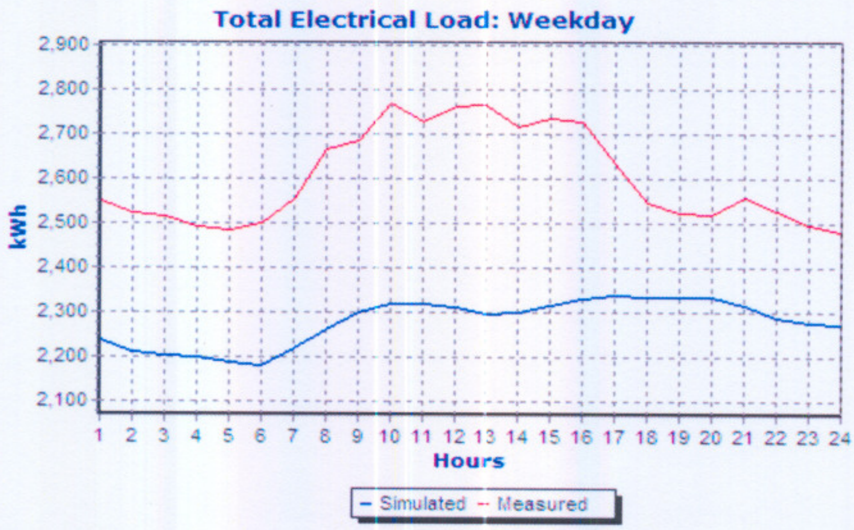


Figure 5-7: TTN Complex: Weekday calibration simulation result

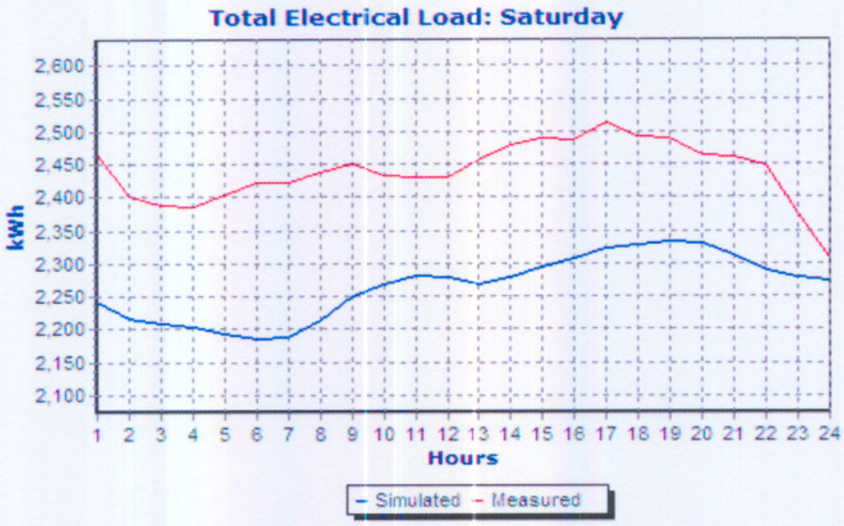


Figure 5-8: TTN Complex: Saturday calibration simulation result

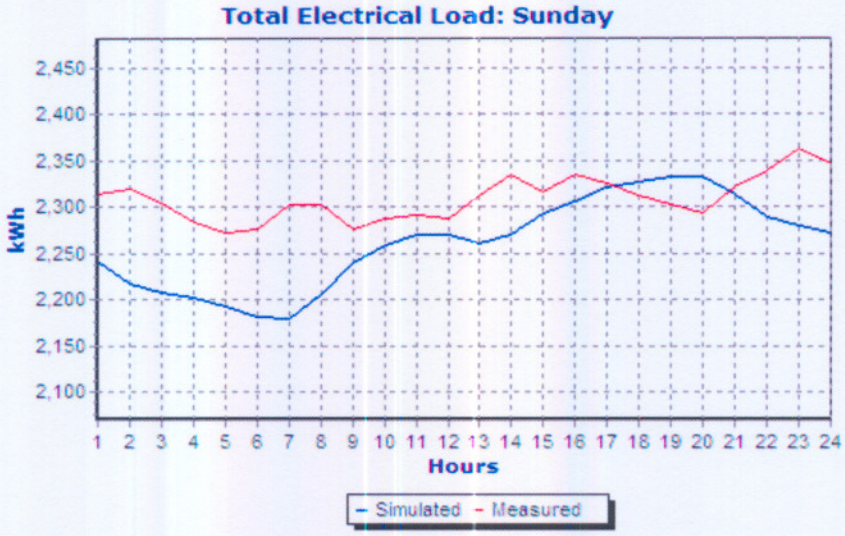


Figure 5-9: TTN Complex: Sunday calibration simulation result

From the graphs it can be seen that the shape of simulated and measured graphs are similar but that the simulation does not accurately represent the building operations. The reason for this is the fact that only design and commissioning data could be used, and that the control of the HVAC systems in TTE and Annex were not operational. Other factor would be the changing operating philosophy due to the breakdown of the ice plant and inefficiencies in the system. The building was commissioned in 1987 and will certainly not be operating according to design [2].

5.8 VERIFY SIMULATION MODEL

Time suggested (3 days), Time spent (2 days)

The verification study is performed in order to verify the accuracy of the simulation model's energy consumption over a typical year. The verification simulation compares the simulated average seasonal energy consumption and maximum demand to the actual building data. The data can be obtained from trended measurements, or from electricity accounts. The annual electricity costs used for the TTN complex were obtained from logged data on the BMS system. The verification table is shown in Table 5-6 below:

Total Seasonal Energy Consumption [MWh]

	Summer	Winter
Simulated	13126	5709
Measured	10115	5113
Error [%]	30	12

Average Seasonal Maximum Demand [kW]

	Summer	Winter
Simulated	2414	2058
Measured	2515	2278
Error [%]	4	10

Table 5-6: Verification study outputs

As can be expected from the calibration results the verification results are not within the limits as required in the ESCO procedure. The model will however still be able to provide relative figures of savings opportunities that to prioritise retrofit opportunities.

5.9 RETROFIT SIMULATION

Time suggested (4 days), Time spent (4 days)

To determine the largest energy users in the building an end-user energy cost breakdown is simulated and shown in Table 5-7. Since the biggest savings opportunity exists on the HVAC system, the contribution of the different HVAC components is also calculated and shown in Table 5-8. The highest energy consumers will have the biggest potential for energy cost savings. If the contribution of each energy user had to be measured, this would have been a very lengthy process.

Building Energy Cost Breakdown				
Description	**Energy (MWh)**	**Energy Cost (R)**	**R/kWh**	**% of total**
HVAC system	6082	730393	0.1201	34
Lights	7621	915306	0.1201	42
Other	4433	532350	0.1201	24
Total	18135	2178050	0.1201	100.00

Table 5-7: TTN building energy cost breakdown

HVAC System Energy Cost Breakdown				
Description	**Energy (MWh)**	**Energy Cost (R)**	**R/kWh**	**% of total**
Cooling	1705	204798	0.1201	28
Heating	0	0	0.1201	0
Ventilation	3150	378303	0.1201	52
Pumping	1227	17291	0.1201	20
Total	6082	730393	0.1201	100.00

Table 5-8: TTN HVAC system energy cost breakdown

From the tables it is obvious that the HVAC and lighting systems are the biggest consumers, and thus present the biggest opportunity for savings. The different retrofit options are described below.

5.9.1 Verification of tariff structure and metering

The building is currently on a standard two-part tariff. This means that the user is billed for total kWh used during the month, the maximum demand recorded and service charges. There are no time-of-use periods and thus energy is charged at a flat rate. For big users such as Telkom the local municipality allows a conversion to a time-of-use tariff structure.

The building simulation model was used to simulate the electricity costs and retrofits should the building be changed to the time-of-use tariff. The results are discussed in Appendix G. The study resulted in a 3% **increase** in the electricity costs should the tariff be changed. This could be expected since the time-of-use tariff is designed to encourage the user to use less energy in peak periods. The building load profile does not change much during the peak periods, and thus the energy costs increases. The retrofits simulation for time-of-use tariff structure is shown in Appendix G.

5.9.2 Power factor correction

The current power factor of the building is approximately 0.8. This is a low power factor, but, as mentioned before, the municipal meter measures several buildings. At this municipal supply point the power factor is 0.94, and thus rather good.

The only benefit that there would be from installing power factor on TTN itself, would be to reduce the losses in the reticulation network, due to the higher current that flows due to the bad power factor. This savings will be small and not worth including as a retrofit. Eskom DSM also does not fund power factor correction projects.

5.9.3 Verify temperature set points

In commercial buildings the zone temperature set points are seldom a problem, or something that cannot be changed much. The buildings tenants complain on a daily basis about too warm or too cold conditions, and the optimum set point that suits everybody is difficult to find. It can be stated the set points in commercial buildings are self regulatory due to the human comfort element.

5.9.4 Verify control system operation

The control system could not be verified on these buildings due to the breakdown in the BMS systems.

5.9.5 Fan scheduling

Fan scheduling involves turning the fans off during unoccupied times. The cost of technical expertise on setting the BMS retrofits is accounted for and the amount is given in the financial analysis. Normally maintenance personnel are not in favour of switching equipment off, and would prefer set point drift. The scheduling times used are shown in Table 5-9:

Weekday	Saturday	Sunday
00:00 – 04:59: OFF	00:00 – 05:59: OFF	00:00 – 23:59: OFF
05:00 - 17:59: ON	06:00 - 13:59: ON	
18:00 – 23:59: OFF	14:00 – 23:59: OFF	

Table 5-9: Fan scheduling times

The simulated energy and demand reduction is shown in Table 5-10:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	1175837	9%	356911	6%	8%
MAXIMUM DEMAND REDUCTION	0	0%	0	0%	0%

Table 5-10: Results: TTN complex fan scheduling

5.9.6 Lights scheduling

For this retrofit the lights are switched off at night and during weekends, for the same period as for the fan scheduling. The retrofit does not assess the influence of energy efficient lighting, but uses the current lighting system in the building. The scheduling of the light can be controlled by the BMS. The scheduling can only be applied in TTN and TTE and not Annex since it is in operation 24-hours of the day. The simulated energy and demand reduction is shown in Table 5-11:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	3845337	30%	1489500	27%	29%
MAXIMUM DEMAND REDUCTION	0	0%	0	0%	0%

Table 5-11: Results: TTN complex light scheduling

5.9.7 Energy efficient lighting

For this retrofit the existing lights are exchanged with energy efficient lights. This is the most effective method for reducing energy usage in the buildings. However, it is the most expensive since all the existing lights have to be replaced by new energy efficient lights and control gear. The simulated energy and demand reduction is shown in Table 5-12:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	3881724	31%	1636386	30%	30%
MAXIMUM DEMAND REDUCTION	5349	28%	2334	29%	29%

Table 5-12: Results: TTN complex installation of energy efficient lighting

5.9.8 Energy efficient and light scheduling

For this retrofit energy efficient lighting is installed and switched off at night and during weekends, for the same period as for the fan scheduling. The scheduling of the energy efficient lights can be controlled by the BMS. The approximate cost of the technical expertise needed to change the BMS set up and the implementation cost of the energy efficient lights are given in the financial analysis. The scheduling can only be applied in TTN and TTE and not Annex, since it is in operation 24-hours of the day. The simulated energy and demand reduction is shown in Table 5-13:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	5479434	43%	1990891	36%	41%
MAXIMUM DEMAND REDUCTION	5434	29%	2358	29%	29%

Table 5-13: Results: TTN complex energy efficient and light scheduling

5.9.9 Night setback/set point drift

Night set point setback involves the adjusting of the building set points during unoccupied times. The cooling set point is raised and the heating set point is lowered during these times. The set points were adjusted according to the schedule shown in Table 5-14:

Weekday	Saturday	Sunday
00:00 – 04:59: 5°C	00:00 – 05:59: 5°C	00:00 – 23:59: 5°C
05:00 - 05:59: 2°C	06:00 - 06:59: 3°C	
06:00 – 06:59: 1°C	06:00 – 06:59: 1°C	
18:00 – 18:59: 2°C	12:00 – 12:59: 1°C	
19:00 – 19:59 3°C	13:00 – 13:59 2°C	
20:00 – 23:59: 5°C	14:00 – 14:59: 3°C	
	15:00 – 23:59: 5°C	

Table 5-14: Set point drift settings

The simulated energy and demand reduction are shown in Table 5-15:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	251316	2%	115296	2%	2%
MAXIMUM DEMAND REDUCTION	0	0%	0	0%	0%

Table 5-15: Results: TTN complex night setback results

5.9.10 Economiser enthalpy control

The buildings (TTN, TTE and Annex) are designed to operate on economiser enthalpy control. Through investigation of the building it was found that the operation of the economisers is faulty. The fresh air and return-air ratios stay constant and is therefore not controlled by the economiser system. Economisers operating on enthalpy control could save energy, because it also takes into account the latent heat of the air. For this retrofit the economisers were simulated on enthalpy control. The simulated zone temperatures for each building are shown in the following figures:

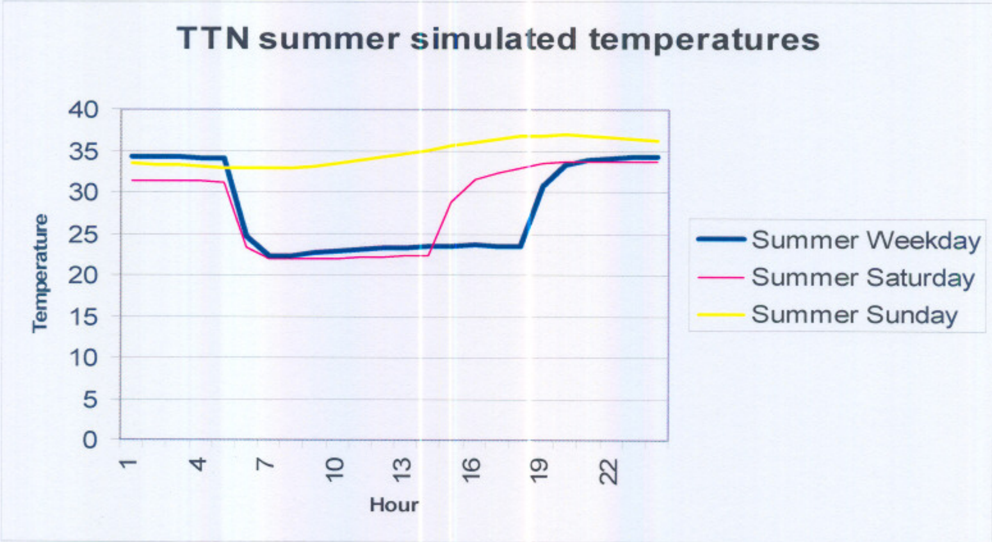


Figure 5-10: Economiser enthalpy control: Temperatures for TTN building (summer)

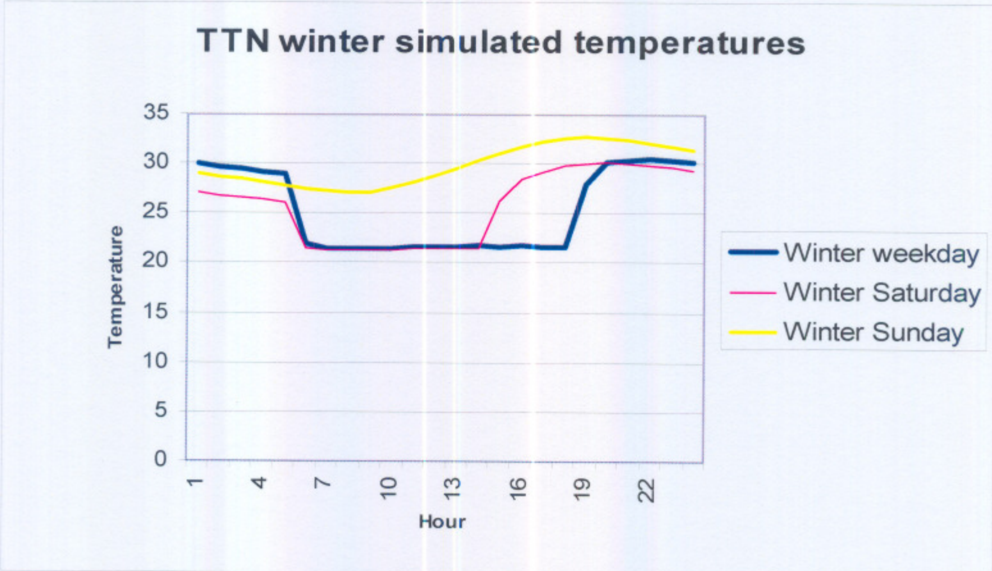


Figure 5-11: Economiser enthalpy control: Temperatures for TTN building (winter)

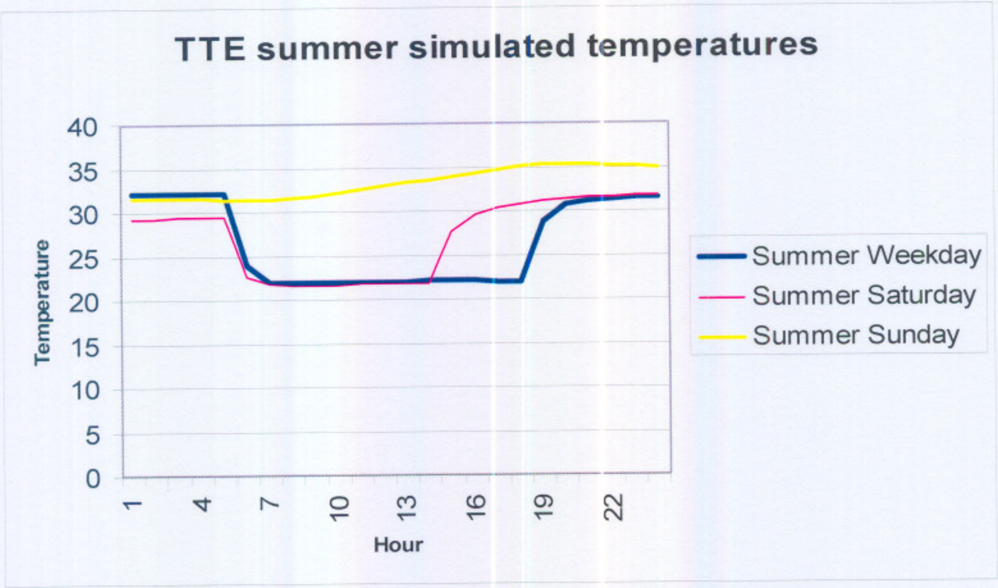


Figure 5-12: Economiser enthalpy control: Temperatures for TTE building (summer)

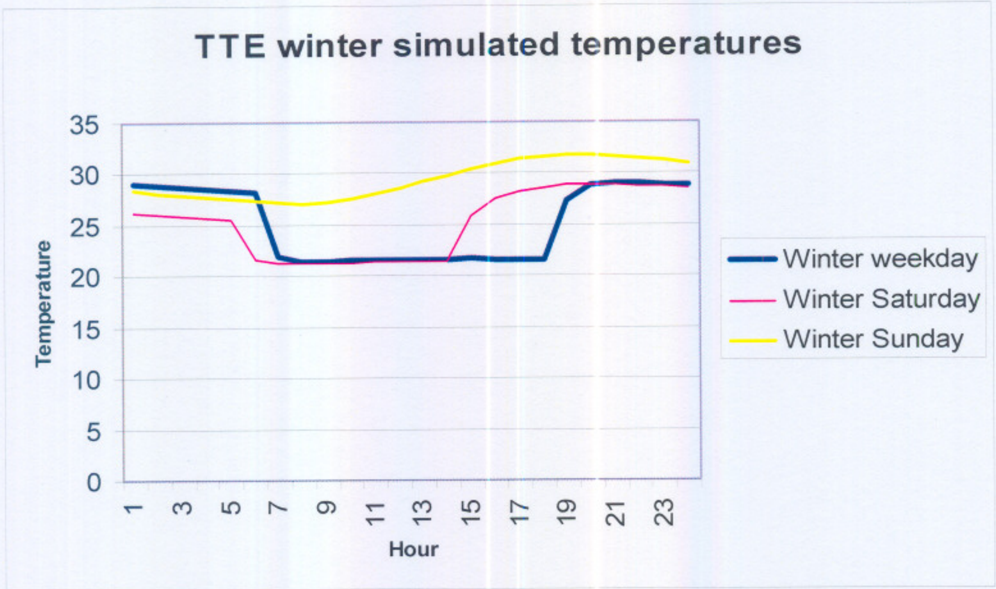


Figure 5-13: Economiser enthalpy control: Temperatures for TTE building (winter)

Once again Annex Building was not included in the simulation due to the 24-hour call centre activities.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	372773	3%	177202	3%	3%
MAXIMUM DEMAND REDUCTION	834	4%	313	4%	4%

Table 5-16: Results: TTN complex economiser enthalpy control

5.10 FINANCIAL ANALYSIS

Time suggested (3 days), Time spent (3 days)

Numerous retrofit options and combinations thereof were investigated through simulation during the project. The most important financial results are displayed in Table 5-17 and Table 5-18. The cost calculations are based on an active energy cost of 12.01c/kWh, and an MD cost of R51.51.

Annual Electricity Cost Savings			
Description	**Simulated Annual Cost**	**Annual Cost Savings**	**% Savings**
Base-year	R3,560,585	-	-
Energy efficient lighting	R2,502,200	R1,058,385	30%
Lighting Schedule office hours and weekends	R2,854,200	R706,385	20%
Energy efficient lighting schedule office hours and weekends	R2,262,100	R1,298,485	36%
Fan Schedule office hours and weekends	R3,362,500	R198,085	6%
Economiser	R3,435,500	R125,085	4%
Setpoint setback	R3,470,900	R89,685	3%

Table 5-17: TTN complex electrical cost savings

Financial Analysis						
Description	**Savings**	**Project cost**	**Direct Payback Period (months)**	**Discounted Payback Period (Months)**	**Loan rate**	**Net Present Value (R)**
						Year 3
Energy efficient lighting	R 1,058,385	R 2,000,000	23.0	24	12%	R 542,063.03
Lighting Schedule office hours and weekends	R 706,385	R 5,000	1.0	1	12%	R 1,691,618.42
Energy efficient lighting schedule office hours and weekends	R 1,298,485	R 2,005,000	19.0	20	12%	R 1,113,742.71
Fan Schedule office hours and weekends	R 198,085	R 5,000	1.0	1	12%	R 470,767.59
Setpoint setback	R 89,685	R 5,000	1.0	1	12%	R 210,409.08
Economiser	R 125,085	R 5,000	1.0	1	12%	R 295,433.90

Table 5-18: TTN complex financial analysis

From the payback analysis it is obvious that the fan scheduling, set point setback and economiser control have an almost immediate payback and should be implemented. The lighting scheduling and upgrade to more efficient lighting are capital intensive but will have a payback within 2 years. The DSM effect of this upgrade is shown below:

	TOTAL SUMMER SEASON	TOTAL WINTER SEASON	ANNUAL REDUCTION	DAILY AVERAGE KW REDUCTION
kWh REDUCTION	5,479,434 kWh	1,990,891 kWh	7,470,325 kWh	865 kW

Table 5-19: DSM effect on TTN Complex

Maximum DSM Funding R / MW	**R 1,600,000**
MW reduction due to retrofits	**0.86 MW**
Effective DSM funding	**R 1,383,393**
50% of cost because EE project	**R 691,697**
Combined retrofits project capital costs	**R 2,000,000**
50% of combined retrofit cost	**R 1,000,000**
Excess/shortage	**R -308,303**

Table 5-20: DSM funding analysis

It can be seen from the above table that the project falls short of full Eskom DSM funding. However, the projects payback is still so good that it will be worthwhile for the client to fund the remaining capital costs.

It is assumed that the scheduling of the equipment will have minimal capital input, as an existing maintenance contract on the BMS will be able to implement these retrofits. For practical purposes it was assumed that capital costs would be covered by a loan with an interest rate of 12% p.a. The project cost prices are general values and does not form part of a cost analysis of a concept design.

5.11 REPORT GENERATION

Time suggested (2 days), Time spent (1 days)

Generating the final report is made easy with the new simulation software. All the results, projects steps and detail about each step were exported into the word processor environment. The auditor can simply edit the report to ensure that all information expected by the client is included in the report. The other advantage is that the reporting format will be consistent between different auditors and different buildings.

5.12 CONCLUSION

The purpose of this case study was to evaluate the application of the new ESCO procedure on a building complex. The TTN complex is unique since the three buildings share a common chilled water system, and is equipped with an ice storage system. Due to the fact that the buildings had a common chilled water system the simulation model was simplified by simulating them as a single building.

The project also presented the ESCO with several problems that had a drastic effect on the implementation of the ESCO procedure. The initial time proposed for the project was 40 calendar days with net results being 46 calendar days. Some of the steps took longer than anticipated, and some shorter due the fact that detail measurements could not be taken and commissioning data was used.

Although the audits had been planned in detail, the breakdown of the some of the HVAC and control systems seriously hampered the investigation. The successful implementation of the ESCO procedure is very dependant on the proper functioning of the HVAC and control systems. The building simulations had to be based on the design and commissioning data. The reduced efficiency of the TTE and Annex HVAC system was determined from actual measurements on TTN versus the commissioning data.

From the calibration results it was seen that the simulated building profile had the same shape as the measured profile, but with an offset. The calibration and verification studies could therefore not be accurately simulated due to the problems with the HVAC and control systems.

Since the savings are based on the difference between the simulated base-year and the retrofit base-year, the retrofit results will still be reasonably accurate. Independent studies have also shown that the lighting control and retrofit studies present the biggest opportunity for energy savings in these buildings [3].

The ice storage system still presents the biggest opportunities for savings. Unfortunately the system was not operational at all during the period of the study and could not be included in the simulation. There will be big savings if the building is changed to a time-of-use tariff structure and the ice plant fully functional. This simulation could be expanded to include the ice storage system and to calculate the savings opportunities when operational.

It can further be concluded that a technician or maintenance officer would not have been able to perform the ESCO analysis taking into account the state of the HVAC system. The detailed commissioning data needed to be analysed and interpreted which falls outside the scope of the ESCO procedure. It also has to be said that this system is by far the most complex HVAC system in the Telkom SA building portfolio. The ice plant is also one of only two plants installed in the Telkom SA building portfolio [4].

5.13 REFERENCES

[1] McNaughton, G., "Personal consultation on numerous occasions throughout 2004-2005", TFMC, Meersig Building, Cnr Lenchen and West Avenue, Centurion, Tel +2712 643 8000.

[2] Havenga, J., "Report for TTN, TTE & Annex Ice Storage System and Diffuser Replacement", ", TFMC: Professional Services, Document Number: N0309 079, Meersig Building, Cnr Lenchen & West avenue, Centurion, June 2004.

[3] Durand, F.D.J., "TTS, TTN, TTE & Annex Office Buildings: Upgrade of Lighting Installation to an Effective and Efficient Operation", TFMC: Professional Services, Document Number: None, Meersig Building, Cnr Lenchen and West Avenue, Centurion, April 2004.

[4] Hannon, K., "Personal consultation throughout 2003 and 2004", TFMC Senior HVAC Maintenance Specialist, TFMC (Pty) Ltd, Tel +2712 643 8000.

6. CASE STUDY 3: DATA AND COMMERCIAL FACILITY WITH INDEPENDENT MULTIPLE HVAC SYSTEMS

6.1 INTRODUCTION

The focus of this report is to evaluate the ESCO procedure on a building with multiple independent HVAC systems. The case study is based on Data Building which is also part of the Telkom Head Office complex. The building is a combination of commercial activity and telecommunication equipment with some floors dedicated only to telecommunications equipment. This scenario has not been simulated in any of the other case studies.

The recommended audit times shown previously were 15 days for a building of about 10 000m^2. Although the Data Building is only 7 000 m^2 it consists of 16 floors, and thus the audit times was kept at the minimum of 15 days due to the complexity of the building and is shown in Table 6-1. The rest of the chapter will discuss the logical implementation of these steps.

Step in ESCO Procedure	Calendar days (7 000m^2)
Step 1: Determine which building to audit	Predetermined
Step 2: Gather preliminary building information	Monday 1- Wednesday 1 (3 days)
Step 3: Walkthrough visit to building	Wednesday 1- Friday 1 (2 days)
Step 4: Customise data acquisition software	Monday 2 (1 days)
Step 5: On-site detail measurements	Tuesday 2-Thursday 2 (3 days)
Step 6: Configure building simulation model	Friday 2- Monday 3 (2 days)
Step 7: Calibrate building simulation	Friday 2- Monday 3 (2 days)
Step 8: Verify building simulation	Friday 2- Monday 3 (2 days)
Step 9: Retrofit simulations	Tuesday 3-Thursday 3 (3 days)
Step 10: Financial analysis	Friday 3 (1 day)
Step 11: Generate final report	Friday 3 (1 day)

Table 6-1: Data building ESCO procedure audit times

6.2 GATHER PRELIMINARY BUILDING INFORMATION

Time suggested (3 days), Time spent (5 days)

The gathering of information took longer since information needed to be gathered by the maintenance personnel. Fortunately the building is also equipped with a BMS system and data on the system layout was available on the BMS [1]. Although the building is small compared to other case studies the building has 16 floors and separate independent HVAC systems from which data was required. The most important building and HVAC system details are summarised in Table 6-2:

BUILDING DESCRIPTION	
Building name	Data Building
Building description	Commercial building
Building location	Pretoria CBD
Number of floors	16
Floor Area	7 000m^2
HVAC system	Multi-zone
Cooling plant	Water cooled and air cooled
Air distribution	VAV and CAV
Control System	BMS

Table 6-2: Data building description

The building can be divided into four main sections, each used differently and supplied by its own HVAC system. The four sections are an office section, a ground floor area, first floor area and a lower ground section.

6.2.1 Office area

The office area is situated on floors 2-13. Each floor is used as office space in an open plan arrangement. The main plantroom of this zone is situated on the 14th floor. The chillers and the main air handling unit (AHU) are also in this room. The cooling towers are on the same level on the roof.

The system is designed as a full fresh air system. Outdoor air is fed to the main cooling coil where it is cooled, and then supplied to induction units situated on the sides of each floor. The main cooling coil is a free coil, which means that the coil is not controlled and that it operates continuously at full capacity (the coil is not equipped with a bypass damper). Electric heaters heat the air when required. In addition to the main AHU the zone is equipped with induction units and ceiling mounted fan coil units (FCUs). The induction units are supplied from the main AHU and are situated on the sides of the floors, and the FCUs re-circulate the air inside the zone and is situated in the center of the floors.

Chilled water is supplied by three water cooled chillers. The chillers supply the main cooling coil, the induction units, and the FCUs with chilled water. The condenser water is cooled by three cooling towers located on the roof of the building.

6.2.2 First floor

The first floor area consists mainly of office space. There is one small room used for equipment, called the Dark Room. The air conditioning of the office area is done by three AHUs. The units consist of a cooling coil, fixed speed fan and electrical heaters. Two air-cooled chillers provide chilled water. The equipment room is conditioned by two down-blow units, and is fed of the main system. The chilled water to the two down-blow units is supplied from the main chillers.

6.2.3 Ground floor

The ground floor of the building is used for office space and telecommunication equipment. The air is conditioned by 10 down-blow units located in a service compartment next to the outer wall of the zone. Return-air is fed to the down-blow units through a common return-air ceiling void. In the units the air is cooled by cooling coils, and humidified if required. No heating is installed. The chilled air is then supplied to the zone through a pressurised under-floor area. The water is chilled by four air-cooled chillers.

6.2.4 Lower ground printing section

The lower ground area is used for printing of the telephone invoices for the Telkom (Pty) Ltd. customers. The area is mainly a large open plan workspace where the printing equipment is located. A few smaller areas such as offices and storerooms also form part of the area, as well as a separate conference room.

The area is supplied by four AHUs. The printing area of the lower ground section is supplied by a variable air volume system. Two air handlers with variable speed drive (VSD) fans, a cooling coil, economiser cycle and electric heaters feed the area. The conference room is supplied by a similar system. The fourth air handler supplies a storeroom. This unit consists of a cooling coil and constant speed fan, with a constant fresh air supply. Chilled water is supplied by one air-cooled chiller.

The description above provides an overview on the complexity of the system but also to provide the necessary background information to be able to understand the simulation models that will be discussed later in this chapter.

The building is equipped with an extensive BMS system. This system is capable of logging and controlling numerous equipment and states in the building and HVAC system.

The HVAC system undergoes regular maintenance. The maintenance personnel were informed on when the detail measurement tests were to be conducted and to ensure that system can be tested at full capacity as required by the ESCO procedure.

The Data Building is also grouped with the other buildings on a single municipal meter. Accounts for this building on it's own were therefore not available. Fortunately powermeters are installed on each transformer on the building and connected to the BMS.

The walkthrough visit and detailed site measurements were arranged well in advance to ensure that no delays were encountered.

6.3 WALKTHROUGH VISIT TO BUILDING

Time suggested (2 days), Time spent (2 days)

During this visit the purpose of the ESCO analysis was communicated to the building and maintenance managers. The required service level agreement for Data Building is higher than the previous case studies, due to the telecommunication equipment located in the building.

No electrical measurement equipment had to be connected to obtain the total building profile, since this data was already available on the BMS. The environmental information was also available on the BMS.

The walktrough audit is a very valuable part of the audit procedure, since the auditor gets a "feel" for the building layout and equipment operation. The design information was compared to the actual system.

6.4 CUSTOMISE DATA ACQUISITION SOFTWARE

Time suggested (1 days), Time spent (1 days)

The simulation model was divided into four zones, with each building section taken as a zone. These areas include:

- Office area, ranging from the 2nd floor to the 13th floor.
- Vacated first floor area.
- Ground floor area, including the office section and equipment section.
- Lower ground printing section.

Figure 6-1 and Figure 6-2 show a schematic drawing of the simulation model water-circuit and the air-circuit.

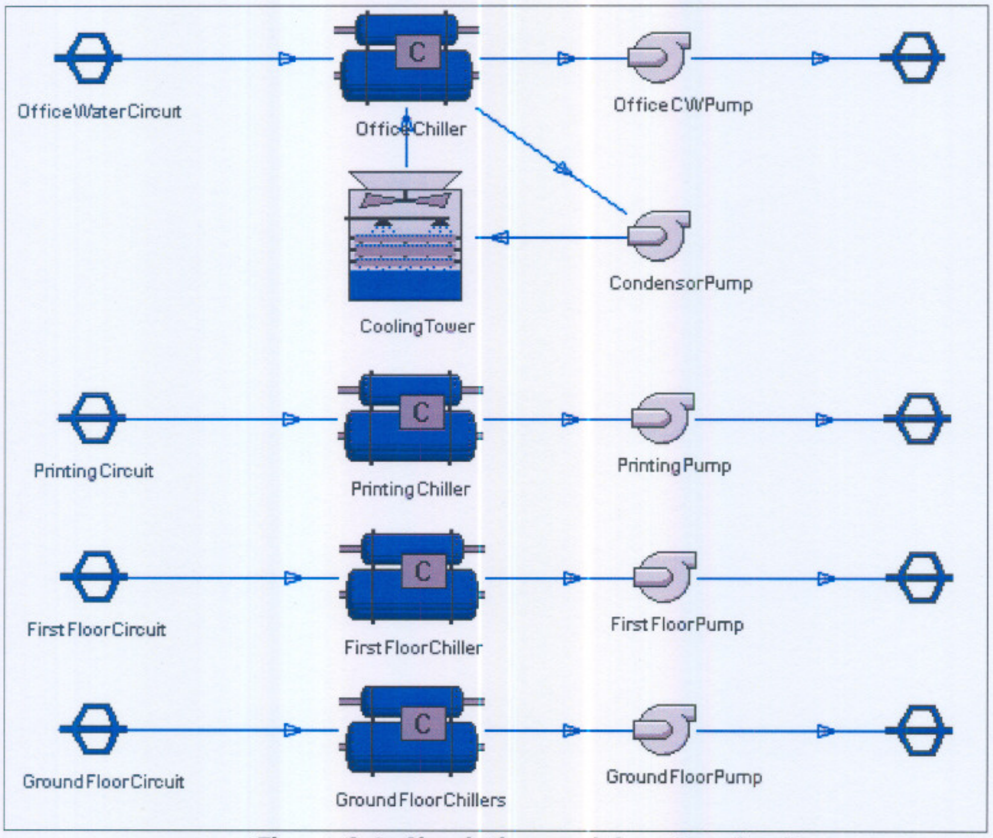


Figure 6-1: Simulation model: water-circuit

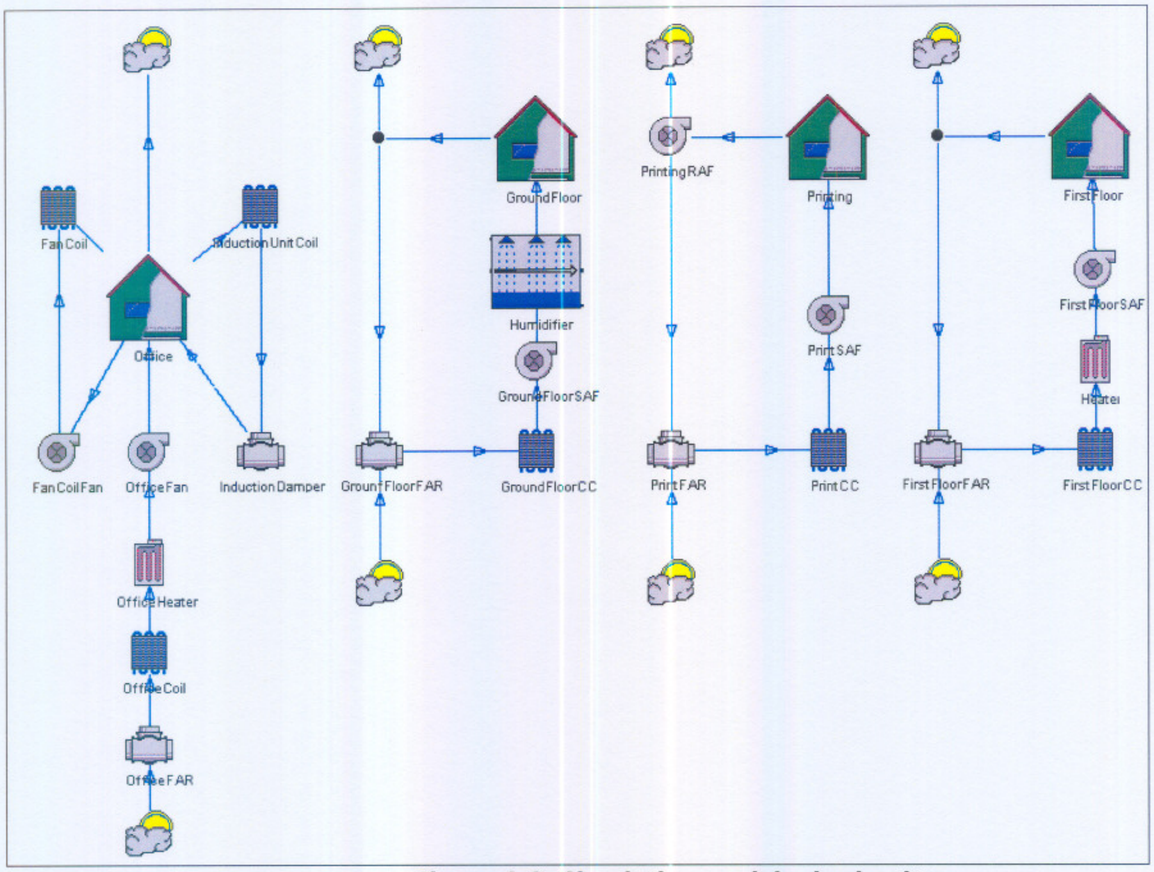


Figure 6-2: Simulation model: air-circuit

6.5 ON-SITE DETAIL MEASUREMENTS

Time suggested (3 days), Time spent (5 days)

Certain information is required to accurately simulate the integrated working of a building with the HVAC system. Firstly, the auditor must have a good understanding of the operation of the building under normal conditions. Secondly, detail measurements of the HVAC equipment is required to calibrate the simulation model.

During a building energy audit it is not unusual to find that the HVAC system does not operate according to designed intentions. This was also the case in the Data Building. The differences between the designed and current system, potential problems and the gathering of calibration measurements are discussed in this section. More detail is provided in Appendix H.

6.5.1 Office area

As stated previously, the office area was designed as a full fresh-air system with a free running coil. The fresh air is supplied to the air handler via a set of grills with fixed openings. During the winter, the system did not operate as a full fresh-air system. The maintenance personnel closed the fresh air supply grills, and opened the doors of the service shafts in the plantroom. The system therefore operated as a fixed percentage return-air system, with the only fresh air supply to the building that which leaks past the closures.

The electric heaters are also turned off because of high temperatures that it reaches when turned on. The probable reason for the high temperatures is the low air flow over the heaters, which also results in less than required heating available in the zone. During the summer, the system is turned back into a full fresh air system. The system currently operates as such.

In addition, the main cooling coil was blocked. Very little airflow is let through the coil. This will have an adverse effect on the potential of the system to maintain comfort in the building. Firstly, this will be because of the reduced airflow over the main coil. Secondly, less "high pressure" air is fed to the induction units, reducing its efficiency. In contrast, it will result in a decreased load on the chillers resulting in decreased energy consumption.

According to maintenance, the system could not generate enough heat to maintain adequate temperatures in the zone. The main reasons for this would be that the full fresh air system is constantly supplied by outdoor air, which could be well below comfort levels. The cold air can then not be heated to comfort levels, as a result of the reduced air flow over the heaters (resulting from the blocked coil). For this reason the fresh air grills were closed. This had the effect of warmer return-air being supplied to the zone, as well as the added heat generated by the equipment inside the plantroom.

During the project, some of the compressors of each chiller were out of commission for servicing.

6.5.2 First floor

The first floor area is mainly designed as office space. Additional to this there is the equipment room, but this area is very small compared to the office area and is supplied by its own system air conditioning system. The whole of the first floor area, except the equipment room, is currently unoccupied. The office area is supplied by three AHUs, and all three are operating.

The first floor area was originally designed as a full fresh air system. This was changed by the building facilitators to a return-air system. One of the three AHUs is operating on full return-air. The two units on the podium share a fresh air inlet. For these units the return-air dampers and fresh air dampers are fully open.

The equipment room is supplied by two down-blow units, which requires chilled water from the chillers on the podium. However, the load of the equipment room is small compared to the chiller size, which then results in chiller cycling when only the down-blow units are operating. The other three AHUs are operating to apply additional load to the chiller, in order to keep it from cycling. This results in relatively high energy consumption in relation to the required heat load.

6.5.3 Ground floor

The ground floor is currently operating below designed capacity. However, there are possible plans to increase the amount of people and equipment in the near future, which will increase the load on the system.

The result of this is that more down-blow units are operating than is required. However, some of the down-blow units cannot be turned off. The reasons for this is because of short-circuit backflow into the unit, causing the fan to rotate backwards. If the unit is switched on then strain is placed on the fan and fan motor, decreasing operating life.

6.5.4 Lower ground printing section

The lower ground air handlers and chillers are currently operating to design conditions. Although this space is used as a printing area, it was not designed as such. When the printing machines are operational, the installed HVAC capacity is not enough to maintain comfort levels in the zone.

The only change to the system from the original is the removal of humidifiers in the AHUs and the electric re-heaters in the ducts.

6.5.5 Building management system

The main drawback of the building management system (BMS) is the extent of the data available in the BMS. The most common issue would be that most of the equipment has a control signal in the BMS, but not an operational signal (eg. a positional, or on/off signal). Therefore, the operator can see the BMS command to the component, but not the response of the unit to the command.

The following information was used to obtain the relevant area, occupancy and load inputs:

- For the lights a figure of 22W/m^2 was obtained from a TFMC lighting audit. This figure also corresponds to typical design values and was verified by spot-checking in the building.
- Assume 330 persons working in the building. This was obtained from building telephone lists.
- Assume that 80% of the occupants operate PCs.

Table 6-3 and Figure 6-3 give the climate data selected to be used in the energy simulation. This climate data is for Pretoria, South Africa. It is calculated from yearly data over the past 20 years. The temperature and relative humidity (RH) is shown.

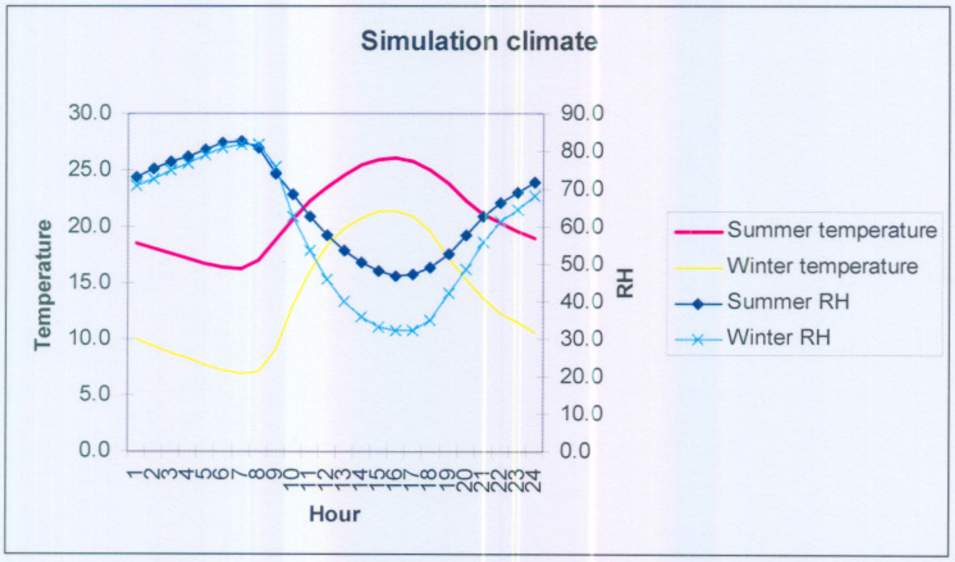


Figure 6-3: Climate data used for simulation

Hour	Summer Temperature	Summer RH	Winter Temperature	Winter RH
0	18.4	73.3	10.0	71.1
1	18.0	75.4	9.4	72.8
2	17.5	77.3	8.8	74.9
3	17.1	78.8	8.3	76.6
4	16.7	80.4	7.8	78.9
5	16.4	82.1	7.2	80.8
6	16.3	82.9	7.0	81.8
7	17.0	80.7	7.1	82.0
8	18.9	74.3	9.0	76.0
9	20.6	68.6	13.1	62.8
10	22.2	62.7	16.1	53.5
11	23.6	57.8	18.3	45.8
12	24.6	53.7	19.9	39.9
13	25.4	50.3	20.8	36.0
14	26.0	48.1	21.4	33.0
15	26.1	46.8	21.3	32.3
16	25.8	47.4	20.9	32.5
17	25.0	49.2	19.6	35.1
18	23.8	52.7	17.2	42.3
19	22.3	57.7	15.3	48.8
20	21.1	62.8	13.6	56.1
21	20.2	66.4	12.3	61.4
22	19.5	69.3	11.5	64.8
23	18.9	71.8	10.6	68.1

Table 6-3: Simulation temperatures

6.6 CONFIGURE BUILDING SIMULATION MODEL

Time suggested (2 days), Time spent (2 days)

The data captured during the building data acquisition phase was uploaded from the PDA device to the simulation software. The tariff rates applied for the Head Office group of buildings were applied to the Data Building. The climate data for Pretoria is one of the preloaded climate databases that is part of the simulation software and was used.

The operating schedules of the different equipment were configured from information obtained from the BMS and discussion with maintenance personnel.

6.7 CALIBRATE SIMULATION MODEL

Time suggested (2 days), Time spent (2 days)

The "calibration" simulation ensures that the current status of the building will be simulated correctly, so that cost savings predictions are realistic. The model is considered calibrated when the predicted daily demand load is within 10% of the measured value 80% of the time.

The calibration simulation compares the total building energy consumption over a weekday, Saturday and Sunday, to measured energy values. One calibration climate input is used for the three simulated days. Figure 6-4, Figure 6-5 and Figure 6-6 show the simulation and calibration data results:

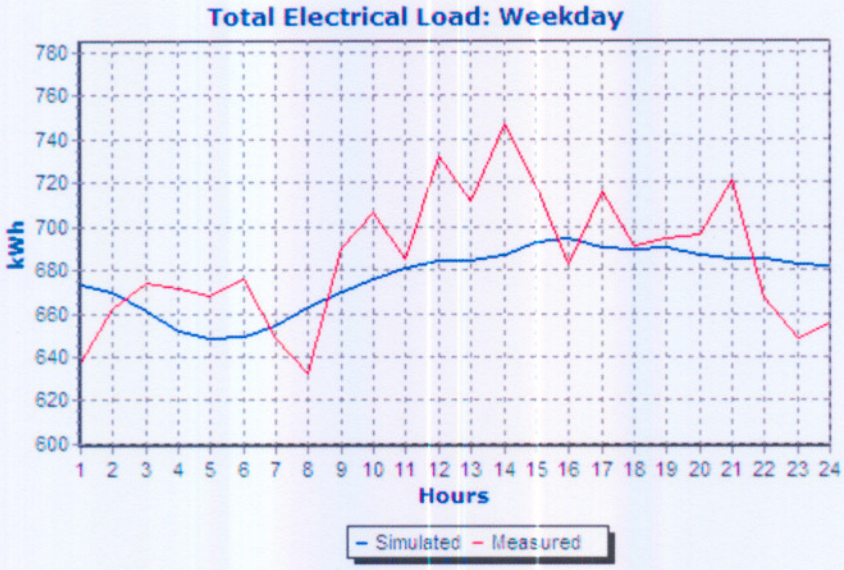


Figure 6-4: Data building: Weekday calibration simulation result

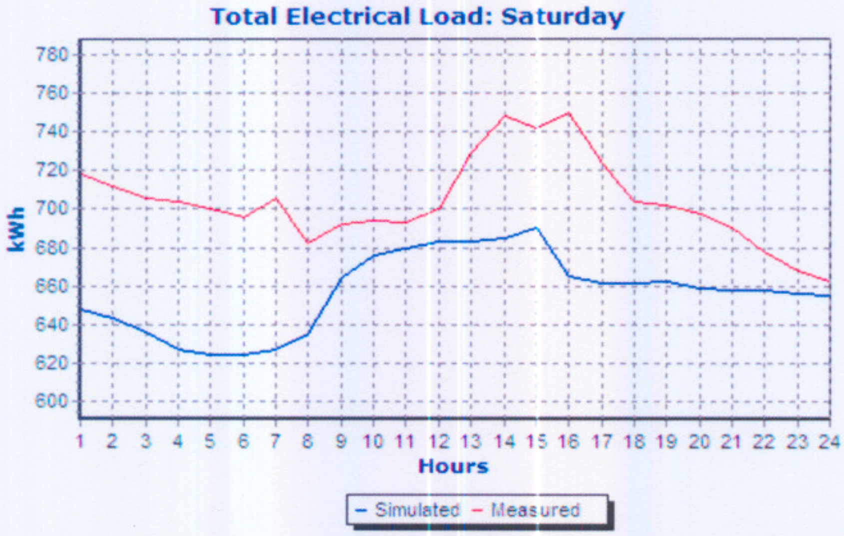


Figure 6-5: Data building: Saturday calibration simulation result

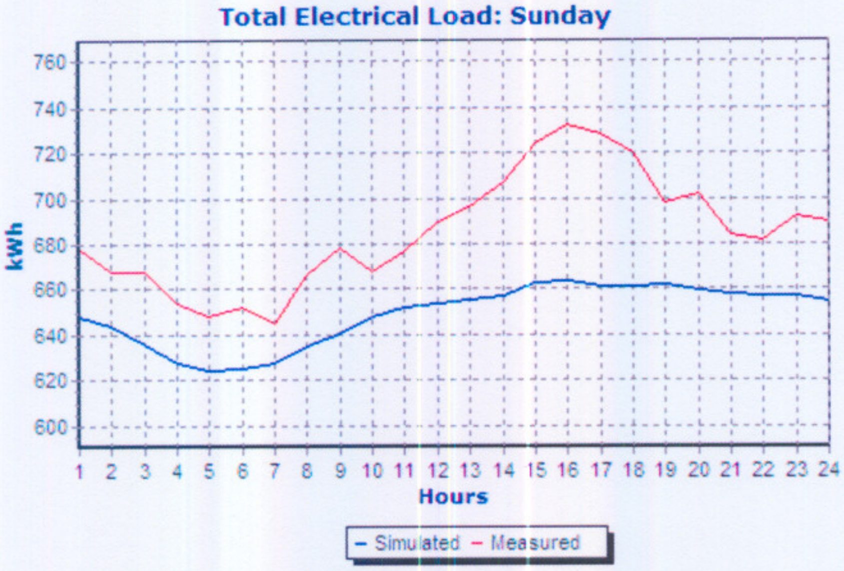


Figure 6-6: Data building: Sunday calibration simulation result

From the figures it can be seen that satisfactory results have been obtained. One must also remember that the simulation program is not a detailed component simulation program, but used to build a model for the whole building.

It is also important to keep in mind that predicted savings are relative values. The savings predicted by the tool is calculated from the base-year scenario, which is a simulated value. The theoretical predicted savings should therefore be the same for the actual building. In addition, the purpose is not to accurately simulate the hourly dynamic response of each component, but rather the average yearly energy consumption.

6.8 VERIFY SIMULATION MODEL

Time suggested (2 days), Time spent (2 days)

The verification study is performed in order to verify the accuracy of the simulation model's energy consumption over a typical year. The verification simulation compares the simulated average seasonal energy consumption and maximum demand to the actual building data. The data can be obtained from trended measurements, or from electricity accounts. The annual electricity costs used for Data Building were obtained from logged data on the BMS system. The verification table is shown in Table 6-4 below:

Total Seasonal Energy Consumption [MWh]

	Summer	Winter
Simulated	3784	1785
Measured	3953	1806
Error [%]	4	1

Average Seasonal Maximum Demand [kW]

	Summer	Winter
Simulated	680	688
Measured	696	623
Error [%]	2	10

Table 6-4: Verification study outputs

It can be seen that the annual simulated values are within 10% for 80% of actual measured values as required. This shows that the simulation model, weather and other seasonal data used in the simulations are accurate enough to perform the retrofit analysis.

6.9 RETROFIT SIMULATION

Time suggested (3 days), Time spent (4 days)

To determine the largest energy users in the building an end-user energy cost breakdown is simulated. These consumers will also have the biggest potential for energy cost savings. If the contribution of each energy user had to be measured, this would have been a very lengthy process. Because of the accurate building simulation model the end-user contribution could be simulated. A building and a HVAC system energy cost breakdown are displayed in Table 6-5 and Table 6-6:

Building Energy Cost Breakdown				
Description	**Energy (MWh)**	**Cost (R)**	**R/kWh**	**% Of total**
HVAC system	3267	646961	0.1201	59
Lights	1263	250154	0.1201	23
Other	999	197774	0.1201	18
Total	**5529**	**1094890**	**0.1201**	**100.00**

Table 6-5: Building energy cost breakdown

HVAC System Energy Cost Breakdown				
Description	**Energy (MWh)**	**Cost (R)**	**R/kWh**	**% Of total**
Cooling	1077	213340	0.1201	33
Heating	210	41623	0.1201	6
Ventilation	1357	268824	0.1201	42
Pumping	622	123175	0.1201	19
Total	**3267**	**646961**	**0.1201**	**100.00**

Table 6-6: HVAC system energy cost breakdown

A number of retrofit options, and combinations thereof, were investigated through simulation. This includes tariff structure evaluation, retrofits or control changes to three of the four building areas. The lower ground printing section is not included in the retrofit study since the existing cooling capacity is already limited. The retrofit options investigated are discussed per building area. The assumptions made for the specific retrofit is also discussed.

6.9.1 Verification of tariff structure and metering

Because the Data Building is also part of the Telkom Towers Head Office complex the same two-part tariff applies as for the other buildings. This means that the user is billed for total kWh used during the month, the maximum demand recorded and service charges. There are no time-of-use periods and thus energy is charged at a flat rate.

The building simulation model was once again used to simulate the electricity costs and retrofits should the building be changed to the time-of-use tariff. The results are discussed in Appendix H. The study resulted in a 2% **increase** in the electricity costs should the tariff be changed. This could be expected since the time-of-use tariff is designed to encourage the user to use less energy in peak periods. The building load profile does not change much during the peak periods, and thus the energy costs increases. The simulated retrofits on the time-of-use tariff structure is shown in Appendix H.

6.9.2 Office area retrofits

The retrofits investigated in the office section include fixing of the main cooling coil, changing of the system to a return-air economiser control, evaporative cooler, light scheduling, fan scheduling, chillers scheduling and night set point setback.

Repair main cooling coil:

Firstly, the influence of repairing the blocked main AHU cooling coil was simulated. This gives a more accurate picture of the operation of the system as per design conditions. The simulation model with the "fixed" coil was then used as the base-year scenario for the rest of the office retrofit comparisons. The energy consumption of the system with the fixed coil would be **more** than with the blocked coil. The reason for this would be the increased heat load on the chillers because of the increased effectiveness of the coil. The new airflow of the coil, and therefore the zone, was calculated from typical design airspeed of 2m/s over the coil face area.

The repair of the cooling coil would however improve the IAQ of the office section, and thus needs to be fixed. It can be seen from Table 6-7 that an increase in energy and demand (negative values) will be caused by the repairing of the cooling coil.

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	-147243.96	-3.89%	8434.64	0.47%	-2.49%
MAXIMUM DEMAND REDUCTION	-141.06	-2.59%	-17.76	-0.65%	-1.94%

Table 6-7: Results: Data Building Office Section– Repair of cooling coil

Return-air economiser control:

Changing of the system to a return-air system would constitute many equipment changes to both the building and HVAC system. This would include the placing of air ducting in the service shafts leading to the main plantroom, motorised dampers to regulate return-air, fresh air intake, and return-air fans to maintain static pressure in the office areas. This option would most likely not be feasible from a payback period perspective, but will also have a positive effect on the comfort in the building and maintenance costs on the system. The simulated energy and demand reduction is shown in Table 6-8:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	128834.30	3.27%	51582.01	2.90%	3.16%
MAXIMUM DEMAND REDUCTION	73.17	1.31%	0.00	0.00%	1.06%

Table 6-8: Results: Data Building Office Section – Return-air economiser control

Evaporative cooler:

The addition of an evaporative cooler will reduce load from the chillers with the use of free cooling. This option will however have penalties from a maintenance point of view, through personnel time and equipment costs such as water treatment. It will also lead to increased water consumption. The simulated energy and demand reduction is shown in Table 6-9:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	**112855.95**	**2.87%**	**-71906.74**	**-4.05%**	**0.72%**
MAXIMUM DEMAND REDUCTION	**-83.19**	**-1.49%**	**-0.89**	**-0.03%**	**-1.01%**

Table 6-9: Results: Data Building Office Section – Evaporative cooler installation

Night setback/set point drift:

Night set point setback involves the adjusting of the building set point during unoccupied times. The cooling set point is raised and the heating set point is lowered. There would be no cost implication in this retrofit as it could be set up on the BMS by maintenance staff. The set points were drifted by the following values:

Weekday	Saturday	Sunday
00:00 – 04:59: 5°C 05:00 - 05:59: 2°C 06:00 – 06:59: 1°C 18:00 – 18:59: 2°C 19:00 – 19:59 3°C 20:00 – 23:59: 5°C	00:00 – 05:59: 5°C 06:00 - 06:59: 3°C 06:00 – 06:59: 1°C 12:00 – 12:59: 1°C 13:00 – 13:59 2°C 14:00 – 14:59: 3°C 15:00 – 23:59: 5°C	00:00 – 23:59: 5°C

Table 6-10: Data Building Office Section - Set point drift settings

The following figures show the summer and winter simulation for a weekday, Saturday and Sunday. From Figure 6-7 and Figure 6-8 it is evident that the building is on set point after the set points are set to normal ranges.

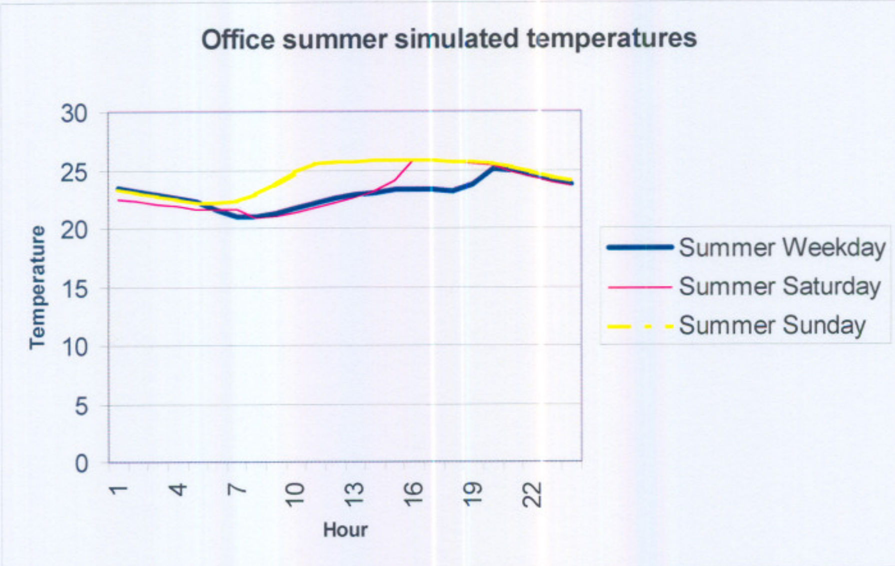


Figure 6-7: Data Building Office Section: Summer simulated temperatures with set point drift

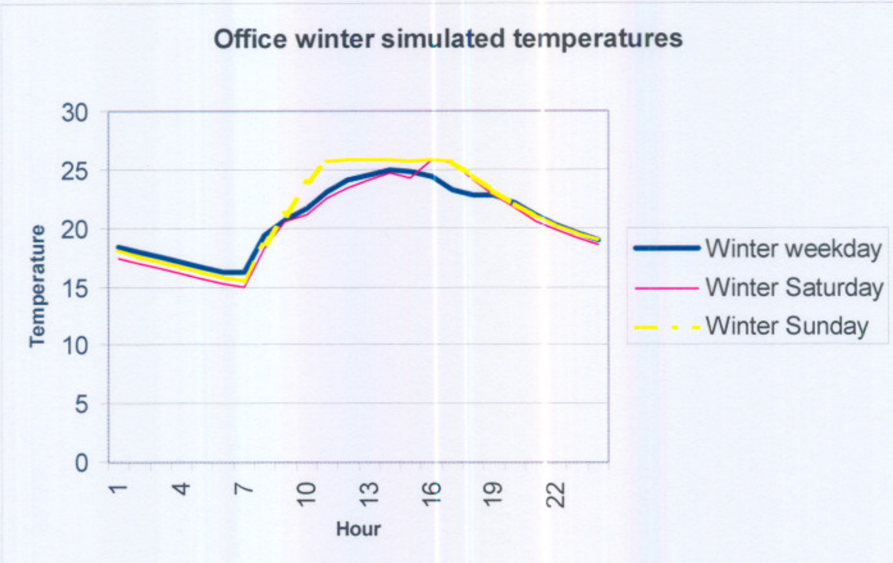


Figure 6-8: Data Building Office Section: Winter simulated temperatures with set point drift

The simulated energy and demand reduction is shown in Table 6-11:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	296794.34	7.54%	53597.00	3.02%	6.14%
MAXIMUM DEMAND REDUCTION	0.00	0.00%	0.00	0.00%	0.00%

Table 6-11: Results: Data Building Office Section – Set point drift/Night Setback

Fan scheduling:

Fan scheduling involves turning the fans off during unoccupied times. The assumption was made that there would be no preliminary cost implication in this retrofit as it could be set up on the BMS by maintenance staff. Normally maintenance personnel are not in favour of switching equipment off, and would prefer set point drift. The times used are shown in Table 6-12:

Weekday	Saturday	Sunday
00:00 – 04:59: OFF 05:00 - 17:59: ON 18:00 – 23:59: OFF	00:00 – 05:59: OFF 06:00 - 13:59: ON 14:00 – 23:59: OFF	00:00 – 23:59: OFF

Table 6-12: Data Building Office Section- Fan scheduling times

The simulated energy and demand reduction is shown in Table 6-13:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	208476.27	5.30%	31573.69	1.78%	4.20%
MAXIMUM DEMAND REDUCTION	0.00	0.00%	0.00	0.00%	0.00%

Table 6-13: Results: Data Building Office Section – Fan scheduling

Fan and Chiller scheduling:

Chiller scheduling involves turning the chillers off during unoccupied times. The assumption was made that there would be no preliminary cost implication in this retrofit as it could be set up on the BMS by maintenance staff. In the simulation model, the chillers were turned on one hour before the fans, to allow the chillers to lower the water temperature to the required set point. This would reduce the workload on the system as compared to the case where all equipment is turned on simultaneously. Normally maintenance personnel are not in favour of switching equipment off, and would prefer set point drift. The scheduling times used are shown in Table 6-14:

Weekday	Saturday	Sunday
00:00 – 03:59: OFF 04:00 - 18:59: ON 19:00 – 23:59: OFF	00:00 – 04:59: OFF 05:00 - 13:59: ON 14:00 – 23:59: OFF	00:00 – 23:59: OFF

Table 6-14: Data Building Office Section- Chiller scheduling times

The following figures show the summer and winter simulated temperatures, for a weekday, Saturday and Sunday case. From Figure 6-9 and Figure 6-10, it is evident that the zone temperatures are in the comfort range during office hours.

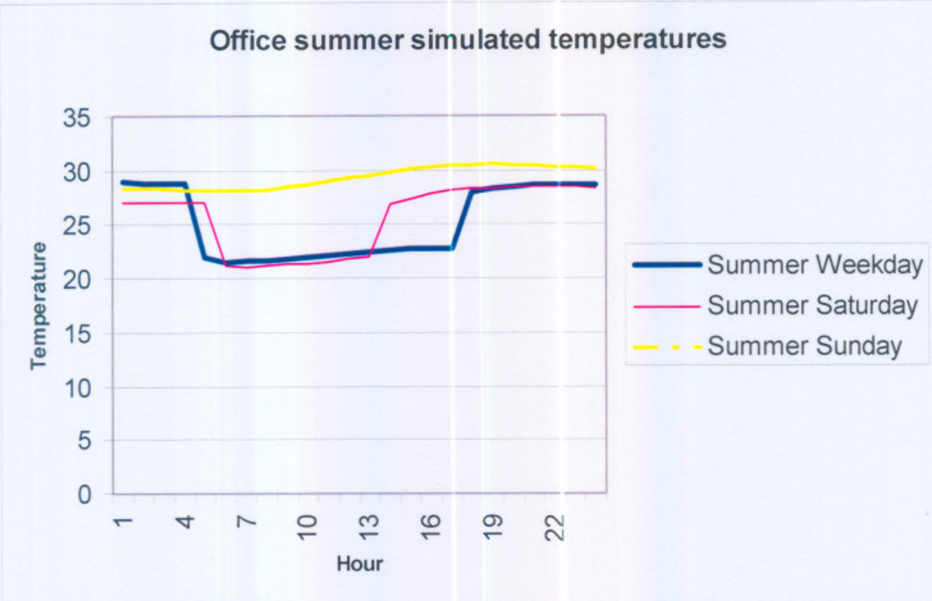


Figure 6-9: Data Building Office Section: Summer simulated temperatures with fan and chillers' scheduling

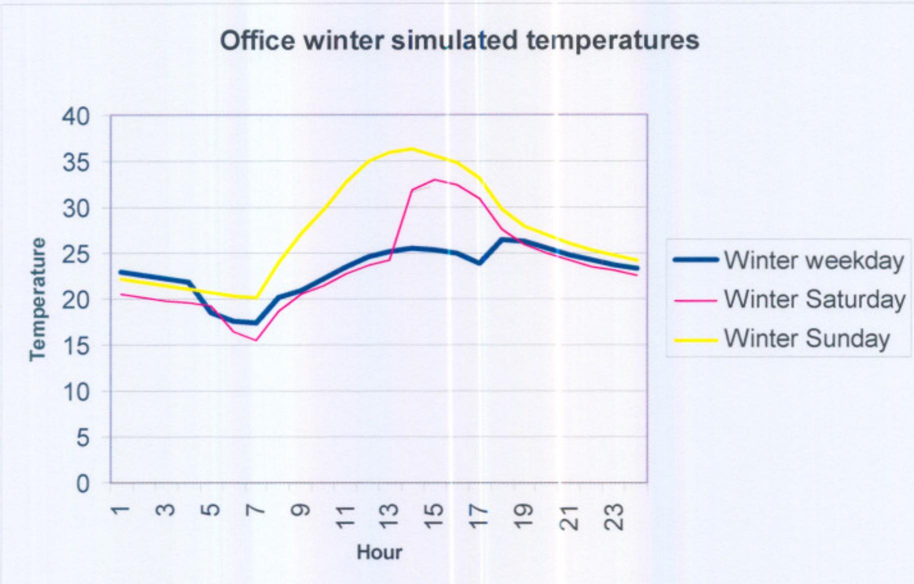


Figure 6-10: Data Building Office Section: Winter simulated temperatures with fan and chillers' scheduling

The simulated energy and demand reduction are shown in Table 6-15:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	433888.43	11.03%	157418.82	8.86%	10.35%
MAXIMUM DEMAND REDUCTION	0.00	0.00%	0.00	0.00%	0.00%

Table 6-15: Results: Data Building Office Section – Fan and chiller scheduling

Combined retrofits

It was mentioned in the previous section that either chiller scheduling **or** set point drift can be applied as a retrofit.

The energy and demand reduction for Data Building using the combination of all the different retrofits and **set point drift** in the office section is shown in Table 6-16:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	620641.13	15.78%	255353.87	14.37%	15.34%
MAXIMUM DEMAND REDUCTION	25.72	0.46%	14.66	0.53%	0.48%

Table 6-16: Results: Data Building Office Section – Economiser, evaporative cooler, light scheduling and set point drift

The energy and demand reduction for Data Building using the combination of all the different retrofits and **chiller scheduling** are shown in Table 6-17:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	723355.54	18.39%	282214.82	15.88%	17.61%
MAXIMUM DEMAND REDUCTION	19.61	0.35%	14.66	0.53%	0.47%

Table 6-17: Results: Data Building Office Section – Economiser, evaporative cooler, light,fan and chiller scheduling

As can be expected the chiller scheduling will have the biggest reduction in energy and demand, since the chillers and fans shut down completely, whereas with set point setback the chiller power will only be reduced. The decision on which retrofits to use will be with the building owner in accordance to life cycle cost of switching the chillers.

6.9.3 Ground floor & first floor

Currently the entire HVAC system of the **first floor** is operating to supply cooling to a very small section of the floor where telecommunication equipment is located. There are plans, however, to move the equipment in the equipment room to another venue. There are no definite plans, known by the building facilitators, to reoccupy the floor.

In the event that the equipment remains in place for some time, it may be efficient to install a dedicated system in the room and permanently switch off the remaining floor HVAC system. It is therefore proposed to install a small split-unit air conditioner in the equipment room.

The **ground floor** area was originally designed as an equipment area. It has an installed cooling capacity of 1 000kW. Less than half of the capacity is currently used. However, the fan of a down-blow unit cannot be turned off because the large under-floor supply pressure causes backflow that causes the fan to turn backwards. If the fan is turned on again, the fan and fan motor is placed under strain and could be damaged.

Therefore, the retrofit proposed is to install a short piece of ducting away from the units to lower the amount of backflow because of the high under floor pressure. Only the number of required units required to maintaining set point can then be used.

There are plans to increase capacity in the ground floor area. No savings will then be possible since all units will be required. For the simulation, it was assumed that the floor is currently operated at half of the heat load, therefore half the units could be switched off.

The combined energy and demand savings for the whole data building (including the retrofits on the office section) for the standard retrofits and **set point drift** for the ground and first floors are shown in Table 6-18 and with **fan and chiller scheduling** shown in Table 6-19:

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	1312980.85	34.67%	629650.29	35.27%	34.86%
MAXIMUM DEMAND REDUCTION	1114.27	20.47%	467.02	16.96%	19.29%

Table 6-18: Results: Data Building Ground and First Floor – Economiser, evaporative cooler, light scheduling and set point drift

	TOTAL SUMMER SEASON		TOTAL WINTER SEASON		ANNUAL REDUCTION
kWh REDUCTION	1396019.98	36.87%	693921.73	38.87%	37.51%
MAXIMUM DEMAND REDUCTION	1086.82	19.97%	467.02	16.96%	18.96%

Table 6-19: Results: Data Building Ground and First Floor – Economiser, evaporative cooler,light, fan and chiller scheduling

6.9.4 Lower ground printing section

The lower ground HVAC system was not designed to make provision for the printing equipment currently installed in the area. The equipment therefore struggles to maintain the required temperature in the area. In addition, the printing equipment cannot be switched off even during times of no printing. These two facts require the HVAC system to operate continually and no savings is possible.

6.10 FINANCIAL ANALYSIS

Time suggested (1days), Time spent (1 days)

6.10.1 Office section

Numerous retrofit options and combinations thereof were investigated in the previous section. The most important financial results are displayed in the following tables. The cost calculations are based on an active energy cost of 12.01c/kWh, and an MD cost of R51.51.

Table 6-20 below shows the building electricity cost for the current building simulation model, and the building simulation with the fixed main coil. From the table it is evident that by fixing the cooling coil it will increase the annual building electricity cost. This repair is however necessary to ensure good indoor air quality.

Electricity cost savings			
Descripton	**Cost (R)**	**Cost savings (R)**	**% Savings**
Current building	1080084	-	-
Repair coil	1094889	-14805	-1.4

Table 6-20: Cost of current building operation versus cost of repaired coil

Table 6-21 gives the total energy cost savings pertaining to the office section. The base-year scenario is the cost of the current building simulation, with the assumption that the main coil is repaired. The cost of the coil repair is therefore not included in the price of the retrofits listed, since it will form part of the normal maintenance costs. No costs were added for scheduling of the lights since this will be part of the BMS.

Annual Electricity Cost Savings			
Description	**Simulated Annual Cost**	**Annual Cost Savings**	**% Savings**
Base year	R1,094,889	-	-
Fresh air ratio economiser control	R1,086,979	R7,911	1%
Evaporative cooler	R1,086,767	R8,123	1%
Night setback/setpoint drift	R1,068,565	R26,324	2%
Fan scheduling	R1,083,729	R11,160	1%
Fan and chillers scheduling	R1,048,886	R46,003	4%
Combined 1: Economiser, evaporative cooler, setpoint drift and light scheduling	R1,001,974	R92,916	8%
Combined 2: Economiser, evaporative cooler, fan and chiller scheduling, and light scheduling	R983,410	R111,479	10%

Table 6-21: Data building office section electrical cost savings

Table 6-22 shows the financial analysis for the office section retrofits:

Financial Analysis						
Description	**Savings**	**Project cost**	**Direct Payback Period (months)**	**Discounted Payback Period (Months)**	**Loan rate (%/year)**	**Net Present Value (R)** **Year 3**
Fresh air ratio economiser control	R7,911	R200,000	279	100	12.00%	R-181,000.27
Evaporative cooler	R8,123	R50,000	49	66	12.00%	R-30,490.69
Night setback/setpoint drift	R26,324	R0	0	0	12.00%	R63,225.47
Fan scheduling	R11,160	R0	0	0	12.00%	R26,805.23
Fan and chillers scheduling	R46,003	R0	0	0	12.00%	R110,492.45
Combined1: Economiser, evaporative cooler, setpoint drift and light scheduling	R92,916	R250,000	34	41	12.00%	R-26,832.17
Combined 2: Economiser, evaporative cooler, fan and chiller scheduling, and light scheduling	R111,479	R250,000	26	30	12.00%	R17,753.53

Table 6-22: Data building financial analysis for the office section retrofits

It can be seen that the economiser and the evaporative cooler retrofits have a very low percentage saving and high projects cost. These two retrofits are thus not viable projects on their own.

6.10.2 Ground and first floors

Table 6-23 and Table 6-24 list the financial retrofit simulation results of the first floor and ground floor areas. The base-year scenario is taken as the current building operation, without the repaired main office coil. The reason for this is that these specific retrofits are not dependant on the correct functioning of the main office system.

Annual Electricity Cost Savings			
Description	**Simulated Annual Cost**	**Annual Cost Savings**	**% Savings**
Base year	R 1,080,084	-	-
First floor	R 972,236	R 107,848	10%
Ground floor	R 1,005,989	R 74,096	7%

Table 6-23: Data building ground and first floor areas electrical cost savings

Financial Analysis						
Description	Savings	Project cost	Direct Payback Period (months)	Discounted Payback Period (Months)	Loan rate (%/year)	Net Present Value (R) Year 3
First floor	R 107,848	R 50,000	6	6	12%	R 209,032
Ground floor	R 74,096	R 40,000	7	7	12%	R 137,965

Table 6-24: Data building financial analysis for the ground and first floor retrofits

6.10.3 Complete building

Table 6-25 and Table 6-26 give the results of the total combined retrofits. These include the first floor and ground floor simulations, as well as the combined office retrofits taking into account set point drift, and fan and chiller scheduling respectively.

Annual Electricity Cost Savings			
Description	Simulated Annual Cost	Annual Cost Savings	% Savings
Base year	R 1,094,889	-	-
Economiser, evaporative cooler, setpoint drift and light scheduling	R 766,827	R 328,062	30.0%
Economiser, evaporative cooler, fan and chiller scheduling, and light scheduling	R 763,370	R 331,519	30.3%

Table 6-25: Data building- Savings for the combined retrofits for the whole building

Financial Analysis						
Description	Savings	Project cost	Direct Payback Period (months)	Discounted Payback Period (Months)	Loan rate (%/year)	Net Present Value (R) Year 3
Economiser, evaporative cooler, setpoint drift and light scheduling	R328,062	R340,000	13	14	12.00%	R447,949
Economiser, evaporative cooler, fan and chiller scheduling, and light scheduling	R331,519	R340,000	13	14	12.00%	R456,252

Table 6-26: Data building- Financial analysis of the combined retrofits for the whole building

It is assumed that the scheduling of the equipment will have zero capital input, as an existing maintenance contract on the BMS will be able to implement these retrofits. For practical purposes, it was assumed that capital costs would be covered by a loan with an interest rate of 12% p.a.

In Table 4-14 the annual kWh reduction for the combined retrofits were shown. The DSM effect of the combined retrofits is calculated in Table 4-17 below:

	TOTAL SUMMER SEASON	TOTAL WINTER SEASON	ANNUAL REDUCTION	DAILY AVERAGE KW REDUCTION
kWh REDUCTION	1,312,981	629,650	1,942,631	225

Table 6-27: DSM effect on Data building

In Chapter 1 it was shown that a guideline price for funding of Energy Efficiency projects is R1.6 million/MW. The minimum kW limit for DSM approval is also 500 kW. The total DSM effect on the Data building is 225 kW and thus less than the minimum requirements for Eskom DSM funding [2].

6.11 REPORT GENERATION

Time suggested (1 day), Time spent (1 days)

Generating the final report is made easy with the new simulation software. All the results, projects steps and detail about each step were exported into the word processor environment. The auditor can simply edit the report to ensure that all information expected by the client is included in the report. The other advantage is that the reporting format will be consistent between different auditors and different buildings.

6.12 CONCLUSION

The purpose of this case study was to evaluate the new ESCO analysis procedure on a medium-sized commercial and data facility with different independent HVAC systems.

The ESCO analysis procedure took longer than initially anticipated. The delays were once again caused by the long time to obtain data on the building design. The total project time was 19 days compared with the 15 days initially planned. It was shown previously that a typical ESCO audits took 45 days for a building of 10 000m^2 [3] The audit time for the new ESCO procedure is thus still significantly less than previous ESCO procedures.

It was seen during the verification phase that the building simulation was very accurate, even with the reduced data requirements of the new procedure. The simulation software accurately represented the HVAC system operation and was successful in simulating the centralised HVAC system.

In the retrofit simulation the repair of the cooling coil *increased* the annual energy consumption. Although this is against the aims of the ESCO analysis, the primary focus should always be to ensure good indoor air quality (IAQ) and to operate according to the service level agreements (SLA). It was proven that the simulation model could be used to simulate repair of HVAC equipment as part of retrofits. The advantage of simulating retrofits is that the cooling coil repair was simulated, and than the other retrofits was applied.

The TFMC maintenance person that assisted with the project would have been able to perform the ESCO procedure if properly trained.

6.13 REFERENCES

[1] McNaughton, G., "Personal consultation on numerous occasions throughout 2004-2005", TFMC, Meersig Building, Cnr Lenchen and West Avenue, Centurion, Tel +2712 643 8000.

[2] Mashao, M., "An overview of Energy Efficiency Implementation programme in RSA Government owned Buildings", Department of Minerals and Energy, Available: http://www.dme.gov.za/energy/ppt/overview_energy_efficiencyimplementation-programme_rsa.ppt, Private Bag X 59, Pretoria, 0001, 2004.

[3] Arndt, D.C., "Personal consultation on numerous occasions throughout 2004", PO Box 1943, Faerie Glen, 0043, Tel +2782 256 0907.

7. CONCLUSION

7.1 EVALUATION OF UNIQUE AND NOVEL CONTRIBUTIONS

The new procedure developed in this thesis was applied to several case studies, in order to verify that the objectives outlined at the beginning have actually been achieved. It was shown that the new ESCO procedure fully addresses the specific requirements of telecommunication facilities. Some of the specific outcomes of the new procedure will be discussed by comparing the results of the case studies with the objectives of the study.

Feasible for a large and diverse portfolio of buildings

Due to the fact that the ESCO procedure is embedded in a procedure and software tools, the procedure can be used by multiple teams. These teams can be trained to use the procedure and implement ESCO investigations in parallel, to evaluate the potential on the large amount of buildings in the portfolio.

In the three case studies, the procedure was also applied to five different types and sizes of building:

- TTS (24000 m^2): Offices, File server room, Cafeteria, Limited telecommunication equipment
- TTN (21 000 m^2): Offices, Gym, Restaurant and Conference venues
- TTE (12 000 m^2): Offices
- Annex (6500 m^2): Offices, Call-Centre
- DATA Building (7000 m^2): Commercial facility and telecommunication equipment

The types and sizes of buildings included in this study did not provide any problems when the ESCO procedure was implemented.

Reduced audit times

The audited times were evaluated to prove that the time taken to perform an ESCO analysis on any type of buildings is drastically reduced, when compared with existing ESCO procedures. A summary of the implementation times for the different case studies is shown in Table 7-1. It can be seen that although certain steps took longer than initially planned, the total audit period was still significantly less when compared with previous procedures.

Audit Steps	TTS 24 000 m^2		TTN 40 000 m^2		Data 7 000 m^2	
	Planned	Actual	Planned	Actual	Planned	Actual
Step 1: Determine which building to audit	-	-	-	-	-	-
Step 2: Gather preliminary building information	5	8	12	15	3	5
Step 3: Walkthrough visit to building	4	4	5	4	2	2
Step 4: Customise data acquisition software	2	2	3	3	1	1
Step 5: On-site detail measurements	5	5	10	15	3	5
Step 6: Configure building simulation model	2	2	3	2	2	2
Step 7: Calibrate building simulation	2	2	3	3	2	2
Step 8: Verify building simulation	2	2	3	2	2	2
Step 9: Retrofit simulations	3	3	4	4	3	4
Step 10: Financial analysis	1	3	3	3	1	1
Step 11: Generate final report	2	1	3	1	1	1
New procedure: Calendar Days	23	27	40	46	15	19
Previous methods: Calendar days*		108		180		32

Table 7-1: Summary of implementation periods

* Based on 45 days for a building of 10 000m^2 as shown in the literature study.

Improved data capturing procedure

A new data capturing procedure was introduced that ensures that no unnecessary data is captured. The data capturing tool, and pre-defining the data that needs to be acquired, ensures that a minimum amount of time is spent on data collection. It is noted that obtaining the input data can have a serious effect on the speed of the process.

As can be seen in Table 7-1, Step 2 (Gather preliminary building information) and Step 5 (On-site detail measurements) caused delays in the case study ESCO procedure. These delays were caused by delays in obtaining information from maintenance personnel. Although the data capturing procedure worked very well, the supply of data from external sources should be proactively managed to ensure that data is received in time.

The successful implementation of the ESCO procedure is very dependant on the proper functioning of the HVAC and control systems. When these systems are not operational, calibration data may be inaccurate. It happened in the TTN complex audit that the failures on the BMS meant that design and commissioning data had to be used as inputs to the process.

Simulate different configuration of HVAC systems found in telecommunication facilities.

A new simplified simulation model was used in the new ESCO procedure to accurately simulate most HVAC system configurations found in the telecommunication facilities. During this study the following HVAC system types were successfully configured in the new procedure. This means that the templates available in the procedure were adequate to represent the different systems:

- TTS HVAC: Multi-zone, Centralised chiller plant (water cooled), VAV and CAV
- TTN complex HVAC: Multi-zone, Centralised chiller plant (water cooled), Ice plant, Shared chilled water circuit (three buildings), VAV
- Data building HVAC: Multi-zone, four independent cooling plants (water and air cooled), VAV and CAV

Simplified but accurate simulation of building model

Novel simulation software was introduced that can accurately simulate the integrated building operations. The possible number of building zones was reduced to seven zones by grouping similar areas together to simplify the simulation model.

The calibration and verification of results was very good for the TTS and the Data building and it can be concluded that the buildings' operations were successfully simulated. On the TTN complex the calibration results for a Weekday, Saturday and Sunday had the same load shape but not within the required range to classify the TTN complex building model as accurate. The reason for the inaccuracy was that design and commissioning data was used for the simulation due to breakdowns on the HVAC and BMS systems. This proves the need for actual system measurements and the proper operation of the HVAC system when the audit is conducted.

Perform retrofit simulations

Retrofit options specifically suited for telecommunication facilities were developed and tested with the integrated building simulation model. Once the simulation model has been verified the different retrofits and combinations thereof can be simulated. On the three case studies numerous retrofits were listed and evaluated. The retrofits with the maximum possible savings for each case study are shown below:

- TTS: Economiser enthalpy control, evaporative coolers, fan & light scheduling- 21% savings
- TTN complex: Energy efficient lighting and scheduling- 36% savings
- Data building: Economiser enthalpy control, evaporative coolers, chiller & light scheduling- 30% savings

From the literature study it was suggested that savings of 30% can be achieved through improved control and retrofits to new and existing building. The retrofit results for this study compares well to this guideline.

Determine DSM potential

The new ESCO procedure quantifies the contribution and the feasibility of the retrofits according to the DSM programme criteria. The retrofits on TTS and Data building was considered to be feasible DSM project, but for TTN additional funding would have to provide by the telecommunications company to make it a viable DSM funded project.

Financial evaluation

The integrated ESCO procedure automatically performs the financial evaluation of the retrofits. Since all these software modules are integrated, the simulated saving from the retrofits are automatically imported into this modules and the financial analysis done. The results of the financial analysis of the different case studies are shown in each case study. The capital costs for the financial evaluation of each retrofit should be requested well in advance as to not delay the process as was the case for the TTS audit.

Results are integrated into a standard reporting format

Results are integrated into a standardised reporting format that is easy to understand. A template is generated to which all of the simulation and financial results are exported into a word processor format. This allows the ESCO to document the findings of the audit in much less time and in understandable format.

Lower qualified personnel

It was concluded that lower qualified and less experienced personnel could be used to perform the new ESCO procedures, than with traditional ESCO procedures. It would actually be beneficial if the maintenance personnel themselves could perform the data capturing of the new ESCO procedure since they are already familiar with the building operations. The process would even be completed in a shorter time period since they would have a thorough knowledge of the building and HVAC system and would not have to spend time to explain the detail HVAC layout and operation to the ESCO.

During the studies we worked very closely with the maintenance personnel. The maintenance personnel, if properly trained, would have been able to perform all the building audits in the case studies, except for the problems that were experienced at TTN. The latter actually falls outside the requirements of an ESCO procedure.

It was proven through implementation that the new ESCO procedure is successful in solving the unique problems experienced in performing ESCO analyses for telecommunications facilities. Valuable insight into the problems that can occur during the ESCO process was highlighted.

7.2 LIMITATIONS OF THE PROCEDURE AND RECOMMENDATIONS FOR ENHANCEMENT

In the Telkom SA building portfolio there are standard types of HVAC systems that can be pre-configured for the different HVAC system types. It is thus suggested that standard templates for each type of HVAC system be preconfigured, to further simplify the customisation of templates before the wide scale use of the ESCO procedure.

The very short timeframe proposed by the protocol does not leave much room for debugging, if it is required. Therefore, when you cannot calibrate the building after the measurements were taken, the specified timeframe of the protocol would most likely be exceeded, in order to pinpoint the problem.

It is a concern that the auditor might have trouble in operating the software and troubleshoot the simulation if problems occur. A suggestion would be to have maintenance personnel perform the data capturing and have an experienced auditor build up the simulation model and perform the retrofit analysis.

The measurements required by the program do not include the logging of detailed demand loads for any equipment units. Experience has shown that the system components do not always operate on the schedule or control that is obtained from the building maintenance officer. By not measuring the equipment units in detail, one could make mistakes in simulating the realistic operation of the system. This could lead to calibration and verification problems.

The ESCO audit procedure attempts to automate the process as much as possible. External information is however still required from the building owner or maintenance personnel. If this information is not available, or it takes a long time to get hold of the information this will delay the process. It is advised that the required information be requested well in advance, before the ESCO procedure actually starts.

7.3 RECOMMENDATIONS FOR FUTURE WORK

The procedure was evaluated on large telecommunication facilities due to their complexity, big savings opportunity (Step 1 in the audit procedure) and long audit times usually involved on large facilities. In the study the recommended audit times for smaller buildings are shown. The procedure should be implemented on these smaller facilities to verify the audit times, and to evaluate the feasibility of retrofits and possible savings.

It is concluded in the study that trained personnel from the facility management company would be able to perform the new ESCO procedure. The relevant personnel should be trained and allowed to perform the new procedure to test if the facility management company would be able to act as the ESCO in the telecommunication environment.

Valuable information is collected as part of the new ESCO procedure. The ESCO procedure should be expanded to calculate inefficiencies of equipment. One calculation that would be very valuable is the coefficient of performance (COP) of equipment. If the data capturing procedure is repeated at regular time intervals, the procedure would indicate deterioration of equipment performance. The data capturing procedure can be incorporated into the planned maintenance programme to assist in identifying problem areas. It is often difficult to motivate funding for repairs that are not critical to operations but that might be wasting energy. A quick simulation can be run to simulate and motivate the savings of a repair.

In Telkom SA the baseline audit programme is also being implemented. The aim of this programme is to evaluate what would happen should a critical failure occur within a building. A typical situation is when the building loses AC power and the standby generator does not start. This situation is re-enacted to determine how long it will take before equipment starts shutting down due to high temperatures. It has happened that due to these tests critical failures occurred, and revenue was lost. The simulation model could be used to simulate the effect of failures in building systems, and should be investigated.

Reduced energy usage will result in less maintenance costs and better reliability of equipment in critical environments like telecommunication facilities. It can be recommended that facility management companies/building owners should incorporate these new ESCO procedures as part of their operations.

The suggested retrofits should be implemented and results compared to simulated values. This will provide credibility to the procedure and prove the value-add to operators of telecommunications facilities.

8. APPENDICES

APPENDIX A: TELKOM SA ENERGY POLICY

SCOPE

To pave the way for the implementation of a comprehensive energy management programme in accordance with the company's environmental policies and strategic objectives. The document defines:

- The company's position on energy optimisation and reduction through an *Energy Policy Statement.*
- The primary and specific objectives of the policy.

Applicable documentation

Telkom's Environmental Policy.

energy policy statement

Telkom SA is committed to managing its energy utilisation and available energy resources with the purpose of optimising operations in accordance with environmental and strategy obligations, and consequently providing the best possible service to its customers, whilst minimising impact on the environment.

PRIMARY objectives

Two primary objectives are identified:

Strategic Objectives

Reduce the annual utility costs.

Environmental Obligations

Telkom's Environmental Policy states that, "when possible we wish to limit negative impacts on the environment and enhance the benefits of our activities".

Accordingly, the company is committed to ensuring that its operations are conducted with optimal energy efficiency, and hence making a sustained contribution to lowering carbon dioxide (CO_2) emissions, and the conservation of fossil fuels.

SPECIFIC objectives

The specific objectives of the policy are to ensure:

- The continued and sustainable implementation of an energy management programme.
- Sound management of the supply and demand of all available energy resources.
- Sound energy management techniques and principles are applied to the energy utilisation of all energy consuming equipment and their respective configurations.
- All energy consumption is accounted for.
- The optimal usage and implementation of energy through promotion and energy awareness to all users.

The above objectives are to be achieved with the explicit purpose of reducing the company's energy consumption, demand and expenditure, without negatively impacting on operations.

Safety, Health and Environmental Management (SHE)

All references to applicable Safety, Health and Environmental Legislation, Policy, Procedures, Standards and Guidelines must be referred to within this section. Particular attention must be given to the Telkom Incident Prevention Plan and the reduction of risks to ensure a workplace conducive to Safe, Health and Environmentally. http://www.she.webfarm.telkom.co.za/

OHSA: All procedures must conform to the Occupational Health and Safety Act 85 of 1993.

Environment: All procedures and waste management must conform to the National Environment Management Act 107 of 1998.

Telkom's Environmental Policy

Telkom's vision is to become an internationally competitive, world-class telecommunications company.

The realisation of this vision through the expansion of our telecommunications network provides an environmentally acceptable mode of communication; facilitating paperless messaging and contributing to the sustainable financial growth and development of our country.

When possible we wish to limit negative impacts on the environment and enhance the benefits of our activities. Telkom is committed to minimising its impact on the environment by:

- Complying with the requirements of all-relevant environmental laws and regulations.
- Continuously improving our environmental performance, taking into account, technical developments, scientific understanding, customer needs and community expectations.
- Integrating environmental considerations into planning activities and business decisions by implementing an environmental management system.
- Conducting environmental education and awareness programmes to enable our employees to implement our environmental policy.
- Striving to reduce raw material consumption, minimising pollution and the generation of waste by promoting appropriate recovery, reuse and recycling of used material.
- Contributing to the development of relevant legislative measures with respect to the protection of the environment.
- Establishing effective communication on relevant environmental issues within the organisation and with external parties.
- Promoting the adoption of this policy by contractors and suppliers acting on our behalf, and where appropriate by binding them contractually to comply with relevant environmental laws.
- Allocating the appropriate resources within our company to give effect to this policy.

APPENDIX B: TFMC ENERGY POLICY

TFMC views on energy and its effective management

TFMC recognises that energy consumption of electricity, etc. represents a large controllable cost in its operations and that there are both environmental and financial benefits associated with increasing energy efficiency.

TFMC also recognises that well designed and efficiently managed services not only result in energy savings, but also in an improved availability and more comfortable working environment for technical and commercial facilities.

TFMC therefore, promote the efficient use of energy in order to reduce costs and the emissions of carbon dioxide (CO_2) and also the conservation of fossil fuels.

Policy Statement on energy and its effective management

TFMC is responsible for ensuring that its operation is conducted with optimal energy efficiency and environmental effective services.

It will therefore seek to:

- Ensure that energy efficiency improvement programs become an integral part of the corporate strategy;
- Rally to the cause and provide full support and enthusiastic participation;
- Applying good energy management practices to reduce the consumption of electricity, lower the demand for electricity and consequently reduce emissions from thermal electrical power generating;
- Improving the company's as well as the customer's financial performance through energy savings.

Implementation Statement:

Short-Term Objectives (within 3 years)

Implement energy efficiency improvement and emissions reduction measures through the following focus areas:

- To gain control at own and contracted facilities over energy consumption by reviewing and improving the relevant operating, motivation and training practices;
- To provide sustainable savings through improved maintenance and hardware configuration management;
- To invest in a rolling programme of energy optimisation measures which will achieve maximum returns on investment;
- To ensure that new facilities, plant and equipment are designed to be energy efficient;
- To ensure refurbishment of existing facilities, plant and equipment are optimised to be energy efficient;
- To establish and maintain management information system which allows effective decision making on energy efficient measures;
- To establish effective energy awareness campaigns aimed at own and customer staff.

Long-Term Objectives

- To achieve award winning "Carbon points" through the significant reduction of the amount of pollution, particularly CO_2 emissions, caused by energy consumption;
- To achieve annual targets set for energy consumption, which will meet or exceed nationally agreed benchmarks;
- To reduce, where possible the dependence on fossil fuels through the use of ambient and renewable energy;
- Provide energy efficient building index classification for own and customer facilities.

APPENDIX C: DATA REQUIREMENTS OF NEW ESCO PROCEDURE

The energy management opportunities are discussed in Chapter 3.6. Some of the underlying data that is required for the ESCO analysis is shown below:

Verification of municipal meter calibration, meter type and tariff structure

- Physical address
- Building name
- Electrical tariff & rates
- Actual measurements form the main metering panel
- Municipal meter number
- Meter type: thermal or digital meter

Power factor correction

- Note if power factor is installed
- Power factor readings (kVA)

Lighting upgrade

- Number of lights, type and power rating should be captured
- The operating hours should be captured

Control of internal building loads

- Electrical equipment such as number of people, PCs, hot water boilers, ovens etc. should be recorded. The ratings, quantity and operating hours should be quantified.
- In telecommunication exchanges the rectifiers feed the power to the telecommunication equipments. To quantify the power drawn by this equipment the power drawn from the rectifiers as well as the efficiency of the rectifiers are required. This used to quantify the building heat load for the building simulation, but cannot be controlled.

Verify temperature set points

- HVAC system type should be recorded
- Current temperature set points of the different zones should be captured

- Design of HVAC system layout should be recorded (might have changed from the initial design)
- HVAC operational data for building the HVAC simulation model

Using Free Cooling SYSTEMS

- Location of free cooling (economiser) systems in the building
- Design of the equipment
- Operational state of the equipment

Verify control system operation

- Control philosophy of the HVAC system
- Operational state of control systems (actuators, valves, sensors etc.)

Replacement of HVAC systems

- Simulation of existing building using information captured during the building audit
- Detail of new design
- Updated simulation to include new equipment

HVAC equipment information

- The detail component information for the water and air circuit is discussed in Appendix D.

APPENDIX D: DETAIL ON THE USE OF DATA ACQUISITION INTERFACES

BUILDING ZONE

The PDA logger zone input screen is displayed in the following figure:

Description: To enter a descriptive zone name click the DESCRIPTION button and enter a name in the provided text box.

Dimensions: To enter all the important building dimensions click on the DIMENSIONS button and complete the zone dimensions input interface.

Structure: To enter the building construction click on the STRUCTURE button and complete all the zone structure input interfaces.

Internal heat generation: To enter internal heat sources (lights, computers, people, etc.) into the building zone click on the INTERNAL HEAT GENERATION BUTTON and complete the input interface.

Control: To specify the zone control set points (temperature, RH, air flow) click on the CONTROL button and complete the interfaces.

Dimensions

The PDA data zone dimensions screen is displayed in the following figure:

North wall length: This is the length of the wall facing north. The user can obtain this information on-site by measurement, or alternatively directly from the building drawings. (This is the total zone north wall length.)

Internal floor area: This is the internal floor area of the zone. This can be calculated from measurements made on-site, or alternatively directly from the building plans. (This is the internal floor area per storey (level) for building zones with more than one storey (level).)

Number of storeys: This is the number of floor levels per building zone.

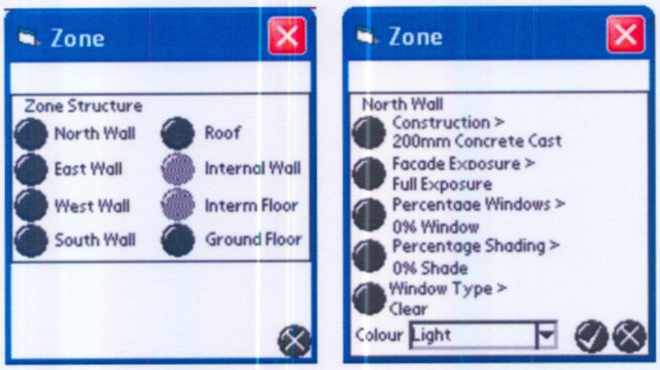
Height of storey: This is the height of one storey from the floor to the ceiling. The height can be measured on-site or taken from the building plans.

Total internal wall length: This is the total length of all the walls inside the zone that do not form part of the zone boundaries (North, East, South, West wall). This information can be found on-site, or from the building plans.

Building orientation: This information can be entered in two ways. Firstly as a positive value, measured clockwise from north, zero at north, to +45°. Alternatively as a negative value, measured anti-clockwise from north, zero at north, to -45°. The information is usually obtained from building plans, but can also be measured on-site.

Structure

The PDA data logger main zone structure and surface structure screens are displayed in the following figure:



Zone structure: To specify the construction of each surface type displayed on the interface click on the respective surface type (North wall, East wall, etc) button and complete the inputs.

Construction: The user can choose a surface construction from a predefined surface database. To select a construction type click on the CONSTRUCTION button and select a type from the menu.

Facade exposure: To specify the exterior exposure of the surface click on the FACADE EXPOSURE button and select either exposed to the climate or to another adjacent building zone.

Percentage windows: This is the window area as a percentage of the total surface area. To specify the percentage click on the PERCENTAGE WINDOW button and select one of the options from the menu.

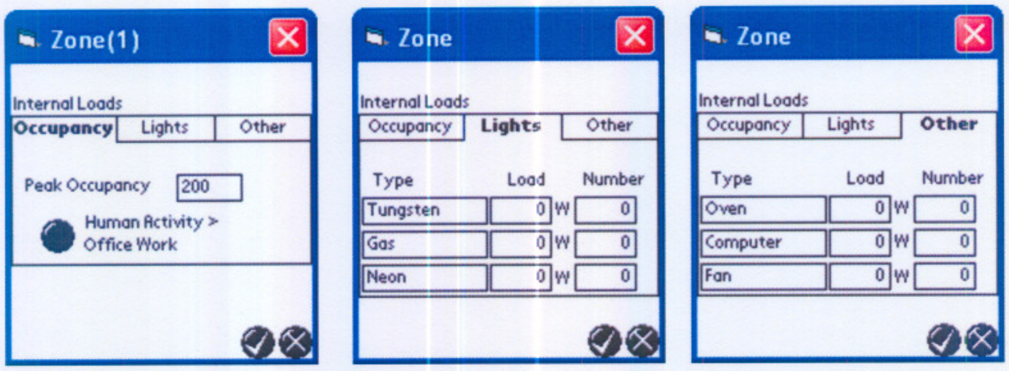
Percentage shading: This is the shaded area as a percentage of the total window area. To specify this percentage click on the PERCENTAGE SHADING button and select one of the options from the menu.

Window type: The user can choose a window type from a predefined database. To select a type click on the WINDOW TYPE button and select a type from the menu.

Colour: This is the exterior colour of the surface. To specify a colour select one from the drop-down list box.

Internal heat generation

The PDA data logger internal heat generation screens are displayed in the following figure:



Peak occupancy: This is the typical maximum number of people inside the building zone at the same time. To specify the number of people enter the value into the text box.

Human activity: This is the typical activity of the people inside the building zone. Specify the activity by selecting one from the menu.

Lights: Here the user can specify three types of lighting fixtures. Enter the type, load and number of each fixture.

Other: Here the user can specify three types of other internal loads (computers, lifts, etc.). Enter a description, load and number of each type.

Control

The PDA data logger zone control screens are displayed in the following figure:

Temperature control: This is the zone temperature control range. The system will control (when the air-conditioning schedule is active) the zone temperature between the entered minimum and maximum temperature inputs.

RH control: This is the zone relative humidity (RH) control range. The system will control (when the air-conditioning schedule is active) the zone RH between the entered minimum and maximum RH inputs.

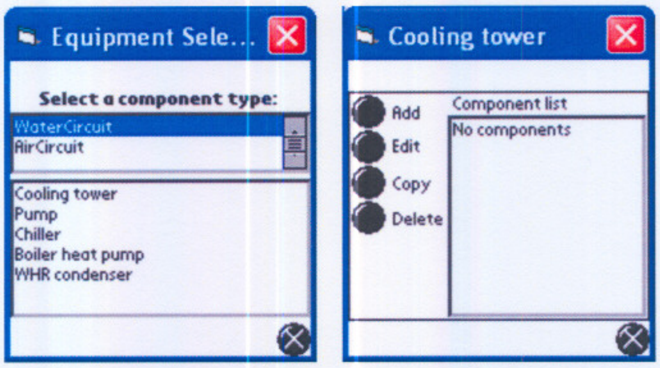
Volume flow: Here the user can either select constant air volume or variable air volume. Variable air volume means the indoor temperature is controlled by supply air dampers in the building zone. The user will have to specify the minimum and maximum air flow to the building zone. The user can either obtain these flow values from the design specifications or measure it on-site.

Maximum flow: This is the air flow rate to the building zone measured at 100% cooling load. This means all the supply air control dampers must be 100% open. To create this scenario lowers the zone set point or warm-up the control sensor.

Minimum flow: This is the air flow rate to the building zone measured at 100% heating load. This means all the supply air control dampers must be at their minimum flow position. To create this scenario increase the zone set point or cool down the control sensor.

AIR-CIRCUIT

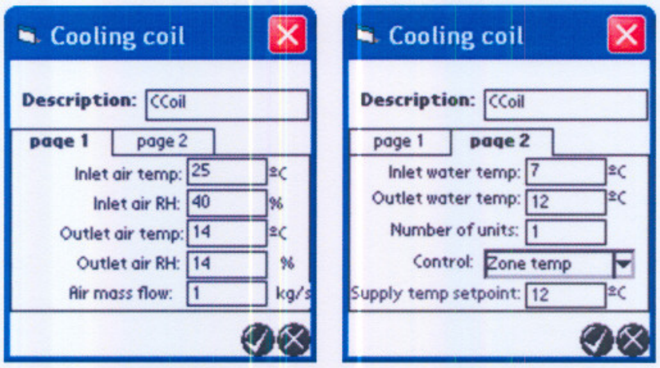
The PDA data logger component selection screens are displayed in the following figure:



Air-circuit: To add a component to the air-circuit, select the air-circuit option and then the component of your choice from the air-circuit list box. The user can now add, edit, copy and delete components to/from the list for each respective component type.

Cooling coil

The PDA data logger cooling coil screen is displayed in the following figure:



All the cooling coil inputs must be given at 100% cooling load. This means no water must bypass the coil. The user can obtain the cooling coil inputs either from the design specifications or measure it on-site. To create this 100% load scenario for measurement, lower the control set point or heat-up the control sensor and wait until steady state conditions are reached. Measure now the required inputs. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Inlet air temperature: This is the inlet air temperature of the cooling coil at 100% cooling load.

Inlet air RH: This is the inlet air relative humidity of the cooling coil at 100% cooling load.

Outlet air temperature: This is the outlet air temperature of the cooling coil at 100% cooling load.

Outlet air RH: This is the outlet air relative humidity of the cooling coil at 100% cooling load.

Air mass flow: This is the air mass flow through the cooling coil at 100% cooling load.

Inlet water temperature: This is the inlet water temperature of the cooling coil at 100% cooling load.

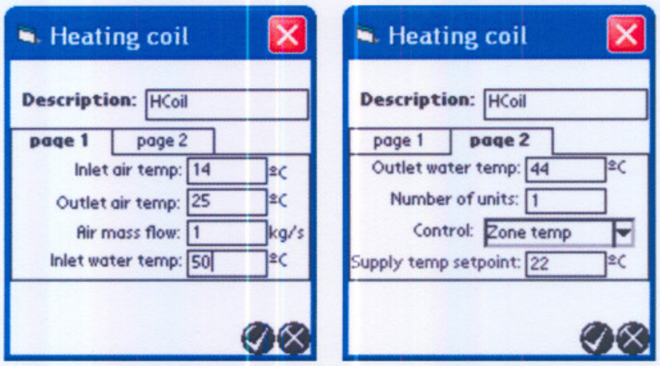
Outlet water temperature: This is the outlet water temperature of the cooling coil at 100% cooling load.

Number of units: This is the number of coils with the same thermal characteristics and control strategy configured in parallel.

Control: This is the control strategy of the cooling coil. Here the user can either select zone temperature or supply temperature. Zone temperature means the coil capacity will be controlled to maintain a constant zone indoor air temperature. The supply temperature option will imply that the coil capacity is controlled to maintain a constant coil leaving air temperature.

Heating coil

The PDA data logger heating coil screen is displayed in the following figure:



All the heating coil inputs must be given at 100% heating load. This means no water must bypass the coil. The user can obtain the heating coil inputs either from the design specifications or measure it on-site. To create this 100% load scenario for measurement, increase the control set point or cool down the control sensor and wait until steady state conditions are reached. Measure now the required inputs. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Inlet air temperature: This is the inlet air temperature of the heating coil at 100% heat load.

Outlet air temperature: This is the outlet air temperature of the heating coil at 100% heat load.

Air mass flow: This is the air mass flow through the heating coil at 100% cooling load.

Inlet water temperature: This is the inlet water temperature of the heating coil at 100% heat load.

Outlet water temperature: This is the outlet water temperature of the heating coil at 100% heat load.

Number of units: This is the number of coils with the same thermal characteristics and control strategy configured in parallel.

Control: This is the control strategy of the heating coil. Here the user can either select zone temperature or supply temperature. Zone temperature means the coil capacity will be controlled to maintain a constant zone indoor air temperature. The supply temperature option will imply that the coil capacity is controlled to maintain a constant coil leaving air temperature.

Evaporative cooler

The PDA data logger evaporative cooler screen is displayed in the following figure:

Efficiency: Evaporative efficiencies range between 75% and 85%.

*Efficiency = (Tdb,in-Tdb,out)/(Tdb,in-Twb,in)*100*

Tdb - Dry bulb temperature (°C)

Twb - Wet bulb temperature (°C)

in - Inlet air condition

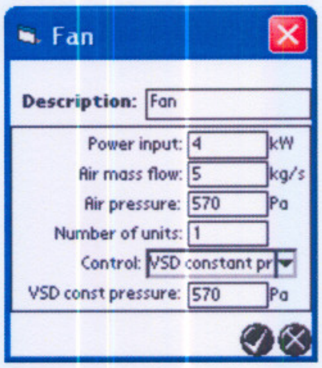
out - outlet air condition

Number of units: This is the number of coolers with the same thermal characteristics and control strategy configured in parallel.

Control: This is the control strategy of the cooler. Here the user can either select zone temperature or none. Zone temperature means the cooler capacity will be controlled to maintain a constant zone air leaving temperature. The none option will imply that the cooler is always at 100% load when active.

Fan

The PDA data logger fan screen is displayed in the following figure:



All the fan inputs must be given at maximum air flow. This means all the supply air control dampers must be 100% open. The user can obtain the fan inputs either from the design specifications (fan curve) or measure it on-site. To create this maximum air flow scenario for measurement, lower the control set point or heat-up the control sensor and wait until steady state conditions are reached. Measure now the required inputs. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Power input: This is the electrical power input of the fan at maximum air flow.

Air mass flow: This is the air flow through the fan at maximum air flow.

Air pressure: This is the total pressure difference over the fan at maximum air flow.

Air pressure $= (P + 0.5\rho v^2)out - (P + 0.5\rho v^2)in$

P - Static air pressure (Pa)
p - Air density (kg/m³)
v - Average air speed (m/s)

Air pressure calculation for constant air volume systems:

*Air pressure = (Power*Eff*1000)/air mass flow*
*Eff = 0.85(motor efficiency)*0.7(fan efficiency)*

Number of units: This is the number of fans with the same thermal characteristics and control strategy configured in parallel.

Control: This is the control strategy of the fan. Here the user can either select constant RPM or VSD constant pressure. Constant RPM means the fan will always operate at a constant RPM. VSD or frequency control at a constant pressure implies that the fan's RPMs will be controlled to maintain a constant total pressure over the fan.

Fresh air ratio

The PDA data logger fresh air ratio screen is displayed in the following figure:

Minimum % fresh air: This is the minimum amount of fresh air as a percentage of the total air supplied to the building zone. This means the fresh air dampers must be at their minimum setting (economiser control). The user can either obtain this value from the design specifications or measure it on-site. To create this minimum % fresh air scenario heat-up the fresh air control sensor.

*% minimum fresh air = (return-air temp – mix air temp)/(return-air temp – fresh air temp)*100*

Control: This is the control strategy of the fresh and return-air dampers. Here the user can either select constant fresh air, economiser, CO_2 or occupancy.

Constant fresh air - No damper control (no economiser)

Economiser - control with a specified minimum fresh air setting.

Occupancy - Economiser control with a specified minimum fresh air setting when the building zone is occupied and a zero minimum fresh air setting when the building is unoccupied.

CO_2 - Economiser control integrated with CO_2 control to keep the building zone within its CO_2 levels (700 ppm CO_2 above the outside CO_2 level)

Cut-off condition: This is the condition used to determine if outside air can be used for cooling or not. Outside air is only used for cooling when the outside air cut off condition is lower than the zone return-air cut off condition.

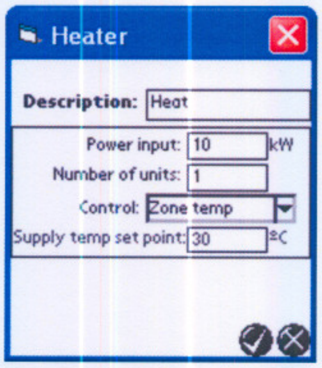
Temperature only - Outside air is used for cooling when the outside air temperature is below the zone return-air temperature.

Enthalpy only - Outside air is used for cooling when the outside air enthalpy is below the zone return-air enthalpy.

Temparute and enthalpy - Outside air is used for cooling when the outside air enthalpy and temperature are below the zone return-air enthalpy and temperature.

Heater

The PDA data logger heater screen is displayed in the following figure:



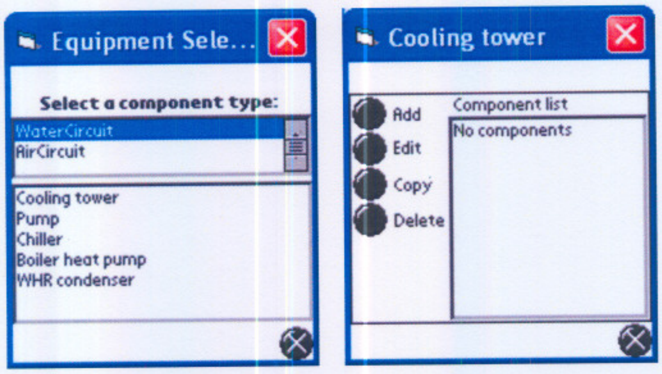
Power input: This is the electrical power input of the heater at 100% load. This means all the heating elements must be active. The user can obtain this input either from the design specifications or measure it on-site. To create this 100% load scenario for measurement, increase the control set point or cool down the control sensor and wait until steady state conditions are reached. Measure now the power input. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Number of units: This is the number of heater banks with the same control strategy configured in parallel.

Control: This is the control strategy of the heater. Here the user can either select zone temperature or supply temperature. Zone temperature means the heater capacity will be controlled to maintain a constant zone indoor air temperature. The supply temperature option will imply that the heater capacity is controlled to maintain a constant heater leaving air temperature.

WATER-CIRCUIT

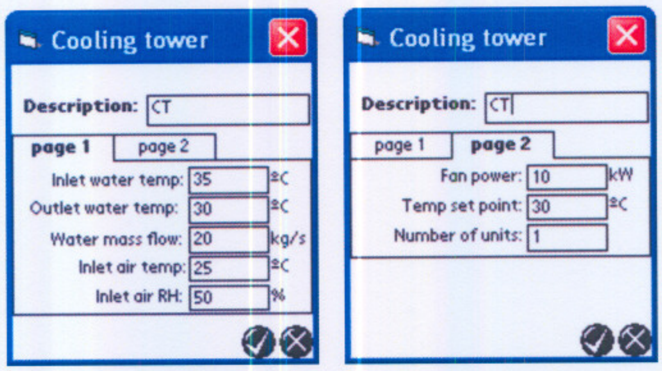
The PDA data logger component selection screen is displayed in the following figure:



Water-circuit: To add a component to the water-circuit, select the water-circuit option and then the component of your choice from the water-circuit list box. The user can now add, edit, copy and delete components to/from the list for each respective component type.

Cooling Tower

The PDA data logger cooling tower screen is displayed in the following figure:



All the cooling tower inputs must be given at 100% cooling load. This means no water must bypass the cooling tower. The user can obtain the cooling tower inputs either from the design specifications or measure it on-site. To create this 100% load scenario for measurement, switch the cooling tower fans off and let the leaving water temperature rises with a few degrees *(5°C)*. Switch the fans back on and wait until steady state conditions are reached. Measure now the required inputs. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Inlet water temperature: This is the inlet water temperature of the cooling tower at 100% load.

Outlet water temperature: This is the outlet water temperature of the cooling tower at 100% load.

Water mass flow rate: This is the outlet water temperature of the cooling tower at 100% load.

Inlet air temperature: This is the inlet air temperature of the cooling tower at 100% load. This means no water must bypass the cooling tower.

Inlet air RH: This is the inlet air relative humidity of the cooling tower at 100% load.

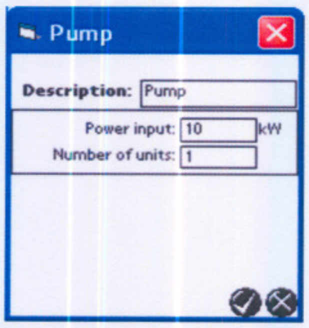
Power input: This is the electrical power input of the cooling tower fan at maximum air flow. This means all the fans must be active.

Temperature set point: This is the control set point of the cooling tower water leaving temperature.

Number of units: This is the number of cooling towers with the same thermal characteristics and control strategy configured in parallel.

Pump

The PDA data logger pump screen is displayed in the following figure:

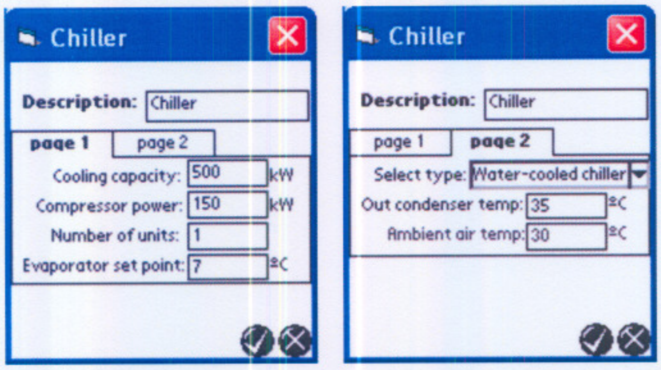


Power input: This is the electrical power input of the pump when in operation. The user can either obtain this value from the design specifications (pump curve) or measure it on-site. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Number of units: This is the number of pumps with the same performance characteristics and control strategy configured in parallel.

Chiller

The PDA data logger chiller screen is displayed in the following figure:



All the chiller inputs must be given at 100% load. The user can either obtain the required inputs form the design specifications or measure it on-site. To create this 100% load scenario, switch the chiller off and let the chilled water temperature heat-up with a few degrees *(5ºC.* Switch it now back on and measure all the required inputs when steady state is reached. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Cooling capacity: This is the cooling capacity of the chiller at 100% load.

Cooling capacity(kW) = Mevap(4.2)*(Tevap,in - Tevap,out)*

Tevap,in - Evaporator inlet water temperature (°C)

T Tevap,out - Evaporator leaving water temperature (°C)

Mevap - Evaporator water mass flow (l/s)

Or for air cooled chiller (100% load):

*Cooling capacity = (Heat rejected by condenser) - (compressor power*0.85)*

Heat rejected by condenser = condenser air mass flow(kg/s)(condenser air temperature out – condenser air temperature in)*

Or for water cooled chiller (100% load):

*Cooling capacity = (Heat rejected by cooling tower) - (compressor*0.85)*

Heat rejected by cooling tower = cooling tower air mass flow(kg/s)(cooling tower air enthalpy out – cooling tower air enthalpy in)*

Compressor power: This is the compressor power of the chiller at 100% load.

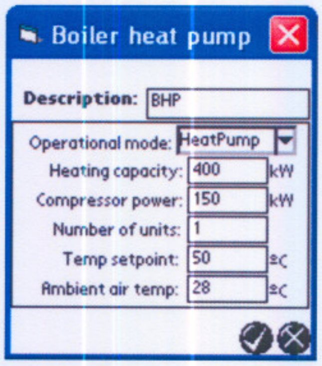
Evaporator set point: This is the evaporator leaving water temperature at set point.

Number of units: This is the number of chillers with the same performance characteristics and operating strategy configured in series or parallel.

Select type: Here the user can either select air cooled or water cooled. When air cooled is selected enter the ambient air temperature at the condenser and for water cooled the condenser leaving water temperature. The user can either obtain this value from the design specifications or measure it on-site.

Heat pump

The PDA data logger heat pump screen is displayed in the following figure:



All the heat pump inputs must be given at 100% load. The user can either obtain the required inputs from the design specifications or measure it on-site. To create this 100% load scenario, switch the heat pump off and let the hot water temperature cool down with a few degrees *(5ºC*. Switch it now back on and measure all the required inputs when steady state is reached. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Heating capacity: This is the heating capacity of the heat pump at 100% load.

Heating load (kW) = Mcon(4.2)*(Tcon,out - Tcon,in)*

Tcon,in - Condenser inlet water temperature (°C)
T con,out - Condenser leaving water temperature (°C)
Mcon - Condenser water mass flow (l/s)

Or for air cooled heat pump (100% load):

*Heating capacity = (Heat absorbed by evaporator) + (compressor power*0.85)*
Heat absorbed by evaporator = evaporator air mass flow(kg/s)(evaporator air temperature in – evaporator air temperature out)*

Compressor power: This is the compressor power of the heat pump at 100% load.

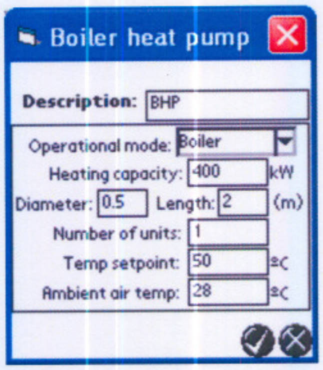
Temperature set point: This is the condenser leaving water temperature at set point.

Number of units: This is the number of heat pumps with the same performance characteristics and operating strategy configured in series or parallel.

Ambient air temperature: This is the ambient air temperature measured at the evaporator. The user can either obtain this value from the design specifications or measure it on-site.

Boiler

The PDA data logger boiler screen is displayed in the following figure:



Heating capacity: This is the heating capacity of the boiler at 100% load. The user can either obtain this value from the design specifications or measure it on-site. To create this 100% load scenario, switch the boiler off and leave it off until the hot water temperature is a few degrees *(5°C)* below its set point. Switch it now back on again and measure the boiler electrical power input at full load. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Length: This is the length of the boiler water tank. The user can either obtain this value from the design specifications or measure it on-site.

Diameter: This is the diameter of the boiler water tank. The user can either obtain this value from the design specifications or measure it on-site.

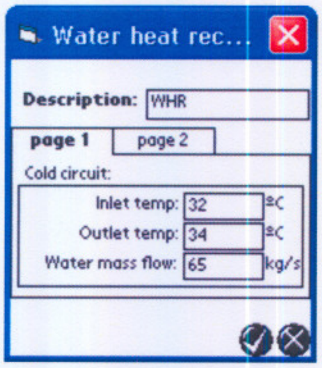
Temperature set point: This is the boiler leaving water temperature at set point. The user can either obtain this value from the design specifications or measure it on-site.

Number of units: This is the number of boilers with the same performance characteristics and operating strategy configured in series or parallel.

Ambient air temperature: This is the ambient air temperature measured at the boiler tank.

Water heat recovery

The PDA data logger water heat recovery screen is displayed in the following figure:



The user can obtain the water heat recovery inputs either from the design specifications or measure it on-site. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Cold circuit inlet temperature: This is the inlet water temperature of the heat exchanger at the cold stream side.

Cold circuit outlet temperature: This is the outlet water temperature of the heat exchanger at the cold stream side.

Cold circuit water mass flow: This is the water mass flow through the exchanger at the cold stream side.

Hot circuit inlet temperature: This is the inlet water temperature of the heat exchanger at the hot stream side.

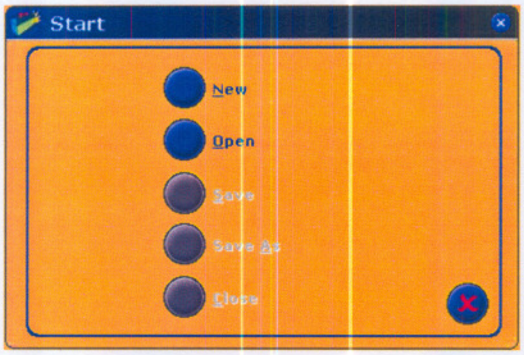
Hot circuit water mass flow: This is the water mass flow through the exchanger at the hot stream side.

Number of units: This is the number of heat exchangers with the same thermal characteristics and control strategy configured in parallel.

APPENDIX E: USE OF SIMULATION SOFTWARE

START

To start a new project or work on an existing project click on the START button on the main simulation interface. The following figure displays the start interface of the simulation tool:



New: To start a new project, click on the NEW button and select one of the default templates.

Open: To work on an existing project, click on the OPEN button and select the project file.

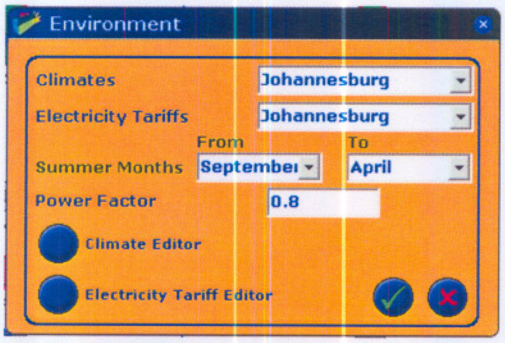
Save: To save the current project file, click on the SAVE button.

Save As: To save the current project file under another file name, click on the SAVE AS button.

Close: To close the current project, click on the CLOSE button.

ENVIRONMENT

To setup the environmental parameters of the project, click on the ENVIRONMENTAL button on the main simulation interface. The following figure displays the environmental interface of the simulation tool:



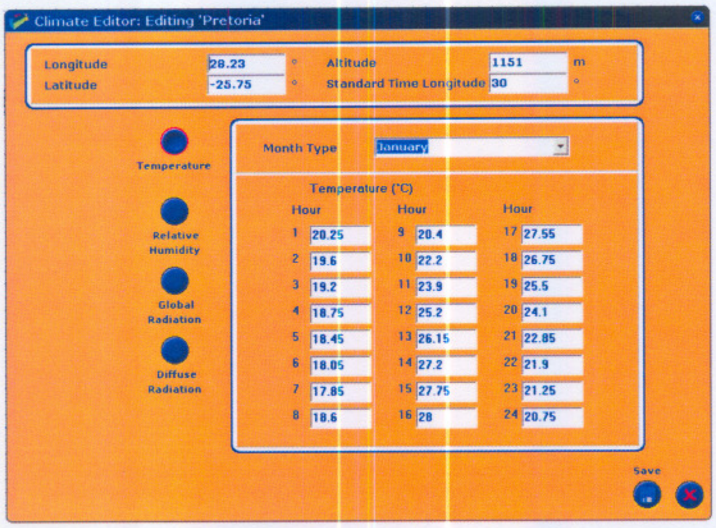
Climates: To select a project climate, click on the climate drop-down list box and select a climate. The selected climate will be used as climate inputs during the verification and retrofit simulations.

Electricity tariffs: To select a project electricity tariff, click on the tariff drop-down list box and select a tariff. The selected tariff will be used for all electricity cost calculations.

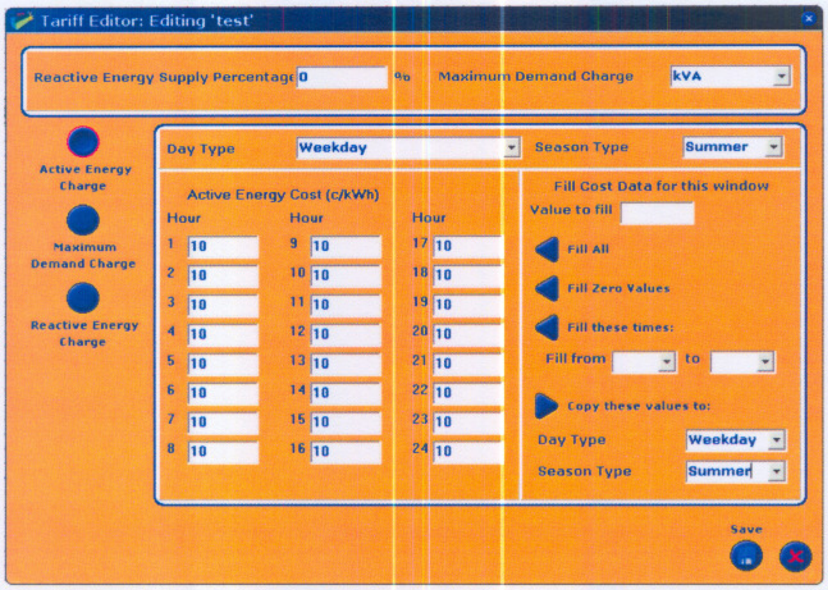
Summer months: To select the summer months, click on the from and to list boxes and specify the summer season. The selected months will be used as the summer season and the other months as the winter season during all the simulation calculations.

Power factor: This is the average power factor (PF) of the building total electricity load.

Climate editor: To add, edit or delete climates, click on the CLIMATE EDIT button. Here the user must enter hourly temperatures, RHs, global radiation and diffuse radiation for each month of the year. The following figure displays the climate input interface:



Electricity tariff editor: To add, edit or delete tariffs, click on the ELECTRICITY TARIFF EDIT button. Here the user will enter hourly active energy, reactive energy and Maximum Demand (MD) rates for each day type and season. The following figure displays the climate input interface:



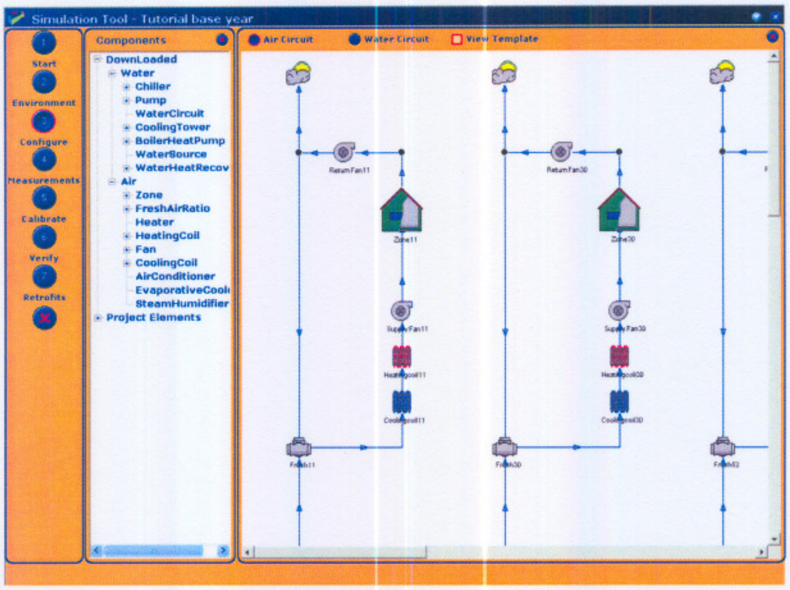
Reactive energy supply %: All reactive energy (KVarh) used in excess of this entered percentage of the active energy (kWh) will be charged against the reactive energy charge.

Maximum Demand charge: Either select KVA of KW from the drop-down menu.

CONFIGURE

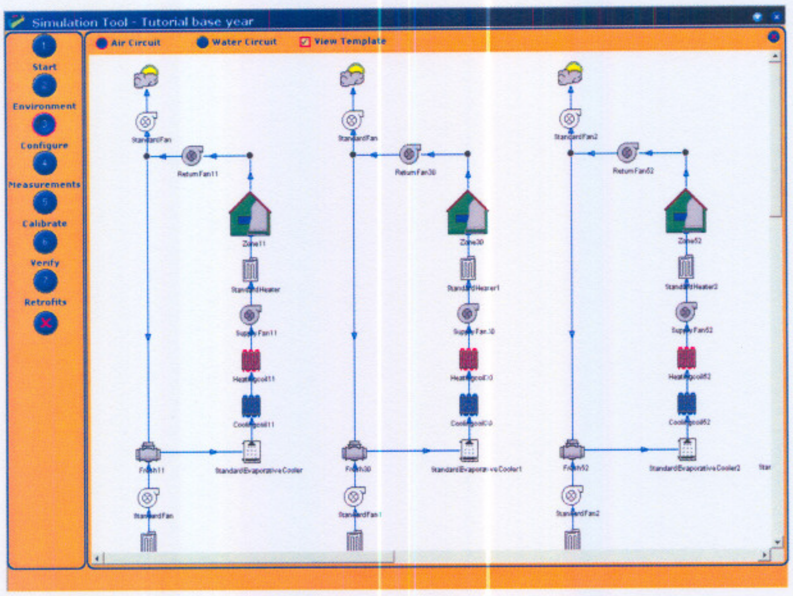
Download palm components

The user will be prompted to download the palm data logger components on to the simulation tool. To download the palm components connect the palm to the PC and press the hotsync button on the cradle. All the palm components will now be available in the component list under downloaded components in the simulation tool. The configure simulation interface can be seen in the following figure:



Customise air and water-circuits

To customise the template, click on the components with the RIGHT MOUSE BUTTON to be included in the simulation. The selected (active) components will now display background colours and the inactive components none. The components can again be excluded by another RIGHT MOUSE click. The following figure displays the template view mode:

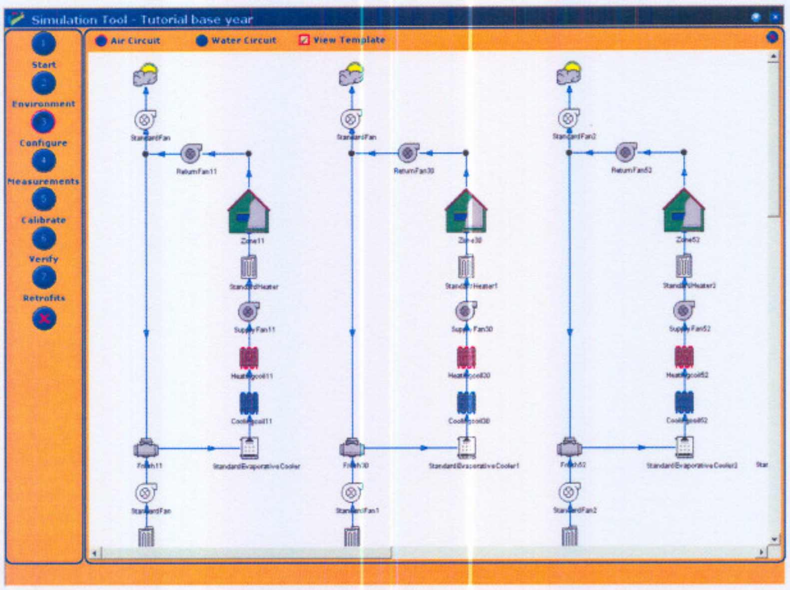


Insert palm components

All the palm components will be displayed under the downloaded list. The user can now drag and drop the components on their respective template positions.

Air-circuit components

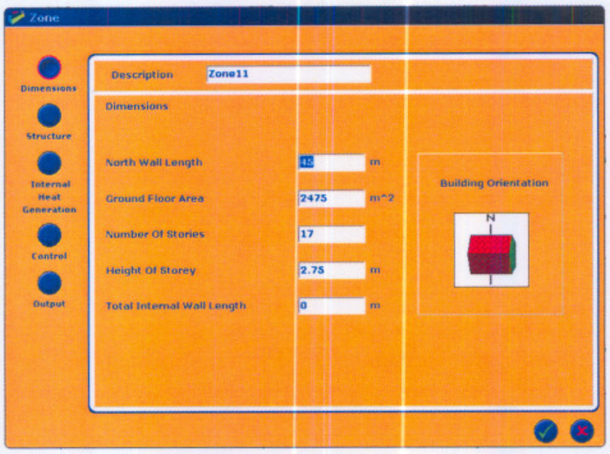
The air-circuit screen is displayed in the following figure:



Air-circuit: To add or edit a component on the air-circuit, click on the AIR-CIRCUIT button. The user can now select the components by a single right mouse click on the icon. To edit the selected component inputs, double click on the component icon.

Building zone

The building zone input screen is displayed in the following figure:



Description: To enter a descriptive zone name enter a name in the provided text box.

Dimensions: To enter all the important building dimensions click on the DIMENSIONS button and complete the zone dimensions input interface.

Structure: To enter the building construction click on the STRUCTURE button and complete all the zone structure input interfaces.

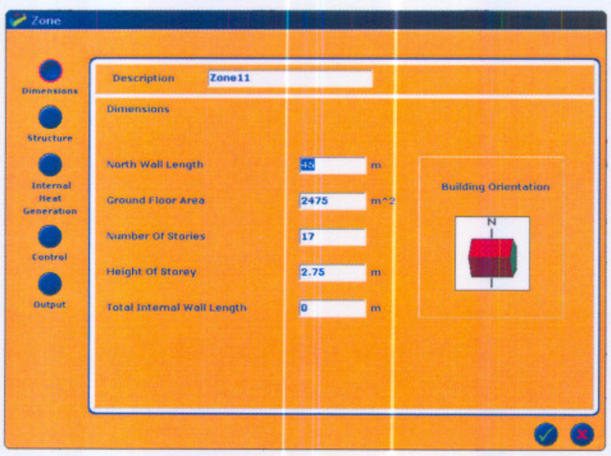
Internal heat generation: To enter internal heat sources (lights, computers, people, etc.) into the building zone click on the INTERNAL HEAT GENERATION BUTTON and complete the input interface.

Control: To specify the zone control, set points (temperature, RH, air flow) and air-conditioning schedules click on the CONTROL button and complete the interfaces.

Output: To view the hourly zone air temperatures and relative humidities, click on the OUTPUT button.

Dimensions

The building zone dimensions screen is displayed in the following figure:



North wall length: This is the length of the wall facing north. The user can obtain this information on-site by measurement, or alternatively directly from the building drawings. (This is the total zone north wall length.)

Internal floor area: This is the internal floor area of the zone. This can be calculated from measurements made on-site, or alternatively directly from the building plans. (This is the internal floor area per storey (one level) for building zones with more than one storey.)

Number of storeys: This is the number of floor levels per building zone.

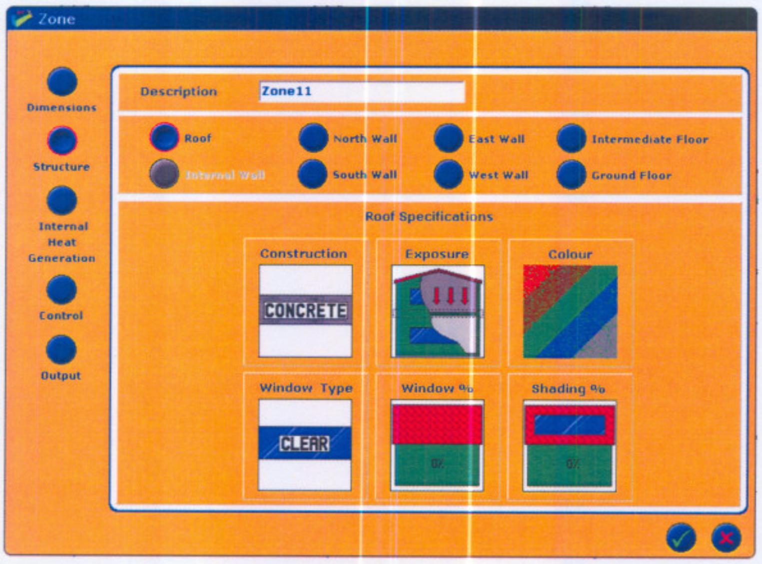
Height of storey: This is the height of one storey from the floor to the ceiling. The height can be measured on-site or taken from the building plans.

Total internal wall length: This is the total length of all the walls inside the zone that do not form part of the zone boundaries (North, East, South, West wall). This information can be found on-site, or from the building plans.

Building orientation: This information can be entered in two ways. Firstly as a positive value, measured clockwise from north, zero at north, to +45°. Alternatively as a negative value, measured anti-clockwise from north, zero at north, to -45°. The information is usually obtained from building plans, but can also be measured on-site.

Structure

The building zone structure screen is displayed in the following figure:



Zone structure: To specify the construction of each surface type displayed on the interface click on the respective surface type (North wall, East wall, etc) button and complete the inputs.

Construction: The user can choose a surface construction from a predefined surface database. To select a construction type click on the CONSTRUCTION icon and select a type from the menu.

Exposure: To specify the exterior exposure of the surface click on the EXPOSURE icon and select a type from the menu.

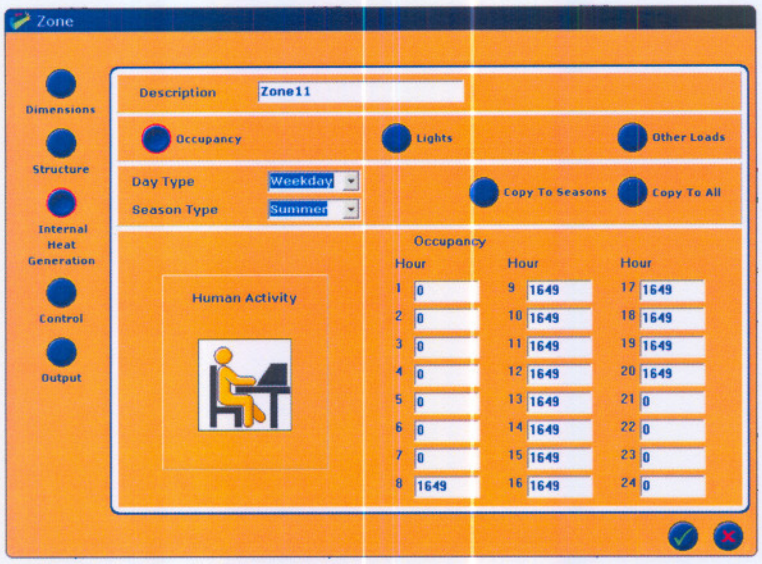
Window %: This is the window area as a percentage of the total surface area. To specify the percentage click on the WINDOW % icon and select one of the options from the menu.

Shading %: This is the shaded area as a percentage of the total window area. To specify this percentage click on the SHADING % icon and select one of the options from the menu.

Window type: The user can choose a window type from a predefined database. To select a type click on the WINDOW TYPE icon and select a type from the menu.
Colour: This is the exterior colour of the surface. To select a colour click on the COLOUR icon and select a colour from the menu.

Internal heat generation

The building internal heat generation screens are displayed in the following figures:



Occupancy: This is the typical number of people inside the building zone at the same time. The user can entered a value for each hour, day type and season. To specify the number of people enter the value into the text box.

Human activity: This is the typical activity of the people inside the building zone. Specify the activity by selecting one from the menu.

Lights: Here the user can specify three types of lighting fixtures. Enter the type, load and number of each fixture. A lighting schedule for each day type and season can be specified.

Other loads: Here the user can specify three types of other internal loads (computers, lifts, etc.). Enter a description, load and number of each type. A load schedule for each day type and season can be specified.

Control

The building zone control screen is displayed in the following figure:

Temperature control: This is the zone temperature control range. The system will control (when cooling and heating schedule is active) the zone temperature between the entered minimum and maximum temperature inputs.

RH control: This is the zone relative humidity (RH) control range. The system will control (when cooling and heating schedule is active) the zone RH between the entered minimum and maximum RH inputs.

Volume flow: Here the user can either select constant air volume or variable air volume. Variable air volume means the indoor temperature is controlled by supply air dampers in the building zone. The user will have to specify the minimum and maximum air flow to the building zone. The user can either obtain these flow values from the design specifications or measure it on-site.

Maximum flow: This is the air flow rate to the building zone measured at 100% cooling load. This means all the supply air control dampers must be 100% open. To create this scenario lower the zone set point or warm-up the control sensor.

Minimum flow: This is the air flow rate to the building zone measured at 100% heating load. This means all the supply air control dampers must be at their minimum flow position. To create this scenario increase the zone set point or cool down the control sensor.

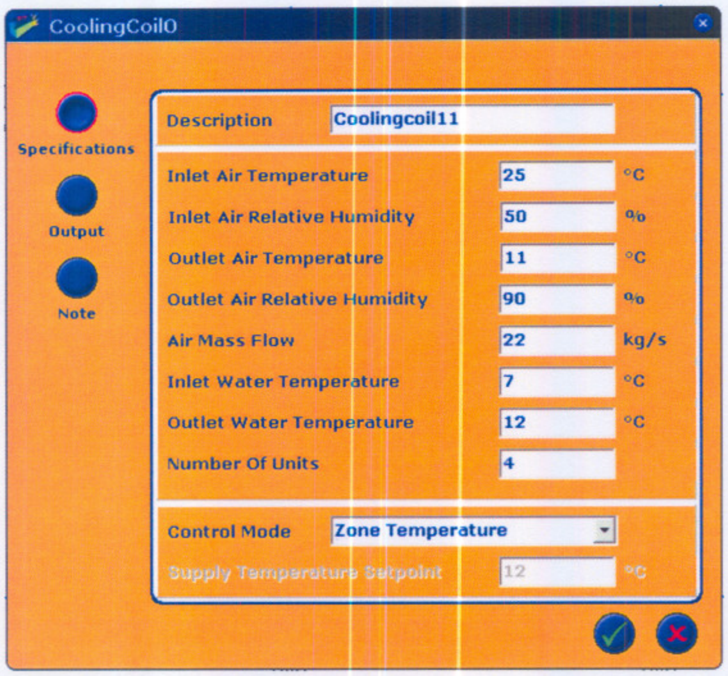
Ventilation schedule: This is the operating schedule of all the fans (fresh air, supply air, return-air and exhaust air fan) of the building zone. The user can specify a schedule for each day type and season.

Air-conditioning schedule: This is the operating schedule of all the heating and cooling elements (coils, heaters, and evaporative coolers) of the building zone. The user can specify a schedule for each day type and season.

Set point setback: This is a specified set point setback temperature for each hour. For example: If 2 is entered at a specific hour, 2 will be added too the maximum and minimum temperature control range for that hour. The user can specify setbacks values for each day type and season.

Cooling coil

The cooling coil screen is displayed in the following figure:



All the cooling coil inputs must be given at 100% cooling load. This means no water must bypass the coil. The user can obtain the cooling coil inputs either from the design specifications or measure it on-site. To create this 100% load scenario for measurement, lower the control set point or heat-up the control sensor and wait until steady state conditions are reached. Measure now the required inputs. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Inlet air temperature: This is the inlet air temperature of the cooling coil at 100% cooling load.

Inlet air RH: This is the inlet air relative humidity of the cooling coil at 100% cooling load.

Outlet air temperature: This is the outlet air temperature of the cooling coil at 100% cooling load.

Outlet air RH: This is the outlet air relative humidity of the cooling coil at 100% cooling load.

Air mass flow: This is the air mass flow through the cooling coil at 100% cooling load.

Inlet water temperature: This is the inlet water temperature of the cooling coil at 100% cooling load.

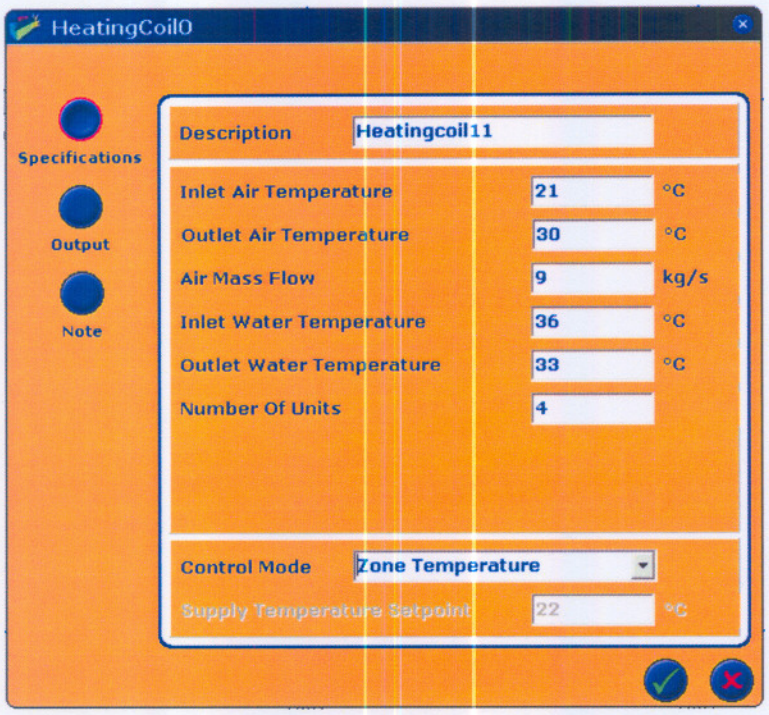
Outlet water temperature: This is the outlet water temperature of the cooling coil at 100% cooling load.

Number of units: This is the number of coils with the same thermal characteristics and control strategy configured in parallel.

Control: This is the control strategy of the cooling coil. Here the user can either select zone temperature or supply temperature. Zone temperature means the coil capacity will be controlled to maintain the zone indoor air temperature at the maximum temperature control range value. The supply temperature option will imply that the coil capacity is controlled to maintain a constant coil leaving air temperature.

Heating coil

The heating coil screen is displayed in the following figure:



All the heating coil inputs must be given at 100% heating load. This means no water must bypass the coil. The user can obtain the heating coil inputs either from the design specifications or measure it on-site. To create this 100% load scenario for measurement, increase the control set point or cool down the control sensor and wait until steady state conditions are reached. Measure now the required inputs. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Inlet air temperature: This is the inlet air temperature of the heating coil at 100% heat load.

Outlet air temperature: This is the outlet air temperature of the heating coil at 100% heat load.

Air mass flow: This is the air mass flow through the heating coil at 100% cooling load.

Inlet water temperature: This is the inlet water temperature of the heating coil at 100% heat load.

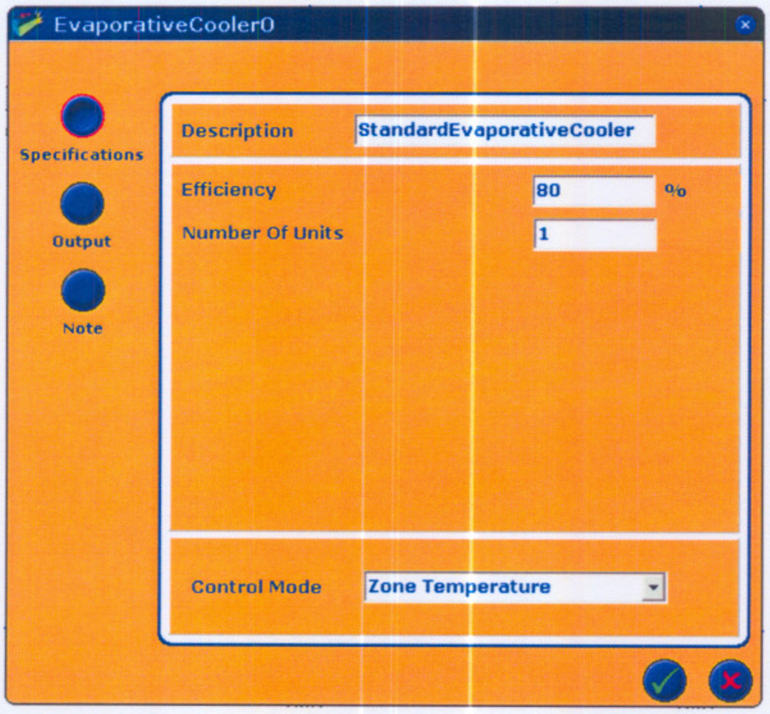
Outlet water temperature: This is the outlet water temperature of the heating coil at 100% heat load.

Number of units: This is the number of coils with the same thermal characteristics and control strategy configured in parallel.

Control: This is the control strategy of the heating coil. Here the user can either select zone temperature or supply temperature. Zone temperature means the coil capacity will be controlled to maintain the zone indoor air temperature at the minimum temperature control range value. The supply temperature option will imply that the coil capacity is controlled to maintain a constant coil leaving air temperature.

Evaporative cooler

The evaporative cooler screen is displayed in the following figure:



Efficiency: Evaporative efficiencies range between 75% and 85%.

$$Efficiency = (T_{db,in}-T_{db,out})/(T_{db,in}-T_{wb,in})*100$$

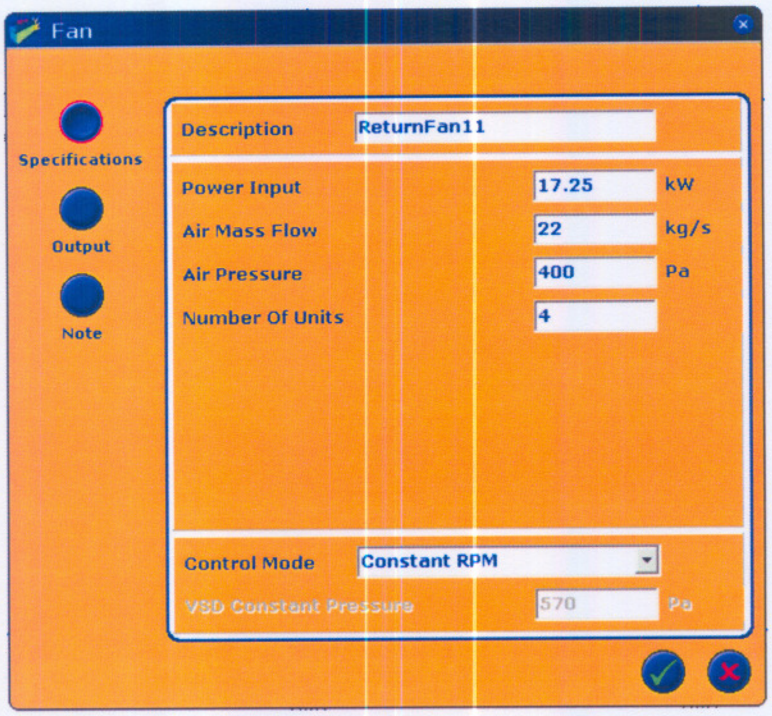
Tdb - Dry bulb temperature (°C)
Twb - Wet bulb temperature (°C)
in - Inlet air condition
out - outlet air condition

Number of units: This is the number of coolers with the same thermal characteristics and control strategy configured in parallel.

Control: This is the control strategy of the cooler. Here the user can either select zone temperature or none. Zone temperature means the cooler capacity will be controlled to maintain a constant zone air leaving temperature at 1°C below than the maximum temperature control range value. The none option will imply that the cooler is always at 100% load when active.

Fan

The fan screen is displayed in the following figure:



All the fan inputs must be given at maximum air flow. This means all the supply air control dampers must be 100% open. The user can obtain the fan inputs either from the design specifications (fan curve) or measure it on-site. To create this maximum air flow scenario for measurement, lower the control set point or heat-up the control sensor and wait until steady state conditions are reached. Measure now the required inputs. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Power input: This is the electrical power input of the fan at maximum air flow.

Air mass flow: This is the air flow through the fan at maximum air flow.

Air pressure: This is the total pressure difference over the fan at maximum air flow.

$$Air\ pressure = (P + 0.5pv^2)out - (P + 0.5pv^2)in$$

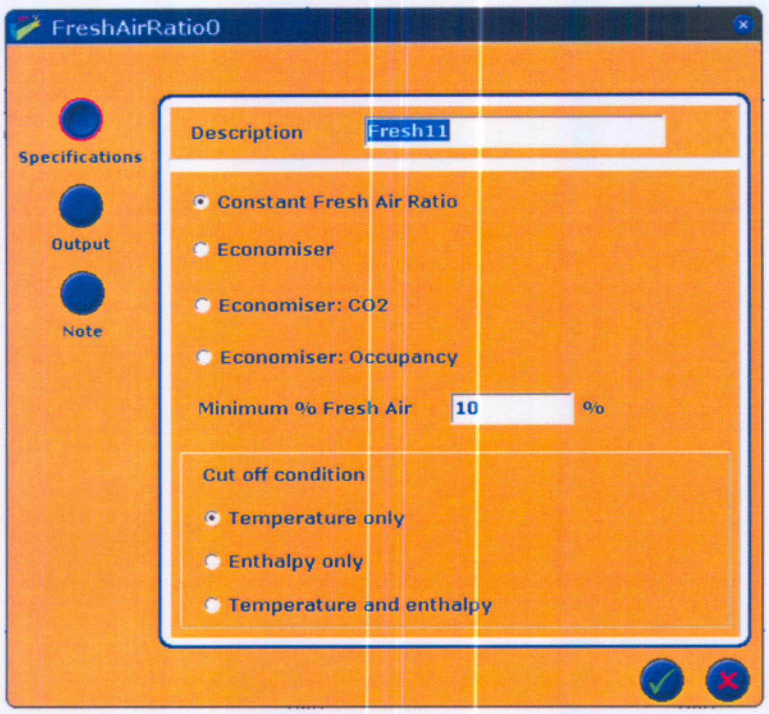
P - Static air pressure (Pa)
p - Air density (kg/m²)
v - Average air speed (m/s)

Number of units: This is the number of fans with the same thermal characteristics and control strategy configured in parallel.

Control: This is the control strategy of the fan. Here the user can either select constant RPM or VSD constant pressure. Constant RPM means the fan will always operate at a constant RPM. VSD or frequency control at a constant pressure implies that the fan's RPMs will be controlled to maintain a constant total pressure over the fan.

Fresh air ratio

The fresh air ratio screen is displayed in the following figure:



Minimum % fresh air: This is the minimum amount of fresh air as a percentage of the total air supplied to the building zone. This means the fresh air dampers must be at their minimum setting (economiser control). The user can either obtain this value from the design specifications or measure it on-site. To create this minimum % fresh air scenario heat-up the fresh air control sensor.

Control: This is the control strategy of the fresh and return-air dampers. The dampers will be controlled to maintain a constant zone temperature at 1°C below the maximum temperature control range value. Here the user can either select constant fresh air, economiser, CO_2 or occupancy.

Constant fresh air - No damper control (no economiser)

Economiser - Economiser control with a specified minimum fresh air setting.

Occupancy - Economiser control with a specified minimum fresh air setting when the building zone is occupied and a zero minimum fresh air setting when the building is unoccupied.

CO_2 - Economiser control integrated with CO_2 control to keep the building zone within its CO_2 levels (700 ppm CO_2 above the outside CO_2 level)

Cut off condition: This is the condition used to determine if outside air can be used for cooling or not. Outside air is only used for cooling when the outside air cut off condition is lower than the zone return-air cut off condition.

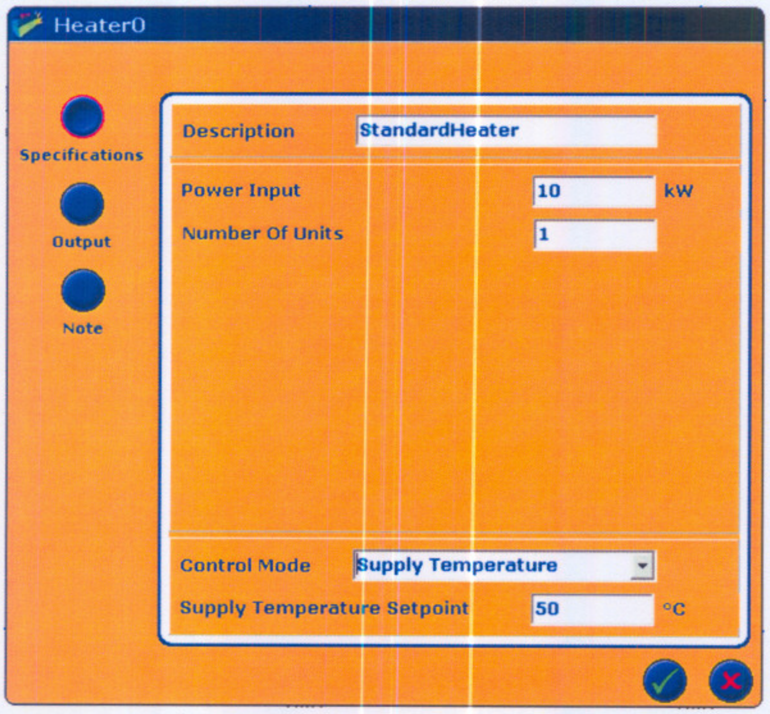
Temperature only - Outside air is used for cooling when the outside air temperature is below the zone return-air temperature.

Enthalpy only - Outside air is used for cooling when the outside air enthalpy is below the zone return-air enthalpy.

Temperature and enthalpy - Outside air is used for cooling when the outside air enthalpy and temperature are below the zone return-air enthalpy and temperature.

Heater

The heater screen is displayed in the following figure:



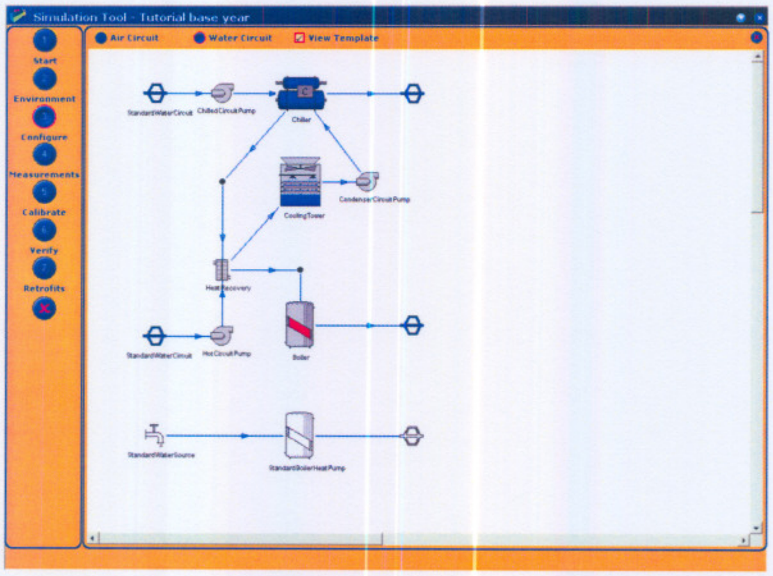
Power input: This is the electrical power input of the heater at 100% load. This means all the heating elements must be active. The user can obtain this input either from the design specifications or measure it on-site. To create this 100% load scenario for measurement, increase the control set point or cool down the control sensor and wait until steady state conditions are reached. Measure now the power input. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Number of units: This is the number of heater banks with the same control strategy configured in parallel.

Control: This is the control strategy of the heater. Here the user can either select zone temperature or supply temperature. Zone temperature means the heater capacity will be controlled to maintain a constant zone indoor air temperature at the minimum temperature control range value. The supply temperature option will imply that the heater capacity is controlled to maintain a constant heater leaving air temperature.

Water-circuit components

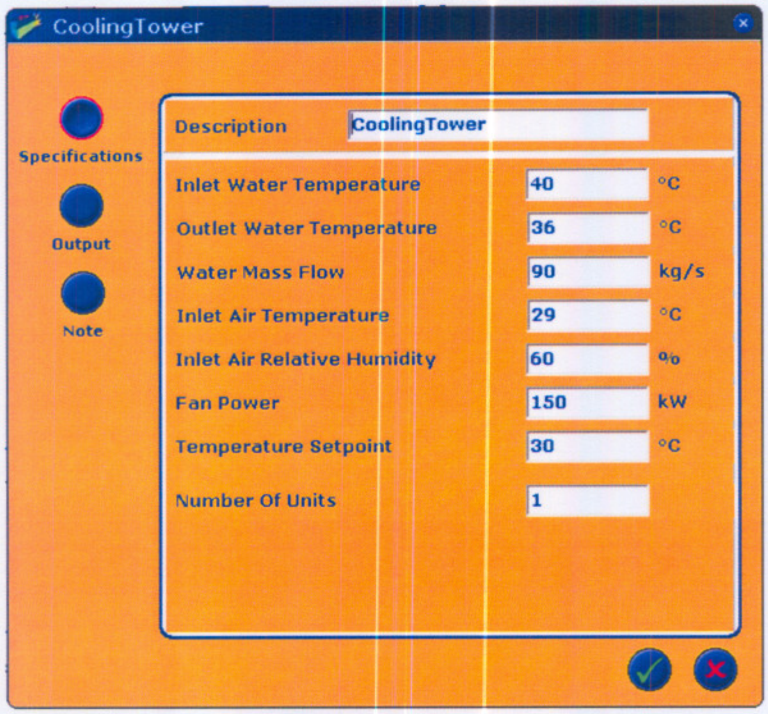
The water-circuit screen is displayed in the following figure:



Water-circuit: To add or edit a component on the water-circuit, click on the WATER-CIRCUIT button. The user can now select the components by a single mouse click on the icon. To edit the selected component inputs, double click on the component icon.

Cooling Tower

The cooling tower screen is displayed in the following figure:



All the cooling tower inputs must be given at 100% cooling load. This means no water must bypass the cooling tower. The user can obtain the cooling tower inputs either from the design specifications or measure it on-site. To create this 100% load scenario for measurement, switch the cooling tower fans off and let the leaving water temperature rises with a few degrees *(5 °C)*. Switch the fans back on and wait until steady state conditions are reached. Measure now the required inputs. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Inlet water temperature: This is the inlet water temperature of the cooling tower at 100% load.

Outlet water temperature: This is the outlet water temperature of the cooling tower at 100% load.

Water mass flow rate: This is the outlet water temperature of the cooling tower at 100% load.

Inlet air temperature: This is the inlet air temperature of the cooling tower at 100% load. This means no water must bypass the cooling tower.

Inlet air RH: This is the inlet air relative humidity of the cooling tower at 100% load.

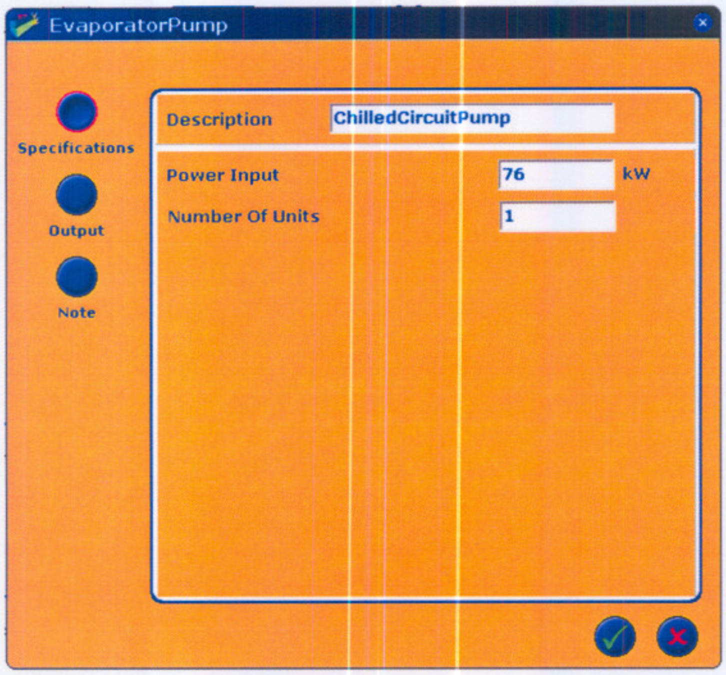
Power input: This is the electrical power input of the cooling tower fan at maximum air flow. This means all the fans must be active.

Temperature set point: This is the control set point of the cooling tower water leaving temperature.

Number of units: This is the number of cooling towers with the same thermal characteristics and control strategy configured in parallel.

Pump

The pump screen is displayed in the following figure:

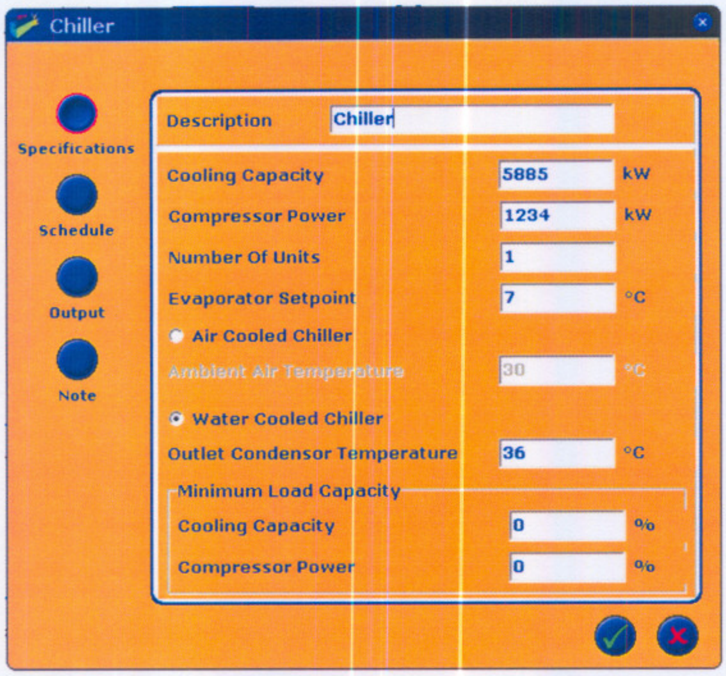


Power input: This is the electrical power input of the pump when in operation. The user can either obtain this value from the design specifications (pump curve) or measure it on-site. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Number of units: This is the number of pumps with the same performance characteristics and control strategy configured in parallel.

Chiller

The chiller screen is displayed in the following figure:



All the chiller inputs must be given at 100% load. The user can either obtain the required inputs from the design specifications or measure it on-site. To create this 100% load scenario, switch the chiller off and let the chilled water temperature heat up with a few degrees *(5ºC)*. Switch it back on now and measure all the required inputs when steady state is reached. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Cooling capacity: This is the cooling capacity of the chiller at 100% load.

Cooling load (kW) = Mevap(4.2)*(Tevap,in - Tevap,out)*

Tevap,in - Evaporator inlet water temperature (°C)
T evap,out - Evaporator leaving water temperature (°C)
Mevap - Evaporator water mass flow (l/s)

Compressor power: This is the compressor power of the chiller at 100% load.

Evaporator set point: This is the evaporator leaving water temperature at set point.

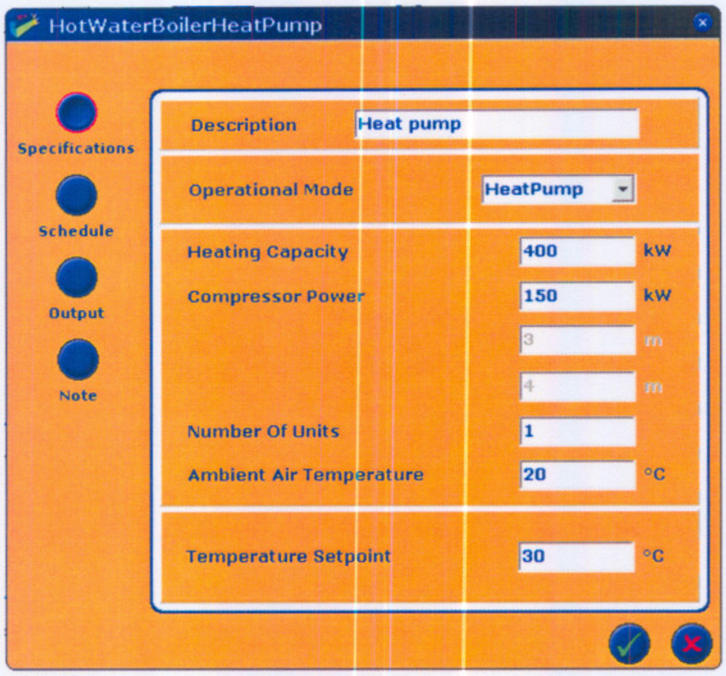
Number of units: This is the number of chillers with the same performance characteristics and operating strategy configured in series or parallel.

Select type: Here the user can either select air cooled or water cooled. When air cooled is selected enter the ambient air temperature at the condenser and for water cooled the condenser leaving water temperature. The user can either obtain this value from the design specifications or measure it on-site.

Minimum load capacity: This is the minimum cooling load (first loading step) of the chiller as a percentage of 100% load and the respective compressor power percentage.

Heat pump

The heat pump screen is displayed in the following figure:



All the heat pump inputs must be given at 100% load. The user can either obtain the required inputs from the design specifications or measure it on-site. To create this 100% load scenario, switch the heat pump off and let the hot water temperature cool down with a few degrees *(5 □ Ç.* Switch it now back on and measure all the required inputs when steady state is reached. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Heating capacity: This is the heating capacity of the heat pump at 100% load.

$$Heating\ load\ (kW) = Mcon*(4.2)*(Tcon,out - Tcon,in)$$

Tcon,in - Condenser inlet water temperature (°C)
T con,out - Condenser leaving water temperature (°C)
Mcon - Condenser water mass flow (l/s)

Compressor power: This is the compressor power of the heat pump at 100% load.

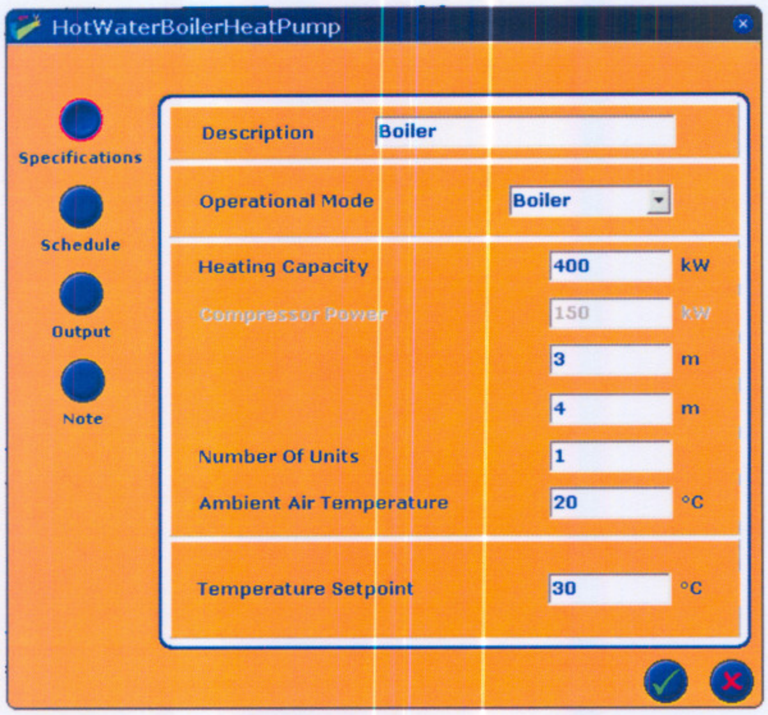
Temperature set point: This is the condenser leaving water temperature at set point.

Number of units: This is the number of heat pumps with the same performance *characteristics* and operating strategy configured in series or parallel.

Ambient air temperature: This is the ambient air temperature measured at the evaporator. The user can either obtain this value from the design specifications or measure it on-site.

Boiler

The boiler screen is displayed in the following figure:



Heating capacity: This is the heating capacity of the boiler at 100% load. The user can either obtain this value from the design specifications or measure it on-site. To create this 100% load scenario, switch the boiler off and leave it off until the hot water temperature is a few degrees *(5°C)* below its set point. Switch it now back on again and measure the boiler electrical power input at full load. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Length: This is the *length* of the boiler water tank. The user can either obtain this value from the design specifications or measure it on-site.

Diameter: This is the diameter of the boiler water tank. The user can either obtain this value from the design specifications or measure it on-site.

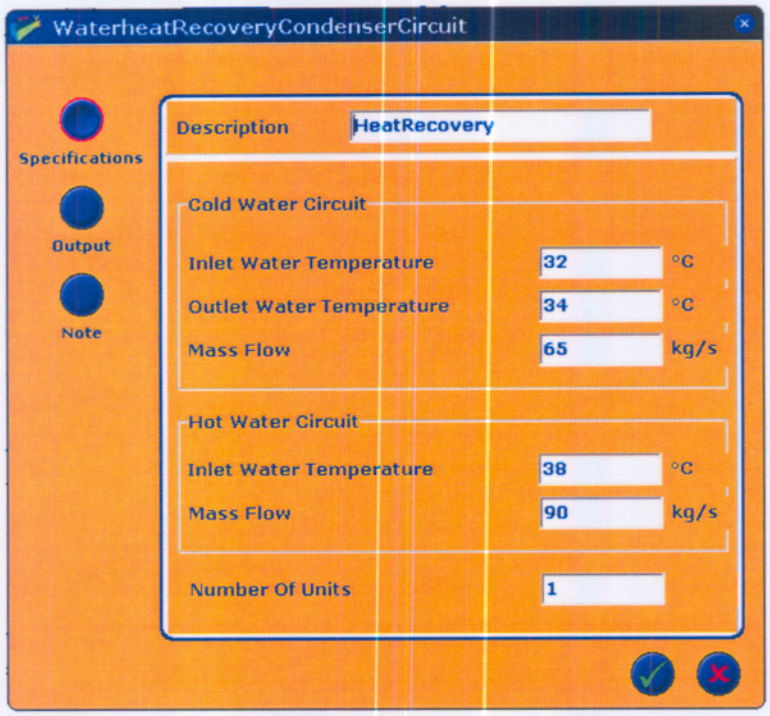
Temperature set point: This is the boiler leaving water temperature at set point. The user can either obtain this value from the design specifications or measure it on-site.

Number of units: This is the number of boilers with the same performance *characteristics* and operating strategy configured in series or parallel.

Ambient air temperature: This is the ambient air temperature measured at the boiler tank.

Water heat recovery

The palm data logger water heat recovery screen is displayed in the following figure:



The user can obtain the water heat recovery inputs either from the design specifications or measure it on-site. ***Remember all the inputs are for one unit only (per unit if more than one unit).***

Cold circuit inlet temperature: This is the inlet water temperature of the heat exchanger at the cold stream side.

Cold circuit outlet temperature: This is the outlet water temperature of the heat exchanger at the cold stream side.

Cold circuit water mass flow: This is the water mass flow through the exchanger at the cold stream side.

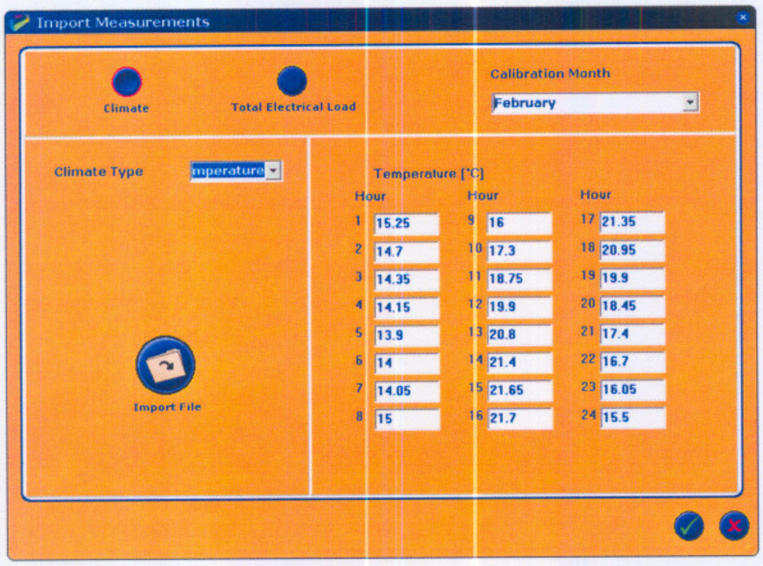
Hot circuit inlet temperature: This is the inlet water temperature of the heat exchanger at the hot stream side.

Hot circuit water mass flow: This is the water mass flow through the exchanger at the hot stream side.

Number of units: This is the number of heat exchangers with the same thermal characteristics and control strategy configured in parallel.

MEASUREMENTS

The calibration measurement screen is displayed in the following figure:

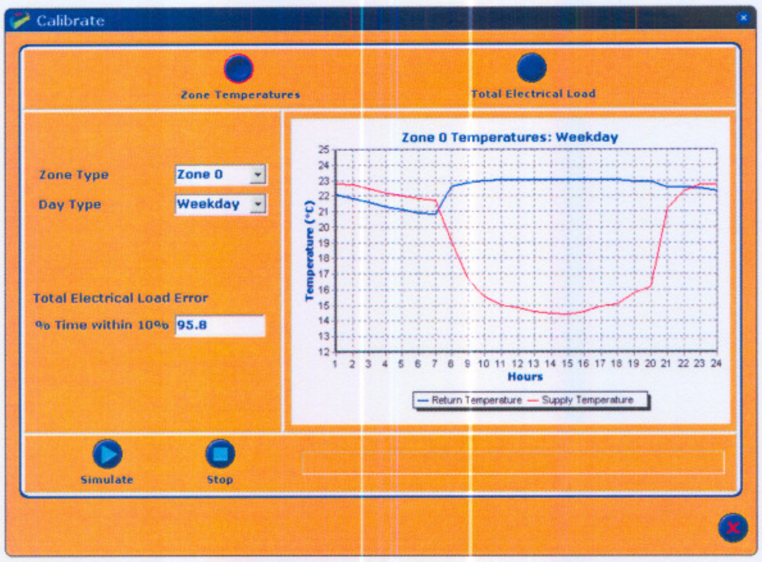


Climate: This is the climate measurements for calibration. The user will have to enter average hourly temperature and relative humidity values for a typical weekday. The calibration simulations will use the radiation values of the selected climate under the environment option. Remember to select the calibration month from the drop-down list box for the correct sun angles.

Total electrical load: This is the total building electrical load measured for calibration (active and reactive energy). The user will have to enter average hourly energy (kWh) values for all the required day types.

CALIBRATE

The calibration output screen is displayed in the following figure:



Simulate: To execute a calibration calculation click on the SIMULATE button. The software will now execute calibration weekday, Saturday and Sunday calculations.

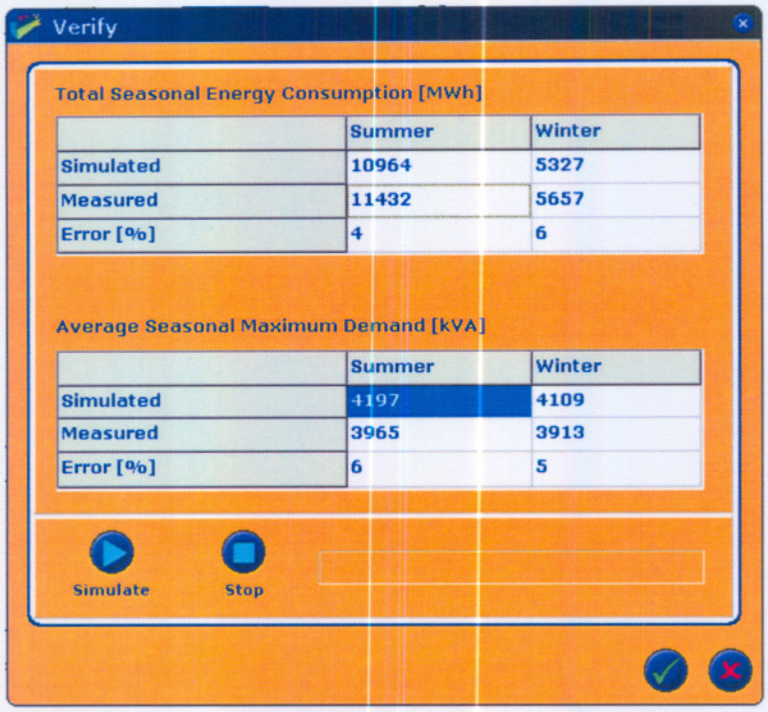
Zone temperatures: To view the simulated zone return and supply air temperatures trends, click on the ZONE TEMPERATURE button.

Total electrical load: To view the simulated and measured total electrical load trends, click on the TOTAL ELECTRICAL LOAD button.

Calibration error: This is the % of time where the simulated energy load trend is within 10% of the measured trend.

VERIFY

The verification screen is displayed in the following figure:



Simulate: To execute a verification calculation click on the SIMULATE button. The software will now execute verification calculations for the summer and winter season.

Measured total energy consumption: Enter the measured energy consumption of the summer and winter months into the respective table cells. Remember the summer months are the months selected on the environment input interface.

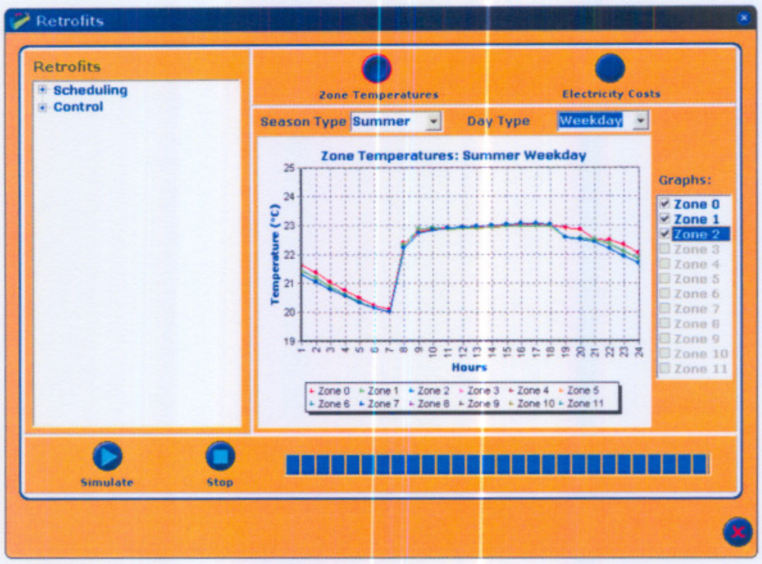
Measured average Maximum Demand (MD): Enter the measured average MD of the summer and winter months into the respective table cells. Remember the summer months are the months selected on the environment input interface.

Total energy consumption % error: abs(measured energy consumption - simulated energy consumption)/(measured energy consumption)*100.

Average Maximum Demand (MD) % error: abs(measured MD - simulated MD)/(measured MD)*100.

RETROFITS

The retrofit screen is displayed in the following figure:



Simulate: To execute a retrofit calculation click on the SIMULATE button. The software will now execute retrofit calculations for the summer and winter season.

Retrofits: Select typical retrofit options from the retrofit list. Click on the option of your choice and the software will take you directly to the selected component interface.

Scheduling: Here the user can change the operating schedules of the air cooling equipment (coils and evaporative coolers), air heating equipment (coils and heaters), the ventilation equipment (fans), the cooling plant (chiller with pumps), the heating plant (boiler/heat pump with pumps) and the lights. The schedules can be change for each day type and season.

Fresh air control: This is the *control* strategy of the fresh and return-air dampers. Here the user can either select constant fresh air, economiser, CO_2 or occupancy.

Constant fresh air - No damper control (no economiser)

Economiser - Economiser control with a specified minimum fresh air setting.

Occupancy - Economiser control with a specified minimum fresh air setting when the building zone is occupied and a zero minimum fresh air setting when the building is unoccupied.

CO_2 - Economiser control integrated with CO_2 control to keep the building zone within its CO_2 levels (700 ppm CO_2 above the outside CO_2 level)

Cut off condition: This is the condition used to determine if outside air can be used for cooling or not. Outside air is only used for cooling when the outside air cut off condition is lower than the zone return-air cut off condition.

Temperature only - Outside air is used for cooling when the outside air temperature is below the zone return-air temperature.

Enthalpy only - Outside air is used for cooling when the outside air enthalpy is below the zone return-air enthalpy.

Temperature and enthalpy - Outside air is used for cooling when the outside air enthalpy and temperature are below the zone return-air enthalpy and temperature.

Set point control: Here the user can either select zone temperature or supply temperature for each air cooling and air heating component. Zone temperature means the coil capacity will be controlled to maintain a constant zone indoor air temperature. The supply temperature option will imply that the coil capacity is controlled to maintain a constant coil leaving air temperature.

Set point setback: This is a specified set point setback temperature for each hour. For example: If 2 is entered at a specific hour, 2 will be added too the maximum and minimum temperature control range for that hour. The user can specify setbacks values for each day type and season.

Fan control: This is the *control* strategy of the fan. Here the user can either select constant RPM or VSD constant pressure. Constant RPM means the fan will always operate at a constant RPM. VSD or frequency control at a constant pressure implies that the fan's RPMs will be controlled to maintain a constant total pressure over the fan.

Zone temperatures: This is the zone air temperature results of each retrofit simulation. To see the zone air temperature results, click on the ZONE TEMPERATURES button.

Electricity costs: This is the electricity cost results of each retrofit simulation. To see the electricity cost results, click on the ELECTRICITY COSTS button.

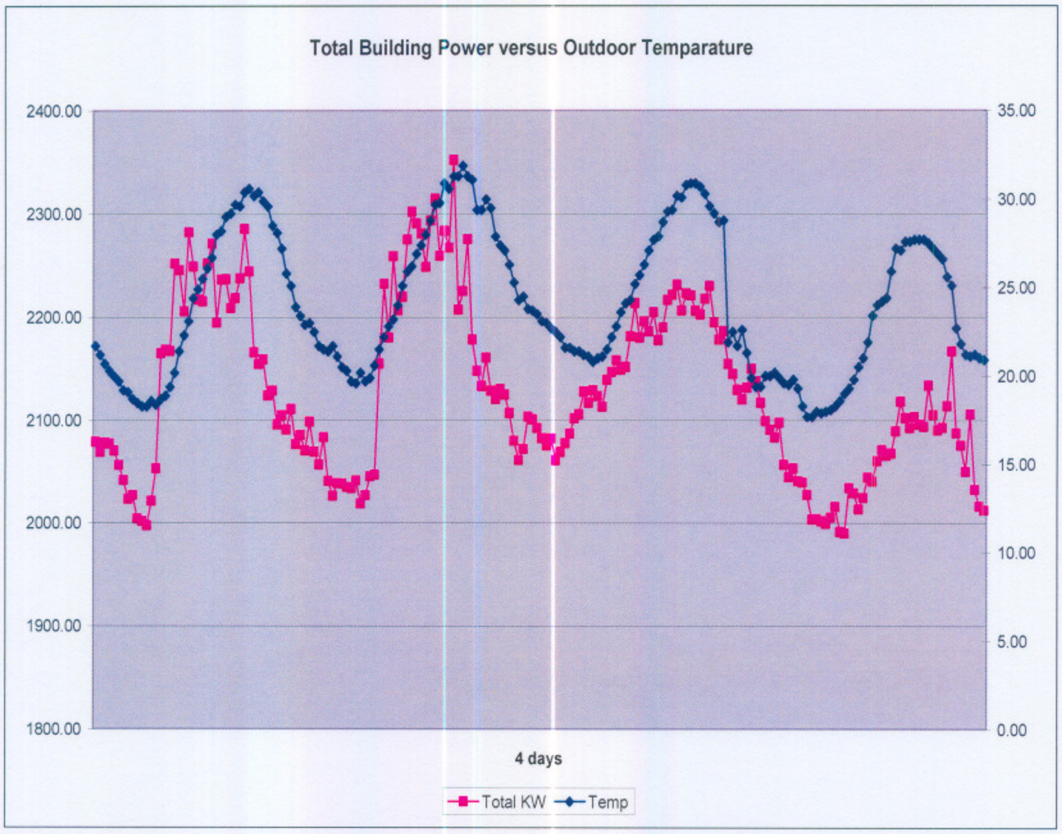
FINANCIAL ANALYSIS

The financial analysis result screen is displayed in the following figure:

Financial analysis: To access the financial analysis tool, click on the FINANCIAL ANALYSIS button on the main ESCO Toolbox interface. This tool will allow the user to calculate electricity cost savings, payback periods and internal rates of return.

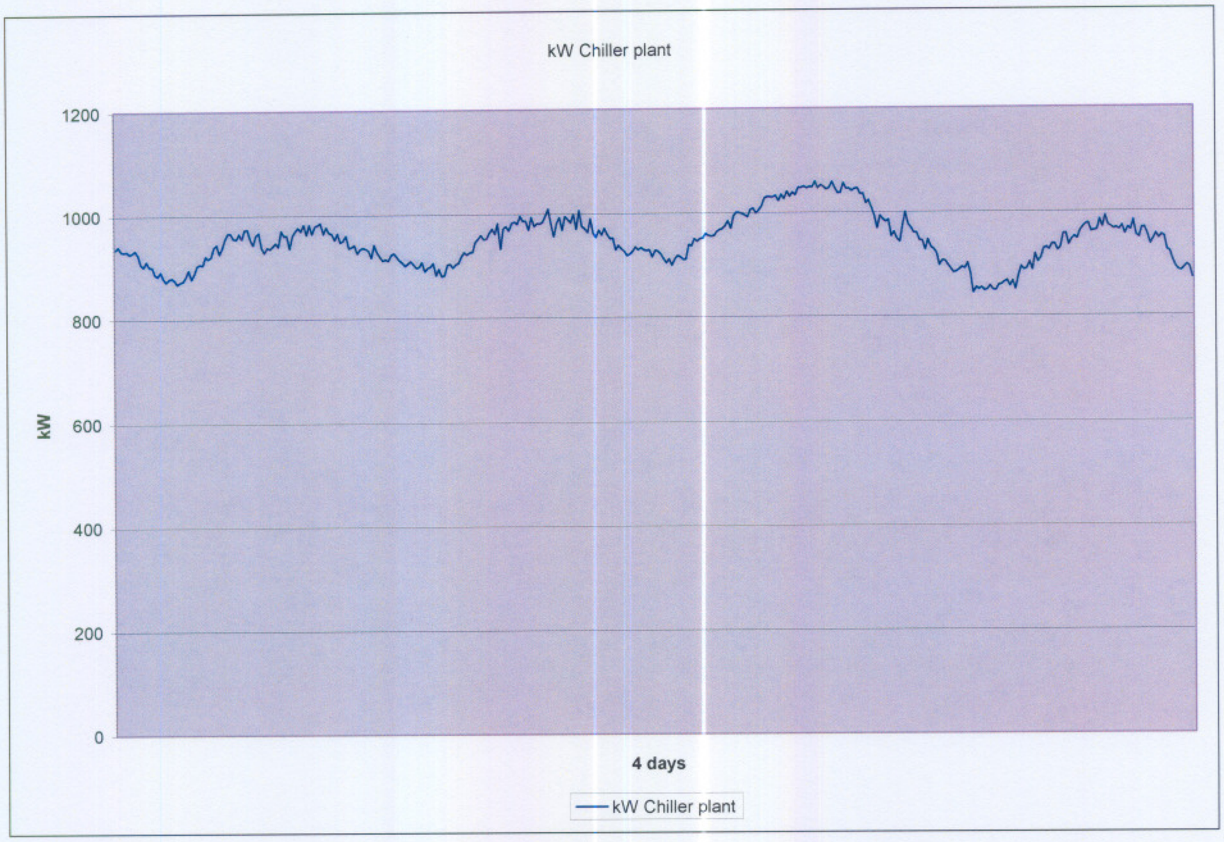
APPENDIX F: ADDITIONAL RESULTS FOR TELKOM TOWERS SOUTH

Power profiles



In the figure above it is shown that the total building power profile is greatly influenced by the outdoor temperature. It is also interesting to note that the building load never drops below 2000 kW. This is abnormal for a typical office building, and can be related to the lights that burn continuously.

In the graph below the corresponding chiller plantroom load is shown. This includes the power used by the chillers, pumps and cooling towers but not the AHUs. Also note that there is a very small difference between full load at peak times, and minimum loading. This is caused by the constant heat load in the building, but can also indicate incorrect control of the chiller system.



BREAKDOWN OF RETROFIT ENERGY COSTS FOR Telkom TOWERS SOUTH

The following tables display the detailed breakdown of the energy cost of each retrofit.

Enthalpy control for economiser

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 691 086	704 945	2 396 031
MAXIMUM DEMAND	1 043 465	464 408	1 507 873
TOTAL	2 734 551	1 169 353	3 903 904

Evaporative cooler

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 607 131	672 952	2 280 083
MAXIMUM DEMAND	1 026 311	421 308	1 447 619
TOTAL	2 633 442	1 094 260	3 727 702

Fan scheduling, night

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 519 578	671 466	2 191 044
MAXIMUM DEMAND	1 106 893	464 776	1 571 669
TOTAL	2 626 471	1 136 242	3 762 713

Fan scheduling, night and weekends

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 461 024	656 926	2 117 950
MAXIMUM DEMAND	1 109 020	465 288	1 574 308
TOTAL	2 570 044	1 122 214	3 692 258

Light scheduling, night

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 376 466	596 349	1 972 815
MAXIMUM DEMAND	1 095 334	468 119	1 563 453
TOTAL	2 471 800	1 064 468	3 536 268

Light scheduling, night and weekends

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 267 650	553 951	1 821 601
MAXIMUM DEMAND	1 085 742	464 041	1 549 783
TOTAL	2 353 392	1 017 992	3 371 384

Combined retrofits

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 153 034	505 886	1 658 920
MAXIMUM DEMAND	1 032 443	426 554	1 458 997
TOTAL	2 185 477	932 440	3 117 917

EVALUATION OF TIME-OF-USE TARIFF ON THE RETROFITS

In this appendix the simulation program is used to investigate a time-of-use tariff structure. The cost of each retrofit calculated with the time-of-use tariff is compared to the cost of the retrofit calculated with the current tariff.

Currently the building is on a standard tariff where the price of energy remains constant throughout the day. In a time-of-use tariff structure the energy cost differs throughout the day. The current tariff price of the building is 12.01c/kWh, and R51.51 for maximum demand. The active energy cost (c/kWh) of the time-of-use tariff that was investigated is as follows:

- 00:00 – 05:59: 7.21
- 06:00 – 06:59: 9.04
- 07:00 – 09:59: 27.62
- 10:00 – 17:59: 9.04
- 18:00 – 19:59: 27.62
- 20:00 – 21:59: 9.04
- 10:00 – 23:59: 7.21

The maximum demand price for the time-of-use tariff is R53.57 per kW.

Base-year scenario:

The following table displays the base-year simulation costs incorporating the time-of-use tariff and the current tariff.

	Active energy (R)	Maximum Demand (R)	Total
Current	2 407 334	1 548 705	3 956 039
Time-of-use	2 469 242	1 611 018	4 080 260
Difference	2.5%	3.9%	3%

From the table it is evident that the current building, on a time-of-use tariff structure, will have a 3% higher electricity cost than the current tariff structure.

Evaporative cooler:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	2 280 083	1 447 619	3 727 702
Time-of-use	2 342 349	1 505 542	3 847 891
Difference	2.7%	3.8%	3.1%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 469 242	1 611 018	4 080 260
Retrofit	2 341 507	1 505 513	3 847 020
Difference	5.2%	6.5%	5.7%

Enthalpy economiser control:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	2 145 941	1 363 878	3 509 819
Time-of-use	2 203 415	1 418 423	3 621 838
Difference	2.6%	3.8%	3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 4692 42	1 611 018	4 080 260
Retrofit	2 203 415	1 418 423	3 621 838
Difference	10.8%	12%	11.2%

Fan scheduling night:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	2 191 044	1 571 669	3 762 713
Time-of-use	2 249 201	1 634 525	3 883 726
Difference	2.6%	3.8%	3.1%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 469 242	1 611 018	4 080 260
Retrofit	2 249 201	1 634 525	3 883 726
Difference	8.9%	1.5%	4.8%

Fan scheduling night & weekend:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	2 117 950	1 574 308	3 692 258
Time-of-use	2 180 899	1 637 269	3 818 168
Difference	2.9%	3.8%	3.3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 469 242	1 611 018	4 080 260
Retrofit	2 180 899	1 637 269	3 818 168
Difference	11.7%	1.6%	6.4%

Light scheduling night:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	1 972 815	1 563 453	3 536 268
Time-of-use	2 045 640	1 625 979	3 671 619
Difference	3.6%	3.8%	3.7%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 469 242	1 611 018	4 080 260
Retrofit	2 045 640	1 625 979	3 671 619
Difference	17%	1%	10%

Light scheduling night & weekend:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	1 821 601	1 549 783	3 371 384
Time-of-use	1 898 378	1 611 762	3 510 140
Difference	4%	3.8%	4%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 469 242	1 611 018	4 080 260
Retrofit	189 378	1 611 762	3 510 140
Difference	23%	0%	14%

Combined:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	1 659 466	1 459 259	3 118 725
Time-of-use	1 737 079	1 517 619	3 254 698
Difference	4.5%	3.8%	4.2%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 469 242	1 611 018	4 080 260
Retrofit	1 737 079	1 517 619	3 254 698
Difference	29.7%	5.8%	20.2%

CURRENT STATE OF THE SYSTEM

During a building energy audit, it is not unusual to find that the HVAC system does not operate according to specification. This was also the case in TTS. Various operational and maintenance problems were found and these will be discussed in this section.

It must be stressed that the aim of the study was not to find problems with the system, but to make recommendations as to the theoretical savings potential of the building. The faults that were found were mostly on the main energy consumers of the building, which formed the main part of the project. The problems were on the BMS, as well as the equipment. Also included in the table is the potential impact of the problem on the energy consumption of the building. A rating between one and five is given, with five having the largest potential impact on the energy consumption. Zero denotes no impact on the energy.

BMS:	
Problem	**Impact**
15th floor eastern perimeter economiser damper position 0% while the BMS call is 100%. This could also be a result of a defective positional sensor.	This could result in increased energy consumption as no outside air is used for cooling.
27th floor northern perimeter air handler economiser damper position is 0%, while the BMS call is 100%. This could also be a result of a defective positional sensor.	This could result in increased energy consumption as no outside air is used for cooling.
During detailed measurement the 15th floor south perimeter air handler fresh air damper was on approximately 30%. The BMS reading was 100%. It may be possible that the damper position was changed in the time between the BMS and the actual reading.	

Equipment:	
Problem	**Impact**
15th floor west perimeter heating coil is blocked.	This results in very little airflow to the zone. This makes the unit ineffective. This will actually result in less energy being used in the building as very little load is placed on the chiller by this unit. However, in the hotter months this may result in warmer temperatures in the zone. This cannot currently be simulated.
15th floor west perimeter cooling coil is not connected to the damper.	The temperature supplied by this unit is therefore not controllable. This may result in energy wastage or uncomfortable conditions.

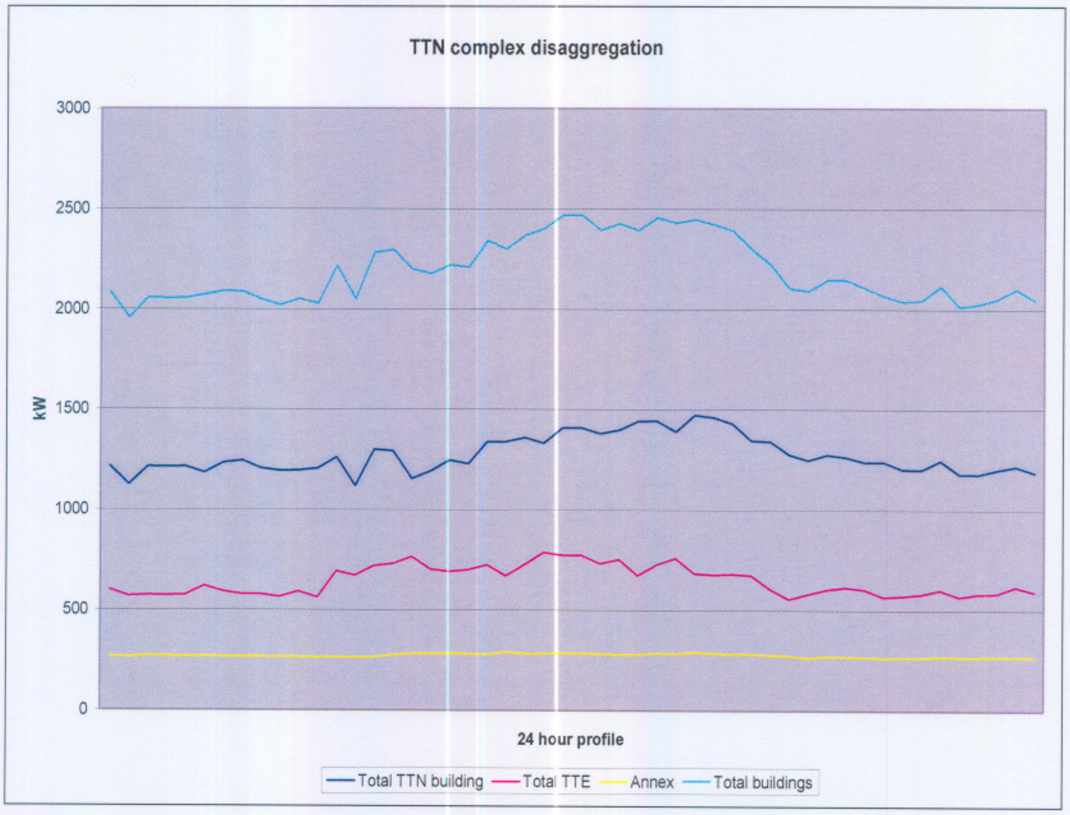
BMS:	
Problem	**Impact**
15th floor east perimeter outside air damper and return-air damper fully open.	This will result in higher energy consumption, as less cold outside air will be supplied to the zone. This cannot be simulated. Under the prevailing conditions at that time the return-air damper should have been closed.
15th floor east perimeter cooling coil was not connected to the damper. This was corrected when the fault was discovered.	The temperature supplied by this unit was therefore not controllable. This could have resulted in energy wastage or uncomfortable conditions.
15th floor north perimeter air handler economiser dampers' may not be working.	This could result in higher energy consumption. If the dampers are operational, the outside air damper should close when the sensor is warm, and open when the sensor cools.
27th floor west perimeter return and fresh air dampers closed. Under the prevailing conditions the fresh air damper should have been open.	This will result in less air supplied to the zone than what should be.
27th floor south internal fresh air and return-air dampers open. The return-air dampers should have been closed.	This will result in higher energy consumption, as less cold outside air will be supplied to the zone. Heating the outside temperature sensor by hand while the outdoor temperature is relatively cold can test this. If the dampers are operational, the outside air damper should close when the sensor is warm, and open when the sensor cools.

General	
Problem	**Impact**
Many of the system controllable parameters were set on manual control. This was done by maintenance personnel to "solve problems on the floor". Examples of this would be some cooling coil valves that were set on 100% open.	Operating the system on manual control could lead to increased system energy consumption, as the control of the BMS is bypassed.
During the time of the study the cooling tower water outlet temperature was set on 22°C.	This also resulted in higher energy consumption. The reason for this was the ongoing maintenance on the chillers and cooling towers, requiring lower water temperatures for the maintenance personnel.

The above-mentioned issues came to light during the study. The aim of the study was not to find operational and maintenance problems, therefore more may exist. Also, some of these problems may have been fixed in the meantime during routine maintenance.

APPENDIX G: ADDITIONAL RESULTS FOR TELKOM TOWERS NORTH

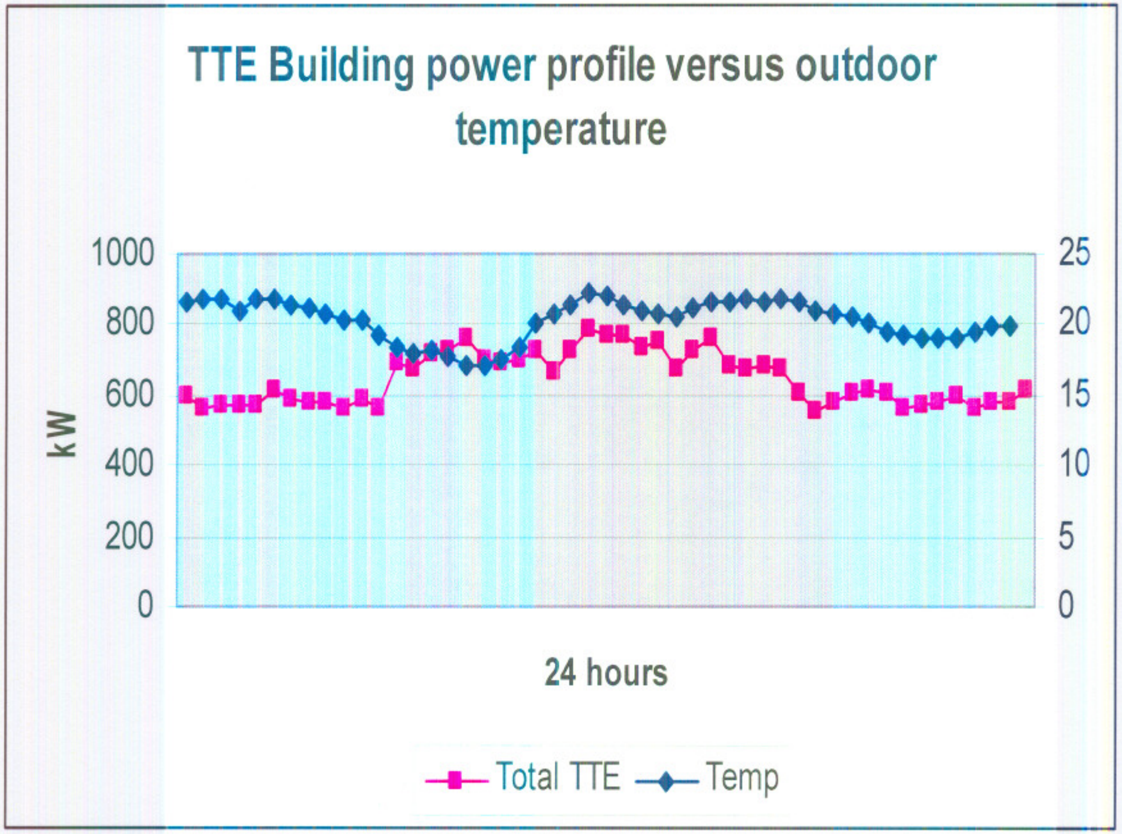
Power profiles

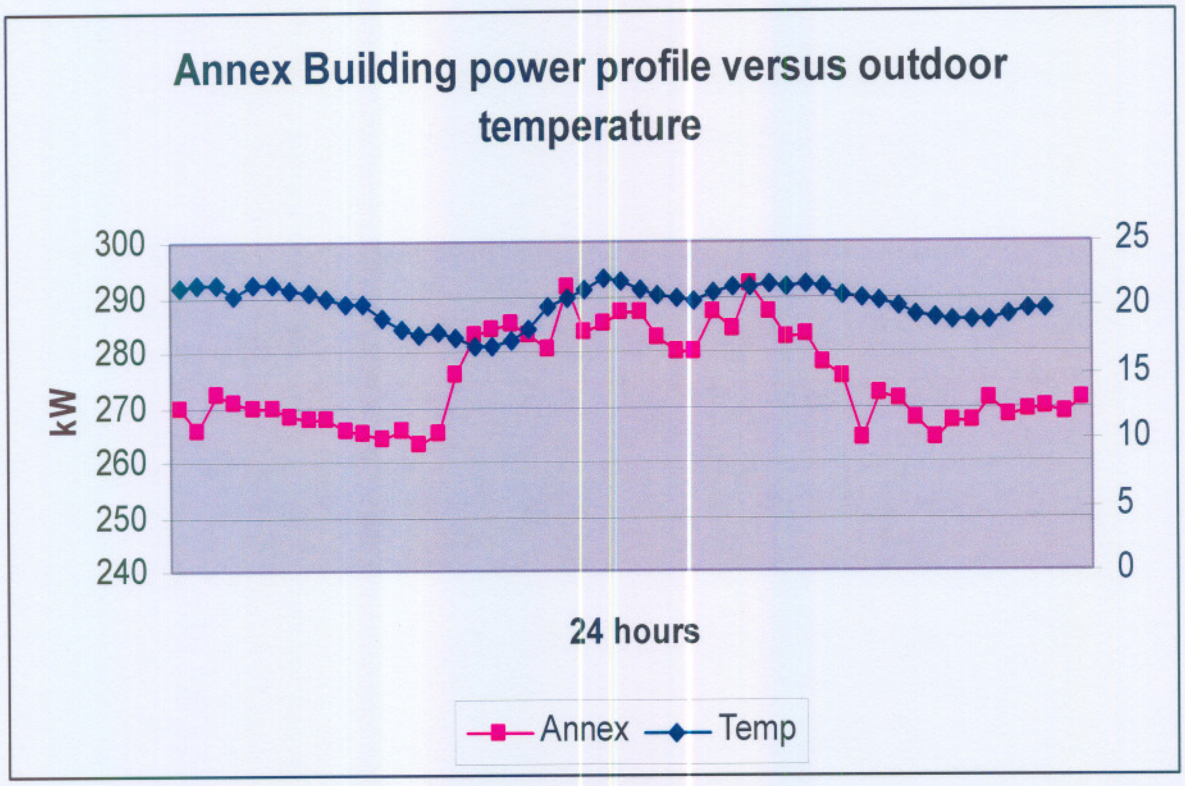


In the figure above the contribution of the different buildings to the total load profile is shown. As can be expected Annex building has a constant load profile due to the 24/7 operations of the call centre. Also note that the majority of cooling equipment (common chilled water-circuit) is located in TTN and that fluctuation due to outside air, would be seen on the TTN power profile.

The power profiles of the individual buildings versus the outdoor temperature is shown below:


Total TTN building
Temp


TTE Building power profile versus outdoor temperature
kW
1000
800
600
400
200
0
25
20
15
10
5
0
24 hours
Total TTE
Temp



BREAKDOWN OF RETROFIT ENERGY COSTS

The following tables display the detailed breakdown of the energy cost of each retrofit.

Enthalpy control for economiser

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 514 530	631 390	2 145 920
MAXIMUM DEMAND	946 980	416 903	1 363 878
TOTAL	2 461 520	1 048 300	3 509 820

Evaporative cooler

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 421 350	602 350	2 023 700
MAXIMUM DEMAND	922 610	372 070	1 294 680
TOTAL	2 343 960	974 420	3 318 380

Fan scheduling, night

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 512 910	600 810	1 955 720
MAXIMUM DEMAND	982 310	420 390	1 402 700
TOTAL	2 337 220	1 021 200	3 358 420

Fan scheduling, night and weekends

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 306 750	588 270	1 895 020
MAXIMUM DEMAND	989 460	419 820	1 409 280
TOTAL	2 296 210	1 008 090	3 304 300

Light scheduling, night

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 199 390	524 100	1 723 490
MAXIMUM DEMAND	976 060	416 870	1 392 930
TOTAL	2 175 450	940 970	3 116 420

Light scheduling, night and weekends

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 096 770	483 660	1 580 430
MAXIMUM DEMAND	967 930	413 060	1 380 990
TOTAL	2 064 700	896 720	2 961 420

Combined retrofits

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	1 000 500	437 600	1 438 110
MAXIMUM DEMAND	932 420	377 370	1 309 780
TOTAL	1 932 920	814 970	2 747 890

EVALULATION OF TIME-OF-USE TARIFF ON THE RETROFITS

In this appendix the simulation program is used to investigate a time-of-use tariff structure. The cost of each retrofit calculated with the time-of-use tariff is compared to the cost of the retrofit calculated with the current tariff.

Currently the building is on a standard tariff where the price of energy remains constant throughout the day. In a time-of-use tariff structure the energy cost differs throughout the day. The current tariff price of the building is 12.01c/kWh, and R51.51 for maximum demand. The active energy cost (c/kWh) of the time-of-use tariff that was investigated is as follows:

- 00:00 – 05:59: 7.21
- 06:00 – 06:59: 9.04
- 07:00 – 09:59: 27.62
- 10:00 – 17:59: 9.04
- 18:00 – 19:59: 27.62
- 20:00 – 21:59: 9.04
- 10:00 – 23:59: 7.21

The maximum demand price for the time-of-use tariff is R53.57 per kW.

Base-year scenario:

The following table displays the base-year simulation costs incorporating the time-of-use tariff and the current tariff.

	Active energy (R)	Maximum Demand (R)	Total
Current	2 143 750	1 379 170	3 522 920
Time-of-use	2 203 010	1 434 330	3 637 340
Difference	3%	4%	3%

From the table it is evident that the current building, on a time-of-use tariff structure, will have a 3% higher electricity cost than the current tariff structure.

Evaporative cooler:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	2 023 700	1 294 680	3 318 380
Time-of-use	2 080 130	1 346 460	3 426 590
Difference	3%	4%	3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 203 010	1 434 330	3 637 340
Retrofit	2 080 130	1 346 460	3 426 590
Difference	5%	6%	6%

Enthalpy economiser control:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	2 145 940	1 363 870	3 509 810
Time-of-use	2 203 420	1 418 420	3 621 840
Difference	3%	4%	3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 203 010	1 434 330	3 637 340
Retrofit	2 203 420	1 418 420	3 621 840
Difference	0%	1%	0%

Fan scheduling night:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	1 955 720	1 402 700	3 358 420
Time-of-use	2 004 740	1 458 800	3 463 540
Difference	0%	4%	3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 203 010	1 434 330	3 637 340
Retrofit	2 004 740	1 458 800	3 463 540
Difference	9%	2%	5%

Fan scheduling night & weekend:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	1 895 020	1 409 280	3 304 300
Time-of-use	1 948 470	1 465 640	3 414 110
Difference	3%	4%	3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 203 010	1 434 330	3 637 340
Retrofit	1 948 470	1 465 640	3 414 110
Difference	11%	2%	6%

Light scheduling night:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	1 723 490	1 392 920	3 116 410

Time-of-use	1 786 640	1 448 630	3 235 270
Difference	4%	4%	4%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 203 010	1 434 330	3 637 340
Retrofit	1 786 640	1 448 630	3 235 270
Difference	19%	1%	11%

Light scheduling night & weekend:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	1 580 430	1 380 990	2 961 420
Time-of-use	1 647 870	1 436 220	3 084 090
Difference	4%	4%	4%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 203 010	1 434 330	3 637 340
Retrofit	1 647 870	1 436 220	3 084 090
Difference	25%	0%	15%

Combined:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	1 438 100	1 309 780	2 747 880
Time-of-use	1 510 030	1 362 170	2 872 200
Difference	5%	4%	4%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	2 203 010	1 434 330	3 637 340
Retrofit	1 510 030	1 362 170	2 872 200
Difference	31%	5%	21%

CURRENT STATE OF THE SYSTEM

During a building energy audit, it is not unusual to find that the HVAC system does not operate according to specification. This was also the case in TTN. Various operational and maintenance problems were found and these will be discussed in this section.

It must be stressed that the aim of the study was not to find problems with the system, but to make recommendations as to the theoretical savings potential of the building. The faults that were found were mostly on the main energy consumers of the building, which formed the main part of the project. The problems were on the BMS, as well as the equipment. Also included in the table is the potential impact of the problem on the energy consumption of the building. A rating between one and five is given, with five having the largest potential impact on the energy consumption.

The following table displays the problems areas encountered for TTN.

Equipment	Impact or comments
AHU 1	
Spray Pump 1 & 2 switched off.	Leaks on seals. The system can therefore not be controlled by the BMS as it should. Also, it can not be ascertained if the BMS will operate as it should.
AHU 2	
Spray Pump 1 & 2 switched off.	Ball valve out of order. The system can therefore not be controlled by the BMS, as it should. Also, it can not be ascertained if the BMS will operate as it should.
Relief-air Fan Nos 1 & 2 not running.	According to the design specifications the return-air fan, or the relief-air fan, should be running. If both are off, there is no control of the fresh air intake into the building. It can also cause static pressure issues in the building.
AHU 3	
Spray Pump 1 & 2 switched off.	Broken flanges. The system can therefore not be controlled by the BMS, as it should. Also, it can not be ascertained if the BMS will operate as it should. The coil associated with these pumps can also not be calibrated by measurements.
Staircase Pressurisation Fan switched off.	Switches back on.
Relief-air Fan Nos 1 & 2 not running.	According to the design specifications the return-air fan, or the relief-air fan, should be running. If both are off, there is no control of the fresh air intake into the building. It can also cause static pressure issues in the building.
AHU 4	
Return-air Fan No 1 switched off.	Faulty. Therefore, there is no control of fresh air intake into the building, which may result in energy wastage.
Spray Pump No 1 switched to Hand on.	Help with cooling. When the system is switched to manual operation, it is not possible to simulate the automatic working of the system.
Spray Pump No 2 switched to Hand on.	Help with cooling. According to the design specification only one pump should be on at a time for temperature purposes. The other pump is used for humidification.
Pre-Cool Pump No 1 switched to Hand on.	The system can therefore not be controlled by the BMS.

Roof Chiller for Executive floors	
Chiller running with Run and Trip lights on.	One complete run other one tripped.
Chilled water pump switched to Hand on.	Not getting signal from the BMS system.
Condenser Pump switched to Hand on.	
Cooling Tower Fan switched to Hand on.	

The following table displays the problems areas encountered for TTE.

Equipment	Impact or comments
16th Floor plant Rooms	
Sultzer Cooling Tower No 5 : no water.	Leak on pump. This could have an effect on the operation of the cooling coil at maximum capacity.
Spray Pump No 6 manually switched on.	Help with cooling. When the system is switched to manual operation, it is not possible to simulate the automatic working of the system.
Spray Pump No 7 manually switched on.	Help with cooling. According to the design specification only one pump should be on at a time for temperature purposes. The other pump is used for humidification.
Spray Pump No 8 manually switched on.	Help with cooling. According to the design specification only one pump should be on at a time for temperature purposes. The other pump is used for humidification.
Pre-cool Pump No 5 switched off manually.	Pump leaking.
Pre-cool Pump No 8 switched off manually.	Leak at coil at AHU. The cooling coil can therefore not be calibrated by measurements for the simulation.
Pre-cool Cooling Tower No 8 switched off manually.	Leak at coil at AHU. The cooling coil can therefore not be calibrated by measurements for the simulation.
AHU no 1: Plenum door propped open bypassing filters.	Filter dirty. This will affect the operation of the building. No fresh air is drawn into the AHU, which could result in energy wastage and uncomfortable conditions. It is also very difficult to simulate, as any airflow measurements will not be relevant to typical operating conditions.
AHU no 2: Plenum door propped open bypassing filters.	Filter dirty. This will effect the operation of the building. No fresh air is drawn into the AHU, which could result in energy wastage and uncomfortable conditions. It is also very difficult to simulate, as any airflow measurements will not be relevant to typical operating conditions.
Return-air Fan No 1 switched off (no amps).	Broken fan blade. This will also effect the operation of the building.
Spray pumps 1 & 2 switched on manually (± 3 amps).	Need to investigate.
Spray pumps 3 & 4 switched off manually (no amps).	Ball valve faulty.

The following table displays the problems areas encountered for ANNEX.

Relief Fan No 1 switched to auto: not running.	When on ±20 Hz no Amps on Amp meter.
Relief Fan No 1 Speed Controller shows fan is running.	Only when speed up.
Relief Fan No 2 switched to off: 23amps.	Fan out for repairs. Amp meter not showing the correct reading. Also, the proper working of the fan cannot be ascertained.
Relief Fan No 2 Speed Controller shows fan is stopped.	Fan out for repairs.
Pre-cool Pumps 1 - 4 switched off: no amps.	Supply line to cooling.
Pre-cool Cooling Tower switched off: no amps.	Towers need to be replaced – rusted.
Pre-cool Cooling Towers empty: out of service.	
Spray pump No 2 switched off.	

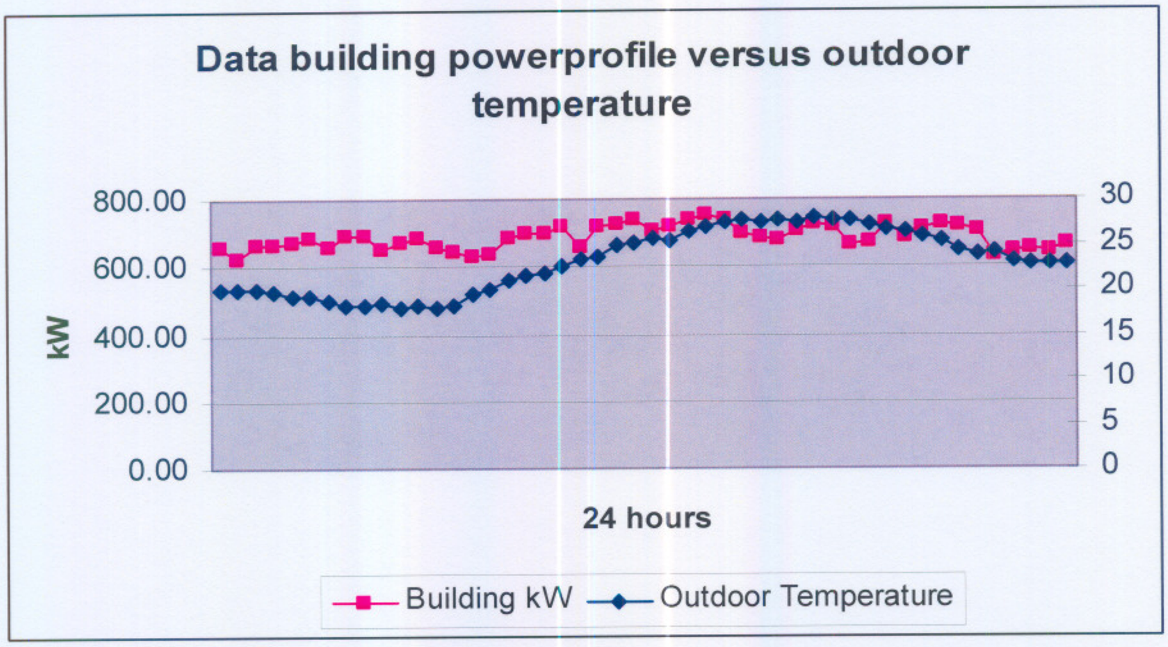
The following table displays the problems areas encountered for the chilled water plant.

2 x Grencos' not running.	Lost vacuum.
1 x York Chiller not running.	Valve plates to be changed.
1 x compressor on second York chiller not running.	Valve plates to be charged.
1 x RC chiller not running.	Condenser shell and tube to be brushed.

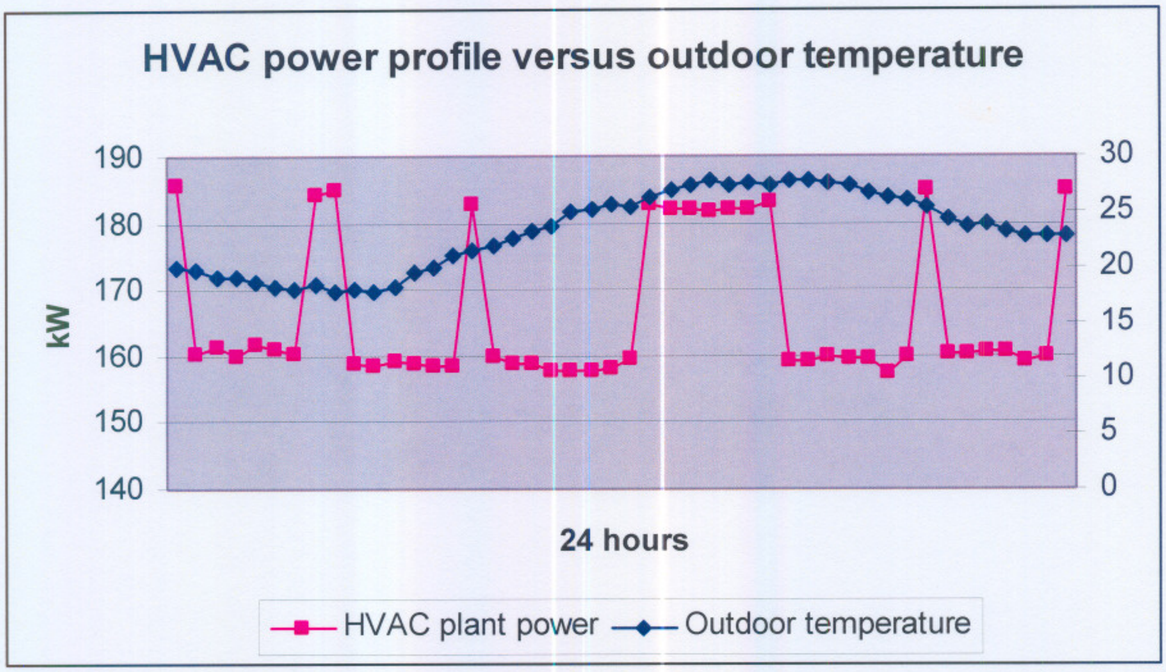
APPENDIX H: ADDITIONAL RESULTS FOR DATA BUILDING

Power profiles

The building versus outdoor temperature profile is show below:



The HVAC power profile (shown below) illustrates the changing duty cycle in the control of the HVAC system in varying outdoor temperatures.



BREAKDOWN OF RETROFIT ENERGY COSTS

The following tables display the detailed breakdown of the energy cost of each retrofit.

Return-air economiser cycle

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	456 986	207 216	664 202
MAXIMUM DEMAND	283 877	141 952	425 829
TOTAL	740 863	349 168	1 090 031

Evaporative cooler

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	458 905	222 047	680 952
MAXIMUM DEMAND	291 931	142 786	434 717
TOTAL	750 836	364 833	1 115 669

Set point setback

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	436 814	206 974	643 788
MAXIMUM DEMAND	290 748	142 170	432 918
TOTAL	727 562	394 144	1 076 706

Fan scheduling

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	447 421	209 619	657 040
MAXIMUM DEMAND	291 335	142 151	433 486
TOTAL	738 756	351 770	1 090 526

Chillers and fan scheduling

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	420 349	194 505	614 854
MAXIMUM DEMAND	285 584	141 552	427 136
TOTAL	705 933	336 057	1 041 990

Economiser, evaporative cooler, light scheduling, set point setback

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	397 920	182 743	580 663
MAXIMUM DEMAND	286 321	141 985	428 306
TOTAL	684 241	324 728	1 008 969

Economiser, evaporative cooler, light scheduling, fan and chiller scheduling

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	385 584	179 517	565 101
MAXIMUM DEMAND	286 636	141 985	428 348
TOTAL	671 947	321 502	993 449

First floor

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	467 721	209 883	677 604
MAXIMUM DEMAND	288 138	143 818	431 956
TOTAL	755 859	353 701	1 109 560

Ground floor

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	422 927	199 840	622 767
MAXIMUM DEMAND	261 117	132 771	393 888
TOTAL	684 044	332 611	1 016 655

Combined retrofits with set point setback

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	297 086	138 803	435 889
MAXIMUM DEMAND	222 984	117 769	340 753
TOTAL	520 070	256 572	776 642

Combined retrofits, with fan and chiller scheduling

	SUMMER (R)	WINTER (R)	TOTAL (R)
ACTIVE	287 113	131 084	418 197
MAXIMUM DEMAND	224 398	117 769	342 167
TOTAL	511 511	248 853	760 364

EVALUATION OF TIME-OF-USE TARIFF ON THE RETROFITS

In this appendix the simulation program is used to investigate a time-of-use tariff structure. The cost of the retrofit calculated with the time-of-use tariff is compared to the cost of the retrofit calculated with the current tariff.

Currently the building is on a standard tariff where the price of energy remains constant throughout the day. In a time-of-use tariff structure the energy cost differs throughout the day. The current tariff price of the building is 12.01c/kWh, and R51.51 for maximum demand. The active energy cost (c/kWh) of the time-of-use tariff that was investigated is as follows:

- 00:00 – 05:59: 7.21
- 06:00 – 06:59: 9.04
- 07:00 – 09:59: 27.62
- 10:00 – 17:59: 9.04
- 18:00 – 19:59: 27.62
- 20:00 – 21:59: 9.04
- 10:00 – 23:59: 7.21

The maximum demand price for the time-of-use tariff is R53.57 per kW.

The retrofits investigated with the TOU tariff include:

- Combined office retrofit with set point setback, as well as fan and chillers' scheduling,
- First floor, ground floor,
- Total combined retrofits, also including set point setback and scheduling.

Base-year scenario:

The following table displays the base-year simulation costs incorporating the time-of-use tariff and the current tariff.

	Active energy (R)	Maximum Demand (R)	Total
Current	669 157	422 216	1 091 373
Time-of-use	685 389	439 061	1 124 450
Difference	2%	4%	3%

From the table it is evident that the current building, on a time-of-use tariff structure, will have a 3% higher electricity cost than the current tariff structure.

Economiser, evaporative cooler, light scheduling, set point setback for office:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	580 663	428 306	1 008 969
Time-of-use	604 724	445 380	1 050 104
Difference	3%	4%	4%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	685 769	439 091	1 124 860
Retrofit	664 724	445 380	1 050 104
Difference	8%	1%	5%

Economiser, evaporative cooler, light scheduling, fan and chillers' scheduling for office:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	565 101	428 348	993 449
Time-of-use	586 764	445 478	1 032 242
Difference	3%	4%	3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	685 769	439 091	1 124 860
Retrofit	586 764	445 478	1 032 242
Difference	11%	1%	7%

First floor:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	677 604	431 956	1 109 560
Time-of-use	698 536	449 172	1 147 708
Difference	2%	4%	3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	685 769	439 091	1 124 860
Retrofit	698 536	449 172	1 147 708
Difference	5%	7%	6%

Ground floor:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	622 767	393 888	1 016 655
Time-of-use	622 303	393 875	1 016 178
Difference	2%	4%	3%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	685 769	439 091	1 124 860
Retrofit	622 767	393 888	1 016 655
Difference	5%	8%	6%

Economiser, evaporative cooler, light scheduling, set point setback, first floor, ground floor:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	435 889	340 753	776 642
Time-of-use	457 570	354 381	811 951
Difference	4%	4%	4%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	685 769	439 091	1 124 860
Retrofit	457 570	354 381	811 951
Difference	35%	25%	36%

Economiser, evaporative cooler, light scheduling, fan and chiller schedule, first floor, ground floor:

Time-of-use tariff versus current tariff:

	Active energy (R)	Maximum Demand (R)	Total
Current	694 195	502 465	1 196 660
Time-of-use	670 055	483 143	1 153 198
Difference	4%	4%	4%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	976 755	623 821	1 600 576
Retrofit	670 055	483 143	1 153 198
Difference	45%	29%	38%

Retrofit cost versus base-year cost for time-of-use tariff:

	Active energy (R)	Maximum Demand (R)	Total
Base-year	976 755	623 821	1 600 576
Retrofit	670 055	483 143	1 153 198
Difference	45%	29%	38%