The Design and Implementation of Information Systems for ESCO Energy Savings Software

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Abstract

Electricity cost of buildings is a major expense for building owners. Improvements in the efficient utilisation of energy is therefore of concern to this economic sector. Unfortunately, existing energy audit tools are costly and time-consuming which militates against their common usage.

The aim of this study was to create software that would reduce the time taken to perform a building audit. In that way it would encourage more building owners to carry out such audits. This would enable them to save electrical energy (and therefore costs) through retrofit projects in existing buildings. As a result, both the economy as well as the environment will benefit.

This objective was reached by means of the design, implementation and integration of three software modules for a building-software package called *Building ESCO Toolbox* (BETB). The modules were integrated into a new building energy audit protocol that reduces the average time of a building audit from 45 days to 17 days. The work in this study was thoroughly verified by means of actual implementation at the CSIR conference centre, the Carlton building in the Johannesburg CBD and the TSI research facility of ESKOM.

The first BETB software module is called the *Palm Data Logger* and captures the required building audit data. This reduces the data-gathering time from 10 to 4 days. The second module, the *Financial Analysis Tool* reduces the creation of financial analysis information from 2 days to 1 day. The third software module is called the *Report Generation Tool* and it compiles a final auditor report from all the BETB study data in one day as compared to the traditional three.

A secondary aim of this study was to design a suitable solution for an improved mine pumping maintenance-information-systems. This product was called the *On-Site Information Management System* (OSIMS) and it was approved of by relevant personnel at the Anglo Gold Kopanang mine. OSIMS acts as support for the mine software, which is called *Remote Energy Management System* (REMS). It optimises mine water pump schedules in a way that avoids using peak time electricity. OSIMS consists of an electronic data-logging device that successfully solves four key problem areas of the current system at Kopanang.

Firstly, OSIMS reduces the loss of maintenance data. Secondly, the OSIMS system increases the probability that maintenance audits are conducted in the correct fashion. Thirdly, it reduces time spent on documentation and, fourthly, it leads to greater data integrity for the Computer Maintenance Management Information System at Kopanang.

In both cases, all the software developments were carried out in a logical engineering fashion. Each software module was first defined and then planned. The required equipment was selected and acquired and all the technical knowledge was integrated. Program development was then conducted. All the needed peripheral program capability was also developed before the verification and validation was done. The modules were then integrated into the overall product.

Samevatting

Die koste van elektrisiteit vir geboue vorm 'n groot deel van die uitgawes wat geboueienaars aangaan. Om hierdie rede is 'n verbetering in die effektiewe benutting van energie belangrik vir hierdie ekonomiese sektor. Tans is elektriese energie-oudit-toerusting baie duur en tydrowend om te gebruik, wat die algemene gebruik daarvan beperk.

Die doel van hierdie studie was om sagteware te skep wat die tyd vir 'n gebou-oudit verminder. Dit sal geboueienaars ook aanspoor om sulke ouditprojekte uit te voer. Hierdie studie sal geboueienaars instaat stel om elektriese energie (en derhalwe koste) te bespaar deur toerusting optimaal te benut. Beide die ekonomie en die omgewing word bevoordeel.

Hierdie doelwit is bereik deur die ontwerp, implementering en integrasie van drie gebou-sagteware modules vir 'n sagteware pakket genaamd *Building ESCO Toolbox* (BETB). Die modules is geïntegreer in 'n nuwe gebou-energie-oudit-protokol wat oudit tyd van gemiddeld 45 dae na 17 dae verminder. Die werk van hierdie studie is deeglik bevestig deur implementering by die WNNR konferensiesentrum, die Carlton gebou en die TSI navorsingsfasiliteit van ESKOM.

Die eerste BETB sagteware module is die *Palm Data Logger* wat nodige geboudata insamel. Data insamelingstyd word van 10 dae na 4 dae verminder. Tweedens is die *Finansiële Analise Module* se doel om finansiële inligting te genereer. Hierdie prosestyd is van 2 dae na 1 dag verminder. Die derde sagteware module word die *Verslag-genererings Module* genoem. Dit stel 'n finale ouditeursverslag van al die BETB studiedata saam in een dag, vergeleke met die tradisionele drie dae.

'n Sekondêre doel van hierdie studie was om 'n toepaslike oplossing te ontwikkel vir die verbetering van die myn-pompstelsel se instandhouding-informasiestelsel. Hierdie produk staan bekend as die *On-Site Information Management System* (OSIMS) en is goedgekeur deur relevante personeel by Anglo Gold se Kopanang myn. OSIMS tree op as ondersteuning vir mynsagteware genaamd die *Remote Energy Management System* (REMS). REMS optimeer myn waterpompskedules sodat 'n minimum piek-elektrisiteitsverbruik plaasvind. OSIMS bestaan uit 'n elektroniese data-insamelingsapparaat wat vier geïdentifiseerde probleme van die Kopanang sisteem suksesvol oplos.

Eerstens verminder OSIMS die verlies aan instandhoudings data. Tweedens verhoog dit die waarskynlikheid dat 'n instandhoudingsoudit korrek uitgevoer word. Derdens verminder dit die tyd wat aan dokumentasie gespandeer word. Dit verbeter ook die data-integriteit vir die Rekenaar Instandhoudings Bestuurs Stelsel van Kopanang.

In beide gevalle is die sagteware-ontwikkeling volgens logiese ingenieurspraktyk uitgevoer. Elke sagteware module is eers gedefinieer en dan beplan. Die nodige tegnologie is gevind en aangekoop, waarna die tegniese kennis geïntegreer is. Programontwikkeling het daarna plaasgevind. Al die nodige verifikasie en bevestiging is uitgevoer voordat die modules in die oorhoofse produk geïntegreer is.

Acknowledgements

I express my gratitude to Prof EH Mathews for his guidance, support and motivation throughout this research project. He contributed both professionally and personally to my development.

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List of abbreviations

AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
BAC	Bulk Air Cooler
BETB	Building ESCO Toolbox
CMMIS	Computer Maintenance Management Information System
CSIR	Council for Scientific and Industrial Research
DSM	Demand Side Management
ESCO	Energy Service Company
ESKOM	Electricity Supply Commission
HVAC	Heating Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IEA	International Energy Agency
OECD	Organisation for Economic Co-operation and Development
OSIMS	On Site Information Management System
PC	Personal Computer
PDA	Personal Digital Assistant
PDB	Palm Database
PLC	Programmable Logic Control
REMS	Remote Energy Management System
RH	Relative Humidity
RTP	Real Time Pricing
SCADA	Supervisory Control and Data Acquisition
SENKOM	Centre for Research and Commercialisation
TSI	Technology Services International

USB	Universal Serial Bus
VSD	Variable Speed Drive
XML	Extensible Markup Language

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Chapter 1 Introduction

Sustainable development aims to meet the energy needs of the present without compromising the ability of the future generations to meet their own needs [1].

1. Introduction

To use energy as productively as possible, is good for the environment as well as the economy. Energy-efficiency means obtaining more work, light, heat, and mobility with less energy. Energy-efficient methods are the surest way of increasing the sustainability of an energy system. Energy efficiency practice accentuates the positive attributes of energy usage by the service it provides. The negative aspects (pollution and financial costs) associated with producing and delivering energy, are reduced with the efficient use of energy.

In Section 1.1 it is explained why research in the energy efficiency field is needed. Current building energy software and mine energy software are discussed in Section 1.2 and Section 1.3 respectively. The need for integrated software tools is explained in Section 1.4. Contributions of this study, and an overview, are outlined in Section 1.5 and Section 1.6.

1.1. Preamble

Real savings potential exists for buildings. Residential and commercial buildings account for about one-third of total energy use in IEA* countries [1]. According to other international studies, building operational costs account for 37 % of the total world primary energy consumption [2]. In the United States, it is estimated that 36 % of the country's energy-supply is consumed in buildings [3].

An analysis of the building sector in the United Kingdom indicated that about 65 % of the energy expenditure was in the housing sector. Commercial and public buildings consumed another 29 % and industrial buildings used only 6 % of the energy expenditure in this sector [4].

In South Africa about 20 % of the total municipal electrical energy consumption is used in commercial buildings [5]. Although the energy use of the housing and industrial sector is the largest, the potential for energy savings is probably the greatest in existing commercial buildings [4]. The total electrical energy usage of South African buildings is depicted in Figure 1 [5].

* The International Energy Agency (IEA) is a body, established within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. One of its aims is to improve the world's energy supply and demand structure by increasing the efficiency of energy use. There are twenty-six member countries.

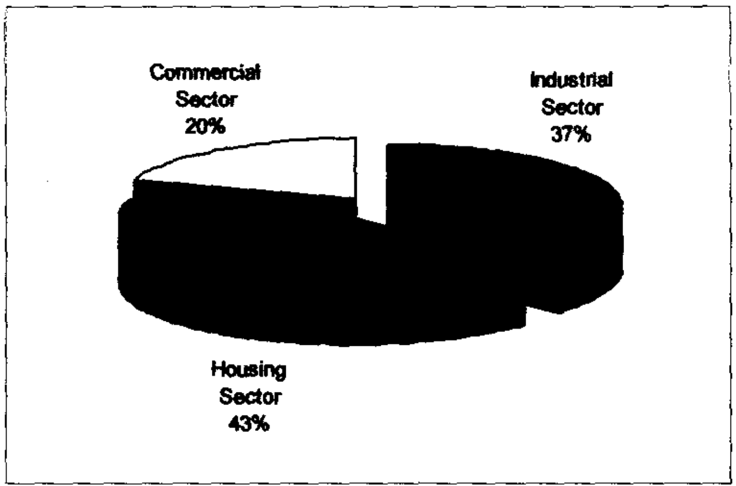


Figure 1 The total electricity use in South African buildings.

Sixty five percent of the energy used in the South African commercial sector is used for air-conditioning purposes. Rousseau and Mathews concluded that more than 10 % of all energy consumed in the world is expended by air conditioning systems in buildings [7].

Forecasts show that the energy consumption of air-conditioning systems will show the highest percentage growth ever for the fifteen-year period ending in the year 2010. This is primarily due to the increase in commercial floor space, and the need for air-conditioning [6].

Energy audits have shown that by retrofitting* existing commercial buildings, energy use for space heating-and-cooling could be reduced up to 35 % [8]. Estimates of the UK Department of Energy also suggest that better design of new buildings could result in a 50 % reduction in energy consumption, and that retrofitting in existing buildings could yield energy reductions of up to 25 % [3].

A realistic savings figure could be set at 30%. This figure could be achieved by improved design, better management-practices and by implementation of retrofit projects in existing commercial buildings [4], [9]. It is evident that an efficiency increase in existing buildings would have a significant impact on worldwide energy savings.

* The act of substituting new and modernized parts for older equipment.

A cost-effective way to improve the energy efficiency of a heating ventilation and air-conditioning (HVAC) system (without compromising indoor comfort), is by using appropriate control strategies. Significant savings could be realised in this way [14], [15]. When the control strategy of a system are changed, however, it is often very difficult to predict what the effect of the resulting changes in the system energy consumption and in-door comfort levels would be. To obtain useful predictions, a dynamic simulation tool is needed.

The ultimate aim of accurate simulation of these complex HVAC systems is to reduce the monthly energy bill, without any compromises.

A real savings potential exists for mines too. The total metal and mineral exports of South Africa amounted to R 76.3 billion in 2000. Of this total, R25.1 billion (32.9 %) was accounted for by gold, and R24.6 billion (32.2 %) by the platinum group of metals [18].

Large and expensive equipment is needed to supply ventilation and cooling for the deep mines of South Africa. It is not only the capital cost of this machinery that is very high, but also the electrical energy usage. The mining and industrial sector consumes about 40 % of the total ESKOM electricity production [4]. About 20 % of the total ESKOM-electricity-production is used by mines. This amounts to approximately R 3 billion of electricity per year, just for gold mines [4].

To be able to effectively achieve feasible gains in this industry an improved management system has to be developed. Because electricity constitutes a substantial part of the expenses incurred by an underground mine, managing this part will achieve the desired goals. As the ventilation, cooling and pumping systems contribute in the order of 25% of the electricity used on an underground mine it can form the basis of a management system and business solution [42].

The cooling principle that is currently used in mines results in a work environment that is cooled to below the design temperatures. This is done by means of cold water that is sent down to bulk air coolers (BAC) or closed circuit cooling units [19].

South African electricity costs have increased dramatically in the past few years. A small number of companies have implemented demand side management (DSM)* projects, although

* Demand side management is the planning and implementation of activities that influence the time pattern of, and amount of electricity used, while still maintaining customer satisfaction. Electricity usage can, for example, be moved to non-peak consumption times. DSM also tries to reduce the total electricity load.

many companies realise the serious need for the implementation of DSM projects. Only recently have the South African deep mines also started to implement DSM projects [19], [11], [20].

The pumping costs associated with large cooling installations are huge. Great potential to reduce these costs exists in optimised scheduled pumping [19], [20].

Energy savings in buildings and mines can lead to many advantages. It is important that implementing energy savings strategies for HVAC systems does not compromise the human comfort in buildings and mines. Satisfactory comfort-levels have a positive influence on productivity in the working environment. Goods can be produced better, faster and more economically. Many modern products could not be produced at all, were it not for the control of temperature, humidity and air quality [10].

Comfort is the state in which humans express satisfaction with their working environment. Factors that determine comfort are: indoor air temperature, relative humidity, air movement, fresh air supply, lighting intensity levels, and indoor air quality. Typical comfort-specifications for buildings are listed in Table 1 [21].

Comfort attribute	Attribute description	Acceptable comfort band
Indoor air temerature	Dry-bulb temperature is the single most important comfort index. It is important where relative humidity falls between allowable levels.	Summer maximum: 24.4 °C Winter minimum: 21.7 °C
Relative humidity	Relative humidty (RH) indicates the percentage moisture in the air. It is the most overlooked factor in HVAC retrofit studies.	RH maximum: 60 % RH minimum: 40 %
Air movement	The human thermal comfort depends a major part on the rate of evaporative heat loss from a person's body.	Maximum flow rate: 5 l/s/m² Minimum flow rate: 8 l/s/m²
Fresh air supply	Fresh air flush contaminated air from buildings. In densly occupied areas greater fresh air supply are needed. The comfort band is for general office buildings.	Non-smoking areas: 10 l/s/person Smoking areas: 17.5 l/s/person
Lighting intensity levels	Lighting intensity and quality is described by the illunination level (lux). The comfort band is also for general office work	Maximum intensity: 500 lux Minimum intensity: 300 lux
Indoor air quality	Carbon dioxide, carbon monoxide, nitrogen dioxide and sulfur dioxide levels is a measurement of air quality.	CO_2 recommended 600 parts per million CO less than 2 parts per million NO_2 average 0.05 parts per million SO_2 average 0.02 parts per million

Table 1 The comfortable environmental requirements for the human body.

Webber-Youngman states that deep level mining in South Africa is dependent on the development and the implementation of new and innovative technologies to ensure that the exploitation of increasingly deeper ore reserves remains economic. Air supply and cooling systems are responsible for high electricity consumption. Running costs will also become increasingly important in South Africa [19].

The main interest groups that will benefit the most using energy efficiently are ESKOM (it can postpone the construction of a new power station), the building and mine owners and the environment. When electricity consumption in peak times of the day is reduced, it will help to postpone the construction of a new power station in South Africa. The potential financial benefit of this for ESKOM is great since the cost of a power station is typically R 16 billion [7]. Building owners benefit because electricity expenses are reduced. Being efficient in the use of all resources makes an important contribution to both environmental and economic sustainability.

Energy Service Companies (ESCO'S) enable energy savings. ESCO companies consist of experts who specialise in the implementation of energy efficiency measures. Extensive developments have taken place in some parts of the world in the application of energy efficiency activities to large buildings.

In the United States, because of the support of their Department of Energy, the ESCO approach was developed [16]. These companies typically supply the skills and financing for system improvements, and accept all the risks in achieving these savings. A part of the savings that are achieved, are paid to the ESCO as reward for their continuous inputs and risk taking. From a business perspective, it is to the advantage of both the ESCO and the building- or mine-owner, to achieve the greatest possible savings.

1.2. Building energy software

There are many existing software programs for building simulation. Some of the most useful energy analysis and system simulation software available, are mentioned in Section 1.2.1. Their major shortcomings are briefly described in Section 1.2.2.

1.2.1. Currently available software and its attributes

According to Arndt there are two main types energy savings software available. The energy-analysis-type has the primary function of calculating the system energy consumption. These tools are usually based on load calculation methods. Probably the most popular and well-known energy analysis tool is VisualDOE. Arndt states that the most-user-friendly product is probably TAS [4], [22].

The second type of software is system-simulation-tools. These try to predict the dynamic thermo-electric responses of the HVAC system and building. They usually take into account the indoor air conditions, system operation points and energy usage. These tools are many times more expert-user oriented. Some system simulation tools include: APACHE [4], QUICKcontrol [23], HVACSIM+ [4] and TRNSYS [4].

1.2.2. General shortcomings of available software

Available tools are used mostly for research purposes and are not intended for practical, routine usage. Therefore they do not promote a process of efficient savings audits. In practice the need is to save time, and be much more user friendly [4].

The available software, as researched by Arndt, does not satisfy the most important technical requirement identified for control simulation, which is the complete integration of the building, HVAC system and its control [4], [11].

A separate load calculation model, based on the response factor method, is used to determine the loads that are used in the building model of HVACSIM+. Problems of varying indoor temperature will be experienced with models of the HVACSIM+ program. Load modelling is excluded from its system simulations [4].

QUICKcontrol and TRNSYS are dynamic and fully integrated products, which satisfy important requirements identified by Arndt. They are also component-based for the configuration of any building and system type. But the QUICKcontrol and TRNSYS simulation tools are very difficult and time consuming to use. A typical building control retrofit study, from audit to report, takes a minimum of 45 days to complete [11].

Furthermore, stable solutions are difficult to obtain by the inexperienced user when solving complex systems. Very few companies have the resources and skills to achieve significant savings [4].

1.3. Mine energy software

There are also many existing energy software programs for mines. Research done by Webber-Youngman provides comprehensive information of the current available software for mining ventilation, cooling and pumping systems. Their major shortcomings are also described briefly [19].

1.3.1. Currently available software and some of its shortcomings

There are many companies that claim the ability to manage and optimise the electricity cost of ventilation, cooling and pumping systems in mines. Many simply provide a system that measures, balances and reports the energy consumption and cost.

These systems typically reconcile the readings from the various electricity meters of the installation with the reading of the utility that supplies the electricity. Sometimes they only allocate electricity costs to sub-sections of an installation or only identify billing problems. Some might identify overall trends and warn users of peak prices. Others can also select the optimum electricity tariff among those offered by utility companies [19].

A good example of a company that provides a system for automated electricity metering and reporting, is IST Otokon (Pty) Ltd in South Africa. The IST Otokon system does remote electricity metering via a data collection network. The data is mainly used for electricity accounting. A user can access the data with their proprietary ecWin™ 5 software.

A second approach to energy management can be described as a real-time, low-level control approach. With this approach a controller apparatus is used to control individual components in such a way that the energy consumption is optimised. Cascia[#] et al. patented a digital controller that implements a control strategy for a cooling and heating plant. The control strategy provides for the calculation of near-optimal global set points for all the main components in real-time. The controller optimises the instantaneous power consumption of an installation, while ensuring that the heating or cooling load is satisfied. However this system is unable to optimise the electricity cost of a ventilation cooling and pumping system. It also does not take thermal storage into account [19].

The third approach to mine energy management involves the measurement, reporting and optimising of the total electricity cost of an installation. The invention disclosed by Irvin et al.[$] monitors and controls variable speed pumps as well as constant speed pumps. Real-time operating cost parameters is calculated. Based on these parameters, the control system suggests the optimum combination of pumps and the optimum speeds of the pumps to a human operator.

[#] From Webber-Youngman: US Patent5963458, 10/1999, Cascia et al.

[$] From Webber-Youngman: US Patent 6178393, 1/2001, Irvin et al.

The system does not use short-term future price and fluid demand information to optimise electricity costs for a certain future time-horizon; instead, it only uses current data.

1.4. The need for new integrated software tools

Innovative software should be developed to exploit the untapped potential. It is shown, in Section 1.1, that the biggest potential for energy savings in commercial buildings, lies in optimising the control of HVAC systems. Typical savings of 25 % of the total building energy consumption can be achieved with a payback period of less than a year.

Optimising building 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 R 280 million per year [13].

Most HVAC consultants do not have the skills, nor the tools, to conduct energy studies in large buildings cost effectively. Building owners are usually not willing to pay almost R 100 000 for an analyst team to conduct an audit of which the value is not certain. However, it has been conclusively proven that HVAC control retrofit is by far the best DSM option.

It is also widely known that especially gold mines are under extensive financial pressure because of increasing costs and fluctuating gold prices as determined by global markets. Mining companies have responded with restructuring and the closure of uneconomical shafts.

This has caused extensive retrenchments, labour- and social turmoil. Much is being done to reduce input cost, but very little in the field of electricity savings [42]. The cooling, ventilation and pumping systems account for about 25 % of the electricity costs.

If a national saving of 10 % in the electricity bill of ventilation, cooling and pumping systems of all the mines in South Africa can be achieved, it can amount to R 105 million per year. Taking the changing electricity industry of South Africa into account, this controllable electricity load can lead to a large financial benefit to the mining industry, consulting companies and the South African electricity market. All that is needed is feasible business solutions to explore and develop this market [43].

1.4.1. The design of an integrated building software system

It is clear that a new building audit approach needs to be developed: an approach that requires much less time for an audit and that requires a lower level of manpower.

Currently, projects that realise the potential savings of building retrofits, need to be implemented on a greater commercial scale. The reason is that an experienced and highly trained engineering team takes approximately 45 days to complete a full investigation for a large building [11], [12], [43]. Such a long time is not often commercially viable.

Fully integrated simulations were complex and not easily performed. Models of these software programs often do not converge. 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 building 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 program. This is the requirement for a cost effective product on a commercial scale.

Building ESCO Toolbox (BETB) is the proposed solution to this problem. The BETB product has to be designed so that it provides an easy-to-use and effective toolkit for semi-skilled technicians to be able to conduct a building audit in about two and a half weeks.

The SENKOM team (see Section 1.6) set out to develop a total integrated control, audit and retrofit toolkit, consisting of a unique data logger, simplified simulation tool, integrated financial analysis tool, automatic report generator, and training manuals. It is envisioned that such a package, including measuring equipment, should not cost more than R15,000 per user once it is commercialised.

Aims of this thesis within BETB:

* Develop and implement a data logging method that captures only the needed BETB data. It has to be a paperless system. The data collection times need to reduce from 10 days to half the time.

* Develop and implement a financial analysis system that automatically extracts information from the retrofit software. It also needs to reduce the current two day user time by half.

* Develop and implement a report generating method that integrates the financial- and simulation tools. Report writing needs to be reduced from 3 days to 1 day.

* The above objectives should integrate with a new BETB protocol. By integration of the above technologies it needs to contribute to the overall aim of BETB that reduce the building audit process from 45 days to half the time. Also it is important to note that less skilled users should be empowered to use this affordable product.

1.4.2. The design of integrated mine software system

According to research by Webber-Youngman, the following needs have been identified that are not satisfied by current software technology mentioned in Section 1.3.1.

A control system that schedules ventilation-, cooling- and pumping equipment twenty-four hours in advance is needed. It should optimise the total electricity cost of an installation. The optimisation needs to be based on predicted electrical loads and electricity prices in a 24-hour forward horizon.

The control system should also optimise the ventilation, cooling and pumping schedules remotely from the installation. The optimised schedules are then sent to the mine control systems via a suitable communication network.

Easy incorporation into existing control or monitoring system is essential. System set points should also not be changed, but the inherent capacity (water in the cooling system) in the system should rather be used to shift load.

As it will be shown later, the SENKOM team set out to develop and implement a system that satisfies these needs. The product that does this work is called the Remote Energy Management System (REMS).

For the REMS system to be able to operate without failure, the equipment (e.g. pumps and settlers) that it controls, need to be available without failure. Therefore a new tool that enhances the reliability and efficiency of the maintenance system is needed. For the purpose of this thesis such a tool will be called the "On Site Information Management Systems" (OSIMS).

The aims of this thesis is the research and development of an OSIMS systems:

* Develop an improved maintenance data logging system.

* OSIMS needs to be integrated with REMS in a supportive way.

1.5. The contributions of this study

The major benefits of this study would be realised by the energy consultants who work for ESCO companies. Energy-savings consultants are better enabled with the BETB product. It will be much more viable for them to do energy audits in buildings, because process-time and cost would be significantly reduced.

ESCO consultants that operate in deep mines are provided with improved system reliability for equipment. OSIMS enables the consultant to provide a much more professional DSM service.

1.6. Overview

The Centre for Research and Commercialisation (SENKOM) is a software development house. Its members consist mainly of programmers, mechanical- and electrical engineers. The work of this study was carried out in the SENKOM environment. This study consists mainly of the original work in Sections 2.3, 2.4, 2.5, 3.3, Chapter 4, and some aspects of Sections 2.6 and 3.4.

Other sections need to be included in this work to enlighten the reader of the greater purpose and scope. An assistant role was played with the work of Sections 2.2, 3.2 and some aspects of Section 2.6 and 3.4.

The main themes of this thesis are explained with the following diagram.

In Chapter 1 (Introduction) it was mentioned that by using energy as productively as possible it is good for the environment as well as the economy. It was shown that a true need for new integrated building and mine software exists. The aims of this thesis were discussed. The contributions of this study were also outlined.

Chapter 2 (New integrated building software) is about the development process of all the elements of the Building ESCO Toolbox product. Energy simulation, data acquisition, financial analysis, documentation and the new audit protocol are discussed.

Introduction

Chapter 2 New integrated building software

International studies have shown that building energy costs account for one third of the total world primary energy consumption [1]. Making more efficient use of energy consumption could make an important contribution to the environmental and economic sustainability of the world energy resources.

2. New integrated building software

In Section 2.1 a brief introduction of HVAC systems is provided. Section 2.2 describes the new energy simulation software that was developed by the SENKOM team. In Section 2.3 the development process of new data acquisition software is described. A new financial analysis tool is described in Section 2.4. The development of new report generating software is outlined in Section 2.5. The integration of all the technology of Section 2.2 to Section 2.5 is described in the new auditor-protocol of Section 2.6.

2.1. Introduction: building zones and air-conditioning equipment

The physical layout of a building can be arranged into zones as far as HVAC systems are concerned. A zone is a section of a building that is usually served by a single air handling unit (AHU). Cold or heated air leaves the AHU and is transferred with ducts, to different zone sections. Used air is extracted from zones via return ducts and fan units. The returned air gets filtered and mixed with fresh air and returns to the AHU. In many HVAC systems, the AHU is the only interface between the air- and water circuit. In Figure 2 a typical AHU is displayed. This AHU is similar to that used in the Conference centre of the CSIR in Pretoria.

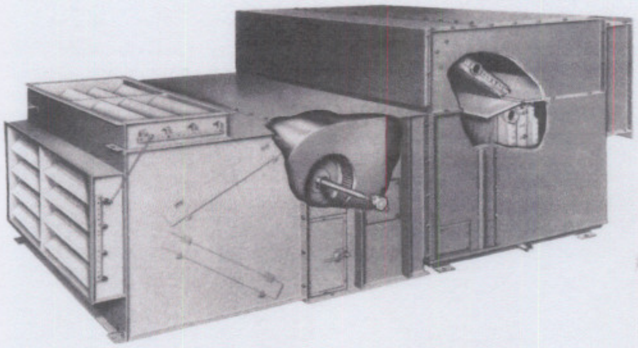


Figure 2 A multi-zone, blow through air handler showing the coils, fan, and filters.

The equipment in a water based HVAC system consists mainly of an air circuit and a water circuit. The air circuit equipment enables the cooling, heating, transfer and humidifying of air. The water circuit enables heat transfer. Coil components serve as an interface between the air- and water circuits, by adding or extracting heat to air.

It will be shown that a complete product package was developed to enable the ESCO auditors to do a complete building audit. In this process all the required new technologies were integrated into a complete product package, called Building ESCO Toolbox (BETB).

A new energy audit protocol is the core of BETB. The first aim of the protocol is to reduce the time of audits. Secondly it lowers the skill that is needed to conduct an audit. This is enabled with the built in "expert" knowledge that guides the user through the audit process. The total product cost is also minimised, to keep it accessible to the ESCO companies.

In the diagram above it is explained how the SENKOM team developed a new simulation program that enables retrofitting in much less time. Data is acquired and delivered to the simulation program in the most efficient way. Output from the energy simulation program is combined and analysed in the financial analysis program. Results from both the simulation program and the financial analysis tool is summarised in the automatic report generator. All the mentioned components are then integrated into the program called BETB.

2.2. A new energy simulation tool

An introduction to the new energy simulation program is provided in Section 2.2.1. The description of the new energy simulation program is provided in Section 2.2.2. The integration of the simulation program in the BETB audit protocol is outlined in Section 2.2.3.

2.2.1. Introduction

The SENKOM team based the development of the new BETB simulation program on the existing QUICKcontrol software. QUICKcontrol is program that was created by TEMM International (Pty) Ltd [43].

Vast improvements on QUICKcontrol were realised in terms of simulation speed, stability, set-up time and the ease of use [31]. With comparison studies it can be shown that the time that the ESCO auditor spent on the computer simulation is dramatically reduced in the retrofit studies [44].

The core of the simulation model is based on an electrical circuit analogue. The "electric circuit" simulates the different heat flow paths. The reason for the use of this model is to integrate the simulation of the building zones with the air-conditioning plant and its controls [45].

2.2.2. Description of the new program

The amount of data required for the new optimiser has been reduced significantly. The new zone model is constructed in a very fast and easy way. No complex technical data is required during the building construction phase. 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 [32].

Sufficient flexibility is built into the new simulation program. Any type of HVAC system found in the industry can be configured. The simulation tool is component based, making it possible to configure any system type intuitively by looking at the actual system. Each component in the tool can be identified with the respective component of the real system. To accomplish this, the program makes use of a graphical representation of the input data.

The component-based philosophy of the program makes it possible to identify any problem areas during the verification stage. It is easy to identify the component that does not perform according to specifications. That component can then be calibrated. This helps to ensure accurate and realistic simulations.

The simulation procedure is greatly enhanced in its speed and stability. This is important because the ESCO auditor's time is money. The use of explicit equations, as opposed to implicit equations, to calculate the output of the components, is the main improvements over QUICKcontrol. This is the main force behind the increased stability and decreased simulation time [11].

Each building zone is also described by a set of explicit equations without being coupled with the other zones. Implicit equations would have required a solver for simultaneous solutions. The use of explicit equations reduces the need for such a solver. Thus time-consuming iterations, that would only increase simulation time, are minimised.

In Figure 3 shows the model-building environment for the air-circuit. The air circuit interface consists of eight components that can be manipulated by he auditor. The components include the cooling coil, heating coil, evaporative cooler, fan, fresh-air-ratio, heater, zone, and environment input components.

Figure 3 The BETB simulation tool: air circuit.

In Figure 4 the water-circuit model building environment is displayed. It consists of the cooling tower, pump, chiller, heat pump, boiler and water-heat-recovery units.

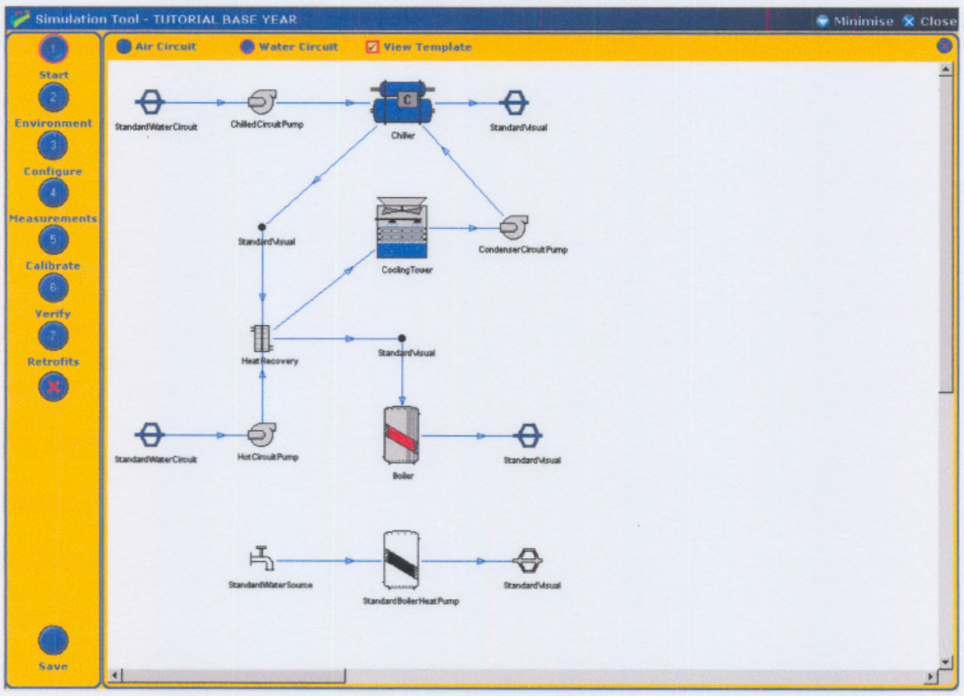


Figure 4 The BETB simulation tool: water circuit.

2.2.3. Integration in the audit protocol

The building simulation model is designed to guide the user in an easy-to-understand process of seven steps (see the left hand pane of Figure 4 for an indication of the interactive buttons for these steps).

First the ESCO auditor should provide the new project with an appropriate name, or open an existing project. In the second step the auditor selects the appropriate climate conditions, where the building is located. In the configuration phase the user inserts all the externally collected data. This will be explained in detail in Section 2.3. Also, the user completes the set-up for all the air- and water circuit components.

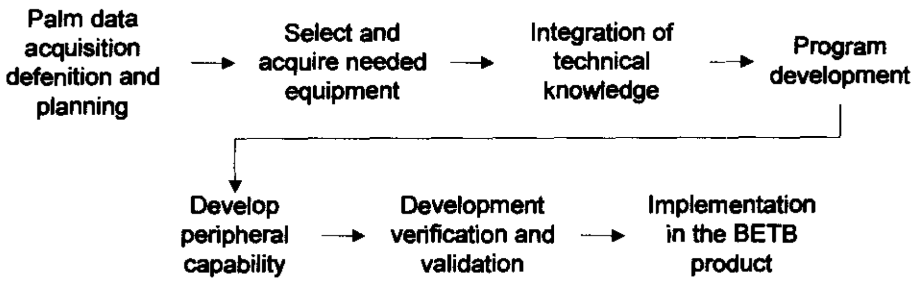
In the fourth phase, the user imports climate data and electrical load data. The fifth phase consists of the important calibration phase of the model. Here the output is Zone Temperature- and Total Electrical Energy graphs. The model is verified in stage six. In the last stage the ESCO auditor explores retrofit options.

2.3. The new data acquisition tool

The data that needs to be collected for a building audit is categorised as "equipment" or "zone" data. Equipment data are divided into the air-circuit and the 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 walk through audit. Studying "as-built" drawings is also useful to obtain equipment specifications.

The new data acquisition system was developed according to a logical process. 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 simulation-tool of Section 2.2 forces the user to collect only essential data. This 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 [11], [45].

A logical process was devised to aid the development process of a palm data acquisition system. The need is defined, the project components are planned and the needed implementation equipment was acquired. Integration of the technical knowledge was completed before program development commenced. Peripheral capabilities were developed and then the technical development and verification took place. The complete program was implemented in the BETB product. See the image below.



The logical process from conceptualisation to implementation is described in Section 2.3.1 to Section 2.3.7.

2.3.1. The *Palm data acquisition* system definition and planning

The primary needs of the BETB data acquisition system was defined in the matrix of Table 2. The proposed solutions of Table 2 has the primary purpose of satisfying the objective of this study (Section 1.4.1).

	Requirement	Proposed solution
1	Create a data logging system that log all the possible needed data of BETB.	Create customised software that collect and store all relevant data.
2	The device should be able to operate in confined spaces.	Use a PDA device.
3	An entirely paperless system would be most appropriate.	Determine all the needed data to collect and cater for the PDA device.
4	Collected data needs to be automatically transferred to the integrated simulation program to save time and minimise errors.	Use PDB database technology, and extract data automatically to needed simulaton program files.
5	The program need to be adequately user friendly: less skilled 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 picutures.
6	Reliability is a priority.	Implement proper software data protection methods.
7	Collected data should be easily obtainable.	Design the program with the advice of experienced audiors. Implement editing capabiities.
8	The auditor should be able to change and view existing data.	User should be able to view records, and change them, in PDB database structures.

Table 2 Identified needs of the new building data logging system.

The main definition purposes were developed and documented in a detailed specification document [11], [17]. The following aspects were included in this documentation and emerged form these discussions:

All the necessary data to be captured was specified. The data grouping and handling specifications with boundary values were set and documented. This was done in close collaboration with the designers of the simulation program as described in Section 2.2.

Data collection interfaces were conceptualised. A best-suited interface layout was designed. The new BETB brand was also maintained. Visually it needed to tie in with the main energy simulation tool's "look and feel".

User-friendly programming aspects were of cardinal importance. Data loss had to be eliminated, and a program without any "bugs" was imperative. Users should be guided in allowable program values. Ultimately the success of this product depends on the user-friendly aspects.

A data download program was defined as the software that creates a communication channel between the PDA device and the PC based main program. The download program enables data transfer form the PDA to the PC based structures. File structure creation and output files were conceptualised for the communication methods.

Zone specifications were integrated with the *Palm data logger* system. Zone attributes were incorporated in the design of the Zone section of the *Palm data logger.* A visual and easy to use representation and usability were designed.

Integration of the equipment specifications with the *Palm data logger* was completed. The attributes for all the heating and ventilation equipment were integrated as separate units in the *Palm data logger* philosophy.

2.3.2. The required equipment for development was selected and acquired

In this phase the appropriate hardware and software technology that could enable the implementation of Section 2.3.1 were acquired.

Available PDA technologies were investigated. PDA operating systems like Windows CE and OS Palm were investigated. The available hardware like the Compaq and Palm units were also investigated. Ultimately, rough estimates indicated that the program size would not exceed 2 MB of RAM. A typical Compaq unit retailed for about R 7000.00 where a Palm unit cost only R

1200.00. On a competitive level Palm handheld technology is the dominant product in the market [24].

The AppForge development software offered all the needed capability for the specifications of the previous section. It was clear that the OS Palm and AppForge [27] combination was the only appropriate technology. The chosen technology is listed in Table 3.

Product	Purpose
Microsoft ® Visual Studio with Visual Basic 6.0	This is the programming environment. Software for the Palm Zire PDA is created in this environment [25].
Service Pack 5.0	Microsoft Visual Studio help files are installed with this software. Visual Basic 6.0 help files are used [25].
AppForge 2.1.1	The AppForge software is add-on components to the Visual Basic 6.0 programmers environment. The OS Palm operating system mainly use visual components of this kind [27].
OS Palm Booster 2.1.1	OS Palm Booster enables necessary integration of the Palm device hardware and applications that was created with AppForge [26].
Palm Conduit CDK 4.02	Palm conduit consists of .dll files that enables communication abilities for the PDA device, desktop software and AppForge software [26].
Palm Zire Desktop software	General Palm applications are included in this software. Program installation functionality also reside here [26].
Palm Zire unit	This is the physical device that has complete computing abilities. User applications that was created with AppForge is executed with this device [26].

Table 3 Equipment selection for the development of the *Palm data logger.*

The complete Palm Zire PDA is shown in Figure 5. It comes complete with desktop software, charger a protective cover and USB connection cable.

Figure 5 The Palm Zire personal digital assistant.

2.3.3. Integration of the technical knowledge

A learning period was needed to master the development technology. Proper integration of the Conduit CDK 4.02 software with the Palm hardware needed experimentation. Tests were conducted to enable download abilities. The Visual Basic 6.0 coding environment was mastered and the AppForge components were integrated. Experimentation with graphics capabilities and PDB technology was done.

2.3.4. Program development

The *Palm data logger* was developed through an 8 phase process. First the main user interfaces were created. An initial equipment-module was developed to enable over-all functionality. After successful completion all the HVAC equipment modules were implemented. Initial zone functionality was developed, and after that completion, the complete zone data capturing was developed. Navigational structures between program elements were created. Implementation of the download program commenced. Proper graphical user interface design was conducted in the last phase [40].

The **main user interfaces** can be seen in Figure 6. When the user starts the *Palm data logger* program the following two interfaces will be displayed first. While databases are initialised the first image will be displayed. After the successful initialisation of the various PDB components, the user sees the main interface.

The main interface enables the user to clear the PDB structures. The auditor can choose between zone or equipment operations.

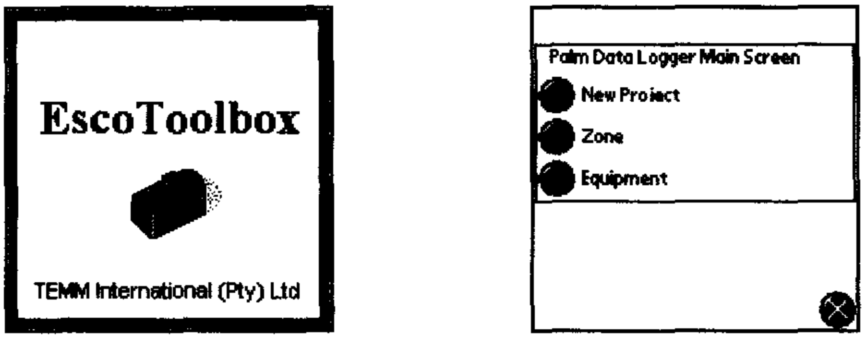


Figure 6 The *Palm data logger* main user interface.

The **initial equipment functionality** was implemented as a base for all the equipment operations of the air- and water circuit sections. A list-box scheme was devised to enable the ESCO auditor to select the appropriate equipment at hand. Once the equipment component is selected the management interface appears. With this interface the user is able to add, edit, copy and delete the component list.

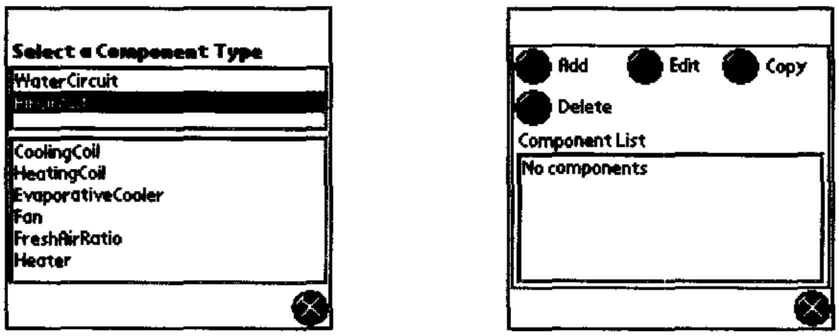


Figure 7 The initial HVAC equipment functionality.

All the **equipment components** were developed. Table 4 provides an impression of the air circuit components that was included in the *Palm data logger* program. For every component a brief functional purpose, example picture and an example *Palm data logger* program interface layout are provided. Table 5 provides an impression of the water circuit components that were included in the palm data logger program.

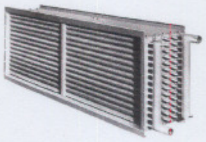
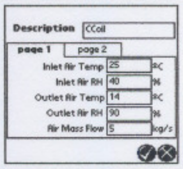
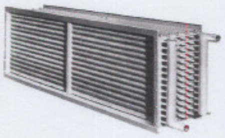
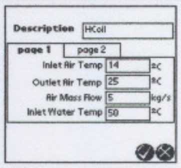
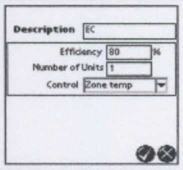
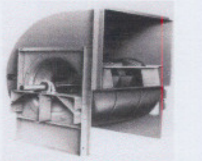
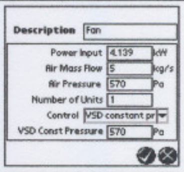
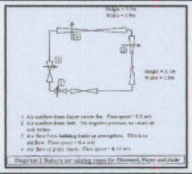
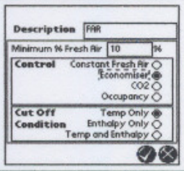
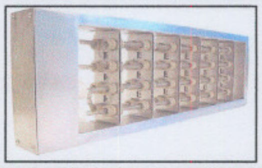
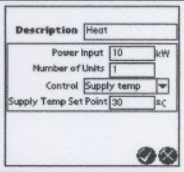
Description of the relevant components.	The purpose of the component in the HVAC system.	Example picture of the equipment.	*Palm data logger* interface.
	AIR CIRCUIT		
Cooling coil	This unit transfer the heat from the air- to the water circuit, thus reducing the temperature of the air. It is usually 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 [30].		
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 [48].		

Table 4 The HVAC equipment of the BETB air circuit.

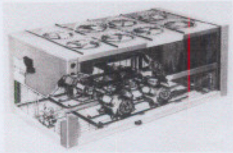
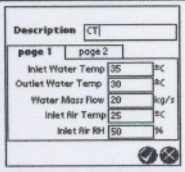
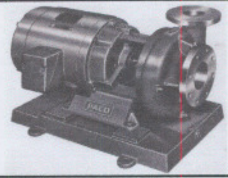
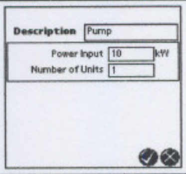
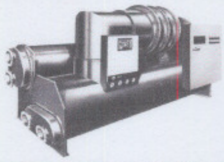
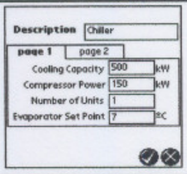
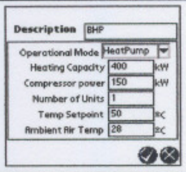
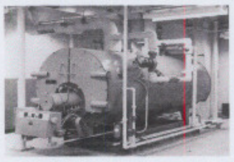
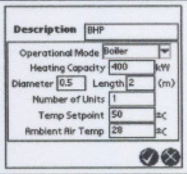
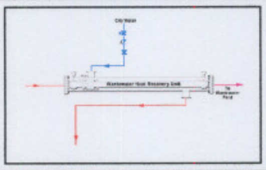
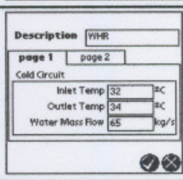
Description of the relevant components.	The purpose of the component in the HVAC system.	Example picture of the equipment.	*Palm data logger* interface.
	WATER CIRCUIT		
Cooling tower	Heat is removed from the water-cooled condensers of air-conditioning systems by contact with the atmosphere. This is accomplished by natural draft or machanical 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. Redistribtion of heat energy within a building structure can be accomplished through the use of heat pumps [47].		

Table 5 The HVAC equipment of the BETB water circuit.

The **initial zone program functionality** consists of an interface that displays the underlying PDB information in a list format. Individual records can be added, edited, copied and deleted. The user selects zone records. The zone attributes are displayed in Figure 8. Zone records are made up of five different data groups: description name, dimensions, structure data, internal heat generation information, and control information.

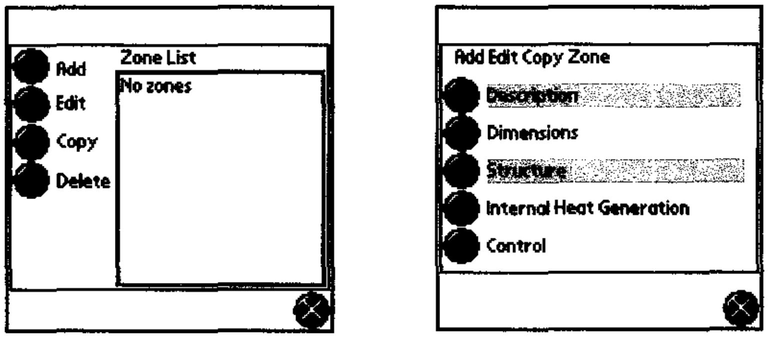


Figure 8 Zone main functionality.

The reader can see the **complete zone functionality** in Figure 9 to Figure 13. The description interface enables ESCO auditors to enter a description of the specific zone at hand (Figure 9).

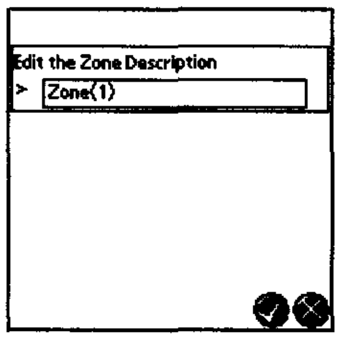


Figure 9 The zone description interface.

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 10.

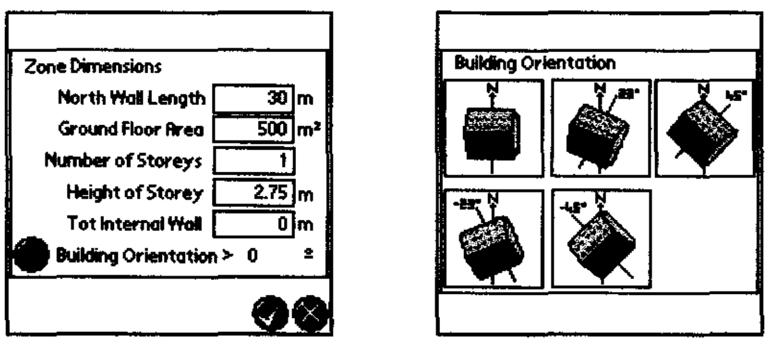


Figure 10 The zone dimensions interface.

The zone structure describes zone surface properties. Thermal characteristics determine how the building behaves with regard to thermal characteristics. The north wall characteristics are entered on the specific button which accesses the related interfaces. In Figure 11 the reader can see wall constructs, roof structures, internal wall and ground floor data. The detail interfaces of the zone structures are displayed in Appendix A.

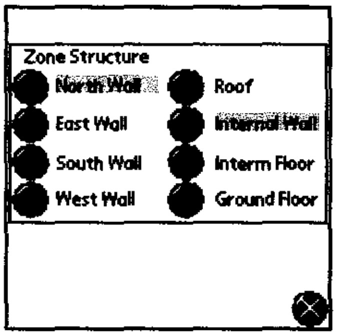


Figure 11 Zone structure section.

Internal heat generation attributes of Figure 12 consist of the internal load occupancy, lights and other unspecified loads. The peak occupancy of the zone is entered. Only three choices of leisure, office work or extensive physical activity is available. Lighting type, number and power consumption are entered. This same information is also entered for unspecified loads.

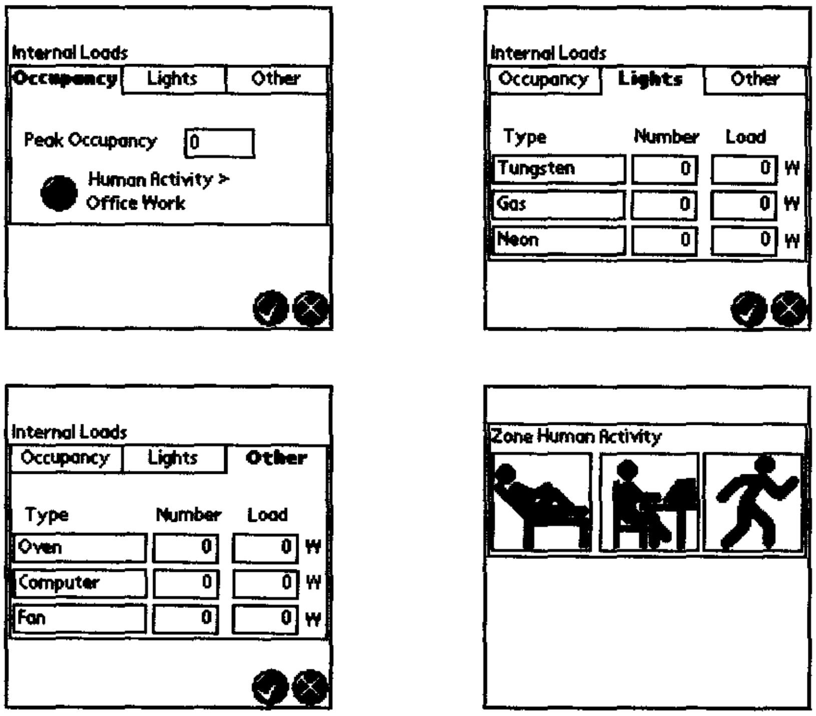


Figure 12 Zone internal loads.

The interface of Figure 13 specifies the control strategies for a specific zone. This is important information for the HVAC system simulation that utilises this data. An explanation of the zone control attributes are provided:

The temperature control of a zone is specified in a control range. The system will control (when the air-conditioning schedule is active) the zone temperature between the entered minimum and maximum temperature inputs.

Relative humidity (RH) of zones are also controlled within a range. The system will control (when the air-conditioning schedule is active) 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.

The maximum flow is the air-flow-rate into the building zone measured at 100% cooling load. This means all the supply air control dampers must be 100% open. To create this scenario the set point can be lowered or the control sensor can be warmed.

Minimum-flow 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 the set point can be increased or the control sensor cooled.

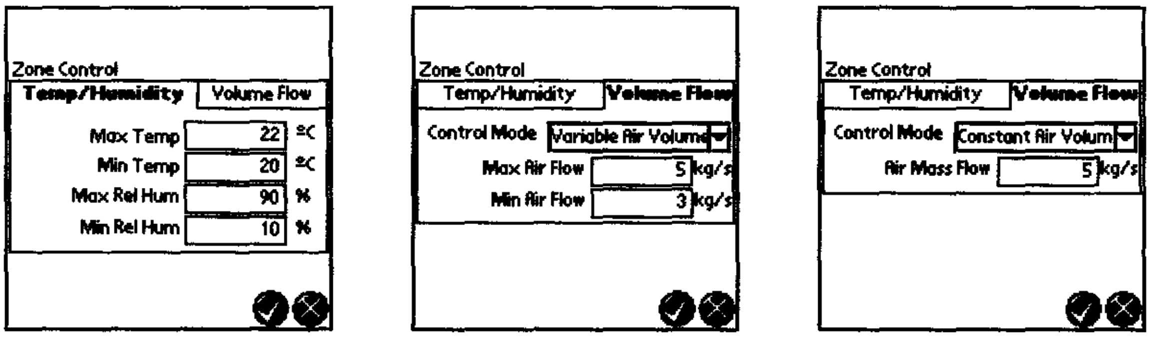


Figure 13 Zone control interface.

The **navigational structures between program elements** ensures navigational integrity. It was chosen so that navigation should generally occur with an "OK" and a "Cancel" button. A generic procedure called "Changeform" was created, to enable the smooth transition form one form to another. It was important that the forms concerned are unloaded form the memory before a new form is loaded. This would ensure program-operational sustainability.

Implementation of the download program main functionality was needed to ensure that the PDA could transfer data to the PC based BETB program. A normal Visual Basic 6.0 application was created to enable this capability. This program is activated by the Conduit CDK 4.02 software. When the ESCO auditor activates the "HotSync" operation, Conduit CDK 4.02 activates the download program's executable (.exe) file.

The download program establishes communication with the PDA, via the USB port, and then accesses the specified PDB system on the hand-held device. Data is downloaded in a binary format to the PC. The download program restructures the downloaded information in special data structures, and thus makes it available for processing. The final routine in the download program places newly created *.ini* files in the correct structure for use by the BETB simulation module of Section 2.2.

Suitable **graphics were created** for the *Palm data logger*. It was decided to conform to the previously established BETB brand. Button and screen layout were standardised to form a unity with the PC based BETB product. Icon and button pictures were also chosen to be as user friendly as possible. Distinctions were made between an active-, pressed- or an inactive button.

2.3.5. The development of peripheral capability

Peripheral capability is needed to make the *Palm data logger* commercially acceptable. User friendliness, interface layout, the download program ease-of-use and general data integrity were developed. Some categories formed part of an extensive iterative process.

The **user friendliness** was a primary concern. Program functionality had to be of such a nature that it was ergonomically efficient. The program needed to ensure an utmost built-in reliability [41].

Figure 14 shows buttons that demonstrate that a user is not able to submit wrong values as program input. When a user, for instance, enters out-of-bound values, he or she should be prompted with allowable values. At critical points in the program, the user had to be prompted with reminder options to safeguard data. The program also maintains automatic referential-integrity with PDB operations.

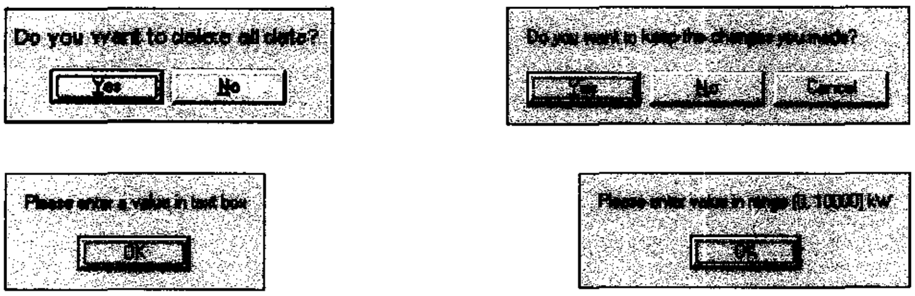


Figure 14 Program message boxes for the *Palm data logger.*

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. Once the selection is made, the "combine" function automatically creates a new entry in the PDB structure, according to the formulas that are listed below (Figure 15).

The cooling coil formulas are used as an example.

$$T_c = \frac{T_1Q_1 + T_2Q_2 + \ldots + T_nQ_n}{Q_1 + Q_2 + \ldots + Q_n} \qquad RH_c = \frac{RH_1Q_1 + RH_2Q_2 + \ldots + RH_nQ_n}{Q_1 + Q_2 + \ldots + Q_n}$$

Q_n : Air mass flow of unit n (kg/s)
T_n : Temperature of unit n (°C)
T_c : Combined temperature of n units
RH_n : Relative humidity of unit n as a percentage
RH_c : Combined RH of n units

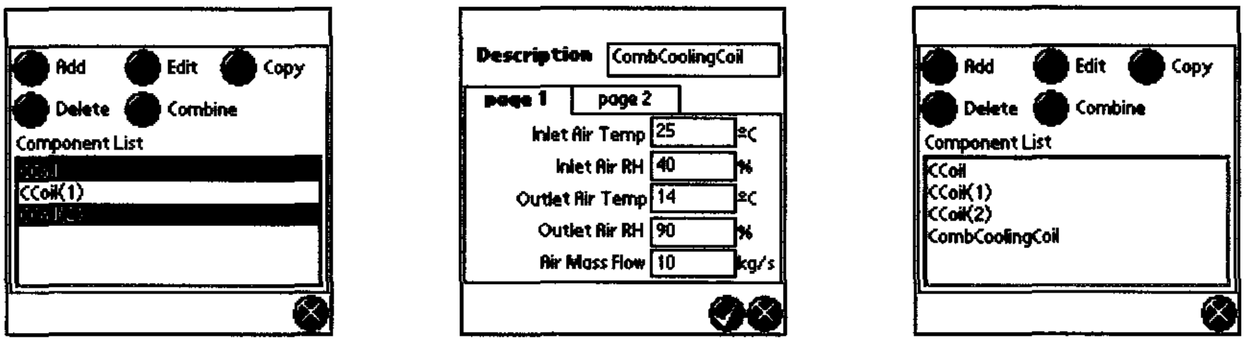


Figure 15 The combine function of the cooling coil component.

The **interface layout** should portray easily understandable language. Icons were designed to comply with uniformity and according to the BETB brand. Buttons also needed to change its appearance on activation events. A button that was disabled will be "grey-scaled", a button that is active is also different form one that is tapped with the PDA stylus.

The **download program should operate with ease of use** and provide proper data integrity. The download program needed to be activated with the HotSync□ operation of the PDA device. The download program had to be included in the BETB "install shield" program. A similar tree structure convention had to be followed for both the *Palm data logger* an the *Simulation tool.*

Some program areas were subject to an iteration process because of system changes and improvements that were constantly in process. Throughout development a constant feedback loop was maintained to ensure that a high quality product was developed.

2.3.6. Development verification and validation

Internal testing was conducted to ensure that all major development problems were solved. Throughout development Mr J de Jongh and Dr R Els conducted data, program functionality and integrity tests. Primary alpha phase testing was conducted by Mr J de Jongh.

□ The process of communication between the PDA device and the PC.

The purpose of alpha testing was to:

- Verify that the *Palm data logger* user interfaces contained the correct information (correspond to the defined specifications). Downloaded output also had to contain the same information.
- Verify that PDB input data and PC downloaded data correlated.
- To ensure that basic functionality worked correctly.
- Identify language errors.
- Resolve all fatal exception error occurrence and stability issues.
- Verify the typical number of record entries needed in the system.

An organised method of improvement documentation was used. Existing lists that contained all needed changes, mistakes, improvements and suggestions were regularly updated. See Appendix B for an impression of the actual lists. This documentation was continuously updated. Through an iterative process the relevant improvements were implemented.

A beta verification and validation of the program code was also conducted by Mr J de Jongh. The purpose of this test was to:

- Determine how logical and user friendly the *Palm data logger* work flow is.
- Establish how useful the *Palm data logger* methods were.
- To use the user manual together with a visit to the CSIR Conference Centre to determine all other relevant problems.
- To evaluate the complete system usefulness.

2.3.7. Implementation of the Palm data logger in the BETB auditor protocol

The completed Palm data logger program was implemented to form part of the BETB product. The download program, help files, training files and the directory structures were all included in an "install shield" program called Ghost installer.

2.4. A new financial analysis tool

The success of an HVAC systems-audit is ultimately measured in the amount of money it saves the building owner or tenant. The *Financial analysis tool* of BETB interfaces with the *Simulation tool* and thus enables the ESCO auditor to create more accurate financial conclusions in a much shorter time. In the diagram below the development method of the *Financial analysis tool* is outlined.

The definition and planning of the *Financial analysis tool* is provided in Section 2.4.2. The technology that was required to develop the new tool is outlined in Section 2.4.2. Program development is explained in Section 2.4.3. Development verification and validation is discussed in Section 2.4.4 and the implementation of the program in the BETB audit protocol is discussed in Section 2.4.5.

2.4.1. The *Financial analysis tool* definition and planning

Currently it takes more than two days to compile the required financial data. Data needs to be gathered in a non-mechanised way from non-integrated and non-user-friendly simulation tools. The new *Financial analysis tool* integrates information transfer with the simulation tool and the *Report generating tool* of Section 2.5.

It extracts retrofit and base year data from the retrofit sections of the *Simulation tool* and process it automatically into the required financial information. The aim was that the new financial analysis process could half the needed user time. The tool also needed to make repetitive work redundant and automate the greater BETB process as much as possible.

2.4.2. Selection and acquisition of the needed equipment

It was decided to use the Solution Toolbox™ environment to implement the financial analysis tool. Solution Toolbox™ is a concurrent development project by the SENKOM team. Solution Toolbox™ is a generic platform that is used for the execution of solutions. Solutions are custom created application programs that are integrated in a seamless way. The purpose of the general application is to assist users in problem solving.

From a Solution Toolbox™ perspective, it can be argued that BETB is one of many existing solutions. Other solutions might include: Diabetics toolbox, How to create a CV etc. For an impression of the Solution Toolbox environment, see Figure 23. Solution Toolbox™ was used to host the Financial analysis tool dynamic link library file. The code writing was conducted with Borland Delphi 6.0 programming software [28].

2.4.3. Program development

The *Financial analysis tool* was developed with five user steps in mind. In Figure 16 the main interface is displayed. The buttons on the far left panel are always visible. The financial analysis process consists of a starting-file-operation. The **initial interface** of Figure 16 enables the user to execute general file and project operations.

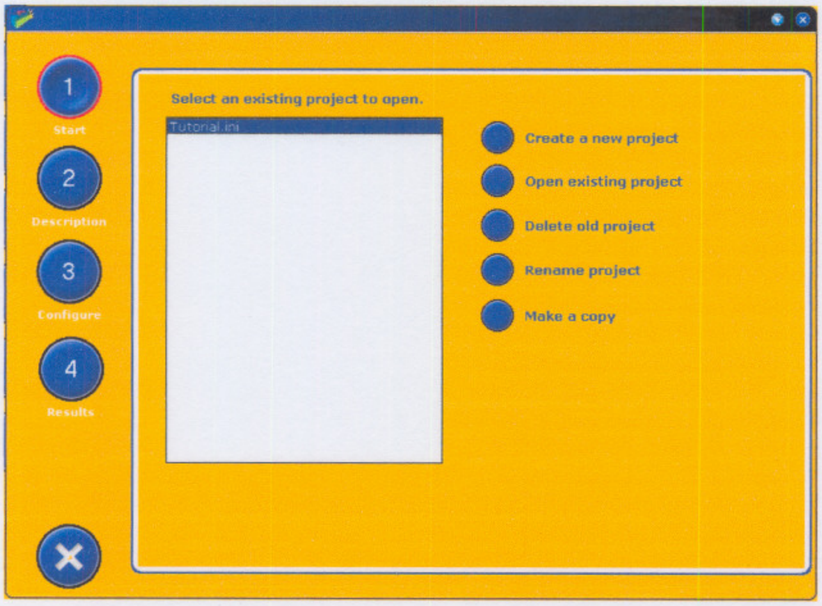


Figure 16 The start menu of the *Financial analysis tool.*

The **building and system description** is entered in the second step of the *Financial analysis tool*. Dropdown-list-boxes make choices easier for users. General building information is entered: the building name, location, physical layout, and equipment definition.

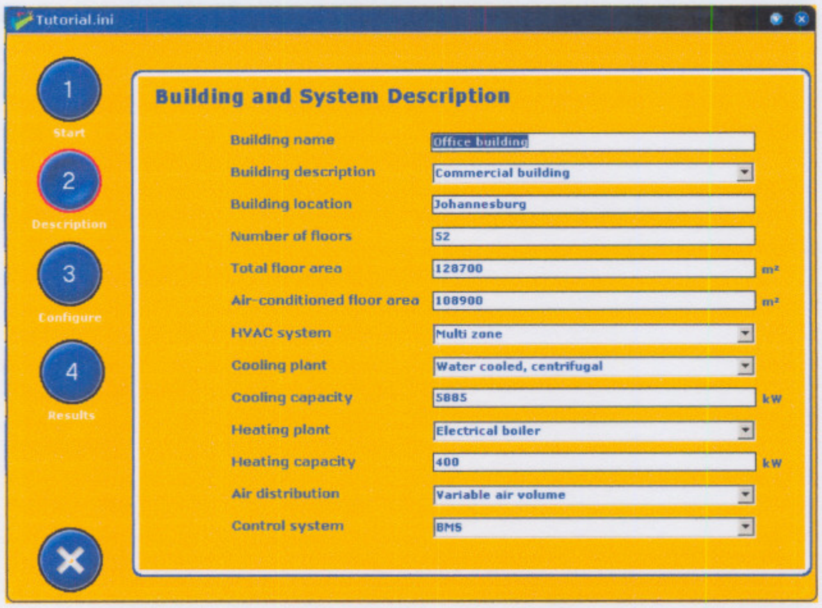


Figure 17 The description interface of the *Financial analysis tool.*

In the **configuration step** of Figure 18 the ESCO auditor selects the matching information that is provided by the *Simulation tool*. Pre-set directory-structure-operations ensure that the user is pointed to the correct directory, but expert users could select files from different locations.

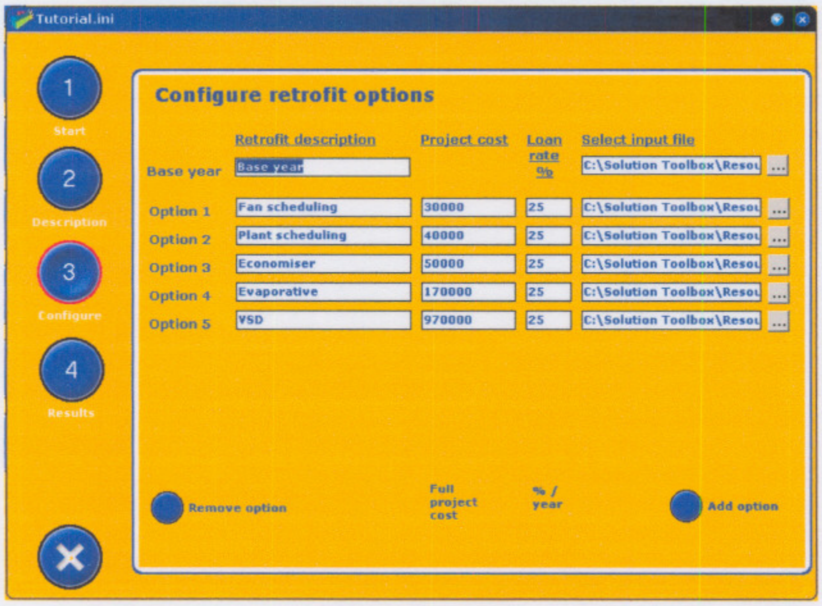


Figure 18 The configuration interface of the *Financial analysis tool.*

The "base year" information is the un-retrofitted model that is available. Its data is selected form the appropriate file selector, and the user provides a name. Space is provided for ten retrofit options. Each retrofit study is also named. The associated project-cost is provided and a financial loan rate is assigned. Again the appropriate simulation file is also chosen from the file structure selection button.

The **results section** of Figure 19 is categorised into four parts. The calibration and verification data is merely re-displayed from the simulation program operations. Cost breakdown data is provided. Electricity cost savings calculations and a simple financial analysis are conducted.

Calibration and verification information is displayed for the base year. The weekly demand load, total energy consumption and average maximum demand figures are also provided. This information is drawn form the simulation program of Section 2.2. Figure 19 displays this information.

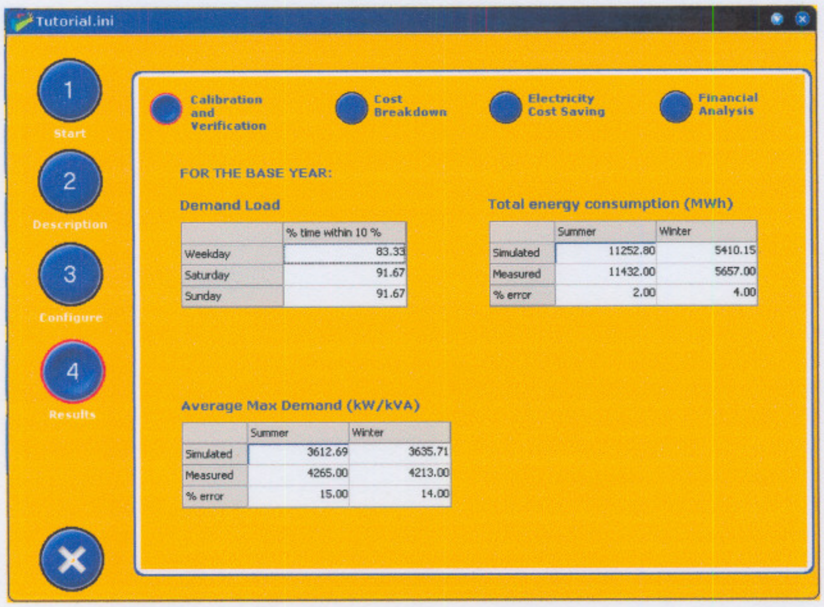


Figure 19 The calibration and verification interface of the *Financial analysis tool.*

Cost breakdown data is provided in the program section of Figure 20. Data is also obtained from the *Simulation tool* section. Energy consumption, associated cost, cost per MWh, and a relative percentage breakdown is provided. The building energy cost breakdown is divided in the HVAC system, lighting and other loads. The HVAC system is sub-divided in cooling, heating, ventilation and pumping loads and costs.

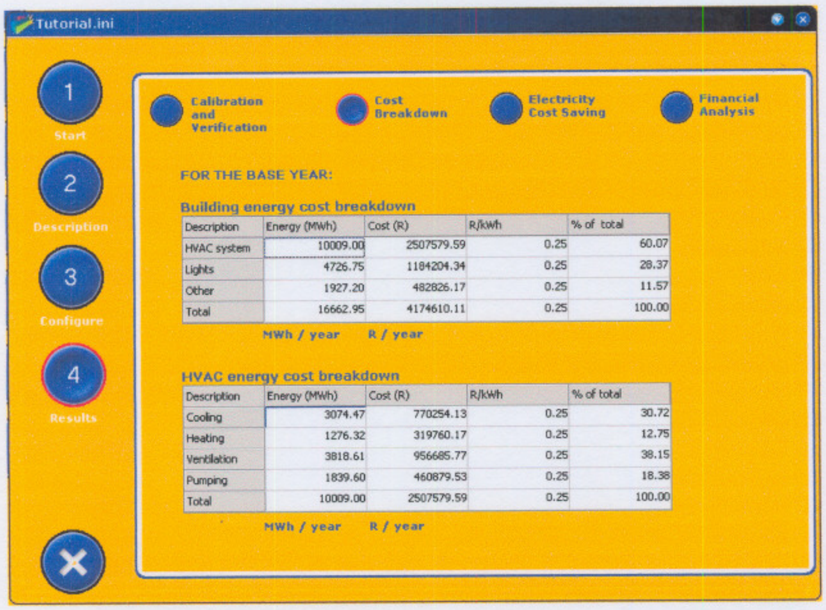


Figure 20 The cost breakdown interface of the *Financial analysis tool*.

The *electricity cost savings* section lists all the cost savings of the relevant retrofit options with comparison to the simulated base year. The specific retrofit or base-year cost is provided, cost saving and the percentage saving are calculated and displayed. Retrofit option name-descriptions are also provided.

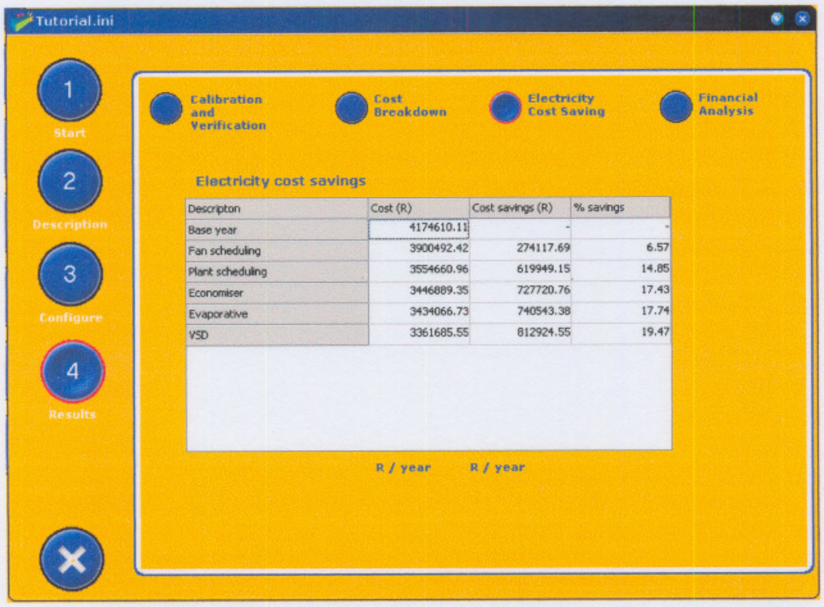


Figure 21 The electricity cost saving interface of the *Financial analysis tool*.

Financial analysis functions were developed according to specifications from TSI [12]. This is typically representative of the information an ESCO auditor needs to supply the building owners and management with.

Project cost, direct payback period, discounted payback period, loan-rate as a percentage per year and the net present value of all the different retrofit options is provided. The user can change the NPV time period to see the immediate financial effect. The payback period is provided in months and the loan rate next to the discounted payback period is used in these calculations.

A discrete payment, discrete compounding and equal payment series formula, shown below, was used to derive the mentioned discounted payback period and net present value figures [29].

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

i : Annual interest rate
n : Number of annual interest periods
P : Prestent principal sum
A : A single payment, in a series of n equal payments, made at the end of each annual interest period

Figure 22 The main *Financial analysis tool* interface.

When the user closes the *Financial analysis tool* an XML file is generated. This file enables data to be transferred to the *Report generation tool.*

2.4.4. The development verification and validation

The product was thoroughly verified and validated by Dr R Els. Calculations were checked by hand to verify the financial figures. It was also determined that proper data integrity was maintained.

2.4.5. The implementation in the BETB protocol

Integration with the simulation software, Solution Toolbox™ software and the relevant file systems was conducted.

2.5. A new interactive report generating tool

The standard form of communication between ESCO auditors, building owners and other stakeholders is with written documentation. In this section the development of an integrated documentation creation system is outlined.

In Section 2.5.1 it is described how the *Report generation tool* satisfies the need of BETB. The needed technology for the creation of the *Report generation tool* is outlined in Section 2.5.2. Program development is outlined in Section 2.5.3. The verification and validation of the development stage is described in Section 2.5.4. The implementation of the *Report generation tool* is outlined in Section 2.5.5.

2.5.1. How the *Report generation tool* satisfies the need of BETB

Previously documentation generation and compilation consumed, on average, three days by a highly trained ESCO auditor team [11]. The new integrated report writer would aim to reduce this workload to one day [43]. The Document generation tool has to automatically receive data from the *Simulation tool* and the *Financial analysis tool.* The ESCO auditor should be left with the minimum work.

2.5.2. Selection and acquisition of the needed equipment

Two technologies were used to construct the report writer. Solution Toolbox™ was used as the integrated platform. Extensible mark-up language (XML) technology was used to enable document generation and interactivity.

2.5.3. Program development

The aspect of Solution Toolbox™ that was used is the interactive word-editing environment. A standard ESCO auditor template was designed to form the basis of the report that it generates. XML technology was integrated with the template to create the basis of the interactive document functionality [11].

When a user "double clicks" on one of the data tables in the report, the *Financial analysis tool* of Section 2.4 would automatically be activated. All the changes that the user makes in the *Financial analysis tool* would be automatically updated in the *Report generating tool.*

To enable this functionality, the standard solution-building environment of Solution Toolbox™ was used. Reports can be edited, printed sent by e-mail, viewed as a slide show or changed into a web page by using the Solution Toolbox™ capabilities. In Figure 23 shows an impression of the Solution Toolbox™ word-editing environment. The visible document is a standard BETB template.

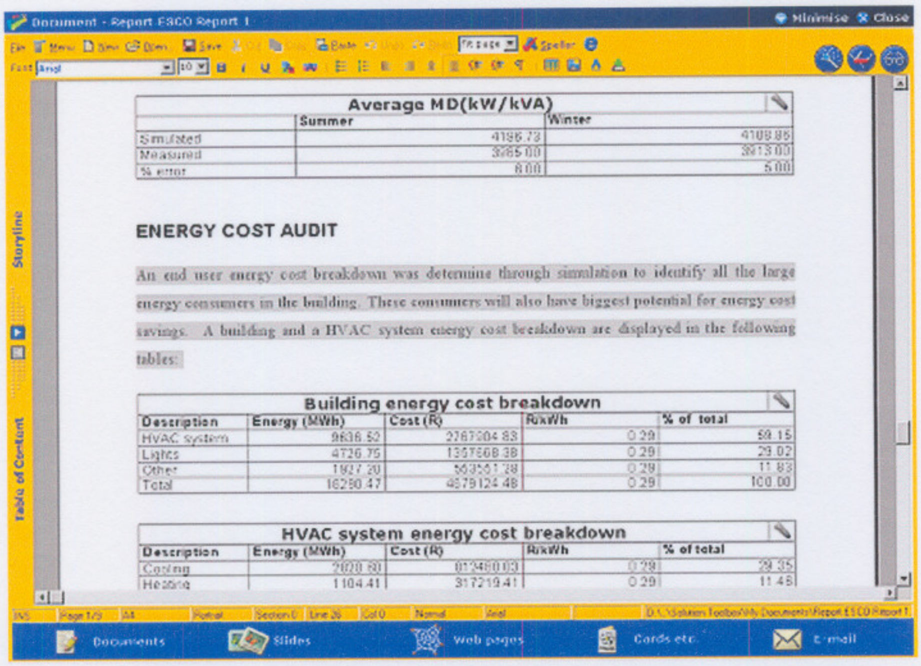
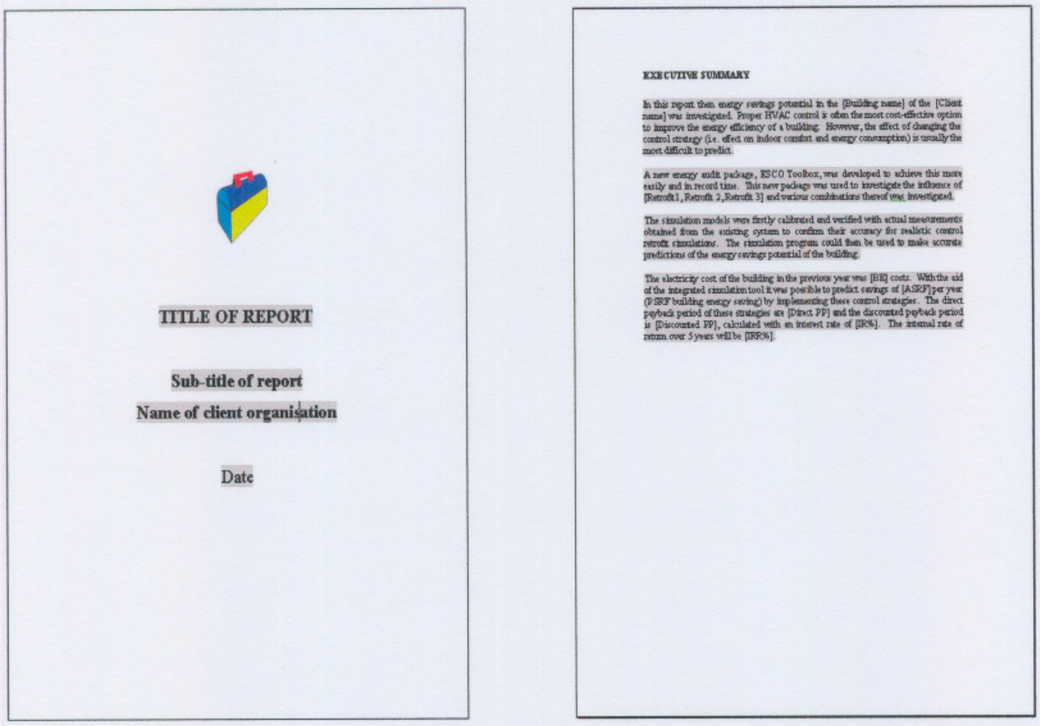


Figure 23 The automatically generated ESCO report in its word-editing environment.

The standard BETB report template consists of a title page, a short executive summary, project information, table of contents, a short introduction, building descriptions, building simulation, energy cost audit, retrofit options, retrofit results and a conclusion. An example of a standard report document that was generated by BETB and Solution Toolbox™ is shown in Figure 24 to Figure 27.

The title page and executive summary is presented in Figure 24. The ESCO auditor has complete access to edit this document. The executive summary is a summary of the important conclusions presented in this document.



TITLE OF REPORT

Sub-title of report

Name of client organisation

Date

EXECUTIVE SUMMARY

In this report then energy savings potential in the [Building name] of the [Client name] was investigated. Proper HVAC control is often the most cost-effective option to improve the energy efficiency of a building. However, the effect of changing the control strategy (i.e. effect on indoor comfort and energy consumption) is usually the most difficult to predict.

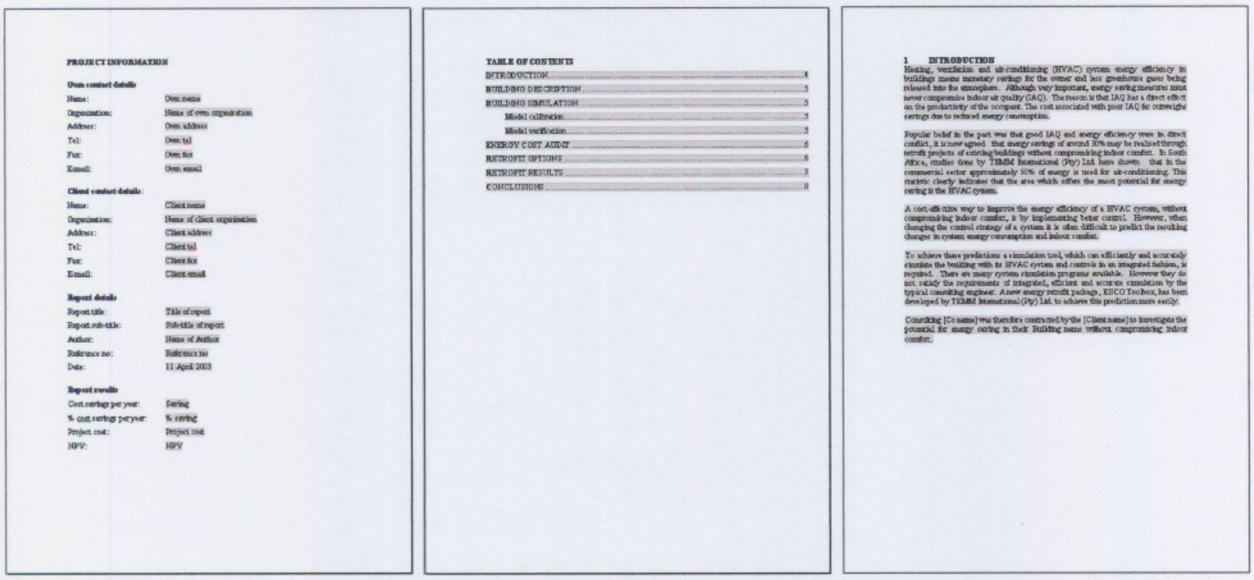
A new energy audit package, ESCO Toolbox, was developed to achieve this more easily and in record time. This new package was used to investigate the influence of [Retrofit 1, Retrofit 2, Retrofit 3] and various combinations thereof was investigated.

The simulation models were firstly calibrated and verified with actual measurements obtained from the existing system to confirm their accuracy for realistic control retrofit simulations. The simulation program could then be used to make accurate predictions of the energy savings potential of the building.

The electricity cost of the building in the previous year was [BE] costs. With the aid of the integrated simulation tool it was possible to predict savings of [ASRF] per year (PSRF building energy saving) by implementing these control strategies. The direct payback period of these strategies are [Direct PP] and the discounted payback period is [Discounted PP], calculated with an interest rate of [IR%]. The internal rate of return over 5 years will be [IRR%].

Figure 24 ESCO report template: title page and executive summary.

Project information, the table of contents and the introduction are presented in Figure 25. Owner, client and auditor details are presented with the report results. In the introduction, general HVAC concepts and introductory information is presented.



PROJECT INFORMATION

Own contact details

Name:	Own name
Organization:	Name of own organisation
Address:	Own address
Tel:	Own tel
Fax:	Own fax
Email:	Own email

Client contact details:

Name:	Client name
Organization:	Name of client organisation
Address:	Client address
Tel:	Client tel
Fax:	Client fax
Email:	Client email

Report details

Report title:	Title of report
Report sub-title:	Sub-title of report
Author:	Name of Author
Reference no:	Reference no
Date:	11 April 2003

Report results

Cost savings per year:	Saving
% cost savings per year:	% saving
Project cost:	Project cost
NPV:	NPV

TABLE OF CONTENTS

1 INTRODUCTION

Heating, ventilation and air-conditioning (HVAC) system energy efficiency in buildings means 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 productivity of the occupant. The cost associated with poor IAQ far outweighs savings due to reduced energy consumption.

Popular belief in the past was that good IAQ and energy efficiency were in direct conflict, it is now agreed that energy savings of around 30% may be realised through retrofit projects of existing buildings without compromising indoor comfort. In South Africa, studies done by TEMM International (Pty) Ltd have shown that in the commercial sector approximately 50% of energy is used for air-conditioning. This statistic clearly indicates that the area which offers the most potential for energy saving is the HVAC system.

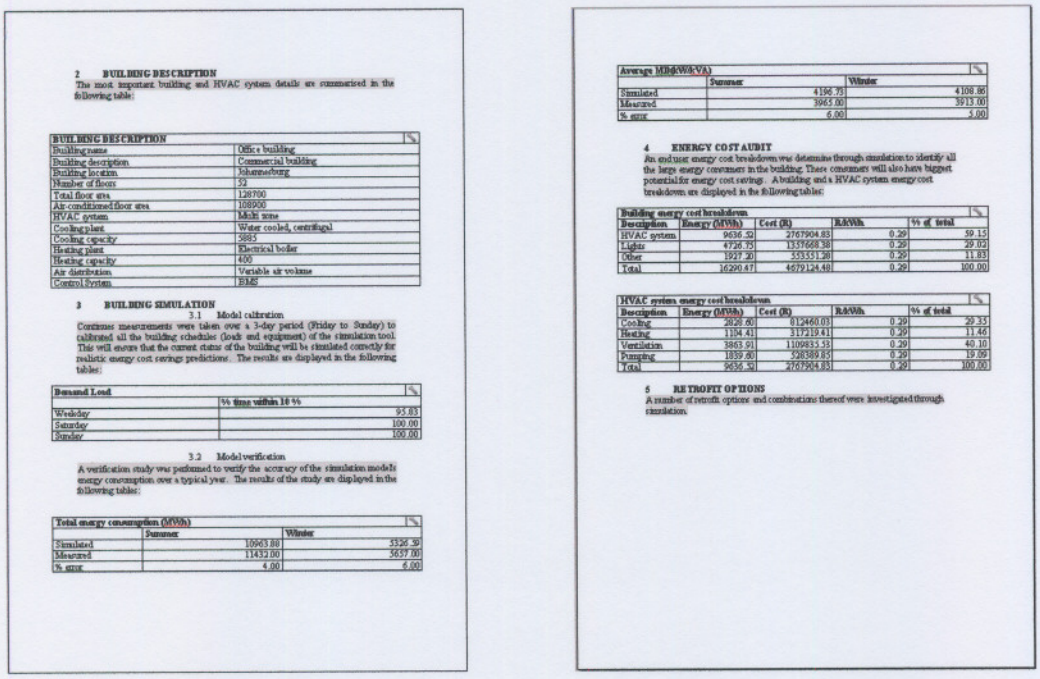
A cost-effective way to improve the energy efficiency of a HVAC system, without compromising indoor comfort, is by implementing better control. However, when changing the control strategy of a system it is often difficult to predict the resulting changes in system energy consumption and indoor comfort.

To achieve these predictions a simulation tool, which can efficiently and accurately simulate the building with its HVAC system and controls in an integrated fashion, is required. There are many system simulation programs available. However they do not satisfy the requirements of integrated, efficient and accurate simulation by the typical consulting engineer. A new energy retrofit package, ESCO Toolbox, has been developed by TEMM International (Pty) Ltd. to achieve this prediction more easily.

Consulting [Co name] was therefore contracted by the [Client name] to investigate the potential for energy saving in their Building name without compromising indoor comfort.

Figure 25 ESCO report template: client detail, table of content and introduction.

Building description information, building simulation results, energy cost audit and retrofit options are discussed in the template section of Figure 26. Simulation results are sub-divided in model calibration, and model verification results.



2 BUILDING DESCRIPTION

The most important building and HVAC system details are summarised in the following table:

BUILDING DESCRIPTION	
Building name	Office building
Building description	Commercial building
Building location	Johannesburg
Number of floors	52
Total floor area	128700
Air-conditioned floor area	108900
HVAC system	Multi zone
Cooling plant	Water cooled, centrifugal
Cooling capacity	5885
Heating plant	Electrical boiler
Heating capacity	400
Air distribution	Variable air volume
Control System	BMS

3 BUILDING SIMULATION

3.1 Model calibration

Continues measurements were taken over a 3-day period (Friday to Sunday) to calibrated all the building schedules (loads and equipment) of the simulation tool. This will ensure that the current status of the building will be simulated correctly for realistic energy cost savings predictions. The results are displayed in the following tables:

Demand Load	
	% time within 10 %
Weekday	95.83
Saturday	100.00
Sunday	100.00

3.2 Model verification

A verification study was performed to verify the accuracy of the simulation models energy consumption over a typical year. The results of the study are displayed in the following tables:

Total energy consumption (MWh)		
	Summer	Winter
Simulated	10963.88	5326.59
Measured	11432.00	5657.00
% error	4.00	6.00

Average MD(kW/kVA)		
	Summer	Winter
Simulated	4196.73	4108.86
Measured	3965.00	3913.00
% error	6.00	5.00

4 ENERGY COST AUDIT

An end user energy cost breakdown was determine through simulation to identify all the large energy consumers in the building. These consumers will also have biggest potential for energy cost savings. A building and a HVAC system energy cost breakdown are displayed in the following tables:

Building energy cost breakdown				
Description	Energy (MWh)	Cost (R)	R/kWh	% of total
HVAC system	9636.52	2767904.83	0.29	59.15
Lights	4726.75	1357668.38	0.29	29.02
Other	1927.20	553551.28	0.29	11.83
Total	16290.47	4679124.48	0.29	100.00

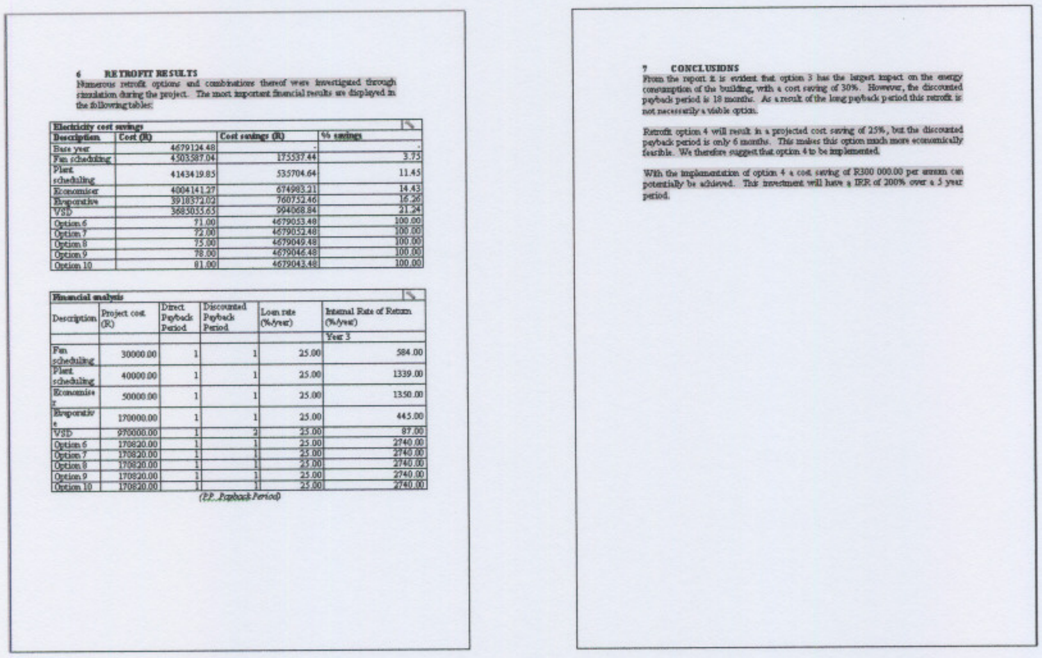
HVAC system energy cost breakdown				
Description	Energy (MWh)	Cost (R)	R/kWh	% of total
Cooling	2828.60	812460.03	0.29	29.35
Heating	1104.41	317219.41	0.29	11.46
Ventilation	3863.91	1109835.53	0.29	40.10
Pumping	1839.60	528389.85	0.29	19.09
Total	9636.52	2767904.83	0.29	100.00

5 RETROFIT OPTIONS

A number of retrofit options and combinations thereof were investigated through simulation.

Figure 26 ESCO report template: building description and building simulation.

The retrofit results that were investigated in the building audit are presented in the sections of Figure 27. Electricity expenditure is summarised, and projected cost savings are shown. The financial analysis table presents the project cost, direct payback period, discounted payback period, loan rate and internal rate of return for each retrofitted option.



6 RETROFIT RESULTS

Numerous retrofit options and combinations thereof were investigated through simulation during the project. The most important financial results are displayed in the following tables:

Electricity cost savings			
Description	Cost (R)	Cost savings (R)	% savings
Base year	4679124.48	-	-
Fan scheduling	4503587.04	175537.44	3.75
Plant scheduling	4143419.85	535704.64	11.45
Economiser	4004141.27	674983.21	14.43
Evaporative	3918372.02	760752.46	16.26
VSD	3685055.63	994068.84	21.24
Option 6	71.00	4679053.48	100.00
Option 7	72.00	4679052.48	100.00
Option 8	75.00	4679049.48	100.00
Option 9	78.00	4679046.48	100.00
Option 10	81.00	4679043.48	100.00

Financial analysis					
Description	Project cost (R)	Direct Payback Period	Discounted Payback Period	Loan rate (%/year)	Internal Rate of Return (%/year)
					Year 3
Fan scheduling	30000.00	1	1	25.00	584.00
Plant scheduling	40000.00	1	1	25.00	1339.00
Economiser	50000.00	1	1	25.00	1350.00
Evaporative	170000.00	1	1	25.00	445.00
VSD	970000.00	1	2	25.00	87.00
Option 6	170820.00	1	1	25.00	2740.00
Option 7	170820.00	1	1	25.00	2740.00
Option 8	170820.00	1	1	25.00	2740.00
Option 9	170820.00	1	1	25.00	2740.00
Option 10	170820.00	1	1	25.00	2740.00

(P.P. Payback Period)

7 CONCLUSIONS

From the report it is evident that option 3 has the largest impact on the energy consumption of the building, with a cost saving of 30%. However, the discounted payback period is 18 months. As a result of the long payback period this retrofit is not necessarily a viable option.

Retrofit option 4 will result in a projected cost saving of 25%, but the discounted payback period is only 6 months. This makes this option much more economically feasible. We therefore suggest that option 4 to be implemented.

With the implementation of option 4 a cost saving of R300 000.00 per annum can potentially be achieved. This investment will have a IRR of 200% over a 5 year period.

Figure 27 ESCO report template: retrofit results and conclusion.

2.5.4. Development verification and validation

The functionality attributes and document content was thoroughly tested. Integration functionality with the interactive components of the document was successfully verified. Data integrity and communication with the *Financial analysis tool* also proved to be successful.

2.5.5. Implementation in the BETB protocol

Relevant document functionality was integrated in the BETB solution-building environment. The document writing section in the BETB solution can be viewed in the fifth solution button in the interface of Figure 29, Section 2.6.

2.6. Building ESCO Toolbox: integrating the various tools

Only by integration of the audit tools can audit time be dramatically reduced [11], [45]. In order to meet the goals of Section 1.4, the different tools of BETB need to be integrated in an auditor-protocol. The BETB protocol integrates the energy simulation software of Section 2.2, data acquisition software of Section 2.3, financial analysis software of Section 2.4 and documentation generating software of Section 2.5 in a seamless fashion.

In this section BETB-energy-savings-tools are viewed as the implementation-enabler of this new protocol. In Section 2.6.1 the ESCO auditor protocol is discussed. Section 2.6.2 is about the BETB solution (the way it was implemented in Solution Toolbox™).

2.6.1. The BETB auditor protocol

The auditor protocol is a ten-step process that will enable auditors to complete the building audit in seventeen (17) days. In Figure 28 the reader can see a graphical representation of the auditor protocol. The five blocks coloured in blue depict the applicable steps to the original work of this study.

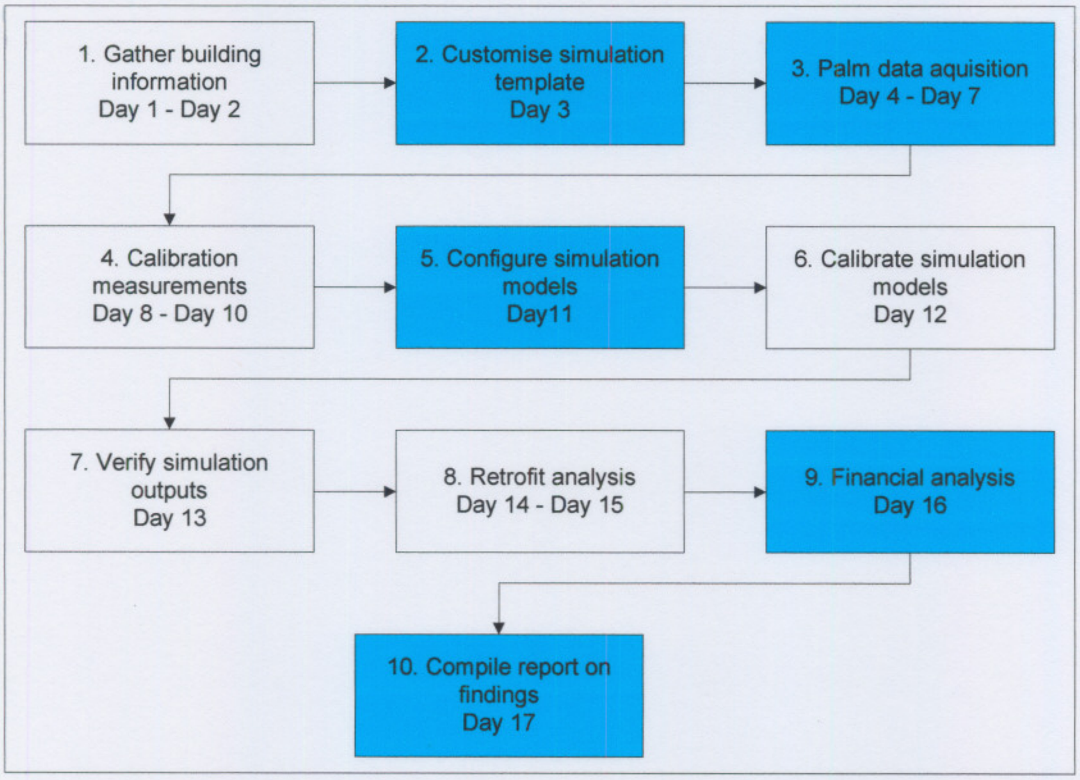


Figure 28 The BETB auditors' protocol.

The seventeen-day period to perform the audit was divided linearly between all the steps in the process:

To **gather building information** it is proposed to use the time frame of Day 1 to Day 2. Building drawings are gathered. Certain building dimensions are required to configure the building zones in the simulation tool. Building drawings will therefore assist the users 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.

HVAC system drawings are collected to conceptualise the HVAC system layout. Drawings will assist the user when customising the air and water circuit templates in the simulation model. System input information required for the *Simulation tool,* such as air flow, water flows and system capacities could also be obtained from the drawings.

HVAC design and operating specification documents (service and maintenance manuals) will supply the consultant 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 equipment component will have to be measured to obtain the required input data.

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

A comprehensive walkthrough investigation on site will provide the consultant with a better understanding of the building. This will also help when planning the calibration measurements and Palm data acquisition phases. After the completion of the walkthrough audit, the consultant is likely to have enough information available to customise the building simulation circuit templates.

The activity: **customise simulation templates** needs to consume only Day 3 of the auditing process. The building zones and the circuit templates need to be customised. The first step is to divide the building into the least possible number of simulation zones. Zones can be characterised into 2 main groups: air-conditioned and non air-conditioning zones.

Usually, the rooms in a building that are served by the same air-handling unit (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 be seen as one building zone.

All the building zones without air conditioning can form one building zone. The virtual construction of this zone is not very important, since we are not interested in its thermal performance but only its internal electricity loads. This zone will be used to calculate the electricity loads such as lights, extraction fans, lifts, etc. of all the zones without air-conditioning.

When circuit templates are constructed, the user needs to make a few assumptions to simplify the buildings' air circuit, if necessary, to match one of the already defined circuit templates available in the *Simulation tool*. HVAC equipment with the same characteristics can be simulated as one template component. All the needed system components are also created on the *Palm data logger*. This prepares the auditor for the data gathering in the data acquisition phase.

The **building data acquisition** needs to be conducted from Day 4 to Day 7. Zone data is collected by using only the PDA hand-held data-logger. Information obtainable from the building is gathered.

The data required for a project was structured in such a way that no detailed building drawings, or prior knowledge of the building are necessary. However, the building plans collected in the first stage proves valuable from a holistic point of view.

All the needed information about HVAC system components is also gathered with the *Palm data logger*. The data required for a project is structured in such a way that the ESCO auditor is most likely only to encounter obtainable data. When data is not available other methods need to be implemented to deduce needed information.

Calibration measurements need to be conducted from Day 8 to Day 10. The total building electricity demand is determined and climate data is gathered. It is important to note that total building electricity and climate data should be recorded during the same time period.

Total building electricity demand (kWh, kVAh) is determined. The average hourly measurements of the total building energy demand (kWh, Power Factor) of a typical weekday, Saturday and Sunday is required. The model needs to be calibrated in order to produce realistic results in the retrofitting stage. Average hourly climate measurements of the temperature and RH for typical weekdays are required for this purpose. These measurements can either be captured by the HVAC control systems or by standalone data loggers.

The **configuration of simulation models** are conducted on Day 11. The *Palm data logger* component information needs to be downloaded to the main PC based system ("drag and drop" all the downloaded Palm components to their respective locations on the air- and water circuit templates of the simulation program). Configuration of the component schedules is also done.

A second configuration stage of component schedules is completed after the downloading of information is complete. All the components in the project component list are edited for all the building and system schedules of the four seasons and day types.

Calibration of the simulation models is done on Day 12. The simulated total building electricity demand has to correspond with the measured load. If this is not the case, the auditor needs to add or delete electricity loads. This is done in zones without air-conditioning (base load) to ensure that the electricity consumption of the large HVAC system energy is correct.

The **simulation outputs need to be verified** on Day 13. This is done according to energy consumption and maximum demand. It is a simulated-year verification, where the summer and winter energy consumption and maximum demand of the total building are compared to the respective measured data of the previous 12 months (electricity accounts).

These results provide a fair indication of the accuracy of all the assumptions made during the project. Results should be within 10% of the measured values to ensure accurate retrofit cost savings during the retrofit analysis.

Retrofit analysis is performed from Day 14 to Day 15. A total of ten typical retrofit simulations can be performed by the BETB program. They are divided into three groups: schedule changes, control changes and implementation or replacement of new equipment. A typical example is provided in the case study of the Carlton building of Section 4.2.

The **financial analysis** is completed on Day 16. The *Financial analysis tool* of BETB calculates the feasibility of all the simulated retrofit options. Annual cost savings, payback periods and rates of return are calculated. This tool also captures all the required simulation data of all the selected options for immediate calculations.

Compilation of findings in report format is conducted on Day 17. BETB is provided with a complete word processing tool to summarise the findings of the project in a report format. A report-writing wizard is available for step-by-step guidance. Relevant simulation- and financial data are automatically imported into the report. A new report can be created within a few minutes.

Training detail and an example-audit is provided with the BETB software. The tutorial material illustrates certain important assumptions to simplify the investigation and reduce valuable project time.

2.6.2. . The BETB solution

The SENKOM team integrated the program components of Section 2.2 to Section 2.5 in the Solution Toolbox™ environment. One can clearly see that the BETB protocol is implemented in the user interface of Figure 29.

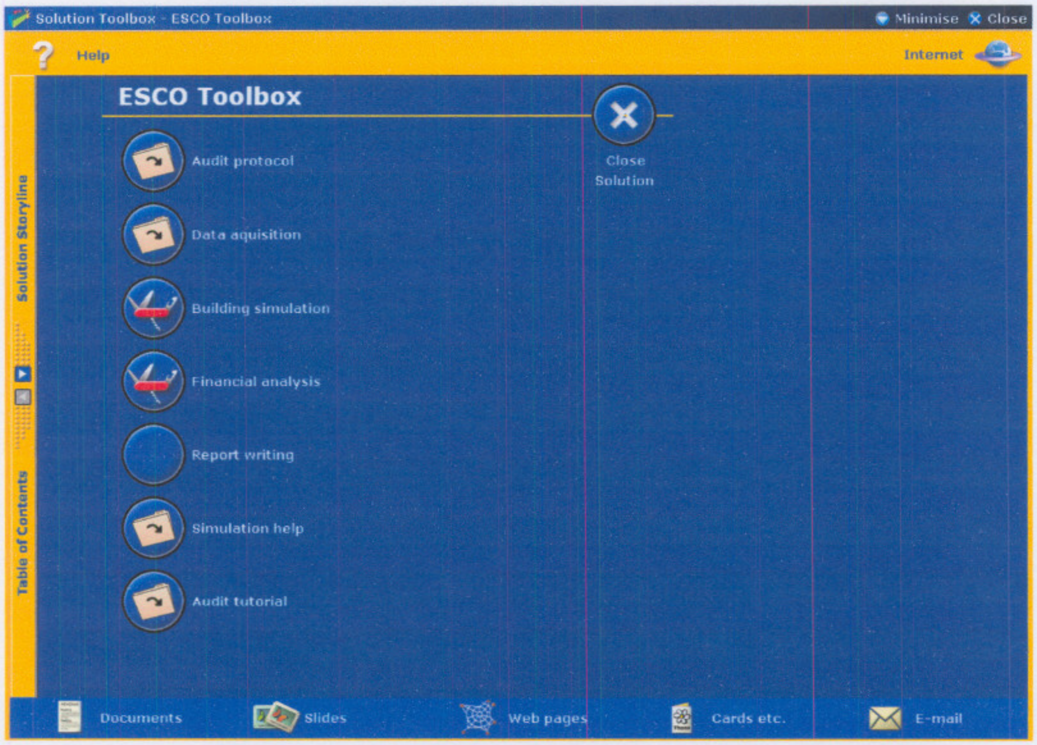
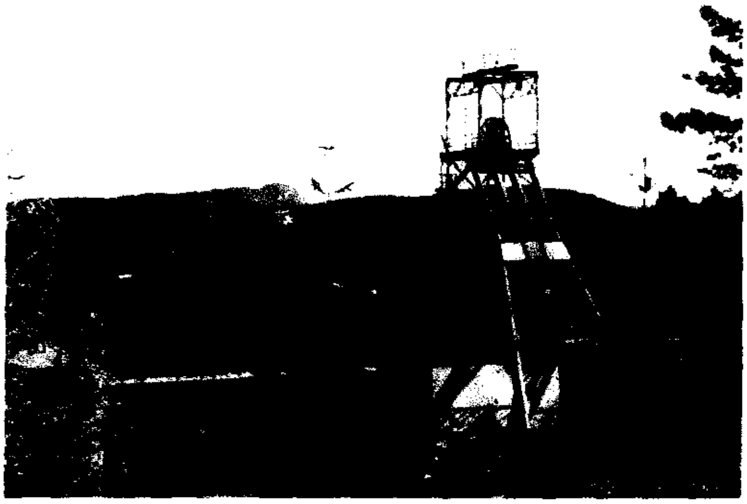


Figure 29 The complete BETB product interface.

All the required BETB information and activities are presented in a logical and sequential way to the ESCO auditor. This creates set standards for ESCO auditors. The ESCO auditor is introduced to BETB by a tutorial of the audit protocol. A data acquisition tutorial is then presented. The third step opens the building simulation activity. This was discussed in detail in Section 2.2. The third step of the protocol is completed by selecting the financial analysis button on the interface of Figure 29. Report writing is the final step of the BETB-auditor protocol. Simulation help and a complete audit-tutorial is also supplied.

Chapter 3 New integrated mine software



About 20 % of the total ESKOM-electricity-production is used by mines. This amounts to approximately R 3 billion of electricity per year, just for gold mines [4].

New integrated mine software

3. New integrated mine software

In Section 3.1 a brief introduction is provided. A new energy simulation program called REMS is described in Section 3.2. The development of the new data acquisition system for mine maintenance, called OSIMS, is outlined in Section 3.3. The integration of the technology of Section 3.2 and Section 3.3 is discussed in Section 3.4.

3.1. Introduction: cold water pumping in deep mines

Mine air ventilation and cooling forms a very important part of the total budget of the capital and running costs of a large deep mine. From Section 1.1 it is evident that the cooling process of deep mines offers the greatest potential in electrical energy savings.

The deep mining industry in South Africa relies very heavily on refrigeration to overcome heat loads and to provide acceptable environmental conditions for workers. Cold water is normally distributed from large centralised refrigeration installations, which are located either on the surface or underground, to heat exchangers, which in turn cool the ventilation air.

Figure 30 on the next page, is a simple diagram of the different types of heat exchange processes, which take place in the supply of cold water. The cold water, and the cooling of the air ensures a safe and healthy working environment. All the cooling and pumping processes are interrelated. Heat energy is removed from water and expelled into the surface atmosphere. The water is then further cooled and sent down the mine where it is used to cool the various mine sections. The warm water is pumped to the surface again, where the process is repeated.

The process is therefore cyclic and interdependent. The amount of air determines the amount of water needed, which in turn determines the amount of water to be circulated, to cater for a specific heat load in the system, and so forth. It is also evident that all these processes involve the utilisation of electricity, which form a very important part of the running cost of any deep mine [19].

The air supply (main fans, booster fans and auxiliary fans) is not shown in Figure 30, but forms an important part of the total heat exchange process and the electricity consumption associated with it. The water and airflows are very much interrelated and the one without the other is not feasible [19]. Note the pumps are indicated with the symbol (P) in Figure 30.

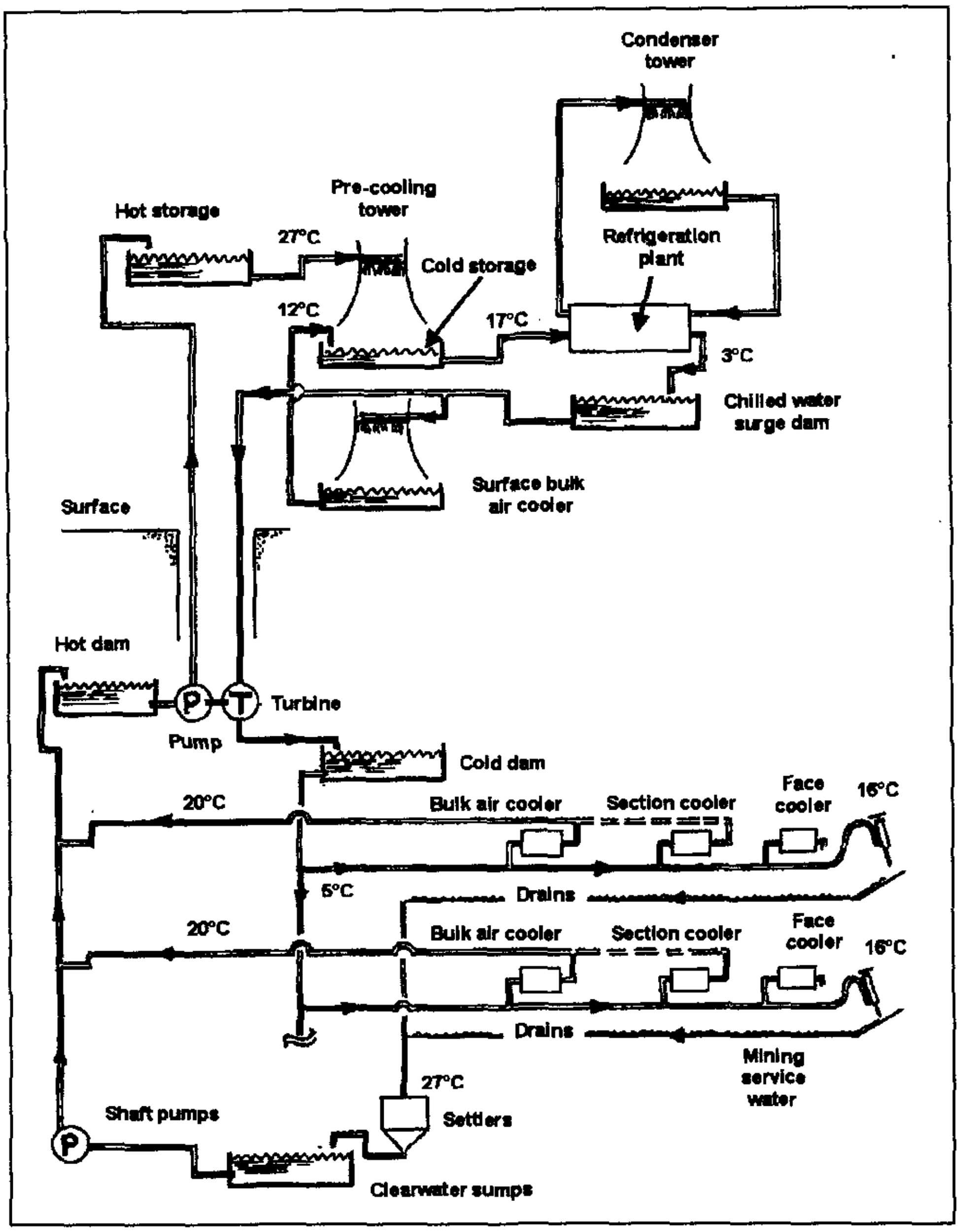


Figure 30 Simplified cooling and pumping interaction of a deep mine.

Water storage dams in the mine provide capacitance for electrical equipment in the pumping system. The SENKOM team developed a new energy optimisation program called the Remote Energy Management System (REMS). REMS enable the pumping system to use the least electrical energy while the needs of the mine are still satisfied. This is in line with the important DSM needs of ESKOM. To ensure that the REMS software is supported by a reliable physical system, the On Site Information Management System (OSIMS) software was created.

3.2. The new REMS energy simulation program

In order to shift electrical loads, an optimised operation schedule for pump usage needed to be created. This new pump schedule needs to satisfy the pumping needs of the mine but also consider the peak electricity prices of ESKOM. REMS provide a very high level of confidence in that these schedule changes will not negatively affect the safety and production of the mine.

This is achieved by simulating the pump systems in exact detail. When building the simulation model for the mine operations, each element in the pumping process had to be simulated in detail. For each element a mathematical model had to be developed which accurately represents that specific dam, pump or settler component. The model for the component was verified to ensure that it reacts in exactly the same way as the real components in the mine.

All the simulated components are combined into an integrated model, which represents the integrated operation of the complete mine pumping system. The mine control system was then integrated with the simulation model to arrive at a "real life" simulation of the mine.

In constructing the REMS program, verification of the virtual mine's cooling and pumping processes are conducted. This makes the simulation model a true representation of the integrated operation at the mine. Figure 31 shows the REMS user interface of a typical pumping and cooling simulation model of a deep mine.

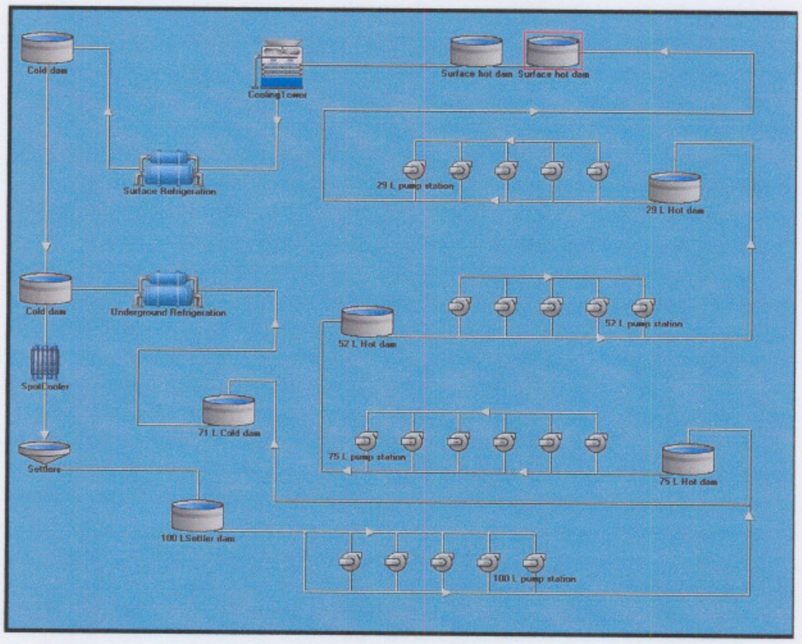


Figure 31 A typical REMS modelling interface.

Once the simulation model is complete and the confidence of the client is obtained, the model is integrated with the SCADA control system of the mine. Other daily varying influences on the final electricity bill, are included in the system: varying weather data, maintenance schedules, the real time electricity prices for that specific day (RTP*), as well as varying water quantities required underground.

The RTP price, as well as the daily weather forecast, is automatically transmitted to the REMS simulation model via the Internet. ESKOM and the weather bureau supply this data. The mine engineer supplies the model with constraints including upper and lower limits for dams, the equipment on and off limits, and any other constraints. Maintenance schedules for the next day are also considered. All this information is taken into account when REMS optimises operations for maximum load shift to cheaper times, leading to minimum electrical energy cost.

The dynamic optimisation procedure is then integrated with all the aforementioned processes to arrive at an optimum schedule. REMS ensures minimum energy cost and maximum load-shift, but takes into account all the safety, health, operation, maintenance and other constraints. REMS enforces the optimised solution using the SCADA system. The SCADA system in turn controls the pumping operations with PLC devices.

The REMS system relies on the availability of pumping equipment to be able to save money. In Section 3.3 an overview of an improved maintenance system called OSIMS will be described.

3.3. A more reliable maintenance information system called OSIMS

The need to improve the current maintenance information system is described in Section 3.3.1. The selection process of the needed equipment is described in Section 3.3.2. A description of program development is provided in Section 3.3.3.

3.3.1. The need to improve the current maintenance information system

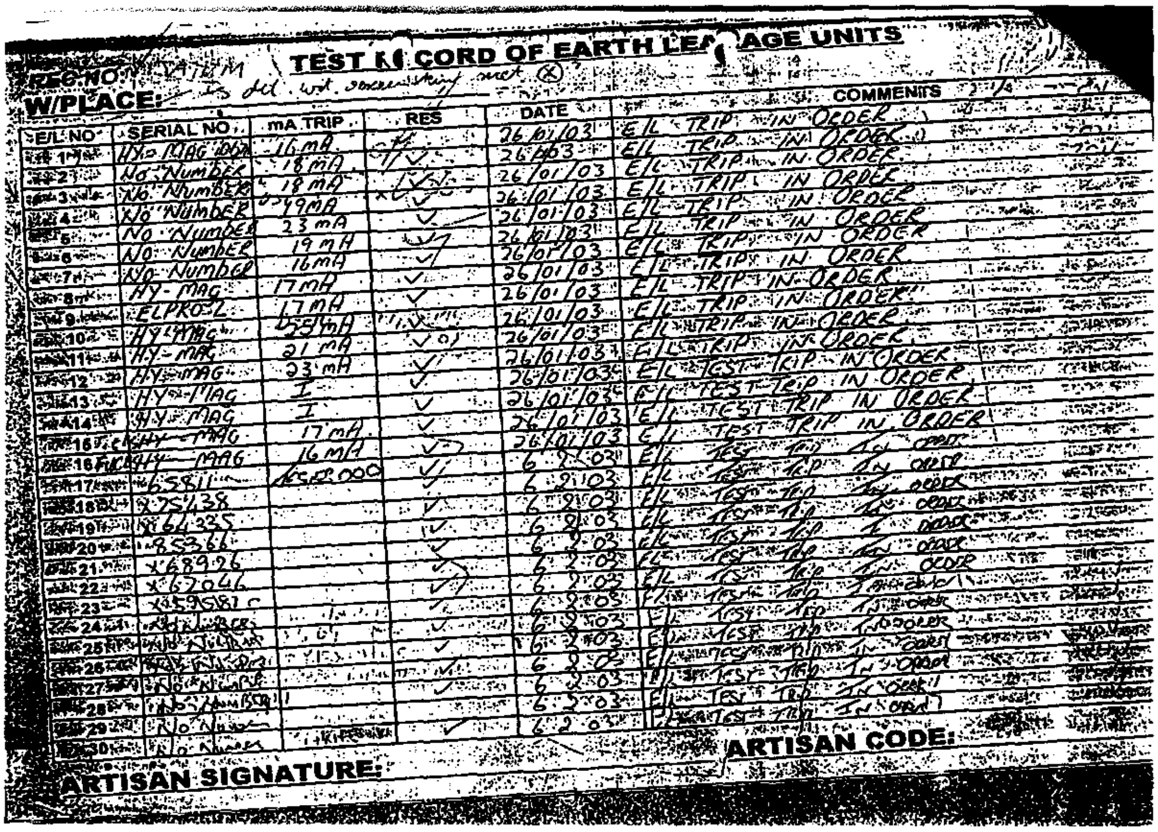
The current maintenance systems that were related to the REMS project were investigated. It was determined that the pump system reliability and its peripheral systems (e.g. earth leakage test record system) needed to be reliable. This will ensure reliable REMS functionality.

* Real time pricing (RTP) is a price structure of ESKOM. This figure is determined on a daily basis and is downloaded by REMS, via the Internet.

An investigation was conducted at an Anglo Gold mine called Kopanang. The earth leakage test method was used to determine the current practice and needs of data logging in deep mines. Although only the earth leakage test-record methods are described in this study, all the other components in the system of Section 3.1 also rely on the same methods.

Routine maintenance tests of earth-leakage-units are conducted by artisan workers. The artisan physically visits the unit inside the mine. A specialised testing device is used to test the earth-leakage unit. Once the test is complete the necessary information is recorded in a log book.

The earth leakage units records contain the following information: the date of the test, level and workplace in the mine where the unit resides, function of the unit, identification number of the unit, the mA value where the unit tripped during the test, functional status of the unit (working or a non-working condition) and the artisan who conducted the test's personnel code. Figure 32 shows the reader an impression of such a list.


TEST RECORD OF EARTH LEAKAGE UNITS

REG NO:

W/PLACE:

E/L NO	SERIAL NO	mA TRIP	RES	DATE	COMMENTS
1	HY-MAG	16 mA	✓	26/01/03	E/L TRIP IN ORDER
2	No Number	18 mA	✓	26/01/03	E/L TRIP IN ORDER
3	No Number	18 mA	✓	26/01/03	E/L TRIP IN ORDER
4	No Number	19 mA	✓	26/01/03	E/L TRIP IN ORDER
5	No Number	23 mA	✓	26/01/03	E/L TRIP IN ORDER
6	No Number	19 mA	✓	26/01/03	E/L TRIP IN ORDER
7	No Number	16 mA	✓	26/01/03	E/L TRIP IN ORDER
8	HY-MAG	17 mA	✓	26/01/03	E/L TRIP IN ORDER
9	ELPRO	17 mA	✓	26/01/03	E/L TRIP IN ORDER
10	HY-MAG	25 mA	✓	26/01/03	E/L TRIP IN ORDER
11	HY-MAG	21 mA	✓	26/01/03	E/L TRIP IN ORDER
12	HY-MAG	23 mA	✓	26/01/03	E/L TEST TRIP IN ORDER
13	HY-MAG	I	✓	26/01/03	E/L TEST TRIP IN ORDER
14	HY-MAG	I	✓	26/01/03	E/L TEST TRIP IN ORDER
15	HY-MAG	17 mA	✓	26/01/03	E/L TEST TRIP IN ORDER
16	HY-MAG	16 mA	✓	6 2 03	E/L TEST TRIP IN ORDER
17	65811	[illegible]	✓	6 2 03	E/L TEST TRIP IN ORDER
18	X 75438		✓	6 2 03	E/L TEST TRIP IN ORDER
19	X 64335		✓	6 2 03	E/L TEST TRIP IN ORDER
20	X 85366		✓	6 2 03	E/L TEST TRIP IN ORDER
21	X 68926		✓	6 2 03	E/L TEST TRIP IN ORDER
22	X 62046		✓	6 2 03	E/L TEST TRIP IN ORDER
23	X 59581		✓	6 2 03	E/L TEST TRIP IN ORDER
24	[illegible]		✓	6 2 03	E/L TEST TRIP IN ORDER
25	[illegible]		✓	6 2 03	E/L TEST TRIP IN ORDER
26	[illegible]		✓	6 2 03	E/L TEST TRIP IN ORDER
27	[illegible]		✓	6 2 03	E/L TEST TRIP IN ORDER
28	No Number		✓	6 2 03	E/L TEST TRIP IN ORDER
29	No Number		✓	6 2 03	E/L TEST TRIP IN ORDER
30	No Number				

ARTISAN CODE:

ARTISAN SIGNATURE:

Figure 32 An example of an earth leakage test record.

The current process that is followed to collect the earth leakage data is described in Figure 33. The artisan finds the data book and the test instrument in the central store (Figure 33, 1). When the artisan goes below the surface the necessary tests are performed on the earth leakage unit. The relevant information is recorded on paper (Figure 33, 2 and 3). On the surface the artisan would normally complete the paper work and file the data book at a central store (Figure 33, 3 and 4).

The engineering co-ordinator finds the same data book in the store and keys the information into the Computer Maintenance Management System (CMMIS). The CMMIS database is "safe" (Figure 33, 5 and 6). Only the Engineering Co-ordinator and the Shaft Engineer has access to this information. The data book is then stored again (Figure 33, 7).

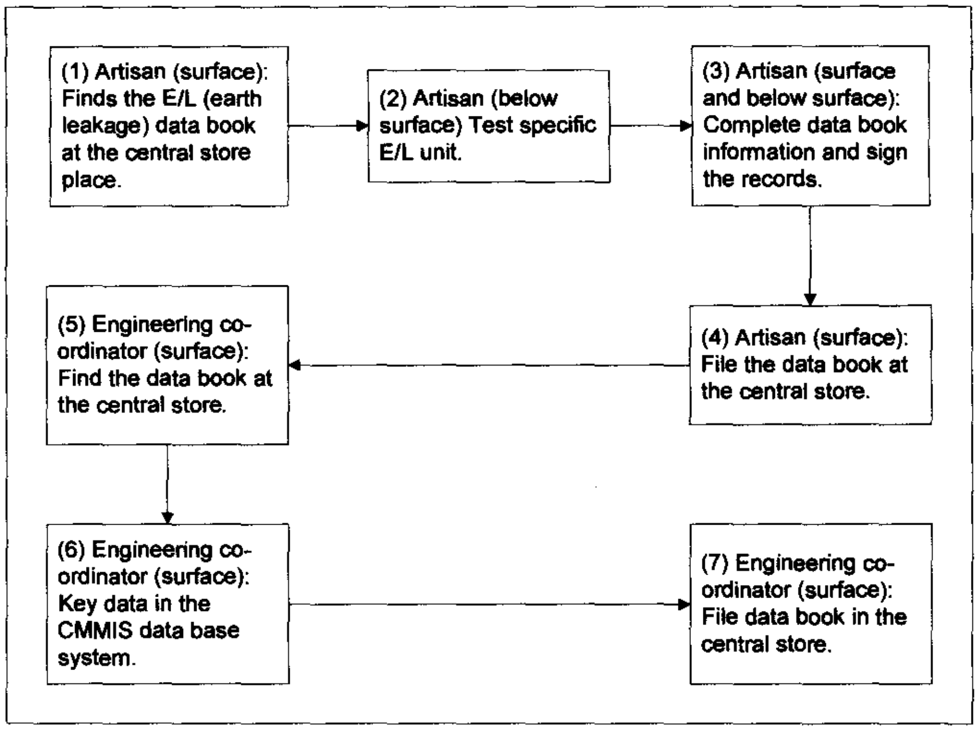


Figure 33 The old maintenance data-collection method.

Four problems exist with the current system as it is described above:

Problem 1: Data books can get lost in the process (Figure 33, 1 and 5).

Problem 2: When artisans work under great time constraint it can happen that the earth leakage unit is never really visited. The artisan could, in such a case, create an un-lawful entry into the data book (Figure 33, 2).

Problem 3: It can happen that the data is incomplete. This usually happens because a very high quantity of repetitive information needs to be recorded by hand, every day.

Problem 4: The engineering co-ordinator needs to re-type all the information that already resides in the data books into the CMMIS system (Figure 32, 6). Double work results.

3.3.2. OSIMS is the solution for the shortcomings

The OSIMS system was developed to solve the problems that were stated in Section 3.3.1. OSIMS is a new improved process that helps that maintenance data is logged correctly, by using less system resources. OSIMS makes use of PDA technology.

A complete paperless system replaces the one described in Section 3.3.1. The PDA device that was decided upon can withstand the harsh environmental conditions of a mine. The industrialised Symbol SPT 1800 PDA met all the set requirements. See Figure 34 for an impression of the device.

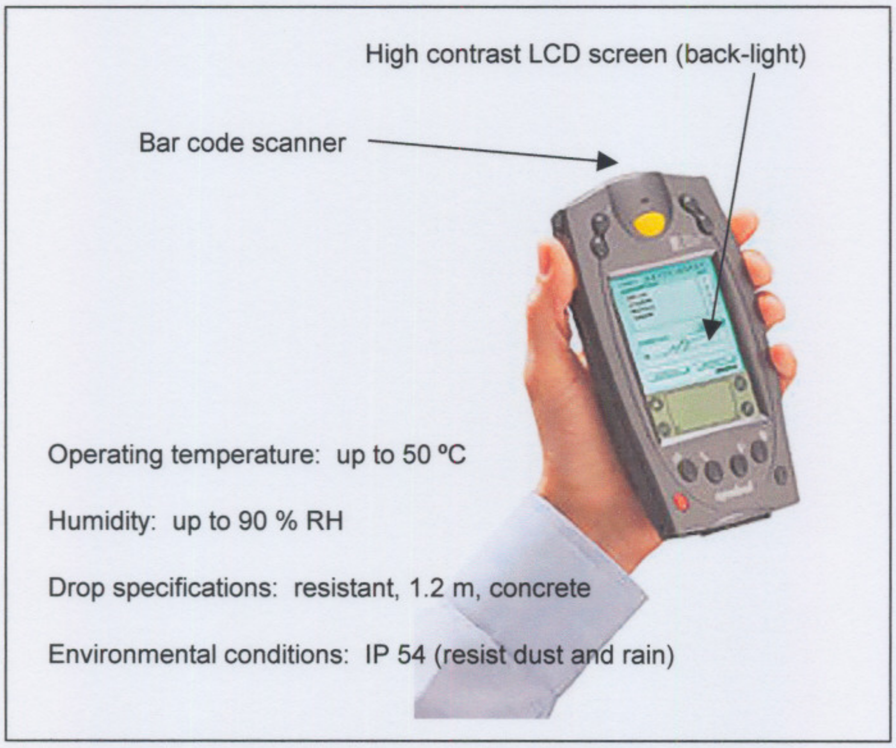


Figure 34 Palm Symbol SPT 1800 programmable barcode scanner.

The new improved process for maintenance tasks is outlined in Figure 35. The artisan takes the PDA device underground. He or she performs the test on the earth leakage unit. The only way to create a test-record-entry is to scan the barcode on the unit (barcode systems are already used by the Kopanang mine). The result of the test is then recorded in the PDB system of the PDA device. If the earth leakage unit is faulty, it gets replaced with a new one with a different barcode (Figure 34, 2 and 3). On the surface the artisan is now responsible for downloading the information to the CMMIS computer before the PDA unit is stored (Figure 35, 4 and 5).

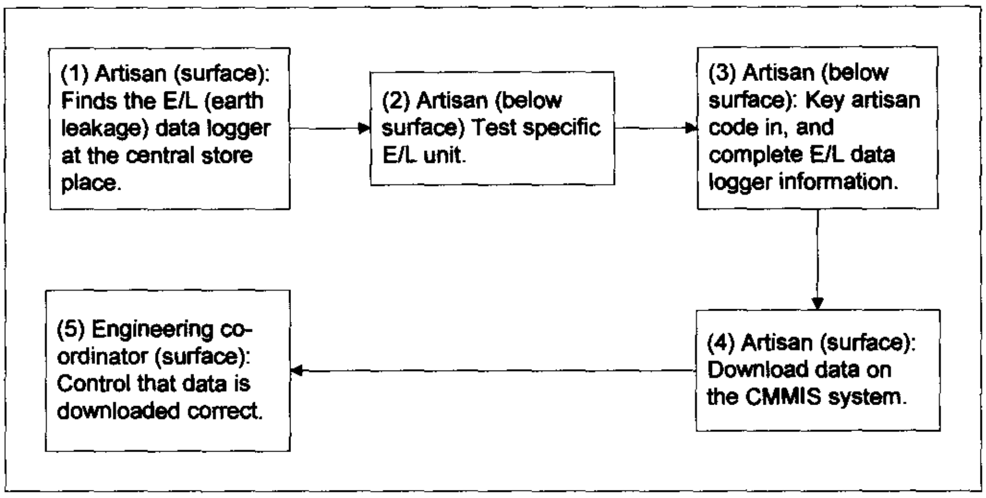


Figure 35 The improved maintenance data-collection method.

The problems of Section 3.3.1, are addressed in the following chronological list of solutions:

Solution 1: Information is only stored in electronic format. The lead-time before the information is stored in the CMMIS system is much shorter. The problem of data books that get lost is eliminated. Because information is processed only once in the audit process it is inclined to be less faulty.

Solution 2: An electronic record can only be created if the artisan actually visits the earth leakage unit in person. Records can only be created once barcodes are scanned. This forces the artisan to actually visit the earth leakage unit, and thus increases the probability of a proper audit.

Solution 3: Dynamic drop-down lists are implemented in the functionality of the program. The idea is that the user can change the lists as the information changes. This greatly eases the task of entering repetitive information. It also saves time because the user can now only select the appropriate choices. To adapt the existing list in the working environment is an elementary process.

Solution 4: Information is saved in an electronic format at the point of inspection. The artisan is now responsible that the information is transferred to the CMMIS system. The engineering co-ordinator is now only responsible for the supervision of the process. Tedious key-in work is eliminated.

3.3.3. Program development

The PDA program was developed according to the same process as described in Section 2.3. Figure 36 is an impression of the earth leakage test logger. The initial screen prompts the user to enter the CMMIS ID number. This is the only way to access the other two interfaces of the program.

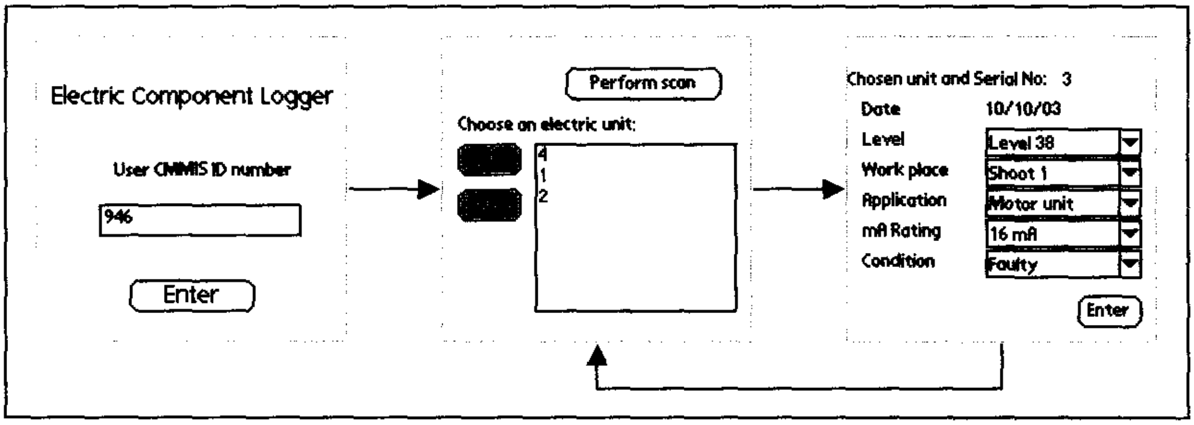


Figure 36 The AppForge earth leakage maintenance data-collection program.

On the second interface a list of all the records are provided. Once the artisan selected one or performed a scanning operation this single record can then be edited and stored in the PDB. When the user activates the HotSync operation the data is automatically downloaded onto the CMMIS system database[☉].

Program development occurred in the same modular way as described in Section 2.3. Other related data books that has an impact on the REMS performance will be developed at a later stage. Some are called the pump maintenance logbook, mini-sub test record, settler log sheets and dam inspection lists. For an impression of some of these data lists see Appendix C.

[☉] The CMMIS system makes use of an IBM DB2 database system.

3.4. Integration of REMS and OSIMS

To shift electrical loads of pumps the operation schedule on a mine need to change. Mines need a very high level of confidence that these changes will not, in any way, affect their safety and production. Therefore the OSIMS maintenance system needs to provide REMS with the added insurance that the complete mine pumping system is more reliable.

Optimal load shift capabilities can only be achieved if the fully integrated operation of the mine can be simulated in exact detail. REMS fulfil this function. An extensive verification process is also implemented through the use of previous years' detailed operational data. This detailed integrated, dynamic, control simulation procedure for the full mine operation is a first on the international market.

Figure 37 provides a graphical layout of the new REMS system and its interaction with the SCADA- and OSIMS systems.

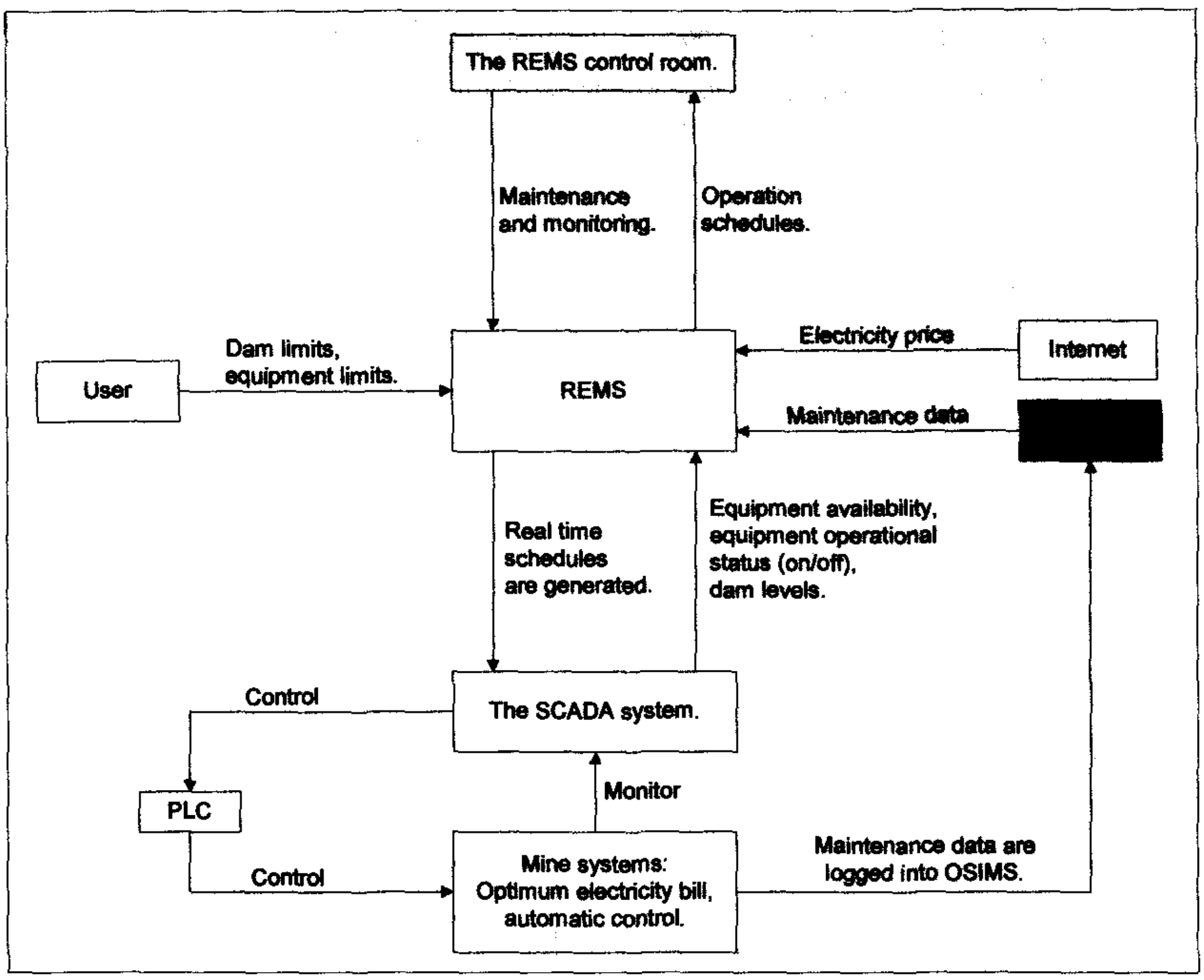


Figure 37 The integration of OSIMS and REMS.

New integrated mine software

Chapter 4 Case studies

CSIR

anglogold

TSI

Technology Services International

Success in business is ultimately measured in the monetary value that products and services generate.

4. Case Studies

In Section 4.1 the CSIR conference centre case study is described. It was confirmed that the *Palm data logger* goals were reached. With the ISKHUS contract, the Carlton building in Johannesburg was audited. Here it was verified that the reporting system functioned correctly. The complete ESCO auditor protocol was also verified in Section 4.2. TSI was the first client to acquire the BETB product. This is discussed in Section 4.3.

Finally Anglo Gold's Kopanang mine was used to develop the OSIMS maintenance data system. The OSIMS product-development was approved of by key-personnel at Kopanang. These ideas are explained in Section 4.4.

4.1. CSIR building: data acquisition verification

The aim of this study was to verify that the data collection procedures proposed by the *Palm data logger* system of Section 2.3 lived up to the goals of this study. The conference centre of the CSIR in Pretoria was used for this test purpose. The outcome of this study was also used by the CSIR-building-manager to plan their electrical-energy-usage better.

Building audits were conducted on two occasions. The first study was conducted in the week of 4 March 2002, by Dr R Els and the author. After this audit, a number of minor adjustments were made to the *Palm data logger* program. The final audit was conducted in the week of 12 March 2002 by Dr R Els, Mr J de Jongh and the author.

Specialised equipment was used to gather data. In Figure 38 from the top left hand corner in a clockwise direction: the anemometer which measures air flow in m/s, a hygro-thermometer with a probe which is used to measure air temperature and relative humidity, the thermometer logging device with a probe which measures temperature over time, the lux meter that measures the amount of light intensity and a simple thermometer with a probe.

The Palm Zire PDA device with the BETB *Palm data logger* program was the only other equipment that was used.

To be able to compare the new logging method with the old one, a "traditional paper" study was conducted in parallel with the one logged by the new PDA device. One auditor used the PDA device and the other auditor used traditional methods. Communication between the different parties were minimised.

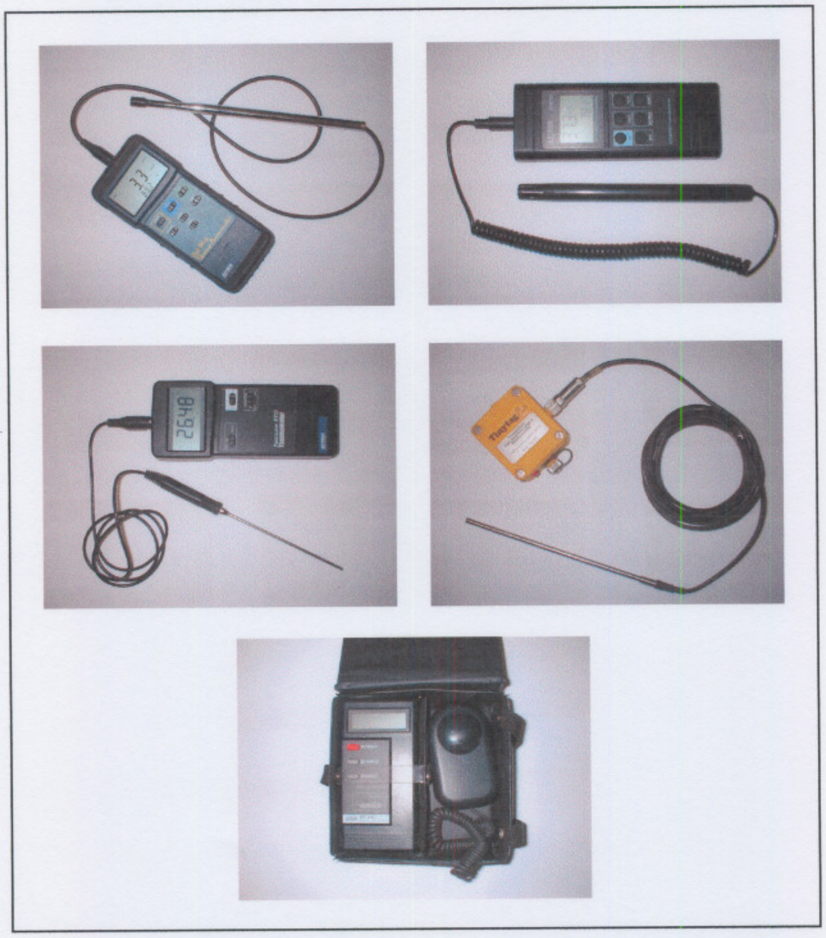


Figure 38 Data collection equipment for a building audit.

4.1.1. Log equipment data

Dr R Els used a "traditional" paper study to conduct the equipment survey for the HVAC system of Appendix D. Confusion and inconsistencies were created by using the traditional way of auditing. Much information that was un-necessary to the simulation process was also gathered, which wasted a lot of time. The "traditional" auditor had to return to the site to collect information that was forgotten the first time. The "traditional" audit took a total of 4 days.

Mr J de Jongh made use of the *Palm data logger* in using the new audit method. For this audit only 2 days were needed. Preparation of the data logging process was much more streamlined. The *Palm data logger* was used to collect all the relevant data. The PDA device was more easily used in the confined spaces of the plant room. The PDB space was ample and no data was lost. The program was found to be user friendly as well.

4.1.2. Log zones data

A "traditional" paper study was also conducted for the zones of the building. Major confusion and inconsistencies were created by using the traditional way of auditing. Too little information that was needed for the simulation process was gathered. This wasted time. The "traditional" auditor had to return to the site to collected information that was forgotten the first time. The "traditional" audit comprised of a total of 6 days.

For the *Palm data logger* study only 2 days were needed. Preparation to execute the methods of the new data logging process was much more streamlined. It was found that the graphical selection process of the Palm was exceptionally successful. This truly is a major advantage of BETB.

4.2. Carlton building: financial analysis and reporting verification

The aim of this study was to verify that the *Financial analysis tool* and *Report generation tool* of Section 2.4 and Section 2.5 satisfied the goals of this study. The Carlton building is located in the city centre of Johannesburg. Dr R Els conducted the energy and operational assessment for ISKHUS Power (Pty) Ltd. The project was completed by using the BETB software.

In Section 4.2.1 a brief summary of the final ISKHUS Power report is provided. The performance of the *Financial analysis tool* is provided in Section 4.2.2. The *Report generation tool* is discussed in Section 4.2.3. The complete integrated BETB audit protocol was also outlined in Section 4.2.4.

4.2.1. Summary of the report generated with BETB

In the report titled "Carlton Centre Energy and Operational Assessment" the energy savings potential in the Carlton Centre of Propnet was investigated. The reader can see the complete ISKHUS report in Appendix E. Good HVAC control is often the most cost-effective option to improve the energy efficiency of a building. However, the effect of changing the control strategy (i.e. effect on indoor comfort and energy consumption) is usually the most difficult to predict.

A new energy audit package, BETB, was developed to achieve this more easily and in record time. This new package was used to investigate the influence of new lights, variable speed drives (VSD) on the chillers, economisers, evaporative pre-cooling, VSD fans and various combinations thereof.

The simulation models were firstly calibrated and verified with actual measurements obtained from the existing system to confirm their accuracy for realistic control retrofit simulations. The simulation program could then be used to make accurate predictions of the energy savings potential of the building.

The electricity cost of the building in the previous year was R 11.47-mil (excl. VAT). With the aid of the integrated simulation tool it was possible to predict savings of R 2.18-mil per year by implementing certain control strategies. The direct payback period of these strategies is 6 years and the discounted payback period is 17 years, calculated with an interest rate of 15%. The internal rate of return over 10 years will be 12%.

4.2.2. Financial analysis

The *Financial analysis tool* was successfully implemented in conducting this study. Previously it took about 2 days to complete a proper financial analysis [42], [45]. With the new BETB *Financial analysis tool* this time is reduced to 1 day [11]. The results is clearly outlined in Appendix E.

4.2.3. Report generation

The *Report generation tool* was successfully implemented in conducting this study. Previously it took about 3 days to generate a proper report [42], [45]. With the new BETB *Report generation tool* this time is reduced to 1 day [11].

4.2.4. Integration

The BETB protocol of Chapter 2 was used to complete the work of this case study. The total active time spent by Dr R Els and his assistants on the ISKHUS project is 17 days [42], [45]. Previously an audit like this would have taken 45 days [11].

4.3. TSI: The first client to acquire BETB

TSI (Technology Services International) is a research subsidiary of ESKOM. One of the functions of TSI is to act as an ESCO that implements DSM projects. In Section 4.3.1 it is described that TSI needed to audit buildings, but did not have the necessary resources. The training for the implementation of, the BETB product at the TSI offices in Johannesburg is described in Section 4.3.2.

4.3.1. TSI as an ESCO

TSI needed to perform energy audits on 43 buildings in a time period of just over a year. The TSI team at that time (2002) consisted of twelve employees. Most of them were intermediate technicians with only four senior engineers. They approximated that a time of about two months is needed per building audit [12]. TSI realised that an alternative approach was needed to audit 43 buildings in one year with the resources at their disposal [38]. TSI did not have the needed level of expertise in their existing staff composition.

BETB empowered TSI with the knowledge to re-structure their audit methods and to reduce the time per building audit. The lower level of expertise required to use the BETB system also suited TSI [11].

4.3.2. Training and implementation

From January 2003 to May 2003 extensive training was provided to the TSI staff. It included the training of the twelve staff members on the operation of the BETB product. The test building that was used was the TSI research building in Johannesburg.

Twelve Palm Zire units were acquired and equipped with the *Palm data logger* program. The training and installation of twelve BETB PC units was completed at their offices in May 2003.

4.4. Kopanang mine: approval of OSIMS

The successful of implementation of the REMS pump optimising software is outlined in Section 4.4.1. In Section 4.4.2 it is explained that the proposed solutions of the OSIMS maintenance system is also accepted by the staff of Kopanang mine.

4.4.1. REMS is successfully implemented

The REMS technology enables users in the mining sector as well as ESKOM to fully benefit from DSM measures. The REMS technology was verified at Anglogold's Kopanang mine through a confidential agreement with the company HVAC International (Pty) Ltd.

To quantify the DSM success for the beneficiaries, two important aspects of REMS were measured. The first was the quantity of load (in MWh) that was shifted out of peak periods. This is important for ESKOM and the mine because they save. The second aspect was the electricity cost savings due to the load shift. This is important for the mines.

The average daily pump load profile, before REMS intervention, the recommended optimised profile and the achieved load profile for the previous 21 months at Kopanang mine are shown in Figure 39. Note that it was previously only possible for this very energy conscious mine to react on the first high RTP price[3] signal (in the morning). However, they were unable to react on the second peak, the most important one.

It is very difficult, if not impossible, to stay within constraints, e.g. dam levels, amount of pumps available, etc. if a full optimisation of the complete system is not carried out, as is possible with REMS. The result is a missed load shift opportunity during the evening peak.

By comparing the "previous" load profile with the "achieved" load profile it can be seen that 2,5 MW load was shifted continuously over the previous 21 months during the evening peak

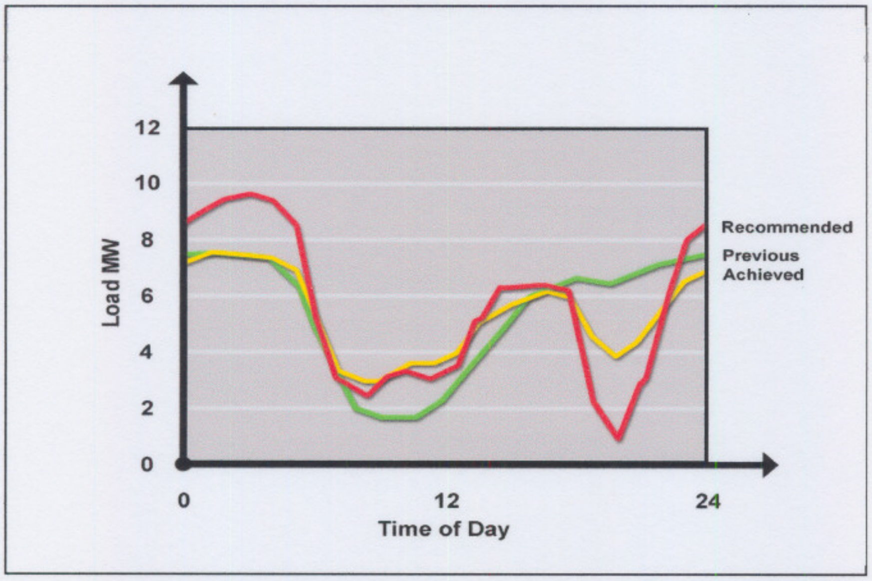


Figure 39 Average daily load profile for Kopanang pumps for the past 21 months.

The area below each line in Figure 39 represents the average daily energy use of the pumps over 21 months. The energy use of each profile is the same. However, the energy usage in peak time is more expensive. Thus, a load shift results in an energy cost saving. The typical monthly savings of the previous 21 months are summarised in Table 6. During this 21 months of operation, almost R900 000 was saved.

[3] Real time pricing is an ESKOM electricity tariff structure.

Month	Saving (R)	Unrealised potential (R)	Maximum Potential
Sep-01	230,720	0	230,720
Oct-01	109,806	19,001	128,807
Nov-01	77,387	17,423	94,810
Dec-01	45,593	36,573	82,166
Jan-02	11,672	0	11,672
Feb-02	8,581	0	8,581
Mar-02	9,288	8,920	18,208
Apr-02	39,132	25,312	64,444
May-02	21,680	22,158	43,838
Jun-02	66,176	20,768	86,944
Jul-02	71,491	13,639	85,130
Aug-02	26,865	0	26,865
Total	*718,391*	*163,795*	*882,186*
Sep-02	11,296	17,840	29,135
Oct-02	3,658	70,357	74,014
Nov-02	-7,078	64,561	57,483
Dec-02	-9,906	16,193	6,287
Jan-03	16,301	0	16,301
Feb-03	54,952	0	54,952
Mar-03	17,776	94,914	112,690
Apr-03	18,357	89,756	108,113
May-03	55,819	65,169	120,987
Jun-03	-7,092	28,375	21,283
Total	*154,083*	*447,164*	*601,247*
Grand Total	*872,474*	*610,958*	*1,483,432*

Table 6 Energy cost savings for Kopanang mine.

The client's business was enhanced with REMS. Figure 40 shows the cent per kWh which Kopanang mine has paid for electricity during the past five years. It is clear that there is a constant decline, which means that Kopanang is following the RTP price signal better every year.

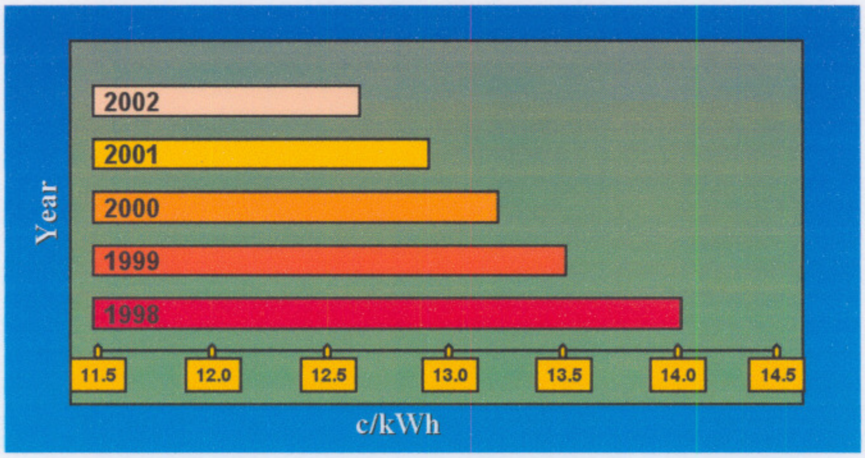


Figure 40 Cent per kWh paid for electricity by Kopanang mine.

Figure 41 compares Kopanang mine's electricity usage to the rest of the mines in the Anglo Gold group. It can be seen that not only do they have the best results in terms of c/kWh, but (except for one mine) also in terms of kWh/ton. On this graph the best results is as low as possible to the bottom of the graph and to the left on the graph as possible. It is accepted by the engineering manager of Kopanang mine that these significant savings could not be realised without REMS technology [46].

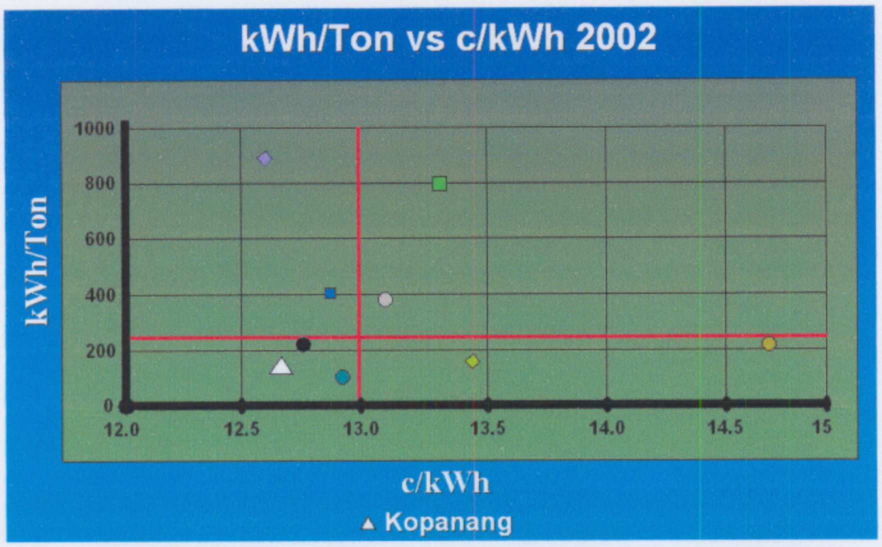


Figure 41 Electricity costs for all the Anglo Gold mines.

4.4.2. The OSIMS maintenance innovation is approved

Consultation meetings were held with Mr D Jonker (the head electrician at Kopanang) on 25 August 2003 to discuss the proposed solutions of OSIMS [34]. A discussion of the same nature was also conducted with Me M Kruger (engineering co-ordianator at Kopanang) on 25 August 2003 [35]. The solution content of OSIMS was proposed to Mr D Wilken on 7 October 2003 and also approved of (shaft engineer at Kopanang) [36].

The proposed solutions offered by OSIMS, was approved of by all the above mentioned Kopanang personnel. It was evident that the proposed OSIMS solution of Section 3.3.2 is the best option to solve the problems of Section 3.3.1.

Because of the sensitive nature of maintenance procedures in the mining environment, the national regulatory board (DME) also had to approve of the new data logging procedures. The DME needs to provide the necessary legal approval. Obtaining approval is currently in process. Only after the necessary approval is provided, can the OSIMS system be implemented at the Kopanang mine. This issue is being looked into by Mr E Coetzee at the Office for Mine Inspectors, Department of Mineral and Energy [37].

Chapter 5 Conclusion

One of the many important ideas Prof EH Mathews teaches his students is that great discoveries are often realised by the integration of technologies from different disciplines [38].

5. Conclusion

A summary of the results for the BETB study is supplied in Section 5.1. In Section 5.2 a summary of the results for the OSIMS study is provided. A brief closure in Section 5.3 ends this work.

5.1. Summary of the results for BETB

An integrated information system was designed and implemented for the BETB product. It consists of the following components: a *Simulation tool*, *Palm data logger*, *Financial analysis tool* and a *Report generation tool*. The program data flow was also successfully implemented.

The core results of BETB is summarised in Table 7. The traditional way of building audits are compared to that of the new BETB method. The time scales are divided according to the BETB protocol phases. All figures are provided in days. The complete building audit, according to traditional methods, are compared to the CSIR and Carlton building case studies [11], [43].

Phase in the BETB audit protocol.		A complete building audit by using traditional methods.	The BETB *Palm data logger*: CSIR.	The BETB *Financial analysis tool* and *Report generation tool*: Carlton building.	A complete audit using BETB: Carlton.
1	Gather building information.	5	-	-	2
2	Customise simulation template.	3	-	-	1
3	*** Data acquisition: equipment.**	4	2	-	2
	*** Data acquisition: zones.**	6	2	-	2
4	Calibrate measurements.	8	-	-	3
5	Configure simulation models.	4	-	-	1
6	Calibrate simulation models.	3	-	-	1
7	Verify simulation outputs.	2	-	-	1
8	Retrofit analysis.	5	-	-	2
9	*** Financial analysis.**	2	-	1	1
10	*** Compile report on findings.**	3	-	1	1
Total amount of days used.		45	4	2	17
Note: the asterisk (*) denotes all the phases that are applicable to the original work of this thesis.					

Table 7 Comparison of a traditional building audit with the new BETB audit.

It is clear that by using the BETB product, the ESCO auditor can reduce the average audit time from 45 days to only 17 days. The BETB also simplifies the building audit process so that it can easily be used by less skilled auditors.

References

Nobel Laureate Francis Crick said of the time he spent with James Watson discovering the structure of DNA, “It seems a ridiculous short period of work, but all the hours and hours of reading and discussion that led to the final model really should be included” [33].

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Appendices

Appendix A: The *Palm data logger* zone structure interfaces.

Appendix B: Impression of the *Palm data logger* improvement documentation.

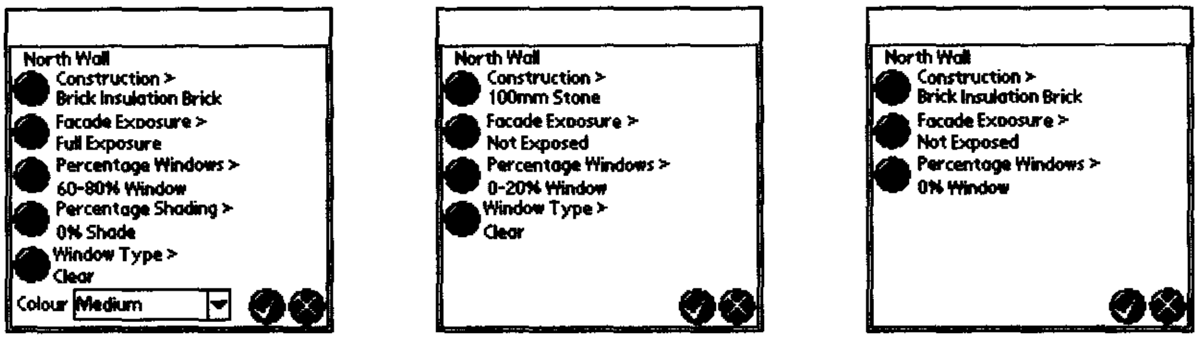
Appendix C: Mine data sheet examples, e.g. mini substations

Appendix D: "Traditional" data logging method at the CSIR

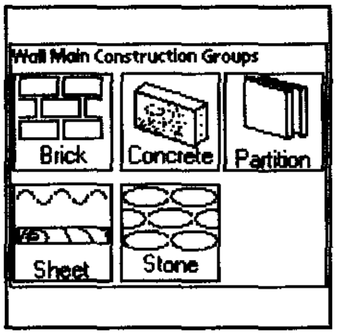
Appendix E: The ISKHUS report.

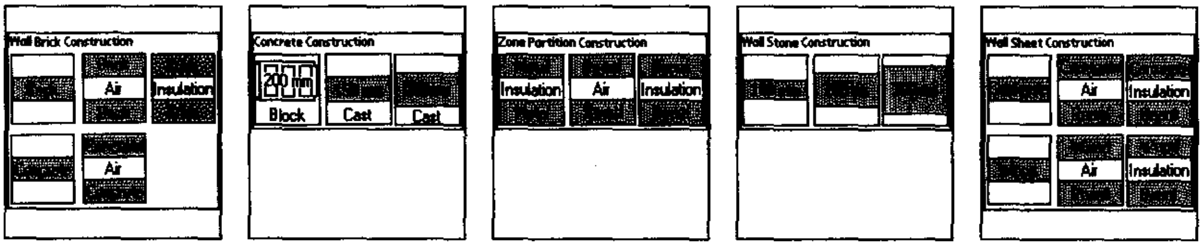
Appendix A: The *Palm data logger* zone structure interfaces

The wall attribute interface is shown below. Only necessary information is shown to the user.

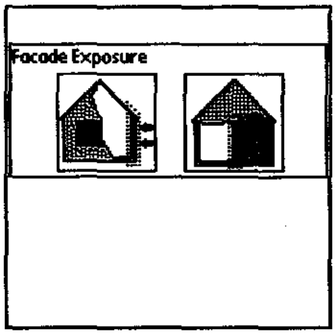


The wall construction groups:

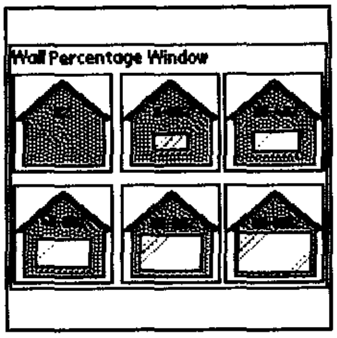




Façade exposure selection:

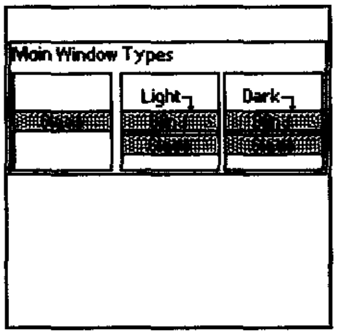


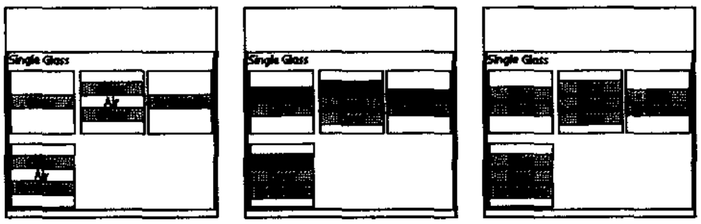
Percentage window selection:



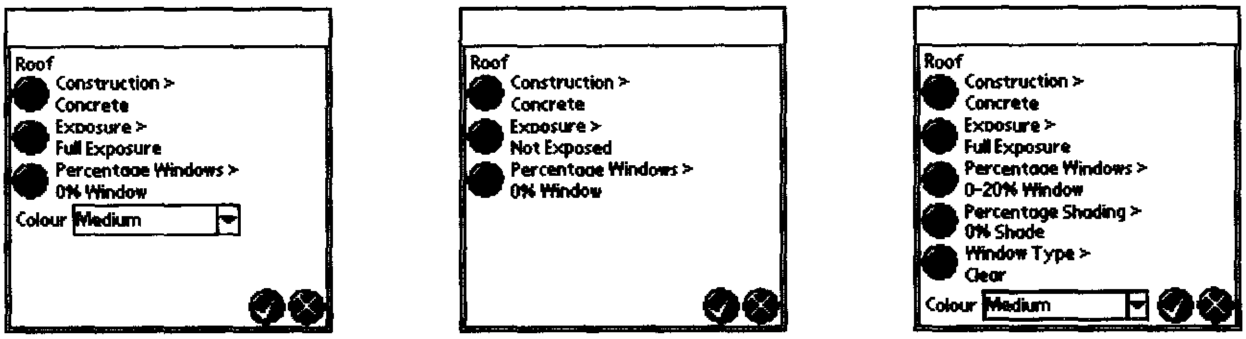
Percentage window shading:

Window type selection:

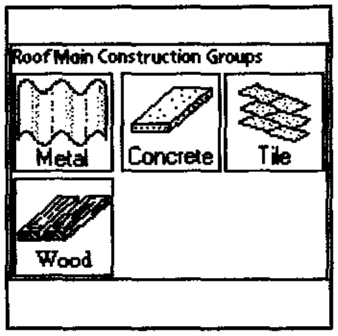


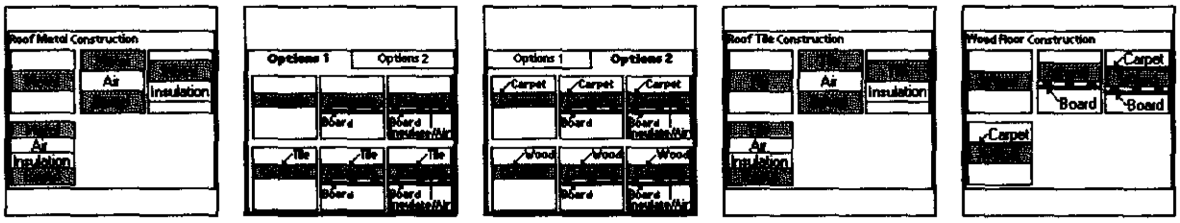


The roof attribute interface is shown below. Only necessary information is shown to the user.

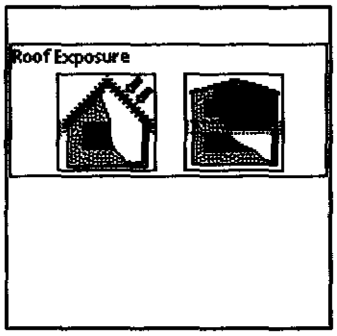


The roof construction groups:

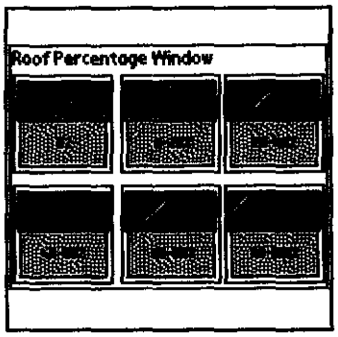




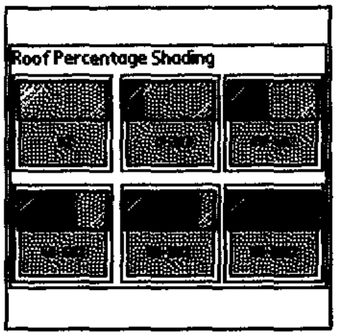
Roof exposure selection:



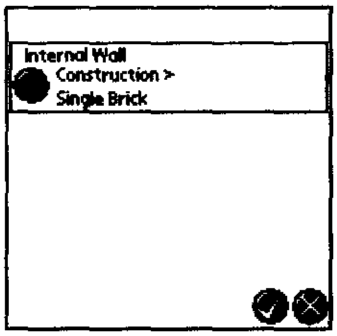
Percentage windows:



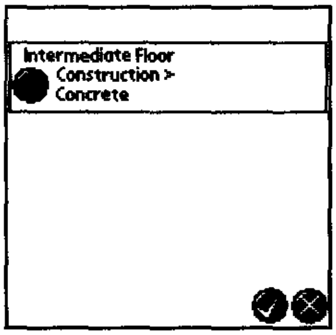
Percentage shading:



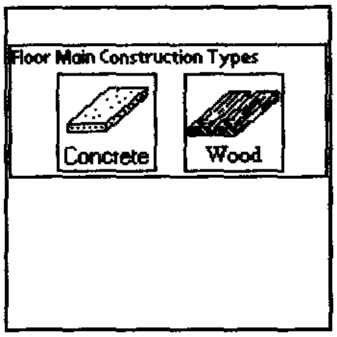
The internal wall attribute interface is shown below.

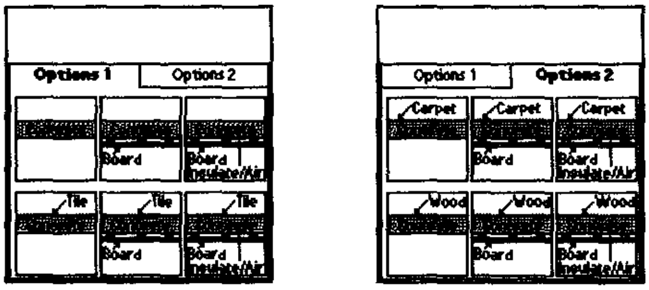


The intermediate floor attribute interface is shown below.

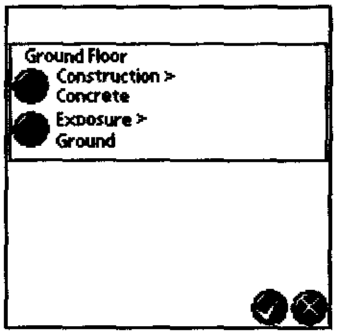


The floor construction types:

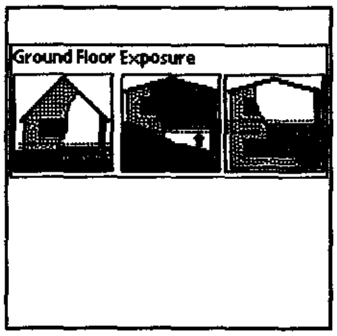




The ground floor attribute interface is shown below.



Ground floor exposure selection:



Appendix B: *Palm data logger* improvement documentation

VeranderingeFouteVerbeteringePalm_3

For DownloadProgram 3 and DataLogger_8 July 2, 2002

✓ Add a copy function when the user is in edit mode

✓ Textboxes should be enlarged to fit 5 characters. It helps the user when editing a component. On the other sheet too.

✓ "New project" button should be activated for Zones. Check proper operation of this button.

✓ Activate Zone copy function.

✓ The Zone section of the program should not be able to accept the same name. The user should be able to make a copy of a Zone, but could be asked by the program to rename the specified Zone to a non-existing one. Ensure that the list boxes in the Zone and Equipment sections do not allow the user to reuse a name. Component list should only accept unique names

✓ VOEG BY May 6, 2002: At the AirHeatRecoverySystem the following:
The "Control" box could be edited
Default values are out of range for allowable values

✓ DEON BY May 8, 2002: At the component list, Do not want the Air, Various, Water anymore! To suit VisualQEC program.

Doen nog ekstra checks op die enter buttons ect

✓ Sorg dat alle vorms en db's toe gemaak is for equipment.

✓ See that all db and forms closes for the Zone side.

Mistakes

✓ CopyCopyCo for the listbox and text box sizes differ for the ZoneMain and ZoneAddEdit forms.

✓ Spelling check. "Pump's" wrong, Pumps correct.

✓ Fault: WestWallFacadeExposed = WestWallConstruction in the Zone section.

✓ Tabs still a problem on some components. Activation and initialization seems to be the problem. VOEG BY May 7, 2002: When user enters cell and ads (I think, or maybe not) a new unit, exits and directly goes back again then the second tab "page 2" is not activated without clicking on the first first! Internal loads se "page 2" tab werk nie sonder om #1 te druk nie! Address on other forms too.

✓ Mistake on "Brick sub form": Only looks like a mistake. There should be two concrete stuff there.

✓ Default main screen for Zones should read "No Zones" instead of "No Components".

✓ Chiller: Vvaporator, spelling should be Evaporator.

✓ 113: FloorCarpetWoodCeilingLevel2.RGX mistake should be fixed. Picture at FloorInternal not correct.

✓ With Chiller: Dropdown box should be activated the other way aroud.

With WHRHeatPump: Edit box only accepts nine characters ect.

Keep eye on the fault at Heater8.qec. 2002-05-17 do not delete copy properly.

✓ NB: When user keys in "5.5" into the text editor of the Palm and select "Done" at the NorthWall the value is displayed as 55 and not rounded up/down to 6 or 5 as should be expected.

Add another field: "Number of Units" 2002-05-24 add to the Cooling Tower.

✓ Correct throughout program: "PDBDeleteRecordEx dbXYZ, afDeleteModeRemove"

✓ Zone description txtBox; Everything is highlighted

✓ See that "story height" dimension could accept decimal numbers.

In the data export program: West wall construction = West wall façade exposed. The same values are exported in the "exe" program.

"The below floor level exposure:" note part of the Floor screen in the Zone did not show detail at some stage. Somehow it did not display.
Moet daar dependency wees by die Steam Humidifier van die dropdown list ect?

10 May, 2002: One of the "disable" buttons gives problems on the return with edit mode!

✓ Evaporative Cooler: Label "Caption" verkeerd

✓ Move "Internal Loads" Zone little down (on the form)

Improvements

Walls: when ticked block out the disable.

✓ When the user is in edit mode of an existing component, and he tap on a textbox, it would appear as if the data disappeared. When user tap in textbox, the box clears automatically.

Colour the insulation and air void with a pattern. Also standardise the pictures of the components.

✓ At Zone: Always asked "do you want to save" even if the user haven't changed anything.

✓ Language of Zone main screen.

✓ Delete at the Zone without asking if sure.

NB: Palm-in-program help should be available. In conjunction with Prikkie.

Change form names to be consistent and representative of project. In conjunction with the Help documentation.

✓ Glass type X would be "glass" only.

Wish list

Have a writing sheet available to collect contingency information. Many times labels of machinery is damaged and as a second alternative the user would like to record the serial numbers and make of equipment.

Have a pointer facility available to remind the user of information still to be entered. This serves as a memory facility to remember important data.

It would be good to be able to save more than one project on the Palm.

The calculator should be available during use of the program. The user should be able to insert information after using it.

A drawing pad could help with layout of buildings and remembering information, the user might prefer a paperless system. On the Zone: Remembers which buttons were edited last. For the sake of discontinuity information gathering. Put colour on button instead of just_visit.

List of activities

Document testing.
Programmer documentation!
Neaten all interfaces and standardize all textboxes ect fonts ect.

Appendix C: Mine data sheet examples

MONTHLY EXAMINATIONS AND MAINTENANCE LOG FOR MINI-SUBSTATIONS

Mini Sub No

SHAFT: .... PLACE: .... MONTH: 0501

ITEMS		✓	×
1.	CLEAN MINI-SUBSTATION AND APPARATUS		
2.	CHECK LOAD		
3.	TEST 27Ω RESISTOR (WITH MULTIMETER)		
4.	NERM/OPERATIONAL/		
5.	CHECK FOR HOT CONNECTIONS ON L.T. BREAKERS		
6.	CHECK PROTECTION SETTINGS OF ADIT RELAY AND RECORD		
7.	TRANSFORMER OIL LEAKS AND OIL STAINS ON FLOOR		
8.	TRANSFORMER TAP SETTINGS AND LOCKED		
9.	CHECK OPERATION OF ADIT RELAY (TEST)		
10.	TRANSFORMER OIL LEVEL		
11.	BUND WALL SOAK PITS		
12.	ALL L T PANELS ARC BARRIERS PRESENT		
13.	UP TO DATE DRAWING AVAILABLE		
14.	SWITCHING HANDLE PRESENT		
15.	MINI-SUB LOCKED		
16.	LIGHTING		
17.	HANGING- AND SIDEWALL IN SAFE CONDITION		
18.	VENTILATION SATISFACTORY		
19.	FIRE EXTINGUISHERS PRESENT		
20.	EXPIRY DATE OF EXTINGUISHERS		
21.	SWITCHGEAR PANEL COVERS SECURED		
22.	H T SWITCHGEAR LABELLED		
23.	L T SWITCHGEAR LABELLED		
24.	ALL CABLE ARMOURING SHEATHS AND EARTH CONDUCTORS BONDED TO MINI-SUBSTATION EARTH		
25.	ELECTRICAL SHOCK, FIRE UNAUTHORISED ENTRY AND DANGER SIGNS (FIVE IN ONE SIGN)		
26.	HOUSE KEEPING		
27.	*CHECK RATING AND OPERATION OF EARTH LEAKAGES IN THE L T PANELS*		
	27.1 ENTER DATA AND RESULTS IN THE SWITCHING AND DATA SECTION		

DATE	REMARKS/DEFECTS AND CORRECTIONS	SIGNATURE

Kopanang Mine

CHECKLIST: KM/CL/WDE/001 OPERATIONAL PROCEDURE: KM/VT/0064

anglogold

WINDER DAILY EXAMINATION INSPECTION LIST

6614 – BMR NO. 2 – GEC (ROCK)

ELECTRICIAN

WEEK ENDING: / /

M	T	W	T	F	S	S	
							Material Over and Underwinds
							Electronic Underwinds
							Tachograph operation
							Slack Rope
							Escort Tacho's
							Supervision Tacho's
							Trip Indication Panel
							DC Drive Motor Commutation
							Visual exam of external Electrical components
							Miscoll Device
							HT Tripping voltage supply
							Vecor Battery Voltage and Charger
							Skip full no discharge device
							Full skip wrong direction creep speed
							Headgear interlocking
							RESPONSIBLE ARTISAN'S DAILY SIGNATURE

6614 – BMR NO. 2 – GEC (ROCK

BOILERMAKER

WEEK ENDING: / /

M	T	W	T	F	S	S	
							Skip Transom & Bridle
							Skip Safety Catches
							Skip Guide Rollers and Brackets
							Skip Guide Liners
							Skip Door and Cylinder arrangements
							Skip Steel Wearing Plates – inside
							Skip Rubber Wearing Liners – inside
							Skip Steel Wearing Liners below Radial Door
							Skip body
							Skip bottom Beam
							Skip general condition
							Headgear and Bank # Gates
							Clamping Bar
							RESPONSIBLE ARTISAN'S DAILY SIGNATURE / ENGINEER'S SIGNATURE & DATE SIGNED

REMARKS:

RUSTENBURG PLATINUM MINES LIMITED

AMANDELBULT SECTION

SECTION: ______________

REGULATION 24.2 CONTROL OF FIRST AID EQUIPMENT

DATE	LOCATION OF BOX	PERSON IN CHARGE	F/A BOX SEALED	CHECKLIST AVAILABLE	SHIFT SUPERVISOR

Appendix D: "Traditional" data logging method used at the CSIR

CSIR Conference Center
Data-logging of the air-conditioning system and testing of the Palm Data Logger program

Study by: Riaan Els and Derek van Rhyn
March 4, 2002

Introduction

The Conference center consists of ten different air supply zones. Names are given to all zones: Crystal, Onyx, Garnet, Amber, Foyer, Jade, Ruby, Coffee, Diamond, Emerald.

The purpose of this study were to install data loggers on the fresh-air and return-air units. These loggers would record the air temperature over a period of weeks in five minute impulses.

The analysts also recorded data (air temperature, relative humidity, air-flow velocity) by using handheld devices. Other data were directly recorded by reading it from inlet and outlet pipes, for instance with the water cooled chillers, air handling units (filter, coil and fan included in one unit).

1. Suggested improvements for the Palm data logger program:

1. Add a copy function when the user is in edit mode
2. Have a writing sheet available to collect contingency information. Many times labels of machinery is damaged and as a second alternative the user would like to record the serial numbers and make of equipment.
3. Have a pointer facility available to remind the user of information still to be entered. This serves as a memory facility to remember important data.
4. When the user is in edit mode of an existing component, and he tap on a textbox, it would appear as if the data disappeared.
5. It would be good to be able to save more than one project on the Plam.
6. The calculator should be available during use of the program. The user should be able to insert information after using it.
7. A drawing pad could help with layout of buildings and remembering information, the user might prefer a paperless system.
8. Textboxes should be enlarged to fit 5 characters. It helps the user when editing a component.
9. Spelling check. "Pump's" wrong, Pumps correct.
10. When user tap in textbox, the box clears automatically. Also see point 4 above.
11. Tabs still a problem on some components. Activation and initialization seems to be the problem.
12. Colour the insulation and air void with a pattern. Also standardize the pictures of the components.
13. "New project" button should be activated for Zones. Check proper operation of this button.
14. Default main screen for Zones should read "No Zones" instead of "No Components".
15. See that "storey height" dimension could accept decimal numbers.
16. Activate Zone copy function.
17. The Zone section of the program should not be able to accept the same name. The user should be able to make a copy of a Zone, but could be asked by the program to rename the specified Zone to a non-existing one.
18. In the data export program: West wall construction = West wall façade exposed. The same values are exported in the "exe" program.

Return air units:

Return air unit 1:

Return-air Onyx		
Inlet-air humidity	52.6	%RH
Inlet-air temperature	24.7	°C
Inlet-air velocity	3.9	m/s
Return-air Emerald		
Inlet-air humidity	61.4	%RH
Inlet-air temperature	23.6	°C
Inlet-air velocity	3.1	m/s
Return-air Ruby		
Inlet-air humidity	55.4	%RH
Inlet-air temperature	24.8	°C
Inlet-air velocity	1.7	m/s
Return-air fan velocity	12.5	m/s

Return air unit 2:

Return-air Coffee		
Inlet-air humidity	52.6	%RH
Inlet-air temperature	24.1	°C
Inlet-air velocity	3.9	m/s
Return-air Amber		
Inlet-air humidity	51.3	%RH
Inlet-air temperature	24.3	°C
Inlet-air velocity	3.9	m/s
Return-air fan velocity	11.5	m/s

Return air unit 3:

Return-air Foyer		
Inlet-air humidity	52.9	%RH
Inlet-air temperature	24.0	°C
Inlet-air velocity	4.8	m/s
Return-air fan velocity	9.0	m/s

Return air unit 4:

Return-air Diamond		
Inlet-air humidity	50.3	%RH
Inlet-air temperature	24.2	°C
Inlet-air velocity	5.7	m/s
Return-air fan velocity	7.0	m/s

Figure 1 Return air units

Chiller room:

Water Cooled Chiller 1:

Evaporator outlet temperature	9.0	°C
Evaporator inlet temperature	14.0	°C
Comperessor power	74.0	kW
Condensor inlet temperature	37.0	°C
Condensor outlet temperature	40.0	°C

Water Cooled Chiller 2:

Evaporator outlet temperature	10.0	°C
Evaporator inlet temperature	13.0	°C
Comperessor power	74.0	kW
Condensor inlet temperature	37.0	°C
Condensor outlet temperature	40.0	°C

Evaporator Pump 1:

Type: Hawker Siddeley Electric

Serial No.	BC6391/2	
Power	15.0	kW
Rotaional speed	1445.0	rpm

Boiler Pump:

Type: Hawker Siddeley Electric

Serial No.	BDZ8000/54	
Power	4.0	kW
Rotational speed	1430.0	rpm
Head	180.0	kPa

Figure 2 Chiller room equipment

Air handling units:

Foyer:			Coil: on/off
Air-in-flow pressure	100.0	Pa	
Air-in-flow velocity	8.5	m/s	
Air-in-flow area	10 x 0.5 x 0.5	m²	
Water mass-flow	n/a	kg/s	
Inlet air drybulb temperature	26.0	°C	
Coil outlet temperature	19.0	°C	
Coil inlet temperature	14.0	°C	
Fan Power	5.5	kW	
Air-outflow temperature	15.5	°C	on

Amber:			
Air-in-flow pressure	100.0	Pa	
Air-in-flow velocity	5.8	m/s	
Air-in-flow area	10 x 0.5 x 0.5	m²	
Water mass-flow	n/a	kg/s	
Inlet air drybulb temperature	26.0	°C	
Coil outlet temperature	19.0	°C	
Coil inlet temperature	11.0	°C	
Fan Power	7.5	kW	
Air-outflow temperature	24.1	°C	off

Ruby:			
Air-in-flow pressure	55.0	Pa	
Air-in-flow velocity	5.9	m/s	
Air-in-flow area	3 x 0.5 x 0.5	m²	
Water mass-flow	n/a	kg/s	
Inlet air drybulb temperature	25.0	°C	
Coil outlet temperature	12.0	°C	
Coil inlet temperature	10.0	°C	
Fan Power	3.0	kW	
Air-outflow temperature	16.7	°C	on

Emerald:			
Air-in-flow pressure	70.0	Pa	
Air-in-flow velocity	4.1	m/s	
Air-in-flow area	2 x 0.5 x 0.7	m²	
Water mass-flow	n/a	kg/s	
Inlet air drybulb temperature	25.5	°C	
Coil outlet temperature	18.0	°C	
Coil inlet temperature	11.0	°C	
Fan Power	1.5	kW	
Air-outflow temperature	18.0	°C	on

Figure 3 Air handling units (1 of 2)

Jade:

			Coil: on/off
Air-in-flow pressure	100.0	Pa	
Air-in-flow velocity	5.9	m/s	
Air-in-flow area	3 x 0.5 x 0.5	m²	
Water mass-flow	n/a	kg/s	
Inlet air drybulb temperature	25.5	°C	
Coil outlet temperature	n/a	°C	
Coil inlet temperature	10.0	°C	
Fan Power	2.2	kW	
Air-outflow temperature	n/a	°C	n/a

Coffee:

Air-in-flow pressure	50.0	Pa	
Air-in-flow velocity	4.2	m/s	
Air-in-flow area	3 x 0.5 x 0.5	m²	
Water mass-flow	n/a	kg/s	
Inlet air drybulb temperature	25.0	°C	
Coil outlet temperature	13.0	°C	
Coil inlet temperature	10.0	°C	
Fan Power	4.0	kW	
Air-outflow temperature	13.9	°C	on

Diamond:

Air-in-flow pressure	55.0	Pa	
Air-in-flow velocity	4.1	m/s	
Air-in-flow area	10 x 0.5 x 0.5	m²	
Water mass-flow	n/a	kg/s	
Inlet air drybulb temperature	25.0	°C	
Coil outlet temperature	15.0	°C	
Coil inlet temperature	12.0	°C	
Fan Power	7.5	kW	
Air-outflow temperature	12.8	°C	on

Onyx First Floor:

Air-in-flow pressure	85.0	Pa	
Air-in-flow velocity	4.5	m/s	
Air-in-flow area	6 x 0.5 x 0.5	m²	
Water mass-flow	n/a	kg/s	
Inlet air drybulb temperature	25.0	°C	
Coil outlet temperature	17.0	°C	
Coil inlet temperature	11.0	°C	
Fan Power	4.0	kW	
Air-outflow temperature	25.7	°C	off

Emerald:

Air-outflow temperature	18.0	°C	on

Figure 3 Air handling units (2 of 2)

CSIR Conference Center
Download of logger data and alternative data collection of the air-conditioning system.

Study by: Riaan Els, Jako de Jong and Derek van Rhyn
March 12, 2002

Introduction

- The Conference center consists of ten different air supply zones. Names are given to all zones: Crystal, Onyx, Garnet, Amber, Foyer, Jade, Ruby, Coffee, Diamond, Emerald.

The purpose of this study were to install data loggers on the fresh-air and return-air units. These loggers would record the air temperature over a period of weeks in five minute impulses.

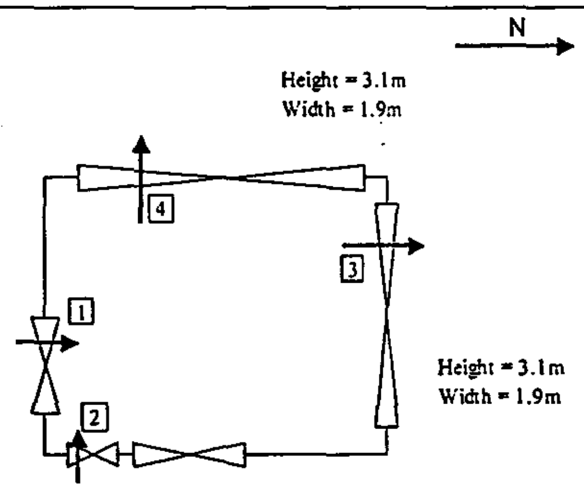
The analysts also recorded data (air temperature, relative humidity, air-flow velocity) by using handheld devices. Other data were directly recorded by reading it from inlet and outlet pipes, for instance with the water cooled chillers, air handling units (filter, coil and fan included in one unit).

Return air units:

	Study 04/04/2002	Study 12/04/2002	
Return air unit 1:			
Return-air Onyx			
Inlet-air humidity	52.6	53.7	%RH
Inlet-air temperature	24.7	23.2	°C
Inlet-air velocity	3.9	4.2	m/s
Return-air Emerald			
Inlet-air humidity	61.4	53	%RH
Inlet-air temperature	23.6	22.3	°C
Inlet-air velocity	3.1	3.7	m/s
Return-air Ruby			
Inlet-air humidity	55.4	51	%RH
Inlet-air temperature	24.8	23.5	°C
Inlet-air velocity	1.7	2.6	m/s
Return-air fan velocity (in)	12.5	8.8	m/s
Fan-motor power	5.5	5.5	kW
Fan-motor speed	950.0	950	rpm
Return air unit 2:			
Return-air Coffee			
Inlet-air humidity	52.6	49	%RH
Inlet-air temperature	24.1	23.5	°C
Inlet-air velocity	3.9	3.4	m/s
Return-air Amber			
Inlet-air humidity	51.3	50	%RH
Inlet-air temperature	24.3	23.7	°C
Inlet-air velocity	3.9	3.7	m/s
Return-air fan velocity (in)	11.5	11.2	m/s
Fan-motor power	4.0	4	kW
Fan-motor speed	950.0	950	rpm
Return air unit 3:			
Return-air Foyer			
Inlet-air humidity	52.9	50	%RH
Inlet-air temperature	24.0	23.3	°C
Inlet-air velocity	4.8	4.6	m/s
Return-air fan velocity (in)	9.0	11.2	m/s
Fan-motor power	4.0	4	kW
Fan-motor speed	950.0	950	rpm
Return air unit 4:			
Return-air Diamond			
Inlet-air humidity	50.3	n/a	%RH
Inlet-air temperature	24.2	n/a	°C
Inlet-air velocity	5.7	n/a	m/s
Return-air fan velocity (in)	7.0	n/a	m/s
Fan-motor power	3.0	3	kW
Fan-motor speed	950.0	950	rpm

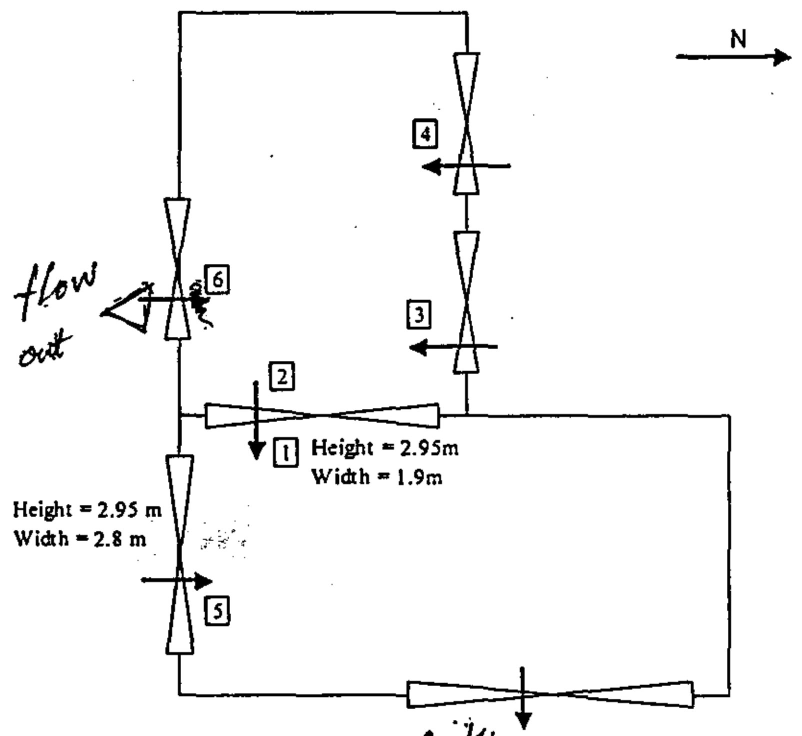
Return air by negative pressure:
Return-air Jade
See Figure 1 for graphical layout

Figure 1 Return air units



1 Air outflow from Foyer return fan. Flow speed = 3.2 m/s
2 Air outflow from Jade. Via negative pressure, no return air unit exists.
3 Air flow from building inside to atmosphere. This is an outflow. Flow speed = 0.4 m/s
4 Air flow to plant room. Flow speed = 0.17 m/s

Diagram 2 Return air mixing room for Diamond, Foyer and Jade



1 Air flow from return fans. Flow ~~speed~~ velocity = 0.93 m/s
2 Air flow from return fans. Flow speed = 0.70 m/s
3 Air flow from return air unit 1 fan. Flow speed = 4.30 m/s
4 Air flow from return air unit 2 fan. Flow speed = 3.47 m/s
5 Air flow from atmosphere into mixing room. Flow speed = 0.33 m/s
6 Air flow from atmosphere into return air room. Flow speed = 0.63 m/s

Diagram 1 Return air mixing room for Onyx, Emerald, Ruby, Coffee and AMBER

Chiller room:

	Study 04/04/2002	Study 12/04/2002	
Water Cooled Chiller 1:			
Evaporator outlet temperature	9.0	10.6	°C
Evaporator inlet temperature	14.0	10.8	°C
Comperessor power	74.0	74.0	kW
Condensor inlet temperature	37.0	32.0	°C
Condensor outlet temperature	40.0	34.0	°C
Water Cooled Chiller 2:			
Evaporator outlet temperature	10.0	9.7	°C
Evaporator inlet temperature	13.0	12.0	°C
Comperessor power	74.0	74.0	kW
Condensor inlet temperature	37.0	32.0	°C
Condensor outlet temperature	40.0	34.0	°C
Evaporator Pump 1:			
Type: Hawker Siddeley Electric			
Serial No.	BC6391/2	BC6391/2	
Power	15.0	15.0	kW
Rotaional speed	1445.0	1445.0	rpm
Boiler Pump:			
Type: Hawker Siddeley Electric			
Serial No.	BDZ8000/54	BDZ8000/54	
Power	4.0	4.0	kW
Rotational speed	1430.0	1430.0	rpm
Head	180.0	180.0	kPa

Figure 2 Chiller room equipment

Air handling units:

	Study 04/04/2002	Coil: on/off	Study 12/04/2002	Coil: on/off	
Foyer:					
Air-in-flow pressure	100.0		100.0		Pa
Air-in-flow velocity	8.5		2.7 (ver reading)		m/s
Air-in-flow area	10 x 0.5 x 0.5		10 x 0.5 x 0.5		m²
Water mass-flow	n/a		n/a		kg/s
Inlet air drybulb temperature	26.0		24.8		°C
Coil outlet temperature	19.0		14.6		°C
Coil inlet temperature	14.0		10.6		°C
Fan Power	5.5		5.5		kW
Air-outflow temperature	15.5	on	14.1	on	°C
Amber:					
Air-in-flow pressure	100.0		100.0		Pa
Air-in-flow velocity	5.8		4.4		m/s
Air-in-flow area	10 x 0.5 x 0.5		10 x 0.5 x 0.5		m²
Water mass-flow	n/a		n/a		kg/s
Inlet air drybulb temperature	26.0		24.8		°C
Coil outlet temperature	19.0		21.4		°C
Coil inlet temperature	11.0		13.4		°C
Fan Power	7.5		7.5		kW
Air-outflow temperature	24.1	off	23.8	on	°C
Ruby:					
Air-in-flow pressure	55.0		70.0		Pa
Air-in-flow velocity	5.9		1 (ver reading)		m/s
Air-in-flow area	3 x 0.5 x 0.5		3 x 0.5 x 0.5		m²
Water mass-flow	n/a		n/a		kg/s
Inlet air drybulb temperature	25.0		24.8		°C
Coil outlet temperature	12.0		14.0		°C
Coil inlet temperature	10.0		14.0		°C
Fan Power	3.0		3.0		kW
Air-outflow temperature	16.7	on	25.0	off	°C
Emerald:					
Air-in-flow pressure	70.0		70.0		Pa
Air-in-flow velocity	4.1		4.0		m/s
Air-in-flow area	2 x 0.5 x 0.7		2 x 0.5 x 0.7		m²
Water mass-flow	n/a		n/a		kg/s
Inlet air drybulb temperature	25.5		25.5		°C
Coil outlet temperature	18.0		16.4		°C
Coil inlet temperature	11.0		9.0		°C
Fan Power	1.5		1.5		kW
Air-outflow temperature	18.0	on	15.1	on	°C

Figure 3 Air handling units (1 of 2)

	Study 04/04/2002	Coil: on/off	Study 12/04/2002		
Jade:					
Air-in-flow pressure	100.0		150.0		Pa
Air-in-flow velocity	5.9		6.2		m/s
Air-in-flow area	3 x 0.5 x 0.5		3 x 0.5 x 0.5		m²
Water mass-flow	n/a		n/a		kg/s
Inlet air drybulb temperature	25.5		24.8		°C
Coil outlet temperature	n/a		15.7		°C
Coil inlet temperature	10.0		11.8		°C
Fan Power	2.2		2.2		kW
Air-outflow temperature	n/a	n/a	14.8	on	°C
Coffee:					
Air-in-flow pressure	50.0		60.0		Pa
Air-in-flow velocity	4.2		3.7		m/s
Air-in-flow area	3 x 0.5 x 0.5		3 x 0.5 x 0.5		m²
Water mass-flow	n/a		n/a		kg/s
Inlet air drybulb temperature	25.0		25.0		°C
Coil outlet temperature	13.0		14.0		°C
Coil inlet temperature	10.0		10.3		°C
Fan Power	4.0		4.0		kW
Air-outflow temperature	13.9	on	24.7	off	°C
Diamond:					
Air-in-flow pressure	55.0		unit off		Pa
Air-in-flow velocity	4.1		unit off		m/s
Air-in-flow area	10 x 0.5 x 0.5		10 x 0.5 x 0.5		m²
Water mass-flow	n/a		unit off		kg/s
Inlet air drybulb temperature	25.0		unit off		°C
Coil outlet temperature	15.0		unit off		°C
Coil inlet temperature	12.0		unit off		°C
Fan Power	7.5		unit off		kW
Air-outflow temperature	12.8	on	unit off	off	°C
Onyx First Floor:					
Air-in-flow pressure	85.0		90.0		Pa
Air-in-flow velocity	4.5		3.7		m/s
Air-in-flow area	6 x 0.5 x 0.5		6 x 0.5 x 0.5		m²
Water mass-flow	n/a		n/a		kg/s
Inlet air drybulb temperature	25.0		25.0		°C
Coil outlet temperature	17.0		14.8		°C
Coil inlet temperature	11.0		11.2		°C
Fan Power	4.0		4.0		kW
Air-outflow temperature	25.7	off	15.5	on	°C

Figure 3 Air handling units (2 of 2)

Appendix E: ISKHUS report

CARLTON CENTRE ENERGY AND OPERATIONAL ASSESEMENT

HVAC and BEMP report: FINAL

ISKHUS
POWER (PTY) LTD

ISKHUS Power

March 2003

EXECUTIVE SUMMARY

In this report the energy savings potential in the Carlton Centre of Propnet was investigated. Good HVAC control is often the most cost-effective option to improve the energy efficiency of a building. However, the effect of changing the control strategy (i.e. effect on indoor comfort and energy consumption) is usually the most difficult to predict.

A new energy audit package, ESCO Toolbox, was developed to achieve this more easily and in record time. This new package was used to investigate the influence of new lights, variable speed drives (VSD) on the chillers, economisers, evaporative pre-cooling, VSD fans and various combinations thereof was investigated.

The simulation models were firstly calibrated and verified with actual measurements obtained from the existing system to confirm their accuracy for realistic control retrofit simulations. The simulation program could then be used to make accurate predictions of the energy savings potential of the building.

The electricity cost of the building in the previous year was R 11.47-mil (excl. VAT). With the aid of the integrated simulation tool it was possible to predict savings of R 2.18-mil per year by implementing these control strategies. The direct payback period of these strategies is 6 years and the discounted payback period is 17 years, calculated with an interest rate of 15%. The internal rate of return over 10 years will be 12%.

PROJECT INFORMATION

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REPORT DETAILS

REPORT TITLE:	CARLTON CENTRE ENERGY AND OPERATIONAL ASSESMENT
REPORT SUB-TITLE:	HVAC and BEMP report
AUTHOR:	Riaan Els
REFERENCE NO:	#
DATE:	March 2003

Report results

COST SAVINGS PER YEAR:	R 2.18 million
% COST SAVINGS PER YEAR:	18.97 %
PROJECT COST:	R 13 million
IRR OVER 10 YEARS:	12 %

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INTRODUCTION

Heating, ventilation and air-conditioning (HVAC) system energy efficiency in buildings means 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 productivity of the occupant. The cost associated with poor IAQ far outweighs savings due to reduced energy consumption.

Popular belief in the past was that good IAQ and energy efficiency were in direct conflict, it is now agreed that energy savings of around 30% may be realised through retrofit projects of existing buildings without compromising indoor comfort. In South Africa, studies done by TEMM International (Pty) Ltd. have shown that in the commercial sector approximately 50% of energy is used for air-conditioning. This statistic clearly indicates that the area which offers the most potential for energy saving is the HVAC system.

A cost-effective way to improve the energy efficiency of a HVAC system, without compromising indoor comfort, is by implementing better control. However, when changing the control strategy of a system it is often difficult to predict the resulting changes in system energy consumption and indoor comfort.

To achieve these predictions a simulation tool, which can efficiently and accurately simulate the building with its HVAC system and controls in an integrated fashion, is required. There are many system simulation programs available. However they do not satisfy the requirements of integrated, efficient and accurate simulation by the typical consulting engineer. A new energy retrofit package, ESCO Toolbox, has been developed by TEMM International (Pty) Ltd. to achieve this prediction more easily.

Consulting ISKHUS Power, along with TEMM International and TSI was therefore contracted by PropNet to investigate the potential for energy saving in their Carlton Centre without compromising indoor comfort.

BUILDING DESCRIPTION

Carlton Centre is a large commercial building situated on the corner of Commissioner and von Willich Street, Marshalltown, Johannesburg. The building complex contain various parts namely an office tower, a shopping centre, a hotel and a ice-skating rink. The ice-skating rink and the hotel is currently in disuse, with only the office tower and shopping centre being occupied and supplied with air conditioned air.

The office tower presents the biggest section of the heating, ventilation and air conditioning (HVAC) and lighting electrical load and therefore form the main focus of the study. The towers has 52 floors of which only about 44 is air-conditioned. The total air-conditioned floor area is 101 200 m^2.

The HVAC system consists out of a central cooling and heating plant. Hot and/or cold water is supplied to twelve air handling units (AHU). These AHU's are situated on different levels of the building (11th, 30th, 52nd), with four units per one of these floors (see ***Figure 1***). Air is heated or cooled according to control and supplied via a variable air volume (VAV) system to the offices.

The volume of air going to an office area is controlled by a combination of temperature sensors spread throughout the area. These sensors control a pneumatic VAV-box that regulates the airflow. There are approximately 30 to 40 VAV-boxes per floor (see ***Figure 2***). Air is distributed to the offices through either diffuser, forming part of the lighting fixture, or fixed diffusers arranged along the outside perimeter of the offices.

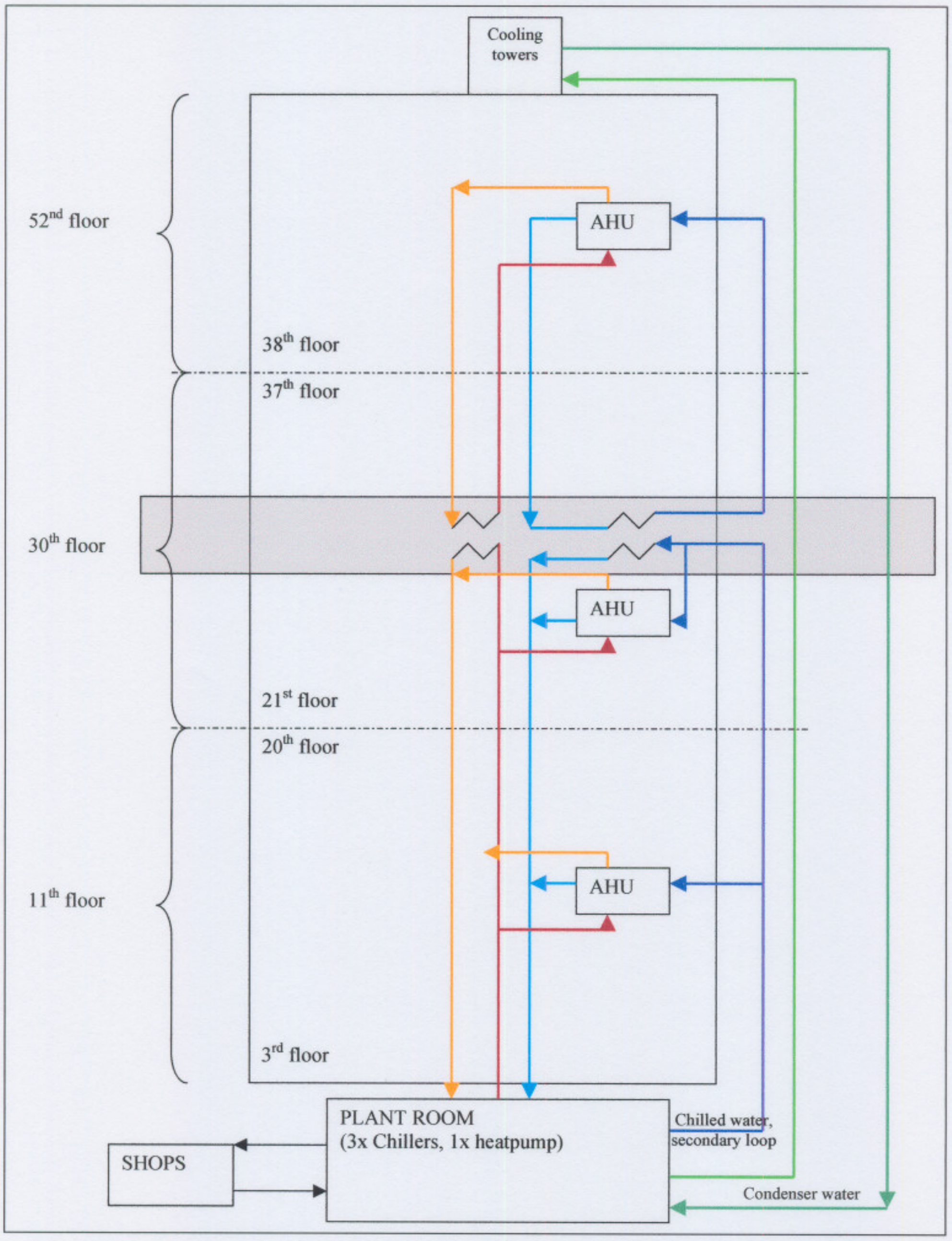

Figure 1: Building HVAC layout

The AHU supplies air to different sections of the offices per floor for a number of storeys (See ***Figure 3***). It has a constant speed supply fan and a variable speed return air fan. A cooling coil provides the bulk of the cooling needed for the air and secondary coils, placed in the three different ducts, provide the finer control on the temperature per section. The valves of the coils are controlled on the temperature and relative humidity (RH) measured in the return air duct. An economiser is also available in the AHU system with pneumatic damper control to regulate the mixing ratio of fresh air and return air.

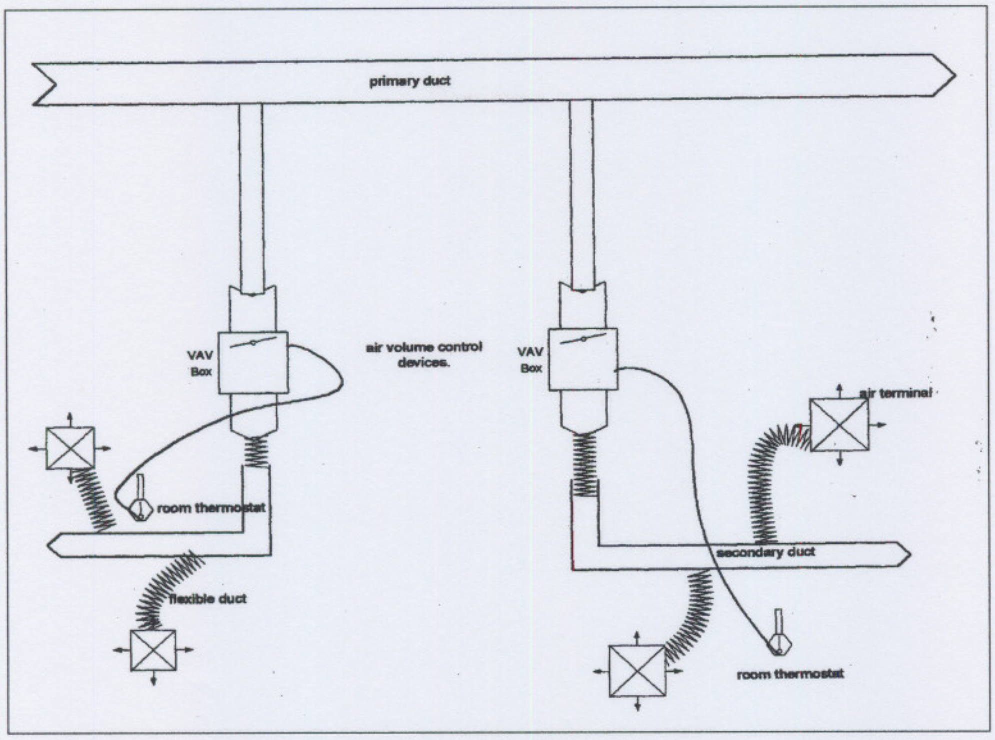

Figure 2: VAV boxes and air distribution

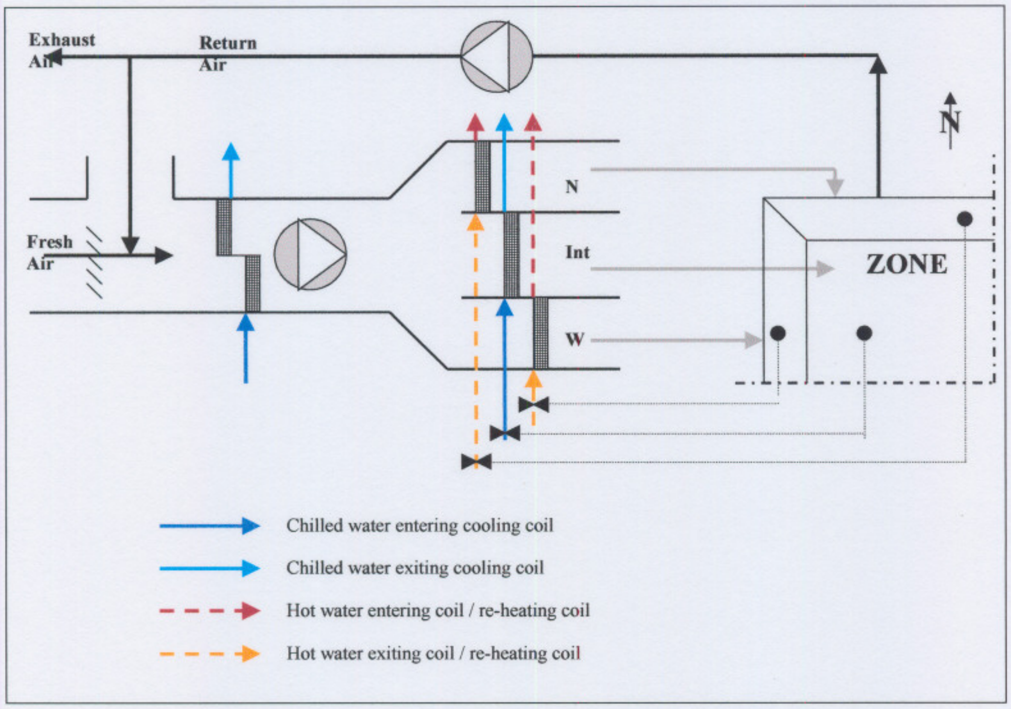

Figure 3: AHU layout and distribution

Cold water is supplied from three chillers in the cooling plant (Cooling capacity of about 5885 kW and a compressor power of 1234 kW). For most of the time only one chiller is needed to supply the required cooled water to the coils (see ***Figure 4***). In extremely hot climate days a second chiller is switched on to maintain the cold water temperature. This over-capacity of chillers is due to the fact that the system was designed to supply cold water to a hotel as well.

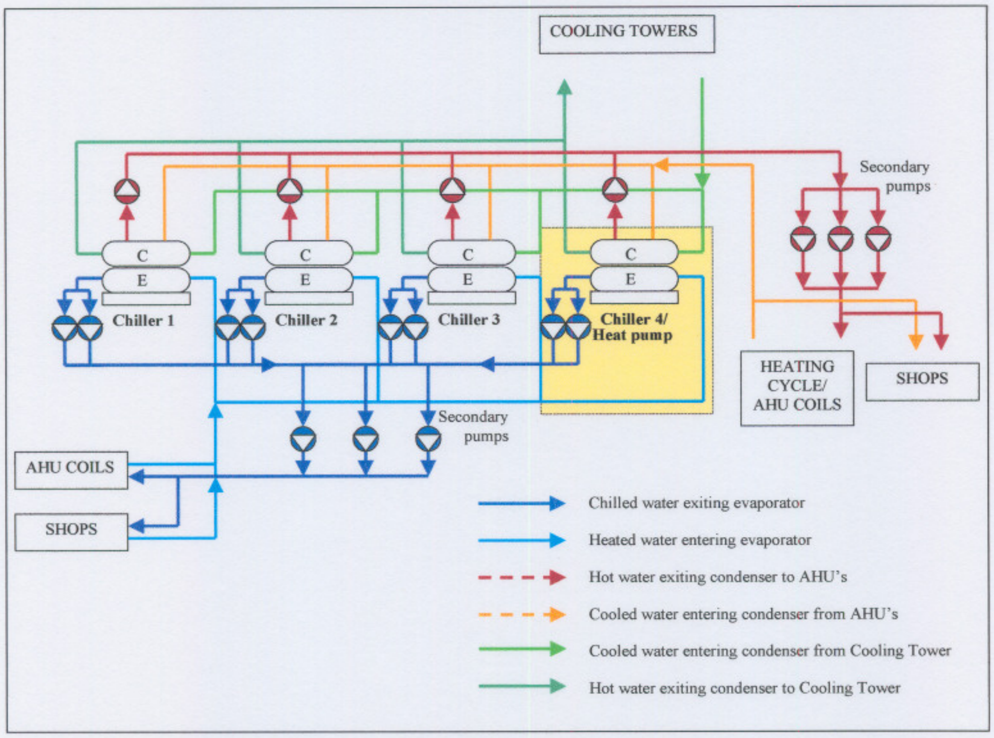

Figure 4: Cooling plant layout

A fourth chiller is available, but it is much smaller than the others and it is mainly used as a heatpump to heat water during the winter. The three main chillers have split condenser units with approximately 60% of the water going to the three cooling towers, situated on the roof, and the remaining 40% serving as hot water for heating the air going to the offices.

BUILDING DESCRIPTION	
Building name	Office building
Building description	Commercial building
Building location	Johannesburg CBD
Number of floors	52
Total floor area	107800
Air-conditioned floor area	96800
HVAC system	Multi zone
Cooling plant	Water cooled, centrifugal
Cooling capacity	18000
Heating plant	Heat pump, centrifugal
Heating capacity	3700
Air distribution	Variable air volume
Control System	BMS

Table 1: Building description

BUILDING SIMULATION

Model calibration

Continuous measurements were taken over a 3-day period (Friday to Sunday) to calibrate all the building schedules (loads and equipment) of the simulation tool. This will ensure that the current status of the building will be simulated correctly for realistic energy cost saving predictions. The results are displayed in the following tables:

Demand Load	
	% time within 10 %
Weekday	83.33
Saturday	87.50
Sunday	100.00

Table 2: Demand calibration results

Model verification

A verification study was performed to verify the accuracy of the simulation model's energy consumption over a typical year. The results of the study are displayed in the following tables:

Total energy consumption (kWh)		
	Summer	Winter
Simulated	34185.58	17081.74
Measured	33641.00	16216.00
% error	2.00	5.00

Table 3: Year energy verification

Average MD(kW/kVA)		
	Summer	Winter
Simulated	9045.14	8805.05
Measured	8645.00	8328.00
% error	5.00	6.00

Table 4: Year demand verification

ENERGY COST AUDIT

An end-user energy cost breakdown was determine through simulation to identify all the large energy consumers in the building. These consumers will also have biggest potential for energy cost savings. A building and a HVAC system energy cost breakdown are displayed in the following tables:

Building energy cost breakdown				
Description	Energy (MWh)	Cost (R)	R/kWh	% of total
HVAC system	13259.86	2967690.39	0.22	25.86
Lights	5420.25	1213106.30	0.22	10.57
Other	32587.20	7293342.12	0.22	63.56
Total	51267.31	11474138.81	0.22	100.00

Table 5: Building energy cost breakdown

HVAC system energy cost breakdown				
Description	Energy (MWh)	Cost (R)	R/kWh	% of total
Cooling	9953.84	2227769.28	0.22	75.07
Heating	184.52	41298.51	0.22	1.39
Ventilation	957.78	214360.36	0.22	7.22
Pumping	2163.72	484262.23	0.22	16.32
Total	13259.86	2967690.39	0.22	100.00

Table 6: HVAC energy cost breakdown

RETROFIT OPTIONS

The following options were investigated for potential energy cost reductions:

- Option 1: New lighting;
- Option 2: VSD on chillers, scheduling, economiser and evaporative pre-cooling;
- Option 3: VSD on chillers, scheduling, economiser, evaporative pre-cooling and lighting;
- Option 4: VSD on chillers, scheduling, economiser, evaporative pre-cooling and VSD on supply fans;
- Option 5: VSD on chillers, scheduling, economiser, evaporative pre-cooling, VSD on supply fans and lighting;
- Option 6: New lighting and scheduling on cooling plant.

A full description of these options are given below and the financial impact and analysis is given later on in the report (see ***Table 7*** and ***Table 8***).

Option 1: Lighting

Due to the current situation with the lighting in the office tower, it was decided to investigate new lighting options for both maintenance and energy cost savings. TSI did a full investigation into the lighting options and came up with a full lighting plan. This was incorporated into the integrated electricity and thermal system of the building to investigate the effect it will have on the electricity cost of the building.

The lighting option looked specifically at new technology to replace the current ligths that are manufactured infrequently and to improve the enenrgy use of these lights. The cuurent light load is about 40 kW per floor and this can be improved to about 20 kW per floor. This will have a direct impact on the energy consumption of the building. It will also have a positive effect on the thermal load of the building during the summer, but it may have a negative thermal effect during the winter.

Option 2: VSD on chillers, scheduling, economiser and evaporative pre-cooling

Firstly, it is important to note that the minimum load that the chiller compressors have vary between 600 to 800 kW. This is the electrical load that the chillers have even when no cooling is needed. This is mainly due to the nature of centrifugal compressors and the split condenser system run on these chillers. The chillers are not capable of cutting back to any lower fraction and there is resistance to the idea of switching these chillers off during no-cooling periods. Because the machines cannot cut back any further, removing load from the offices will have little effect because the chiller will always use this high minimum load.

With variable speed drives (VSD) on the compressors the chillers can be cut back to its minimum settings and reduce the electrical load. The VSD also allow the option of soft-starting the chillers and then gradually increase the load on the system. It also has built-in logic to seek the optimal operating point and coefficient of performance (COP) for every operating setting. This is something done by York in their overseas plants, but it is fairly new in South Africa, therefore the implementation cost, estimated at about R 2-mil per chiller, is only an estimate and a more accurate figure has yet to be determined.

With the VSD in place switching the machines off during no-cooling periods will be come more feasible with far less risk to starting failures. Because the chiller will now be capable of cutting back further and reduce its load, removing using free cooling can also now be looked at to reduce the load placed on the chillers. Two such methods are economisers and evaporative pre-cooling. Both are fairly inexpensive and offer thermal load reductions.

Option 3: VSD on chillers, scheduling, economiser, evaporative pre-cooling and lighting

In this option the effect of changing the lights to the new lighting option, discussed in Option 1, combined with Option 2 was investigated for the thermal and electrical effect it will have on the energy consumption and the electricity costs.

Option 4: VSD on chillers, scheduling, economiser, evaporative pre-cooling and VSD on supply fans

In this option the effect of changing the constant speed drives on the supply fans of the AHU's are combined with Option 2 was investigated for the thermal and electrical effect it will have on the energy consumption and the electricity costs.

Option 5: VSD on chillers, scheduling, economiser, evaporative pre-cooling, VSD on supply fans and lighting

In this option the effect of changing the lights to the new lighting option, discussed in Option 1, combined with Option 4 was investigated for the thermal and electrical effect it will have on the energy consumption and the electricity costs. This is also the option that provides the biggest savings potential on the electricity bill as well as energy and demand reductions.

Option 6: New lighting and scheduling on cooling plant

With the new lighting installed, the scheduling of the cooling plant is included to investigate the financial benefit of this option. The cooling plant is basically switched off during the night on weekdays and Saturdays and only run for certain hours on a Sunday.

RETROFIT RESULTS

Numerous retrofit options and combinations thereof, were investigated through simulation during the project. The implementation costs used are estimated costs and may change when actual and detailed quotes are received for these options. The most important financial results are displayed in the following tables:

Electricity cost savings			
Description	**Cost (R)**	**Cost savings (R)**	**% Savings**
Base year	11474138.81	-	-
New lighting	10411747.74	1062391.07	9.26
VSD on chillers, scheduling, economiser and evaporative pre-cooling	10586556.42	887582.39	7.74
[redacted]	[redacted]	[redacted]	[redacted]
VSD on chillers, scheduling, economiser, evaporative pre-cooling and VSD on supply fans	10382858.51	1091280.30	9.51
VSD on chillers, scheduling, economiser, evaporative pre-cooling, VSD on supply fans and lighting	9297768.18	2176370.63	18.97
New lighting and scheduling on cooling plant	10050079.32	1424059.49	12.41

Table 7: Electricity cost savings per retrofit option

Financial analysis					
Description	**Project cost (R)**	**Direct Payback Period**	**Discounted Payback Period**	**Loan rate (%/year)**	**Internal Rate of Return (%/year)**
					Year 5
New lighting	9118000.00	9	100	15	0.00
VSD on chillers, scheduling, economiser and evaporative pre-cooling	2700000.00	4	5	15	20.00
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
VSD on chillers, scheduling, economiser, evaporative pre-cooling and VSD on supply fans	3908000.00	4	6	15	13.00
VSD on chillers, scheduling, economiser, evaporative pre-cooling, VSD on supply fans and lighting	13026000.00	6	17	15	0.00
New lighting and scheduling on cooling plant	9118000.00	7	24	15	0.00

Table 8: Financial analysis of retrofit options

Savings analysis					
Retrofit measure	**Annual MWh Reduction**	**Annual kVA Reduction**	**Annual cost reduction (R)**	**Implementation cost (R)**	**Straight payback (years)**
New Lights	3029	1157	1062391	9118000	9
VSD_Chiller	3503	298	603420	2000000	4
Plant_Scheduling	2506	0	281113	100000	1
Evaporative pre-cooling	17	29	15923	350000	22
Economiser	1	0	8757	350000	40
VSD Fans	645	207	197306	1200000	7
VSD_Chillers, scheduling, economiser, evaporative pre-cooling and lighting	8904	1533	1988571	11818000	6
VSD_Chillers, scheduling, economiser, evaporative pre-cooling, VSD_Fans and lighting	9523	1733	2176371	13018000	6

Table 9: Savings analysis of retrofit options

CONCLUSIONS

Retrofit option 3 (VSD on chillers, scheduling, economiser, evaporative pre-cooling and lighting) will result in a projected cost saving of 17.3% (R 1.99-mil per year), but the discounted payback period is 16 years, mainly due to the lighting cost. Without the new lights (Option 2: VSD on chillers, scheduling, economiser and evaporative pre-cooling), the saving is only 7.7% (R 0.89-mil) of the current cost, but it has a payback period of only 5 years and an internal rate of return (IRR) of 20%.

From the report it is evident that option 5 (VSD on chillers, scheduling, economiser, evaporative pre-cooling, VSD on supply fans and lighting) has the largest impact on the energy consumption of the building, with a cost saving of 19%. However, the discounted payback period is 17 years. As a result of the long payback period this retrofit is not necessarily a viable option.

Retrofit option 6 (New lighting and scheduling on cooling plant) will result in a projected cost saving of 12.4%, but the discounted payback period is only 24 years, mainly due to the lighting cost. This makes this option much more economically feasible.

It is important to remember that the lighting option cause the implementation cost of these options to rise dramatically. Justifying these costs through energy cost reductions may prove to be ineffective, but when justifying it through improved maintenance and maintenance cost reductions, these options are feasible.

If the funding is available it is recommended that Option 3: VSD on chillers, scheduling, economiser, evaporative pre-cooling and lighting, is considered as it yields the highest saving for the financial input. It will also offer maintenance advantages to the customer.

APPENDIX: Addendum to report

This addendum is based on additional questions asked by ISKHUS that are not necessarily related to original reporting steps and answered as accurately as possible.

a) Definition / description

VSD on supply fans

Definition: With variable speed drives (VSD) on the fans the motors can be cut back to its minimum settings and reduce the electrical load. The load can be increased according to the demand on the airflow.

Description: The VSD also allows the option of soft-starting the fans and then gradually increases the load on the system. It also has built-in logic to seek the optimal operating point and efficiency for every operating setting.

Scheduling of cooling plant

Definition: Scheduling of the cooling plant refers to the seasonal operating schedule by which the cooling plant (Chillers and pumps) is switched on or off for non-cooling periods.

Description: The chillers and the associated pumps will be switched off during periods where no cooling is needed by the building. This schedule will be based on the ability of the chillers to reach the desired temperature and the thermal storage capacity of the building.

Evaporative pre-cooling

Definition: Using free-cooling available in the evaporative process of water to reduce the temperature of air entering a cooling coil or air-handling units (AHU).

Description: Evaporative coolers will be placed before the cooling coils in the AHU. This will reduce the air temperature entering the coils, improving the coil's efficiency and it will reduce the cooling load on the chillers.

Economiser

Definition: Economiser is used to utilise ambient air or climate conditions to pre-condition air entering an AHU if these conditions are more favourable than the air returning form the system.

Description: Currently, there is an economiser system installed in the HVAC system of the building. This system is however not functioning to its optimal point. If the climate or outside air is cooler or has lower enthalpy than the air returning from the zones, then this outside air will be used. This will reduce cooling load on the coils and therefore the chillers.

d) Operational implications

ii) Practical implications

VSD on chillers

- Lower power demand and energy consumption during non-cooling periods;
- Better control on the system;
- Continued optimal operating due to improved control.

VSD on supply fans

- Lower power demand and energy consumption during low airflow periods;
- Better control on the system;
- Continued optimal operating due to improved control.

Scheduling of cooling plant

- Lower power demand and energy consumption during non-cooling periods;
- Risk of tripping or non-starting in the mornings;

Economiser

- Lower energy consumption during morning and evening periods in the summer;
- Lower workload on chiller;

Evaporative pre-cooling

- Lower energy consumption for cooling purposes;
- Lower workload on chiller;

iii) Integration with other systems

VSD on chillers

- Any savings or reduction of work on the chiller will directly influence the pumps associated with it;
- If the cooling load is reduced that the AHU's have to handle, the chiller will actually be able to benefit from this option.

VSD on supply fans

- It will make the use of damper control (if any is still used) redundant;
- If the pneumatic damper control is removed from the AHU, it will decrease the load on the air compressors.

Scheduling of cooling plant

- Any savings or reduction of work on the chiller will directly influence the pumps associated with it;
- This will work best if run from the Building Management System (BMS) but it can be operated manually.

Economiser

- This will reduce the cooling load on the system for certain periods of the day and will therefore impact on the cooling plant;

Evaporative pre-cooling

- This will reduce the cooling load on the system and will therefore impact on the cooling plant;
- It may also help with the humidity of the system and zones;

iv) Control requirements

VSD on chillers

- Much of the control is done by the variable speed drive (VSD) itself through its internal control;
- Setpoints on the chillers can remain the same, but with the VSD these setpoints can be maintained to a much more optimal and economical degree.

VSD on supply fans

- Much of the control is done by the variable speed drive (VSD) itself through its internal control;
- Setpoints on the AHU and the supply fan can remain the same, but with the VSD these setpoints can be maintained to a much more optimal and economical degree.

Scheduling of cooling plant

- Control can be run through either the BMS or it can be done manually;
- Through the BMS the benefits will be more sustainable;
- A control feedback will be required to ensure the scheduling is occurring as planned;

Economiser

- Using temperature and enthalpy and comparing the outside air temperature and enthalpy to the return air will be sufficient;
- With a temperature and humidity sensor this control can be done through the BMS;

Evaporative pre-cooling

- The temperature before the evaporative cooler will be used to determine the evaporation supply ratio. This can be done with temperature and humidity sensors before the cooler.

e) Maintenance implications

i) Life cycle maintenance requirements

VSD on chillers

- Improved maintenance due to softer starting and more gradual loading on the compressor;

VSD on fans

- Improved maintenance due to softer starting and more gradual loading on the fan motor;

Scheduling of cooling plant

- Higher maintenance due to stop-starting of equipment. Can be reduced by soft starters or VSD;

Economiser

- Higher maintenance on actuators of the AHU's;
- Reduces maintenance on cooling plant and AHU's due to reduced cooling load on chillers and

coils;

Evaporative pre-cooling

- Reduces maintenance on cooling plant and AHU's due to reduced cooling load on chillers and coils;

f) Financial implications

ii) Operational cost

VSD on chillers

- Reduced operational cost due to better control of VSD;

VSD on fans

- Reduced operational cost due to better control of VSD;

Scheduling of cooling plant

- Increased operational cost;

Economiser

- Reduced operational cost;

Evaporative pre-cooling

- Increased operational cost;

iii) Maintenance cost

VSD on chillers

- Reduced maintenance cost;

VSD on fans

- Reduced maintenance cost;

Scheduling of cooling plant

- Increased maintenance cost;

Economiser

- Increased operational cost;

Evaporative pre-cooling

- Increased operational cost;

v) Cost savings

VSD on chillers

- Reduced electricity cost;

VSD on fans

- Reduced electricity cost;

Scheduling of cooling plant

- Reduced electricity cost;

Economiser

- Reduced electricity cost;

Evaporative pre-cooling

- Reduced electricity cost;