

A customisable data analysis interface for an online electrical energy information system

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Abstract

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In South Africa the main electricity supplier “Eskom” is struggling to meet the increasing demand. To lower the problematic electricity demand, demand side management projects are implemented by large electricity consumers. Measuring equipment is installed as part of these projects to monitor and manage the electricity consumption.

Measured data is stored and can be analysed to produce information used for energy management. This, however, is a difficult and time-consuming task, because there are large volumes of data to filter through. It is repetitive work which can be automated. Various data analysis methods are available. These include plotting charts and tables using software packages or data management products. Manually analysing the data using different methods and software packages can be a long and painstaking process especially with large volumes of historical data.

Information needs to be customised for different users. For example, managers need to view the end power usage and the amount of electrical energy that can be saved or was saved. Technical personnel need more detail about the electricity consumption by individual components in their system. To interpret the data in different ways a powerful tool is needed. There are many existing tools and software packages available, but most of them focus on buildings or factories. The software packages also have fixed reporting methods that are usually not customisable.

In this study a customisable data analysis interface was developed to provide a solution for all the different needs. This interface is user friendly without limiting its customisable functionality. Data is received via emails, processed and then stored in a database hosted by a web server. Users access a website and configure custom charts and tables using the available data. The

charts and tables are then displayed on the client's own home page when the client logs onto the website.

This interface was implemented on a website. The results of the interface were tested by automating existing reports using the customisable data analysis interface. Also when compared with the previous data analysis methods it was easily customisable, where it was very hard to customise the previous data analysis methods.

It was found that the development of the customisable data analysis interface reduced man-hours spent on reporting with 70% to 80% for large energy consumers by automating the reports. The man-hours are estimated to have a value of R 20 000 to R 60 000 per month, depending on the salaries of the personnel and the volume of reports. It will help the Demand-Side Management (DSM) projects to become a continuous system to lower electricity consumption by providing information that is useful for energy management.

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Nomenclature

BL	Baseline
CEO	Chief Executive Officer
COO	Chief Operating Officer
CSV	Comma Separated Values
DAI	Data Analysis Interface
DSM	Demand Side Management
EA	Energy Audit
EEM	Enterprise Energy Management
ENMS	Energy Management System
ERD	Entity Relationship Diagram
ERP	Enterprise Resource Planning
ESCo	Energy Service Company
HTML	Hyper Text Markup Language
IDE	Integrated Development Environment
IDM	Integrated Demand Management
ISO	International Standards Organisation
KDDM	Knowledge Discovery via Data Mining
M&V	Measurements and Verifications
OPC	Open Platform Communication
PC	Performance Contract
PDCA	Plan-Do-Check-Act
PDF	Portable Document Format
PHP	Hypertext Pre-processor
PK	Primary Key
PLC	Programmable Logic Controller
POD	Point of Delivery
PTB	Process Toolbox
RDBMS	Relational Database Management System
SCADA	Supervisory Control And Data Acquisition
XML	Extensible Markup Language

CHAPTER 1

INTRODUCTION

1. Introduction

1.1. Background

The growing world population increases the demand for energy [1], which contributes to the depletion of energy resources [2]. Energy supply struggles to match the rising demands, causing rising energy costs [3]. This creates a problem where the supply of electrical energy cannot meet the demand.

South Africa's electricity demand has been sustained from the stock of energy infrastructure built up to 1994. After 1994 not much investment was done to increase the electricity capacity. However the electricity demand kept rising, because the modern economy kept growing [4]. Eskom is South Africa's main electrical energy supplier. From 2008, Eskom has struggled to meet the country's electricity demand [5].

In 2008 Eskom was forced to implement load shedding. Load shedding involves a part of the power grid's energy supply being disconnected. The users connected to that part of the grid have no electricity for the load shedding period [6]. In 2011, 89% of Eskom's capacity was utilised which is above the recommended 85% [7]. The internationally accepted utilised capacity ranges from 82% – 85%, to allow maintenance to be carried out.

Projects implemented to reduce electricity usage and cost help solve the problems caused by the increasing demand. An example of these projects include load shifting, where large consumers shift their demand in peak times to standard and off-peak times [8]. Energy efficiency projects are also implemented to lower the total electricity consumption [9]–[11]. To implement these projects however is expensive and takes a long time.

Figure 1-1 illustrates all the stages and the interaction in the implementation of the various stakeholders in these projects. In South Africa there are three stakeholders involved in these projects. Eskom is the first stakeholder. The Eskom Integrated Demand Management (IDM) sends out a request for proposals for projects developers. The project developers have 30 days to submit a proposal. The proposals are then evaluated using an IDM scorecard [12].

The project developer is the second stakeholder. The project is carried out by the developer and to prove the success of the project the third stakeholder is needed. Eskom Energy Audit department appoints the third stakeholder. This is a Measurement and Verification (M&V) team.

They measure electricity consumption before the project is implemented and then verify the results by comparing measurements taken after the project has been implemented.

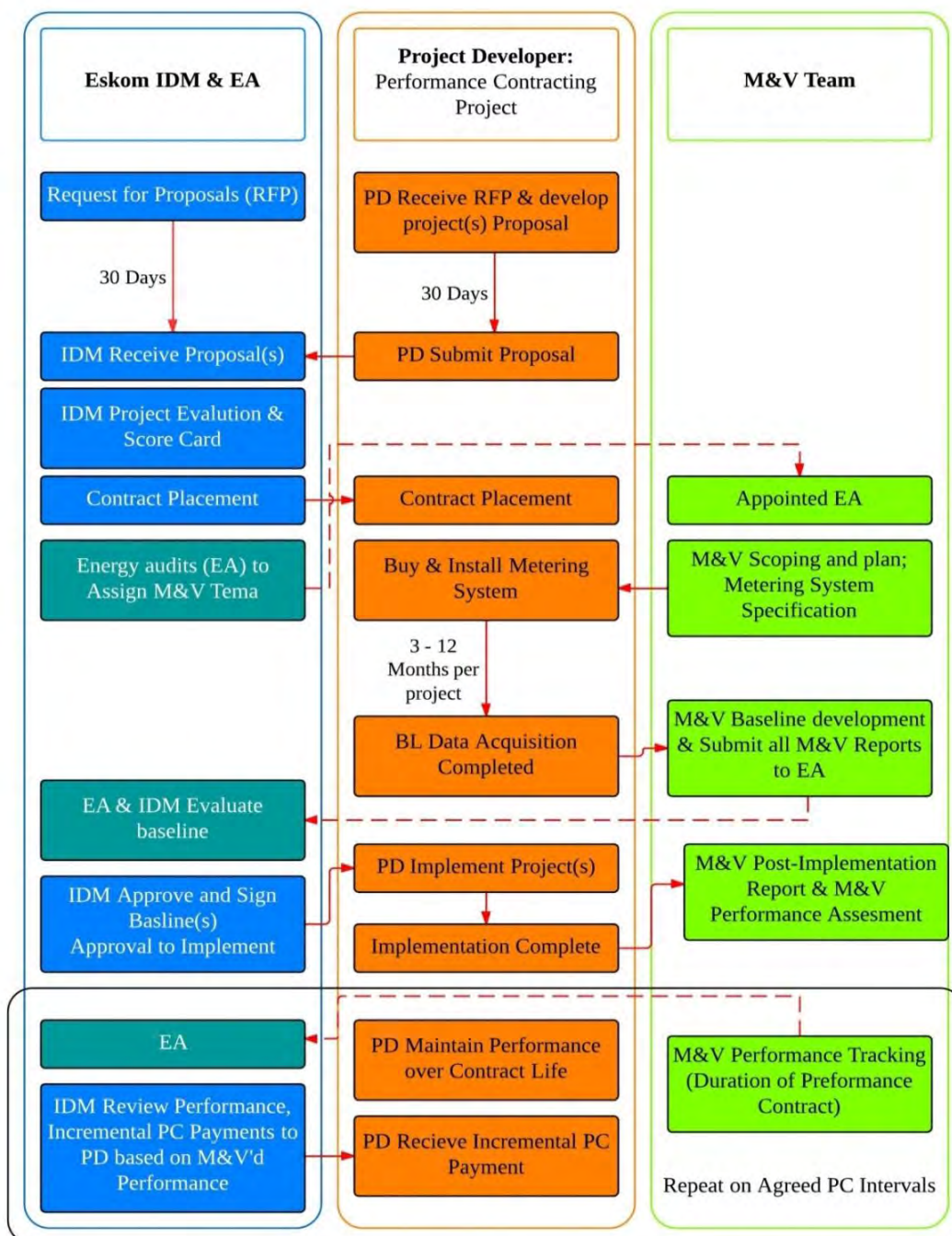


Figure 1-1 Project stages and stakeholder interaction [12]

When these projects are implemented control systems are installed that have measuring tools that periodically store measurements [10], [13]. Collected measurements create large volumes of data. Substation outputs have meters that measure the electricity consumption. Each component

connected to the substation has a meter that measures how much it consumes. These components include pumps, compressors, mine shafts, cooling auxiliaries, fridge plants, bulk air coolers and even lighting.

All this data is stored for the purpose of energy management. By analysing the data, information can be obtained to help with energy management and making the projects more sustainable [14], [15]. Analysing the data can be difficult and may require a specialist or someone familiar with the system. This person would have to know where to find the data and which data is significant.

Knowledge Discovery via Data Mining (KDDM) is a multiple phase process. The KDDM process aims to extract knowledge from historical data [16], [17]. *Figure 1-2* displays a typical KDDM process and its phases. *Table 1.1* explains all the different phases shown in *Figure 1-2* in more detail.

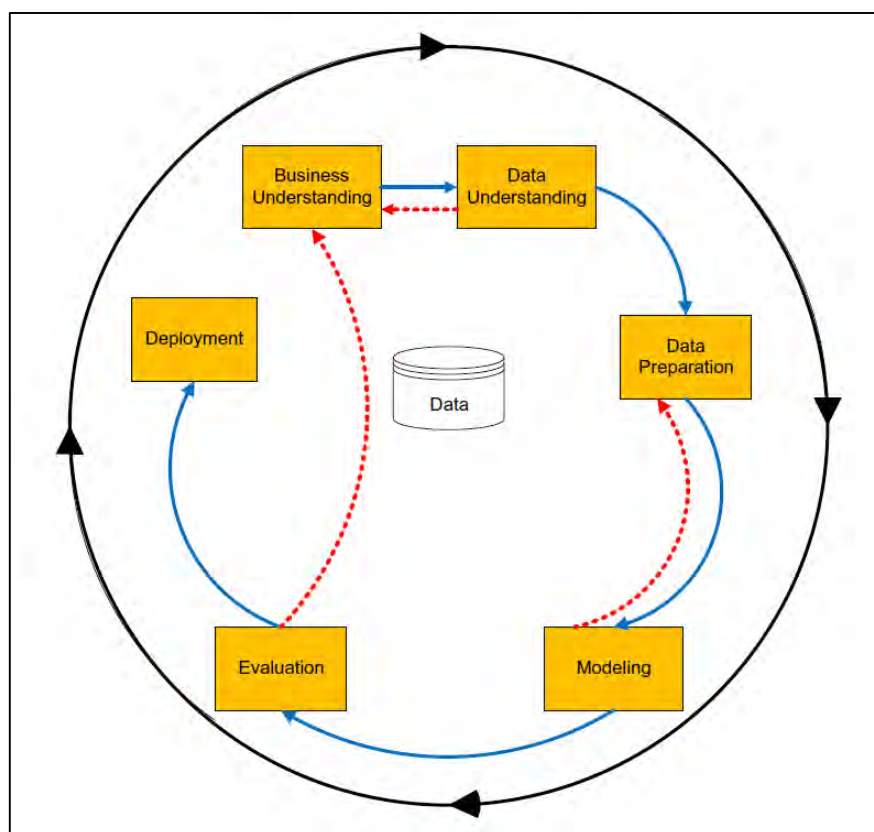


Figure 1-2 Typical view of KDDM process models [17].

Many different types of measurement provide different information. Electrical energy consumption data will help determine the cost whereas combining production data with consumption data will determine efficiency.

Large energy consumers require energy personnel to produce energy reports to help with energy management. An example of this is calculating energy budgets. To create the report is a very long and painstaking process, because employees have to sift through large volumes of data. The employees usually have data stored in word processing files, especially comma separated values (CSV) files, and use spreadsheet applications such as Microsoft Excel to create monthly reports of the usage.

Phase	Description
Business understanding	This initial phase focuses on understanding the project objectives and requirements from a business perspective, then converting this knowledge into a Data Mining problem definition and a preliminary plan designed to achieve the objectives.
Data understanding	This phase starts with an initial data collection and proceeds with activities in order to get familiar with the data, to identify data quality problems, to discover first insights into the data or to detect interesting subsets to form hypotheses for hidden information.
Data preparation	This phase covers all activities to construct the final dataset (data that will be fed into the modelling tool(s)) from the initial raw data. Data preparation tasks are likely to be performed multiple times and not in any prescribed order. Tasks include table, record and attribute selection as well as transformation and cleaning of data for modelling tools.
Modelling (Data Mining)	In this phase, various modelling techniques (e.g. decision tree, regression, clustering) are selected and applied and their parameters are calibrated. The CRISP data mining (DM) documentation points out that typically, there are several techniques for the same Data Mining problem type. Some techniques have specific requirements for the form of data and therefore, stepping back to the data preparation phase is often necessary.
Evaluation	This phase of the project consists of thoroughly evaluating the model and reviewing the steps executed to construct the model to ascertain that it properly achieves the business objectives. A key objective is to determine if there is some important business issue that has not perhaps been sufficiently considered. At the end of this phase, a decision on the use of the Data Mining results should be reached.
Deployment	Creation of the model is generally not the end of the project. Even if the purpose of the model is to increase knowledge of the data, the knowledge gained will need to be organised and presented in a way that the customer can utilise. According to the CRISP DM process model, depending on the requirements, the deployment phase can be as simple as generating a report or as complex as implementing a repeatable Data Mining process across the enterprise.

Table 1.1 Phases of the Knowledge Discovery and Data Mining (KDDM) process [17]

By attending meetings on site it was found that the energy personnel generally select the data they need to analyse and then make the necessary calculations to interpret the required information. If energy personnel make a template that stores the calculations, they do not have to repeat the development of the formulas necessary for the calculations. However, energy personnel still need to find the correct data. Finding the data is time intensive, using a lot of man-hours and keeping the personnel from their other obligations.

An automated way to analyse different data types in different ways to produce useful information is needed [18]. Using this information facilitates better energy management. A customisable Data Analysis Interface (DAI) is necessary to analyse the data for all the different required information. The interface should be generic enough to handle all the different needs as well as simplistic enough not to need a specialist to use the system. The interface must be as user friendly as possible.

Making the interface accessible online is a great advantage because then one central location can manage all the data and software. The centralised data from different sites makes it possible to view different sites' information simultaneously. The functionality will be increased by adding a reporting function to the DAI. This function creates a report of the information currently viewed on the website.

The website must be able to accommodate all the different authority levels, from technical personnel who need access to detailed data, to the management levels that are more interested in the overall totals and budgets. The data should be simple to navigate as well as ensuring data integrity. When all these requirements are fulfilled the interface can be used for energy management.

1.2. Data mining

Obtaining the data required for comprehensive analysis is done through a data mining process. Data mining has become very affordable and simplistic when compared to the recent past. Advancements in technology, for example, increased processing speed, more storage capacity and decreasing hardware costs have caused a great boom in data acquisition.

In the past, data gathering was a long and painstaking process. For example, measurements were written by hand, which is very unpractical if a record is needed every two minutes. Today

engineers use automated measurement systems. This is made up from different devices that work together to form a unit that can be controlled using software [19].

Data sources

The measurement devices and equipment used on mines, industrial plants and other large energy consumers remain mostly the same for all the different consumers. *Figure 1-3* displays the data flow in the equipment. These tools include metering and actuating equipment, Programmable Logic Controllers (PLC), Supervisory Control And Data Acquisition (SCADA) systems, Open Platform Communications (OPC) connections and an Energy Management System (EMS) or database component [9], [10]. These devices communicate with each other and store the data in the database. The SCADA also has the capability to represent data visually.

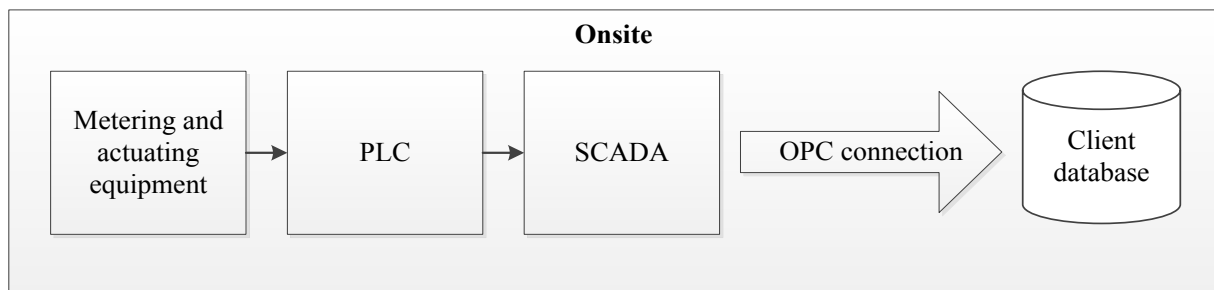


Figure 1-3 Overview of data flow on a site [9]

Metering and actuating equipment

This is all the equipment that is physically attached to the components that consume energy, for example loggers attached to pumps and compressors. It can be measurements from point of delivery (POD) and incomers [9]. Different measurement can also be taken from a single component. For example, from the following components the listed measurements can be taken:

- Compressor
 - Power usage
 - Pressure
 - Temperature
- Pump
 - Power usage
 - Temperature
 - Flow

PLC

The PLC system controls the actuating equipment and reads data from the metering and actuating equipment. Control signals are received from the SCADA, which is made up of set-point values, start/stop signals and on/off signals [20], [21].

SCADA

The SCADA system receives the measurement data from the PLC and it has a user interface with equipment that is controlled by the PLC. Control signals are also sent from the SCADA system to PLCs to actuate these control instructions [20], [21].

OPC connection

An OPC server is hosted on the SCADA, which enables other systems to access the data on the SCADA. The data is sent to control systems and historical data are stored electronically. Data tags can also be configured on the SCADA system. Data is assigned to the tags and can easily be grouped together [20]–[22]. Tags are representations of data groupings, for example, electricity consumption of a pump can be assigned to one tag while the flow of water is assigned to another tag.

Database

Finally, the data reaches the database where it is stored. Gaining access as close as possible to the origin is the best solution. *Figure 1-4* illustrates the ideal scenario where the energy management database used for the data analyses can connect to the client database.

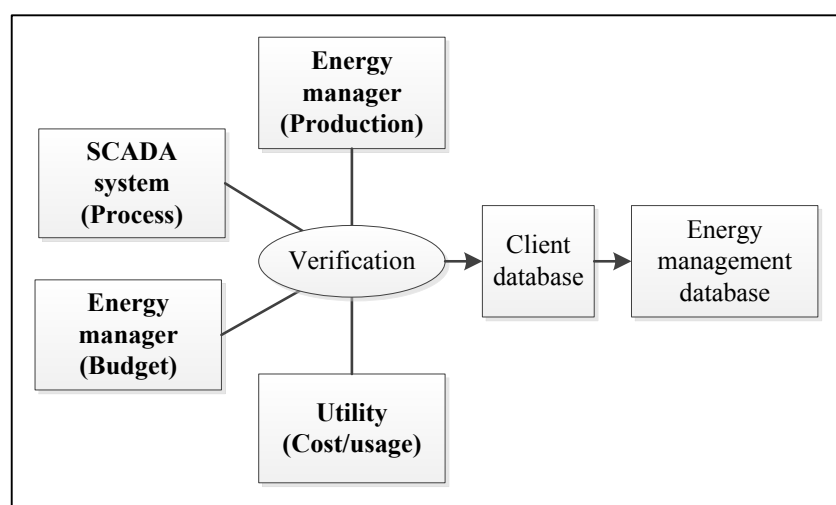


Figure 1-4 Ideal data retrieval scenario [23]

Retrieving the data from all the different operations, for example consumption data or production data, in this manner is unrealistic. Different mining and industrial operations create data in different formats, therefore processes that can handle these formats need to be implemented [23].

The different data formats include process data retrieved from the SCADA systems, billing reports contain cost and usage figures in pdf formats. Budgets and production data is stored in spreadsheets and reports. *Figure 1-5* illustrates the above mentioned data formats and possible retrieval processes [23].

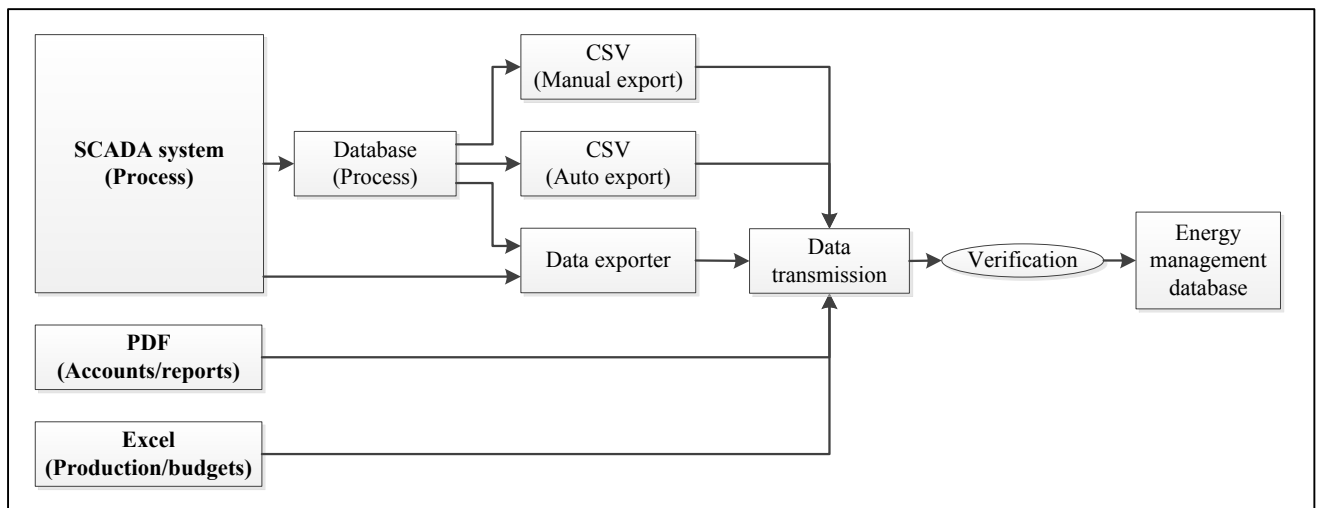


Figure 1-5 Data retrieval overview [23]

Figure 1-5 shows different modes of accessing the data. From the SCADA, data can be exported in real-time using a data exporter. Exporting data in real-time can be unreliable, so historical data is sent automatically daily as CSV files from the database. Personnel on-site can also export the data from the SCADA and email to the energy management database.

All the different large energy consumer groups such as mines, cement plants and steel manufacturers have different data formats and reporting methods. One mining group can have up to 15 different mines, where each mine has its own SCADA system. Each SCADA system has a data format that is usually different for each system.

To effectively analyse data, the data has to be stored in a single format in the energy management database. This can be done by using different software packages that consolidate and process the data.

1.3. Existing data analysis methods

This section explores the different existing data analysis methods that mainly consist of Enterprise Resource Planning (ERP) systems, where the resource is energy. The section discusses available solutions as well as their limitations. Some solutions focus mainly on buildings and factories where others are solutions for larger energy consumers. A table compares all the different solutions by summarising their capabilities at the end of this section.

Enterprise resource planning

To maximise the benefits from constrained resources, ERP systems are used. These systems achieve efficiency from the constrained resources by automating and integrating business processes. An ERP system is a tool to make a business more competitive in the market place [24].

Correctly implemented ERP systems can increase Intelligence Density. Intelligence Density is the number of informed decisions made, divided by the time spent making the decisions. ERP supplies information that is used to make these decisions, by analysing data. For this fundamental capability the user needs access to real time data [25].

Enterprise energy management

Enterprise energy management (EEM) is an ERP that focuses on energy. The EEM systems are used to set goals, track performance and communicate results. This is done by capturing data, analysing the data by creating charts, tables and reports for managers or any energy project participants. This information system has a potential to achieve much greater energy savings than the savings realised by traditional tactical practices alone [26].

EEM systems are commercially available, but to apply a system to a specific enterprise is difficult, because each enterprise is unique. Therefore trying to apply the same system to every enterprise is likely to cause some problems [24]. For an EEM to be effective certain elements must be in place, *Table 1.2* lists these elements.

One of the different commercially available EEM systems is AspenTech's Aspen InfoPlus.21®. This product allows the user to view real-time tag data on a web interface. Appendix A is a brochure of the web interface of AspenTech's Aspen InfoPlus.21®[27].

Tags are different groupings of measurements. As an example, tags can be the measurements of a pressure valve or the summation of a few power loggers. The user can change the timeline as well as choose the data that needs to be viewed. The chart is a fixed line chart that displays the tag data exactly as it is stored [27].

Element	Description
Corporate commitment	An effective strategic management plan requires a strong commitment to continuous improvement throughout the organisation.
Evaluate current performance	Conduct an inventory and energy audit, and then create a profile and baseline of energy use at all key points.
Set performance goals	Energy performance goals provide direction for decision making and serve as a foundation for tracking and measuring success.
Action plan	The action plan drives and guides everyone in the organisation to focus and prioritise their energy efficiency efforts.
Educate and motivate participants	The ultimate success of a plan will depend on the motivation and capability of the managers and employees implementing its components
Evaluate ongoing performance	Sustaining improvements in energy performance and guaranteeing long-term success of a plan requires a strong commitment to continually evaluate performance.
Communications strategy	A communications strategy provides the framework for promoting energy management efforts throughout an organisation.
Recognition strategy	Identifying and communicating the contributions of all participants provides a solid foundation on which to build a successful energy management strategy.

Table 1.2 Elements of strategic energy management [26].

Rockwell Automation has created a Software Enterprise Energy Management Solution. This product also has a web based portal that gives users access to real-time and historical data. Many of the reports come “out of the box”, but they can also be customised to fit the users’ preference. This product is for building energy consumption [28].

Schneider Electric developed StuxureWare Energy Operation that stores the data in a secure cloud to be analysed. Similar to Rockwell's product it is meant for buildings only [29]. Another product called Lightapp is used for factories. It is also used by pharmaceutical companies, airport terminals and food industries [30].

PowerLogic® created an energy management solution that works on mines. The solution was implemented on a mine, but the energy manager only used the solution to acquire the data. The energy manager still had to analyse the data manually by creating his own reports using Microsoft Excel®. PowerLogic's® solution had a reporting function, but it was not customisable enough to fit the energy manager's needs. The reports that could be generated automatically showed each tag's information. The energy manager wanted an overview of each operation's power usage and not the individual components or tags.

Process Toolbox (PTB) extracts data from the SCADA with an OPC connection discussed in Section 1.2. PTB processes the data in a fixed format that is ready to be analysed. PTB has a reporting tool that can be accessed by plant personnel. It also generates reports, for example reports displaying savings achieved, maintenance completed and unscheduled downtime [10]. The reports are highly customisable, but the reports are not automated. Therefore, with a report the user will need to select the data for the report manually. The layout of the PTB Energy management system is shown in *Figure 1-6*.

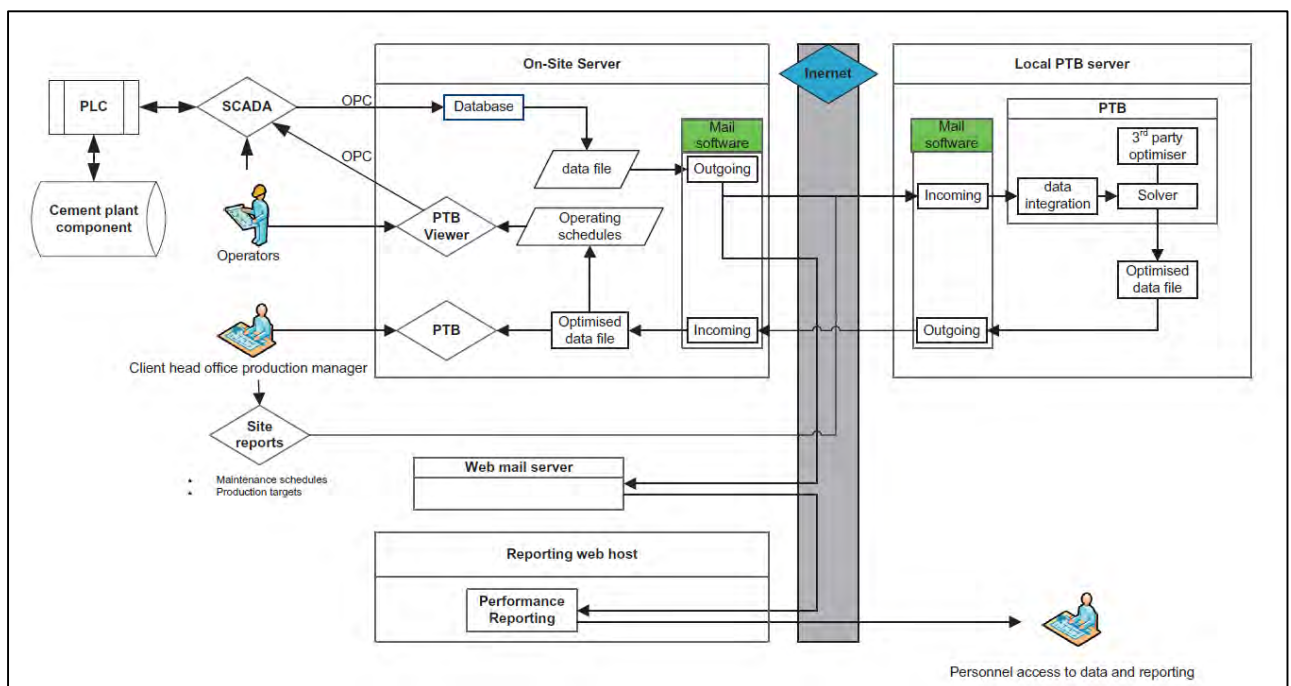


Figure 1-6 Layout of the PTB Energy management System [10]

In *Figure 1-6* the database compiles a data file and stores it on the on-site server. The file is then sent to a local PTB server and a web mail server using an automated email. The files on the web mail server are used to create the performance reports. The local PTB server integrates the data into a simulation package to create an optimised operations schedule.

Goosen developed a monitoring system for compressed air savings on mines [9]. This system creates daily reports that show a 24-hour profile of compressed air savings projects that were implemented. The user can also choose to generate monthly reports or choose the start and end date. The reports, however, always had the same charts and tables and would require a lot of effort and time to change.

There are four main processes in an enterprise energy management system namely;

- data collection
- analysis
- reporting, and
- action or decision making.

Figure 1-7 illustrates the life cycle of these processes.

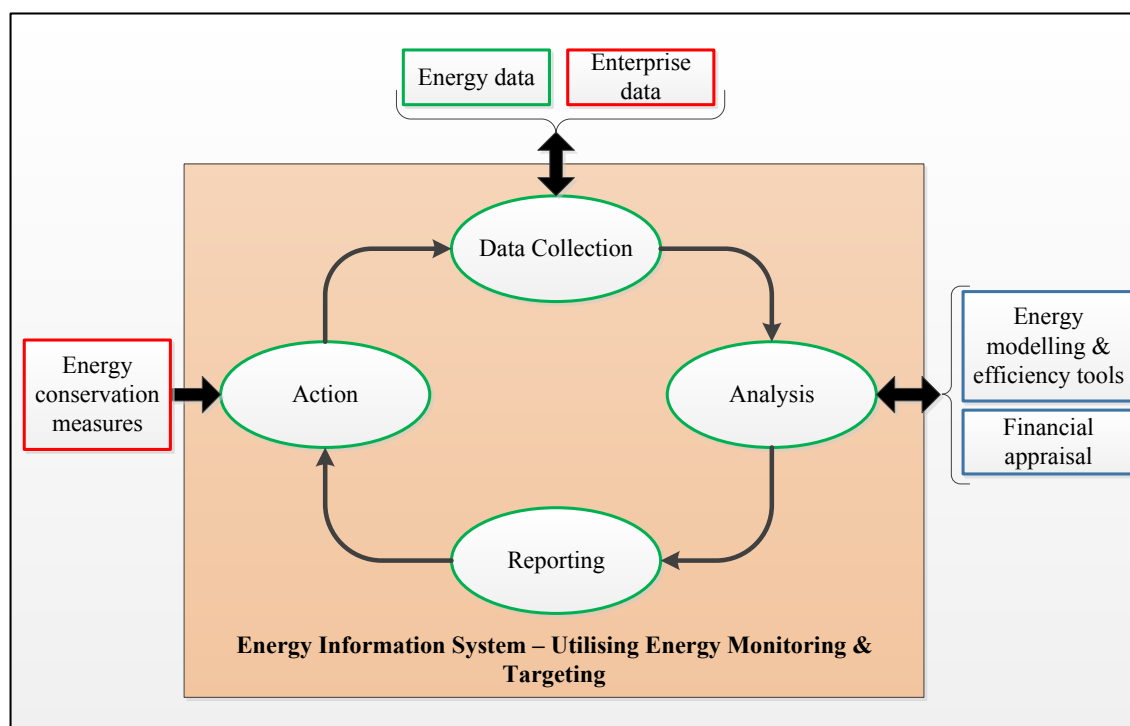


Figure 1-7 Enterprise Energy Management operational cycle [31].

Data collection is done by various data mining processes discussed in Section 1.2 and usually stored in databases. Secondly analysis is done by energy personnel with the help from some software packages and tools. Thirdly the energy personnel configure reports. Limited reports can be automated using software packages. After the personnel obtain the information contained in the reports decisions can be made. These decisions include creating budgets, using energy more efficiently and optimised schedules for operations.

Limitations of existing systems

Many different solutions for energy management exist as mentioned, but they all have some limitations and shortcomings. They have automated report functionality, but the customisability is too limited. Most of the solutions do not focus on large energy consumers such as mines and plants.

They are suitable for specific applications such as buildings or factories only. All of the mentioned solutions only facilitate electricity data, which include real-time power (kW) data or historical electrical (kWh) data. It can be useful to plot production data, flow data and cost data as well for comprehensive energy management [32]. *Table 1.3* summarises each system mentioned using three categories, that include focus area, level of customisability and report automation.

System name	Focus area	Level of customisability	Report automation
AspenTech Aspen InfoPlus.21®	Large energy consumers (Electricity)	Low	Yes
Rockwell	Buildings (Electricity)	Medium	Yes
Schneider Electric StruxureWare	Buildings (Electricity)	Medium	Yes
Lightapp	Factories (Electricity)	Low	Yes
PowerLogic® CEMS	Large energy consumers (Electricity)	Low	Yes
Goosen System	Large energy consumers (Electricity)	Low	Yes
Process Toolbox (PTB)	Cement plants (Electricity)	High	No

Table 1.3 Summary of existing data analysis system

1.4. User input and requirements

With the necessary data available, research was done to determine how to best utilise the information. This was done by looking at existing charts and tables in reports that have been used for electricity management. Users were also asked what information they would like to access and in which format they would like it. These users were the personnel working for Energy Service Companies (ESCO) and ESCo clients.

Large energy consumer personnel

Research was done by asking for large energy consumers' energy reports. These reports were studied and then duplicated by using the interface. The interface will then automatically be able to create the report for any given period, selected by the user or client. *Figure 1-8* and *Figure 1-9* illustrate the hierarchy structure of two different mine groups.

The large energy consumer groups have specific employee hierarchies. Referring to *Figure 1-8* the top authority is the financial director. The financial director needs to report information on the total energy use of the whole group. This information indicates whether the usage was within the calculated budget as well as how much savings were achieved or could have been achieved. The financial director will need the information monthly and annually [33], [34].

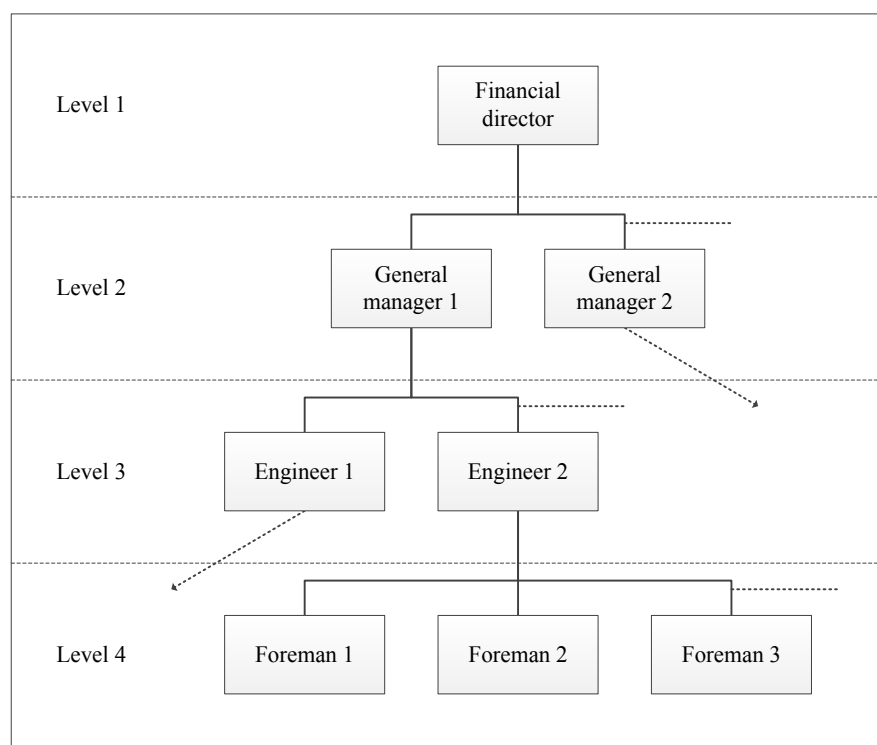


Figure 1-8 Example of a hierarchy structure on mine group 1

The general managers need information about all the operations for which they are responsible, for example the comparison of different shafts on their mine or plant performance and efficiency. The engineers need to view information about their operation and may need to see some technical information as well. The engineers will look at the operations' overall performance and consumption and with the information identify anomalies and trends. Engineers will use the information on a daily basis.

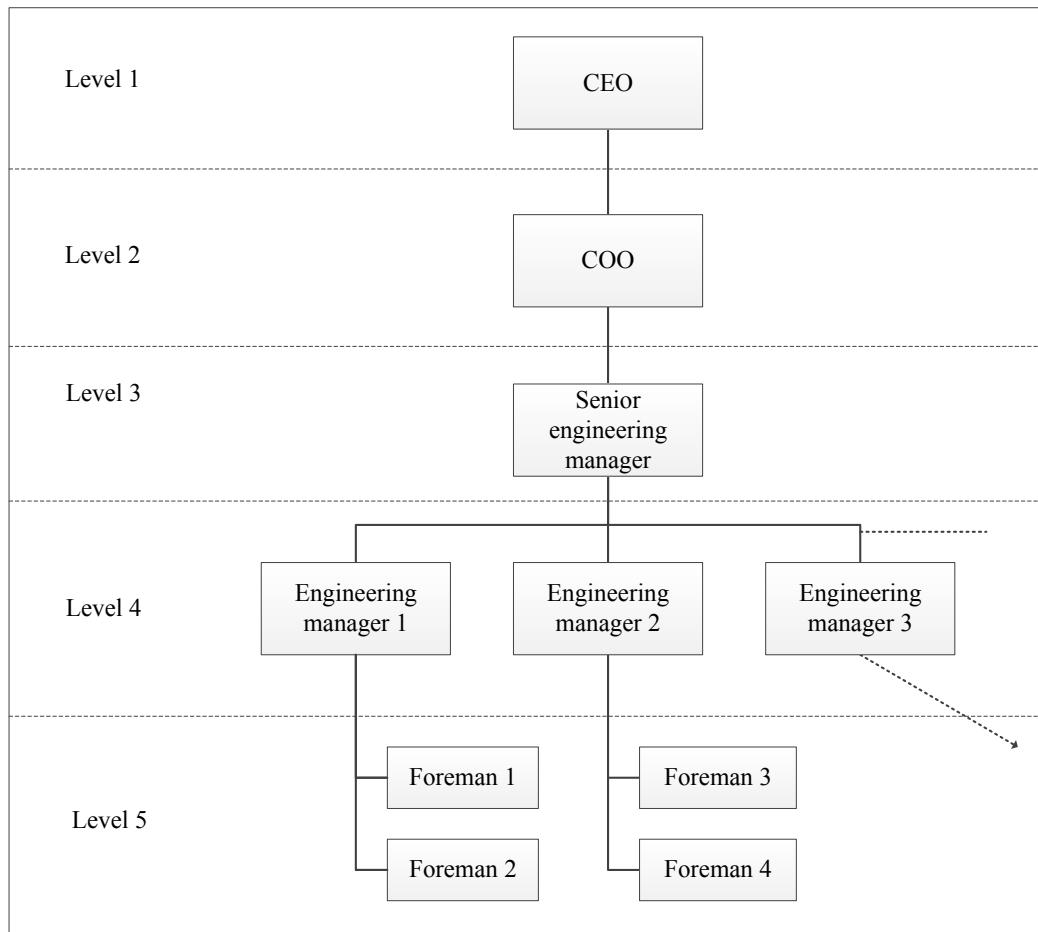


Figure 1-9 Example of a hierarchy structure on mine group 2

Foremen need technical information, for example, a daily profile of a components power usage for example pumps, compressors, winders etc. They need the information to find anomalies in the consumption behaviour and identify potential risks and danger. For example, when dam levels are too high or low, when temperatures rise and might cause a fire. Foremen will use real-time and hourly data to, for example, monitor temperatures, dam levels and air pressure.

Figure 1-9 has a different structure, but the principles are more or less the same. The Chief Operations Officer (COO) will be more involved on a daily basis than the Chief Executive

Officer (CEO) and therefore need the information more frequently. The CEO will only need to view the information monthly or when problems are reported from the COO. The CEO will need the same information as the financial director in *Figure 1-8*.

Examples of information ESCo and energy personnel use

Figure 1-10 through to *Figure 1-15* and *Table 1.4* are examples of graphs and tables used by ESCo personnel and energy personnel. Before each table and figure a brief description will explain what is illustrated and who might find it useful.

Information displaying electricity savings and losses

In this section some examples of electricity savings or losses are shown using graphs and tables. *Table 1.4* is a table displaying daily savings achieved by reducing compressed air usage on five different mines. This can be very useful for the COO that needs to monitor operations on a daily basis as well for the ESCo personnel as proof that they have achieved savings.

	Daily energy efficiency [MWh]	Eskom evening peak reduction [MW]	Cost saving [R/day]
Mine A	0.67	1.90	R 13 280.00
Mine B	3.62	1.11	R 63 630.00
Mine C	6.01	4.95	R 92 020.00
Mine D	0.56	3.37	R 14 700.00
Mine E	1.49	6.07	R 33 020.00
Total:	12.35	17.4	R 216 650.00

Table 1.4 Example of a table used by ESCo personnel [35]

Figure 1-10 shows the average power reduction achieved on a project aimed at the optimisation of a mine compressed air system. This figure will be useful for ESCo personnel who implemented the project as well as the mine energy personnel who want to see the savings. These personnel include the general manager or engineering manager.

Figure 1-11 shows the monthly power consumption and electricity cost of a gold mine. This figure also shows three trend lines namely the default allocation, the reference consumption +2% and the reference consumption +10%. The graph illustrates how much the cost increases if the consumption exceeds the reference consumption +10% line. The information will help managers to motivate less power consumption.

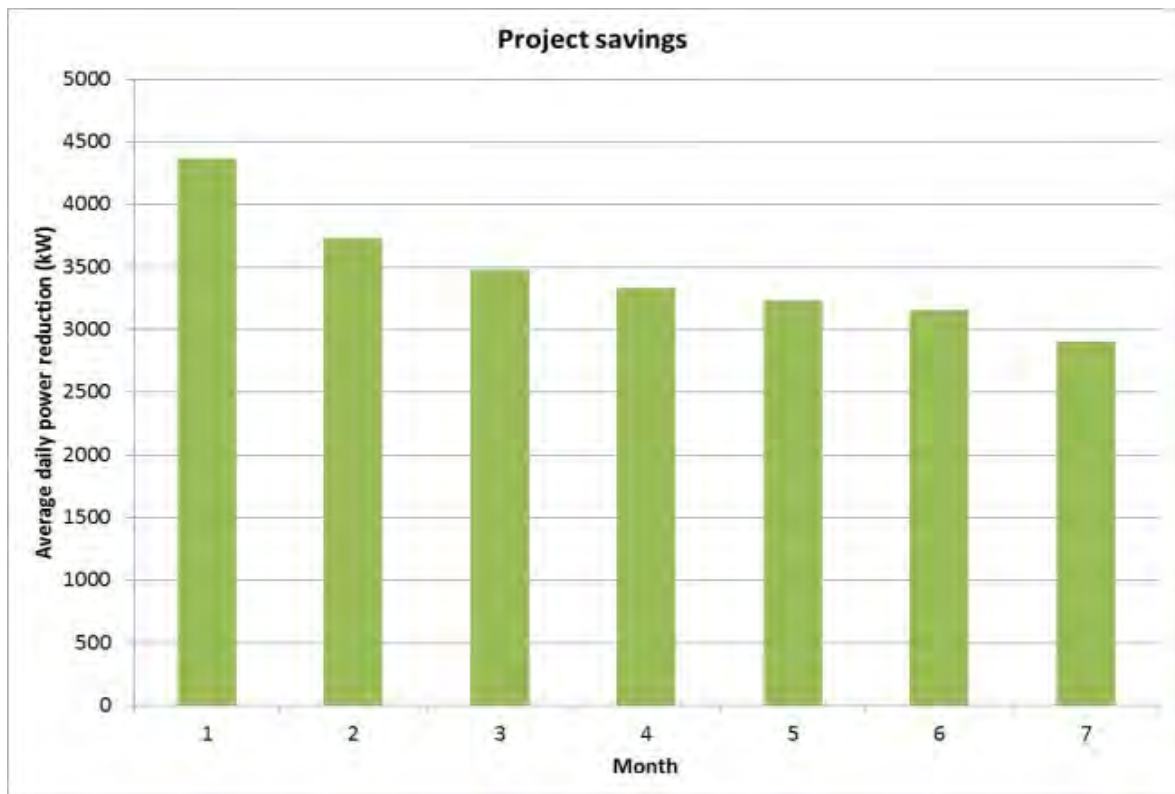


Figure 1-10 Example of projects savings achieved monthly [33]

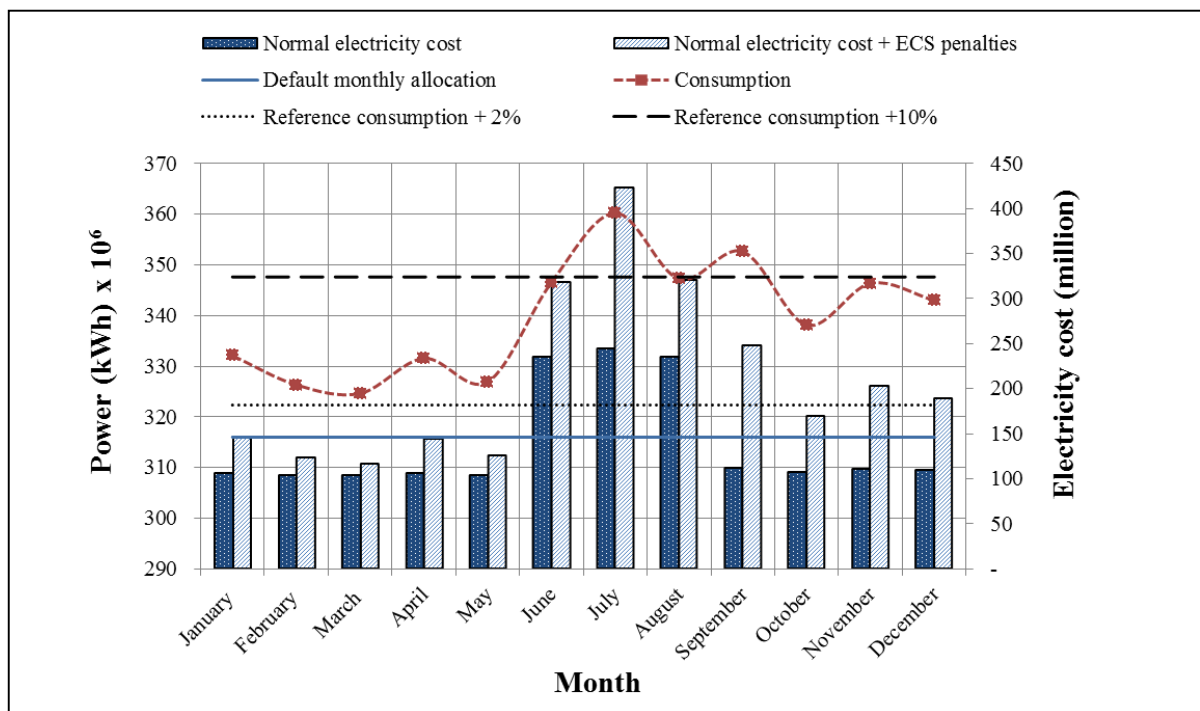


Figure 1-11 Example of a monthly consumption [34]

If, however, the consumption cannot be lowered, a new reference line can be identified using the information provided by the graph. The new reference line can be discussed with the electricity

supplier. If the new reference implemented the fixed electricity cost to the supplier will rise, but the penalties for exceeding the reference line will decrease. By observing *Figure 1-11* it is seen that is necessary to create a new reference for the three winter months June, July and August. The reference line will help avoid losses.

Electricity cost breakdown

In this section an example is shown for how much electricity all the different components use on a mine. *Figure 1-12* illustrates the average electricity consumption for the different processes on a mine. This is useful to identify and prioritise areas to implement demand side projects. ESCo personnel and management personnel on a mine can use the electricity cost breakdown.

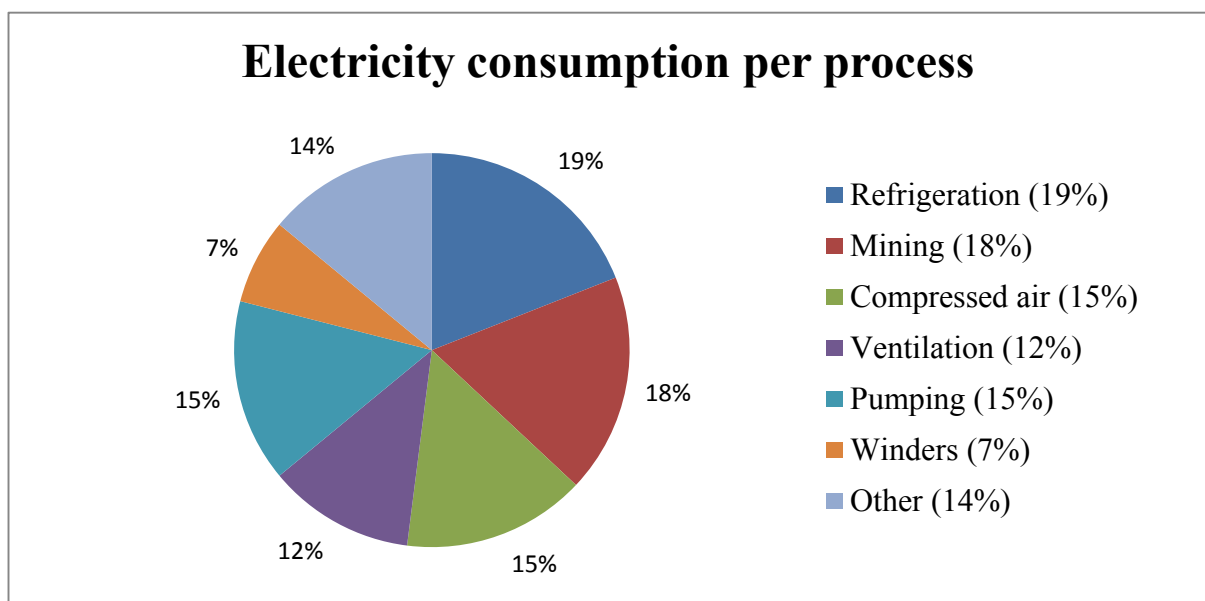


Figure 1-12 Average mine process electricity consumption [36]

Production

In this section an example of production information is given. By comparing production data with electricity data energy intensity can be identified that can help to identify energy efficiency possibilities.

Figure 1-13 shows production data (total tonnes broken) on a mine for each month from March 2007 to March 2012. The graph's trend line shows that the production is steadily decreasing over time on an average of 4.6% per year. This is useful for management to determine how long the mine will still be profitable.

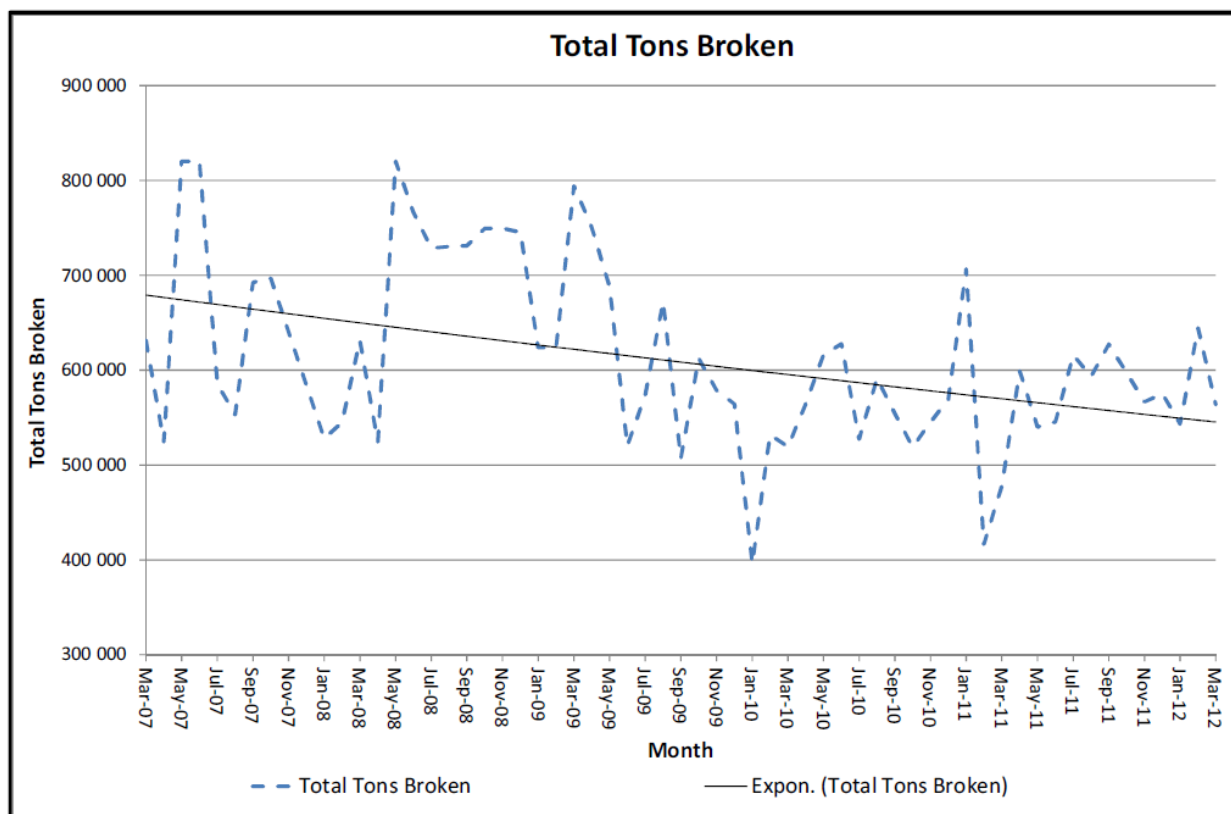


Figure 1-13 Production example on a mine plotted monthly [37]

Daily profiles

In this section there are two examples of daily profiles. This is useful to identify whether implemented load shifting projects run according to schedule and had the planned results. Also potential projects can be identified by studying the information provided. Incidents can be identified that caused, or may cause, problems in the future, for example when valves malfunction or when control systems set points are defective.

Figure 1-14 shows three hourly power profiles, the dashed lines are baselines. Baselines are calculated by using historical data over a time period and using the average values of that period. By comparing the new optimised profile with the baselines, engineers can view the power savings achieved during Megaflex time of use peak times.

Figure 1-15 shows an hourly air pressure profile for a compressed air network at a gold mine. ESCo personnel can use it to show the lowered air use achieved compared to the previously measured baseline.

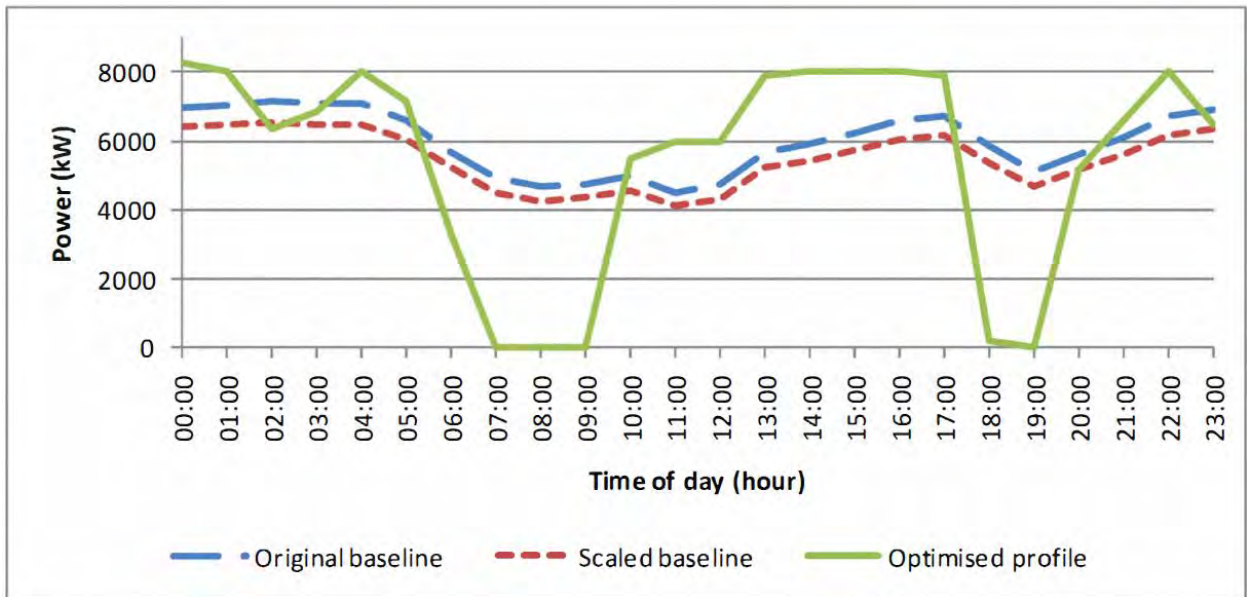


Figure 1-14 Example of an hourly power profile [32]

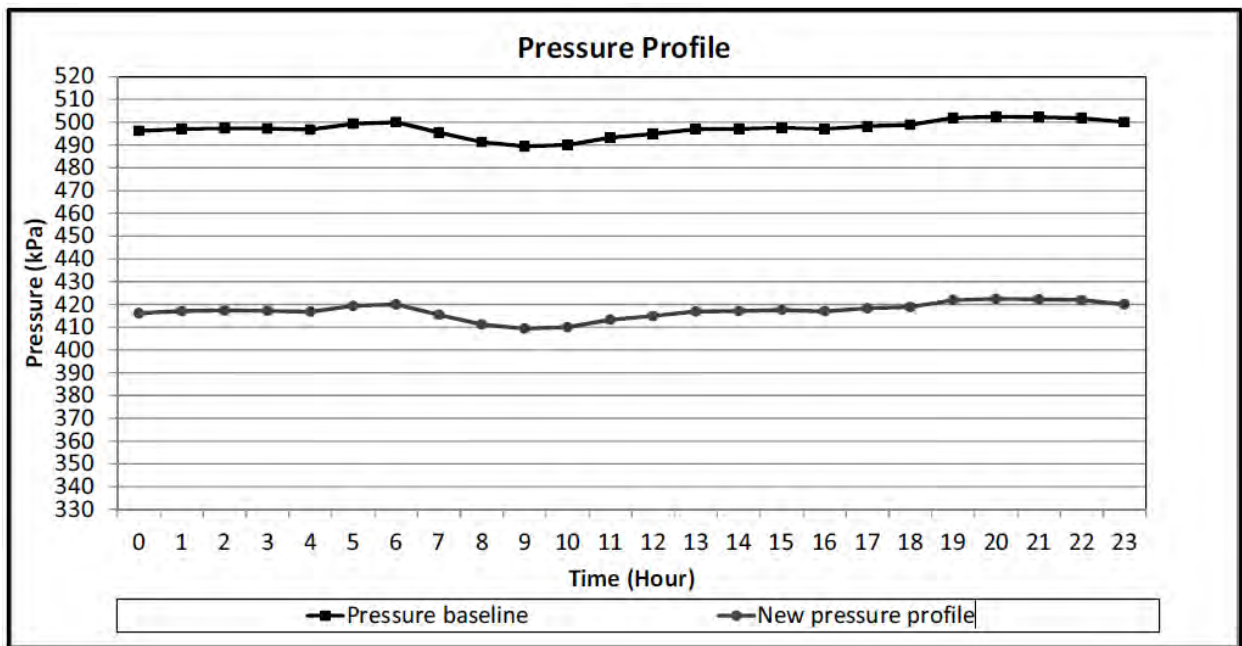


Figure 1-15 Example of an hourly pressure profile [38]

1.5. Objectives of this study

Section 1.1 identified the need to analyse data to produce information for sustainable energy management. This need requires the analysis of data from large energy consumers. The data exists in large volumes that overwhelm the user or energy personnel that need to analyse it [39].

Data stockpiles have formed due to the technological advancements mentioned in Section 1.2. The new challenge is to manage and make good use of the data. To find what the information engineers require, they have to filter through large volumes of data. This is a painstaking and time consuming process. One method of solving this problem is using software solutions.

To ensure sustainable energy management, an automated data analysis system is required. To effectively analyse the data, the interface must be customisable to produce information to satisfy different user needs.

The goal of this research is to develop a customisable web interface that displays graphs and tables of electrical energy consumption data. This interface will be used for data analysis. The interface must be generic and customisable so that new graphs and tables can be added with the minimum effort. It will have a great effect on the energy reporting, energy savings and reducing man-hours needed for energy management.

Placing the interface online will enable users to log on from any location and view the information. The data can be centralised and grouped together. This will enable data from different locations data to be viewed together. The interface must provide for different management levels. When the interface is implemented correctly the graphs and tables can identify problem cases and help with energy management.

1.6. Problem statement

The research presented in Section 1.4 involved questioning energy personnel and ESCo project engineers. It identifies the requirements and specifications that the typical user needs from a DAI. Section 1.3 discussed the existing data analysis systems and their suitability for large energy consumers. It also identified the shortcomings and limitations of the existing data analysis methods.

The investigations found that energy personnel and engineers had to create energy reports. They were using Excel as no alternative software was available. This was a very repetitive task that

was very demotivating and time consuming. Therefore a need is identified to automate these reports or information that would make the task less daunting. Problems and shortcomings of existing data analysis methods are discussed in the following categories: practical limitations and compliance issues.

Practical limitations

The first limitation is all the different formats of the different data analysis reports that need to be created. As discussed in Section 1.3 the current methods are not generic enough to satisfy all the different needs. Also when the systems become more generic they tend to become more complex. A specialist is then required to operate the software.

Sometimes the software needs installations on-site to be operational. These installations can be quite expensive and specialists have to perform the installation. Some software is only functional when the necessary hardware is installed. Therefore the data needs to be transferred in a certain format using a specific protocol.

Another limitation is the limited customised accessibility of the information. Different users will need to access different information, some of which may be confidential. The information must be sorted and structured in a logical way. The information display needs to be as generic as possible without being complex. Access to the data must also be secure as well as easy to navigate and set up the interface.

When the data is available in the correct format, it must still be retrieved somehow. Energy personnel on the site could email the data, but think it is a low priority task and often neglect to do this. This is also only practical if the information is needed on a daily basis. The ESCo employees can fetch the data, however they have to travel far and this is expensive.

Also, when the data is needed on hourly or a daily basis, it is not viable sending someone to fetch it every day or hour. The best solution is to pull the data from the site automatically sending it to the energy management database. This is not always allowed, due to strict security policies applicable to data networks on client sites.

The data integrity must be verified, for example identifying data loss. The data must be up to date or updated in real-time if possible. The interface must be able to facilitate all the different needs for users mentioned in Section 1.4.

Compliance issues

Energy personnel are very busy, because they usually have other responsibilities. For example a shaft engineer also has to report on the energy usage of the shaft, but the reporting is always a low priority compared to running the shaft operations. Consequently they do not familiarise themselves with new energy management or reporting software.

With so much data available, finding the correct information is very difficult. When users retrieve data they have to filter through datasets, containing thousands, and sometimes even millions of entries. This overwhelms the user and causes confusion.

It is difficult to prioritise which data is relevant. This is also disconcerting and will withhold the users to familiarise themselves with the system. This creates the challenge to create a user interface that navigates through the data that is both user-friendly and generic. The interface must also be as simple as possible for the user to configure the necessary views.

If users store data in the wrong format, it cannot be imported into the energy management database. If a few small changes are made to the data format, it can become an automated process. Users also periodically change the format of their reports that also makes it unable to automate the reports.

1.7. Overview of dissertation

Chapter 1: Introduction

In this chapter the need for large energy consumers to implement energy savings is investigated. Data gathered when energy savings projects are implemented is discussed and how the data can assist with energy management and energy savings. Existing energy management systems and data analysis methods are investigated. The existing system's limitations and shortcomings are identified. The objectives of this study are stipulated and finally the problems that may occur are stated.

Chapter 2: A new data analysis system

Chapter 2 refers briefly to the problems and limitations of energy management systems. It discussed the ISO 50001 and how it can contribute to this standard. Thereafter design requirements and specifications are identified. The new data analysis system is then development using the identified specifications and requirements.

Chapter 3: Results

The data analysis system is implemented on six large energy consumers. Two large gold mining groups are used test the system and compare the different requirements. One large steel manufacturing group is used to display its customisable capabilities for different operation structures and data formats. In conclusion, the specifications of the systems is reviewed to confirm successful development and implementation of the system.

Chapter 4: Conclusion and recommendations

The results presented in Chapter 3 are used to draw conclusions regarding the new data analysis system. Recommendations for future study and work are also presented.

CHAPTER 2

A NEW DATA ANALYSIS SYSTEM

2. A new data analysis system

2.1. Preamble

Existing data analysis methods are time-consuming and painstaking processes as they are usually not fully automated. The work needed is very repetitive and can be demotivating for the person responsible. Designing a new method for analysing data for large energy consumers will help improve and sustain energy efficiency and energy saving projects.

The International Standards Organisation (ISO) announced the ISO 50001 energy management standard in 2011 [40], [41]. The ISO 50001 introduced a Plan-Do-Check-Act (PDCA) cycle in order to ensure continuous improvement of energy management systems [40], [42]. Large energy consumers started implementing the standard, for example PPC SA and Toyota SA.

Figure 2-1 shows a simplified illustration of the PDCA cycle. The new data analysis will help improve the “Check” and “Act” stages of the PDCA cycle.



Figure 2-1 Continuous improvement cycle of the ISO 50001 standard

2.2. Design requirements

Bearing in mind the problems stated in Section 1.6, requirements for the customisable DAI were identified. The requirements can be divided into the following four categories:

- data collection and processing;
- data navigation and access;
- information display configuration; and
- information access.

Data collection and processing

As *Figure 1-5* in Section 1.2 shows, the data will be collected in different formats and from different sources. These sources may include amongst others the SCADA, production data from reports and electricity accounts. To process and consolidate the data and achieve the correct format for the energy management database two different software packages will be used.

PTB was discussed in Section 1.3 and will be used in the short-term when the data arrives in a new format which cannot be imported automatically. PTB uses macros to consolidate the data in a format that can be processed automatically. The consolidated data is then sent to a mail server, where another software package processes it and stores it in the database [43]. PTB will be used as a preprocessing tool if the data is not in the correct format. PTB is only used in the short term, because some phases have to be done manually by ESCo personnel.

For long-term data, processing software was developed that processes and consolidates the data in any necessary format as long as the incoming raw data has a fixed format. The software receives the data through automated emails or direct connections to databases. The data is then consolidated in the necessary format, then processed and stored in the energy management database.

Data navigation and access

Searching for data that can be used to create useful information can be a difficult process when working with large data sets. The data must therefore be grouped and organised with labels that make it easy to navigate through the data.

Section 1.4 identified what the user needs and wants. This helps to organise the data in such a way that is user-friendly and easily accessible. A method to navigate through all the data stored in the energy management database that is generic and well defined was created. This method is able to facilitate the structures of the different large energy consumers.

The best way for the data to be structured is for each large energy consumer to have its own data structure, because each consumer has its own operational structure. The users can configure the structures and then the data can be assigned to certain nodes of the structure. The nodes can represent entities such as a mine or cement group, a shaft of plant, etc. Users should be able to add, remove or edit nodes.

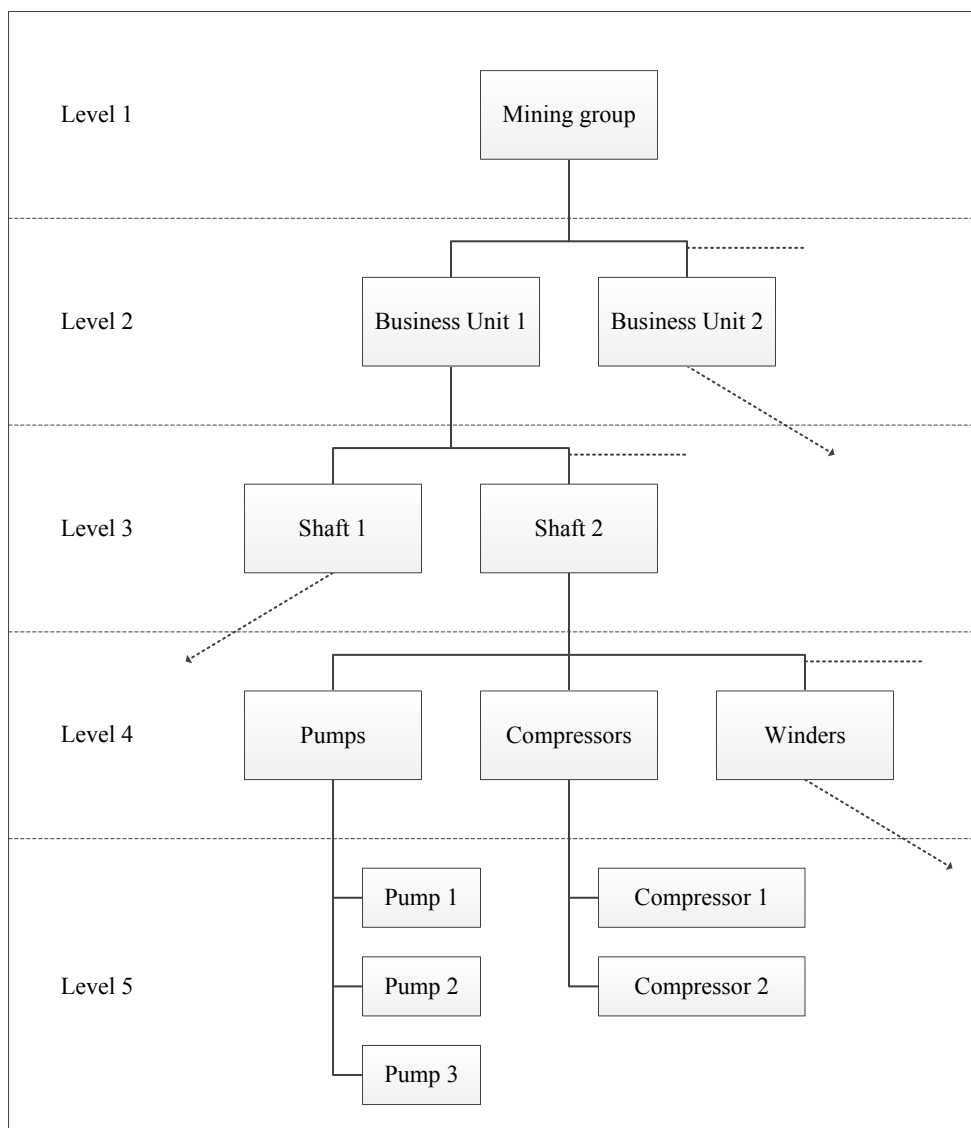


Figure 2-2 Example of energy systems of a mine group [44]

Figure 2-2 illustrates an example structure of a mining group and Figure 2-3 shows a possible structure for a cement manufacturing group. The node structure can be set up using an existing node tool. The tool allows the user to build a node structure and stores the structure in the energy management database. Each node is saved in the database as a certain type, for example a business unit, pump, compressor, shaft, mill, etc.

The user who configures the display for the client, will access the data. ESCo personnel send the information to the large energy consumer employees. The ESCo personnel can then access the data on the energy management database through a website. An administrator account can grant access to a specific user to access data using the created structure.

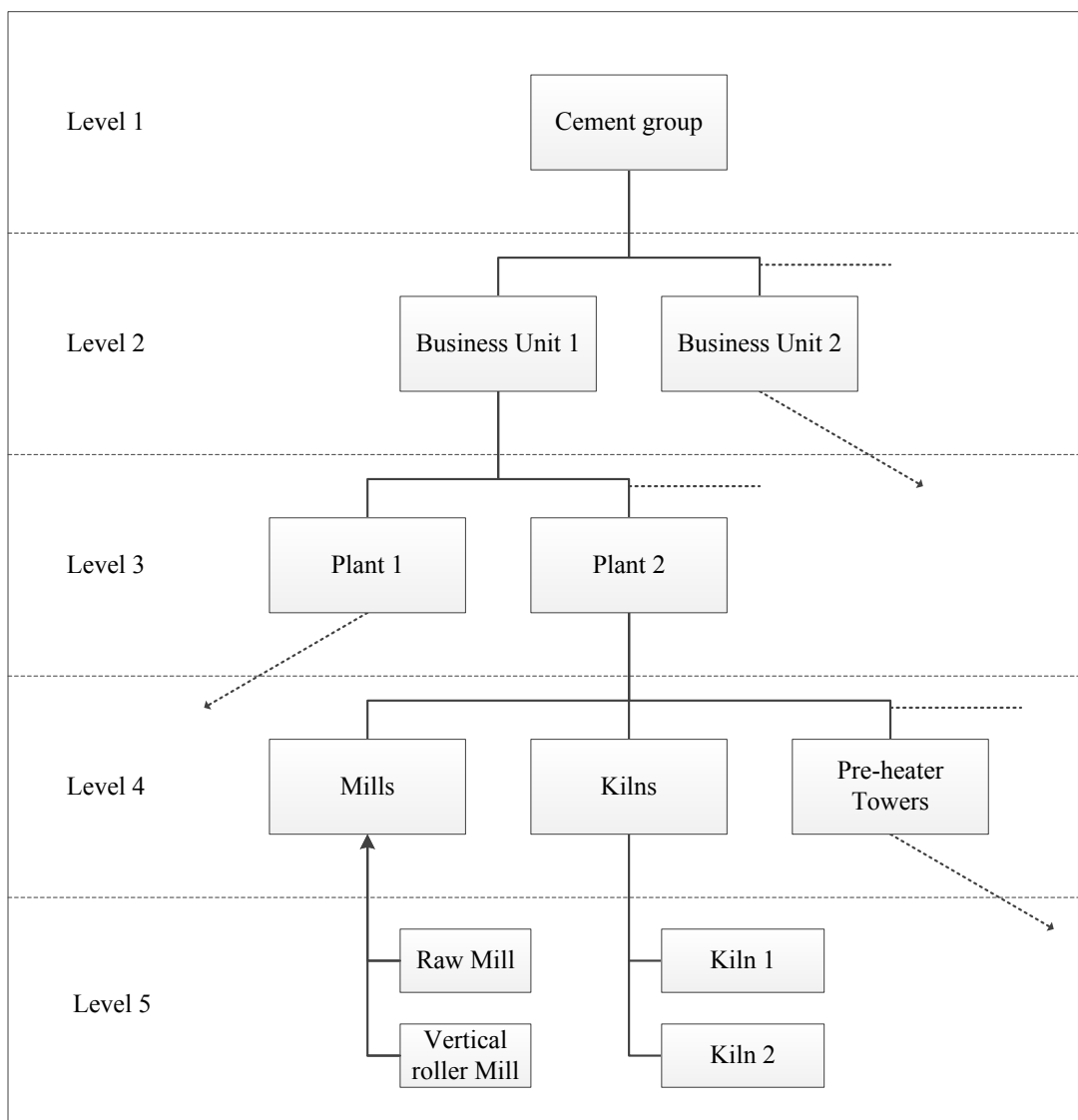


Figure 2-3 Example of energy systems of a cement group [45]

Information view configuration

When the user is familiar with the operational structure of the large energy consumer and has consulted with the client, the view can be configured. This will be done by creating different graphs and tables. A graph consist of series that are linked to certain data sets, the data will be retrieved according to the date period selected. Separate interfaces are needed to create the graphs and tables.

Calculations must be performed with the data sets to maximise the customisability of the information. Therefore an interface is needed to create these custom data sets, as well as interfaces to link the data to the graphs and tables.

Information access

After a user has configured a view that analyses data to create information for energy management, the client must be granted access to the information. *Figure 2-26* shows the process discussed to configure a view. In some cases the client would like to see more than one view. Therefore multiple views should be able to link to a client user.

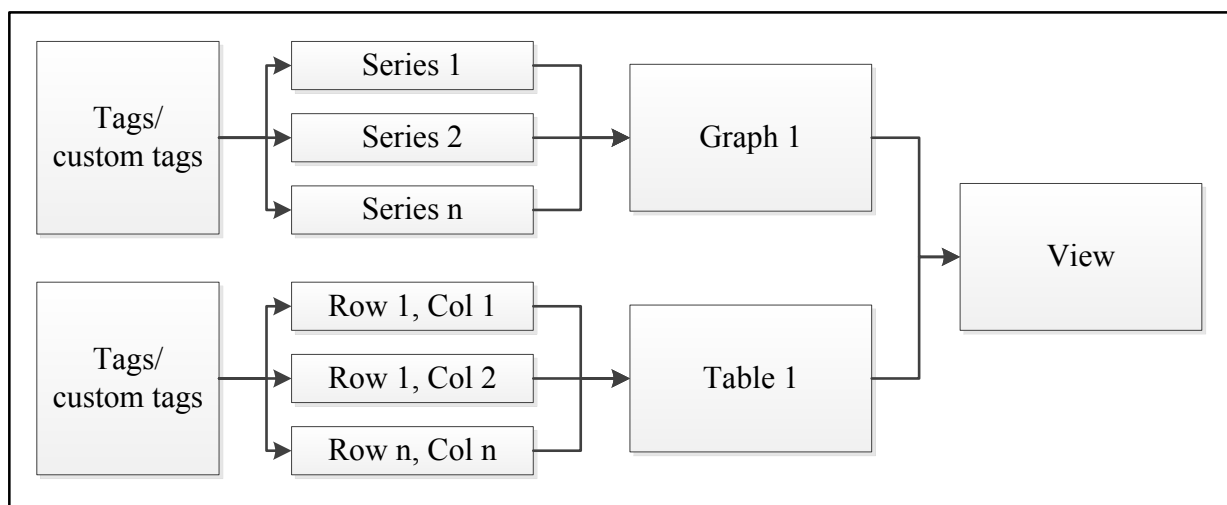


Figure 2-4 View configuration process [23]

An account should be created on the energy management website for the client user. For the client to view the information, they are required to log into their account. If multiple views are linked to the client they should be easy to switch between views. There should also be a functionality that generates a report of the selected view.

2.3. Specifications of the new data analysis system

Based on the design requirements in Section 2.2, the DAI has the following requirements and specifications:

- Raw data needs to be imported on a daily basis.
- Raw data should be processed on a daily basis.
- New data formats must be processed by PTB initially.
- Reports and accounts must be available on a monthly basis.
- Accounts data should be processed automatically.
- Reports must be duplicated using the interface.
- Reports must be customisable without needing programming changes.
- The customisability must provide for the necessary needs.
- The view configurations must be done on a central server from different locations.
- Users must gain access to the information using a web interface.

The types of data analysis methods required:

- Graphs: This will include all the different types of graphs and the different series the graphs have. For example:
 - Bar graph
 - Line graph
 - Area graph
 - Stacked graph
 - Pie graph
 - Combo graphs
- Tables
 - Tables will consist of rows and columns with individual cells. Each cell's value will be defined separately by linking it to data or enter a fixed value, etc.

2.4. Technical development details

The customisable DAI was integrated on an existing system of an ESCo. The existing system was already being used by the ESCo personnel and the ESCo's clients. The system is

implemented on an on-line web-server with an energy management database. The data process software is also part of the existing system.

Programming environment and languages

The ESCo's system used the programming language Hypertext Pre-processor (PHP) for the server-side processes and Hyper Text Markup Language (HTML) and JavaScript for the client side interface and processes. Therefore, it was necessary for the customisable DAI to be written using the above mentioned programming languages used for the existing ESCo system.

All the code was written using PHPDesigner as the Integrated Development Environment (IDE). PHPDesigner was chosen, because it is an editor for PHP, HTML and JavaScript. By using PHPDesigner all the different programming languages could easily be edited in one file, which made the coding process faster. Also, PHPDesigner is fast and powerful enough for the necessary applications[46].

Graphic components

The existing ESCo system used FusionCharts as a charting tool. FusionCharts is Flash Chart components, each component has its own Flash file. For example there is a Flash file for pie charts, combo charts, bar charts, etc. The user does not need to know any Flash programming to use FusionCharts. FusionCharts uses Extensible Markup Language (XML) as its data interface [47].

FusionCharts was also used for the customisable DAI for the following reasons:

- Not requiring Active-X or extended controls.
- Adding life like aesthetic effect to the site.
- Reducing server load.
- Being compatible with the necessary scripting languages.
- Changing the dynamic database of client.
- Appending other features in the graph [47].

Integration with existing system

The existing ESCo system uses a website where the user logs in to their account. Once the user is logged in several icons appear. These icons are called toolboxes. If the user clicks on one of the

toolboxes they are navigated to other pages where energy information is displayed and more icons appear for more information options.

Another toolbox called *Home* was added for the customisable DAI. If the clients log into their accounts and click on the *Home* toolbox they are navigated to the configured customisable DAI. *Figure 2-5* is a screenshot of the log in page and *Figure 2-6* is a screenshot of the page with all the toolboxes displayed after the user logs in.

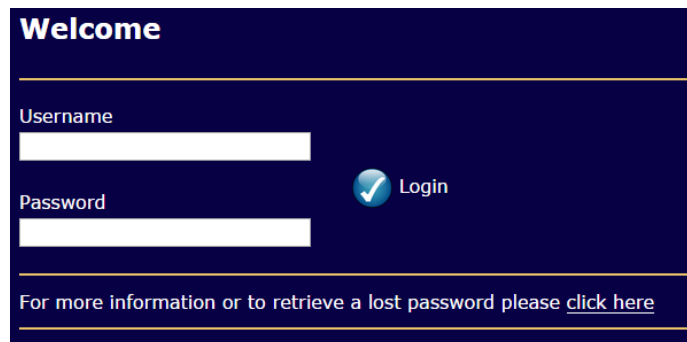


Figure 2-5 Screen shot of the log-in screen for the website

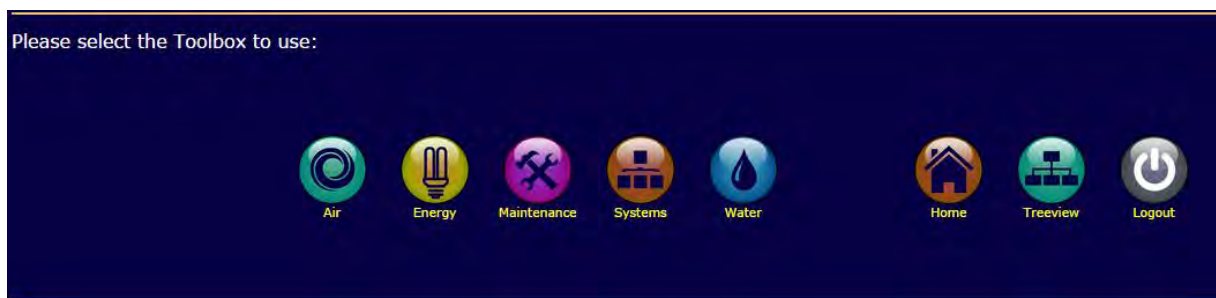


Figure 2-6 Screenshot of the page after log in showing the toolboxes

The ESCo personnel configured the customisable DAI for the clients. To do this, the ESCo personnel needed interfaces and menus to interact with the database. These interfaces and menus were accessible when the user logged into an admin account of the existing ESCo website. The developed interfaces and menus for this study will now be discussed in detail.

2.5. Menu and user interface development

Overview of the system

When the data is stored in the energy management database the processes necessary to configure the customisable DAI can start. *Figure 2-7* shows a simple summary of the processes needed to

create a view using the DAI. All of these processes use the energy management database. Graphical user interfaces were developed to help the user with the processes.

The processes in *Figure 2-7* are labelled from A to E. Processes A and C are done when new tags are needed. Process B is done when new nodes are needed. Process D uses the existing tags to configure the graphs and tables. Every time a new graph or table needs to be added to a view, the top half of *Figure 2-7* is repeated. Processes A to E will now be discussed in detail, each heading will start with the process letter it applies to.

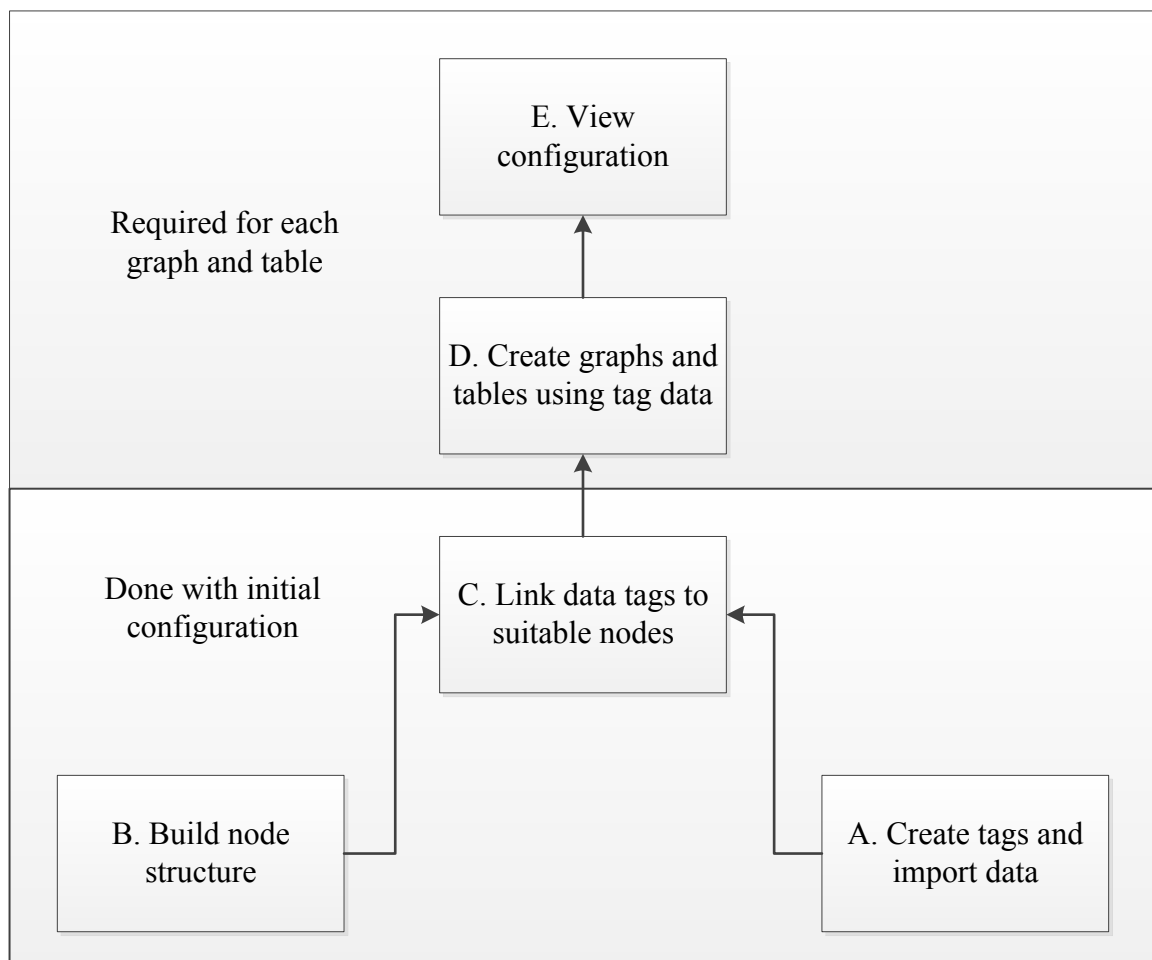


Figure 2-7 Overview of processes in creating of the DAI

Process A.1 – Tag creation and data import

Tags are automatically created when data is imported. The software mentioned in Section 2.2 was developed to create the tag in the energy management database if the tag does not exist yet. The data is processed and linked to a tag in the format shown in *Figure 2-8*.

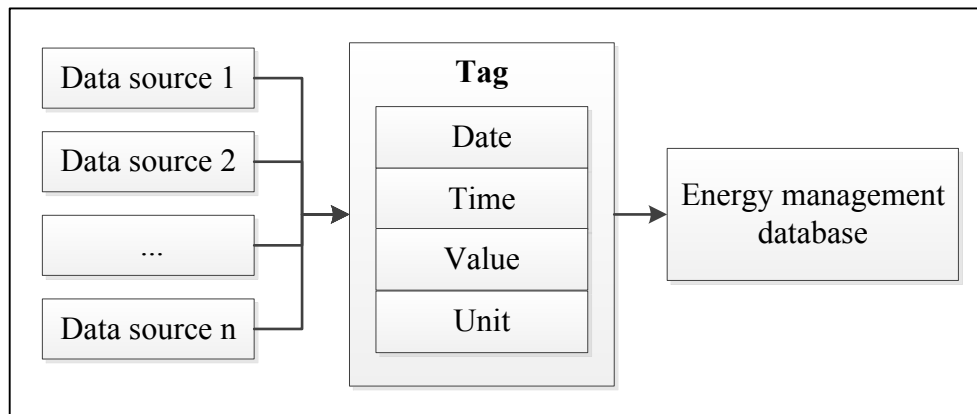


Figure 2-8 Data consolidation process [23]

When the data is imported, all data values are linked to existing tags in the energy management database. The value of a specific tag is stored for a specific date and time. This design accommodates values that are available in a one-minute, hourly, daily, monthly or yearly resolution.

Tags can also be added manually using a developed graphical user interface. Data linked to already existing tags can be exported into CSV files. These csv files can also be populated with data and imported into the energy management database. *Figure 2-9* shows the graphical user interface used to add tags manually.

In *Figure 2-9*, each tag has a name, description, unit, value type set and tag source. The name and description usually describe where the data physically originates. The unit is used to scale the data or convert values when needed, for example when 48 electrical energy values are measured in a day and needs to be converted to a power profile kW.

Every value is stored as an energy (kWh) unit. The electrical energy (kWh) values are the average power divided by 2. There are 24 hours in a day, if 48 values are stored; it is a value for every 30 minutes. The values are divided by 2 or multiplied by $\frac{1}{2}$, because they are taken over a half-hour period. Therefore, to plot the power (kW) profile the values will need to be multiplied by 2.

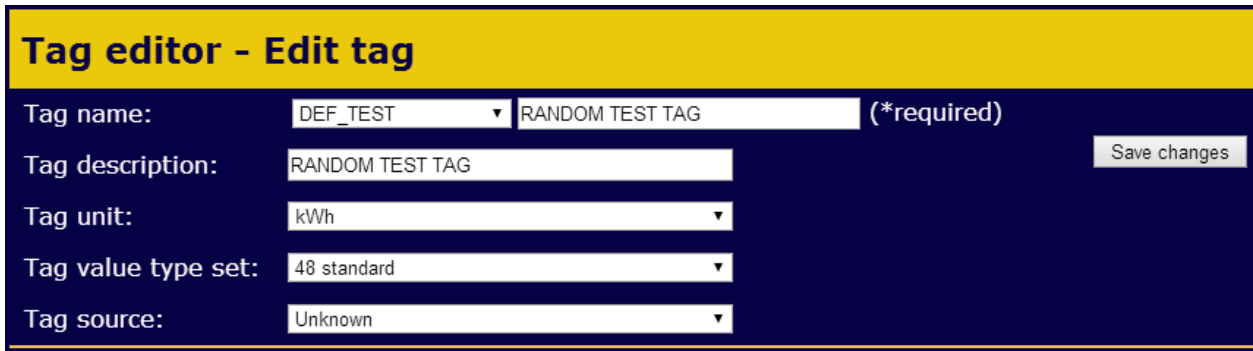


Figure 2-9 Screenshot of graphical user interface used for adding tags manually

The value type set is the number of values for each day, therefore if the value type set is 48 and the unit is kWh then a kWh measurement is stored every half hour. Tag source is the data source from where the data is received. For example the data can come from reports, the ESCo server or the SCADA.

Process A.2 – Programmable tag creation

Sometimes it is necessary to do calculations with tag values. Programmable tags are required to do this. Programmable tags consist of different calculations done with existing tags. Figure 2-10 shows the processes required to create a programmable tag.

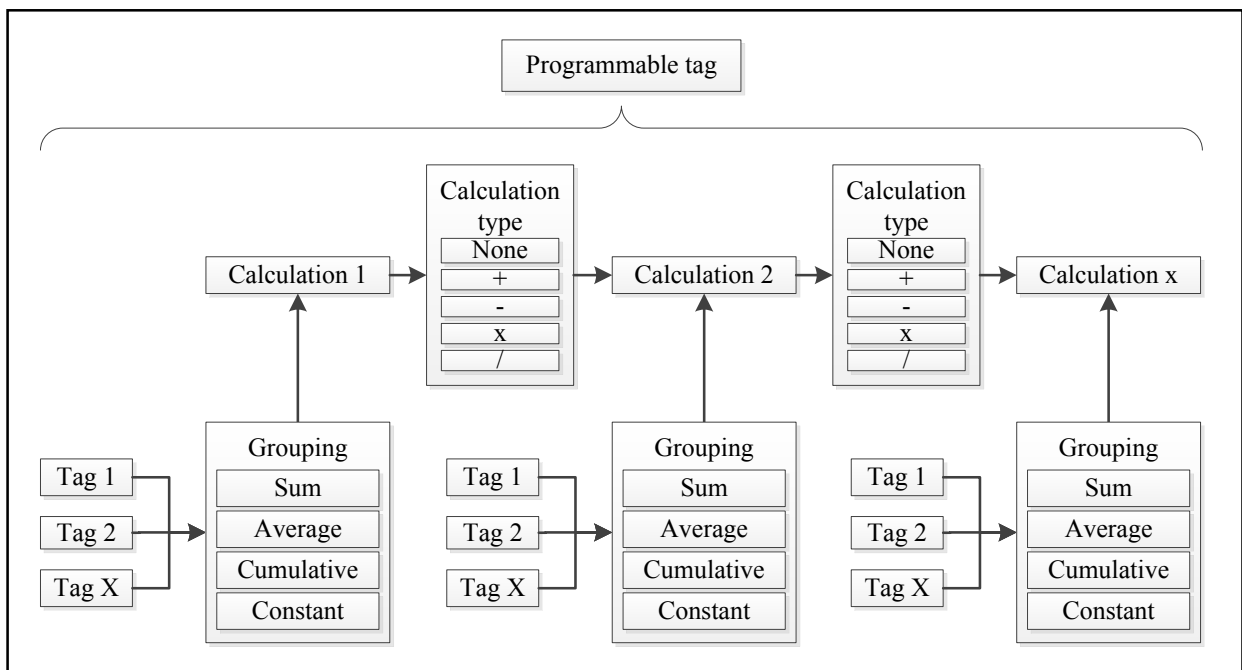


Figure 2-10 Programmable tag configuration process [23]

As shown in *Figure 2-10*, tags can be grouped together as a summation, average or cumulatively sum. If the grouping is a constant, no tags are linked to the calculation. More groupings can be added for additional functionality, however the groupings will have to be added in the database. When they are added in the database the necessary functionality will also need to be programmed. A grouping tariff cost is an example of extended functionality. These groupings use additional tables in the energy management database to calculate the cost of the electricity used if the tag unit is kWh.

The calculation type in *Figure 2-10* determines whether the calculation will be added, subtracted, multiplied or divided. The first calculation does not have a calculation type. Each calculation also has preceding and succeeding brackets specified by the user to determine the order in which the calculations should take place.

Figure 2-11 shows the graphical user interface used to configure programmable tags. In *Figure 2-11* each programmable tag has a name, description, unit, value type set and tag source like the normal tags. The programmable tags have an additional property called calculations.

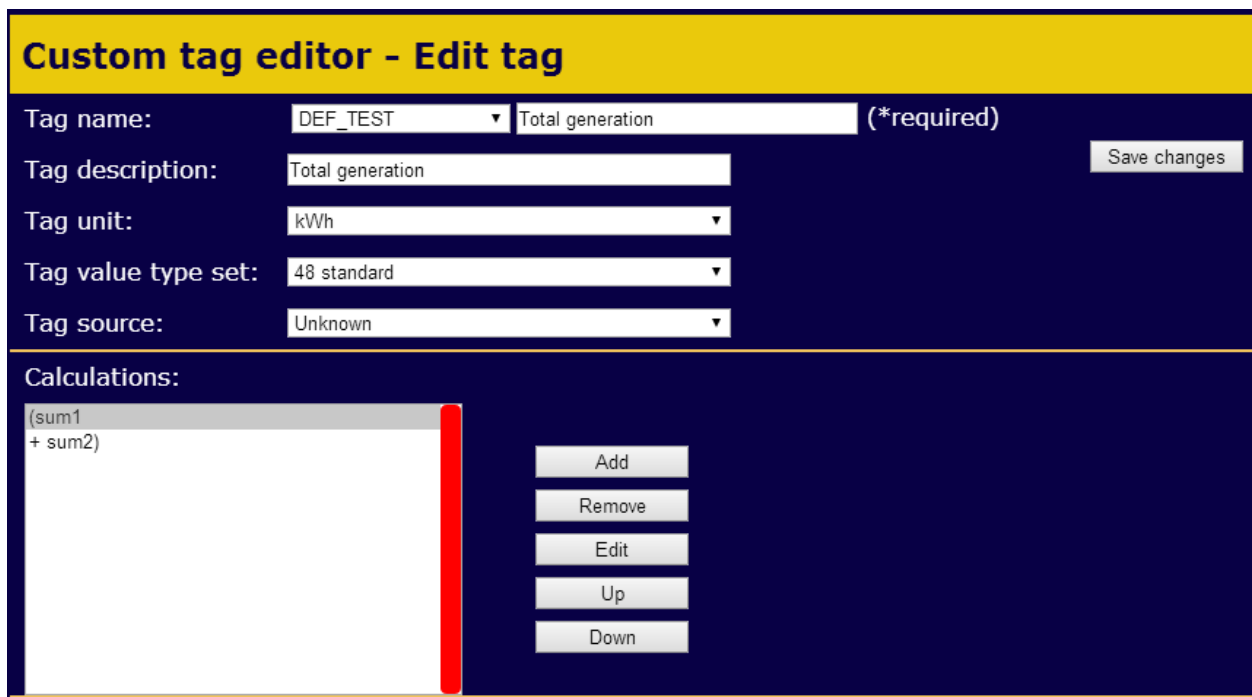


Figure 2-11 Screenshot of graphical user interface to add a programmable tag

Figure 2-11 shows $(sum1 + sum2)$ in the list box table labelled “Calculations”. This means calculation *sum1* has one opening bracket and no calculation type, because it is the first calculation. Calculation *sum2* has an addition (+) calculation type and one closing bracket. In

this way many tags can be added, averaged or cumulatively added together. Then addition, subtraction, multiplication and division can be done with summation and averaged tags. The order of the calculations can also be customised using the “Up” and “Down” buttons in *Figure 2-11*. The brackets also determine the order in which the calculations take place.

Figure 2-12 shows the calculation menu that appears when the “Add” button in *Figure 2-11* is clicked. As shown in *Figure 2-12* each calculation has a name, grouping, calculation type, the number of opening brackets, the number of closing brackets and the linked tags. The Calculation name field is for the user to describe the calculation. The Calculation grouping field determines what calculation will be performed with the tags linked to the calculation. For example, will they all be added together in a summation, or will the average be calculated. The calculation type is used between the calculations. Programmable tags can also be linked to calculations to create a programmable tag.

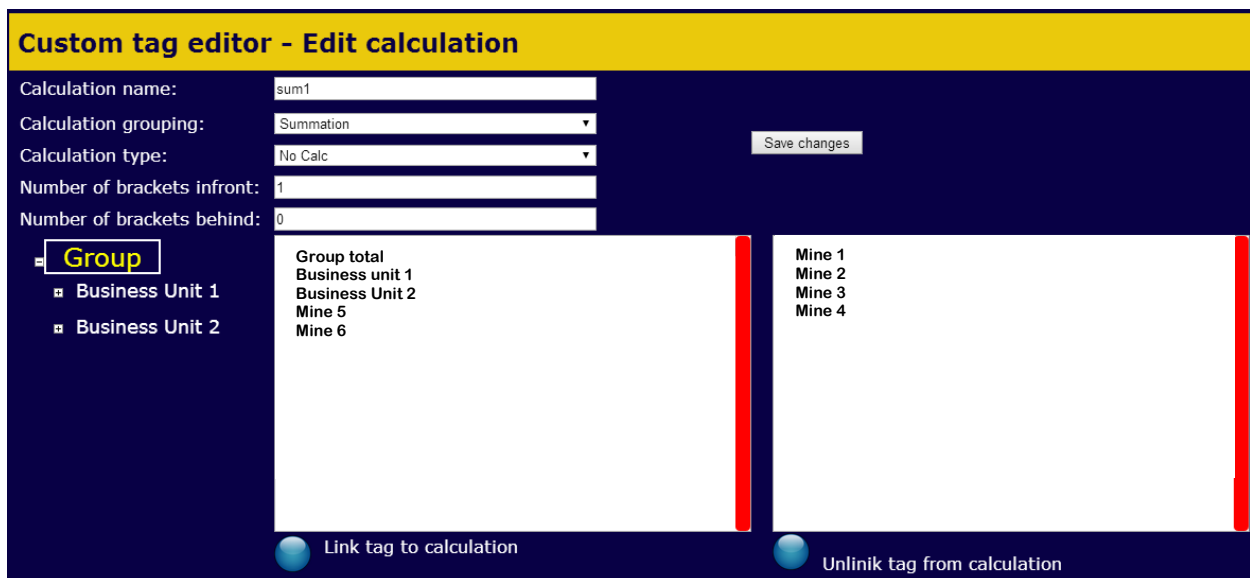


Figure 2-12 Screenshot of graphical user interface to add calculation to programmable tag

Process B – Building node structures

A node tree structure was used to represent each large energy consumer group as shown in Section 2.2. To create the tree structure the MTB node tool application is used. The application stores the node and its properties in the energy management database.

Figure 2-13 is a screenshot of the MTB node tool. New nodes are created by double-clicking, entering the name and the choosing type of node is chosen. A node structure class was written to

use the node tree structure to navigate through the data. This structure is used to link tags to nodes. After the tags are linked to nodes, the node structure is used to filter the tags when the tags are used to create programmable tags, graphs and tables.

The node structure class is used in menus to display the nodes in a user-friendly display. The user selects the structure and the tree structure is built. The user navigates through the tree much like a file tree. Using the + and - signs to expand and collapse a node and show or hide all the node's descendants. Clicking on the node will select it and reload the page.

Examples of this node display can be seen in *Figure 2-13* and *Figure 2-14*. The display is customisable and has different functions when the node it selected. The selected node has a white rectangle around it when it is selected.

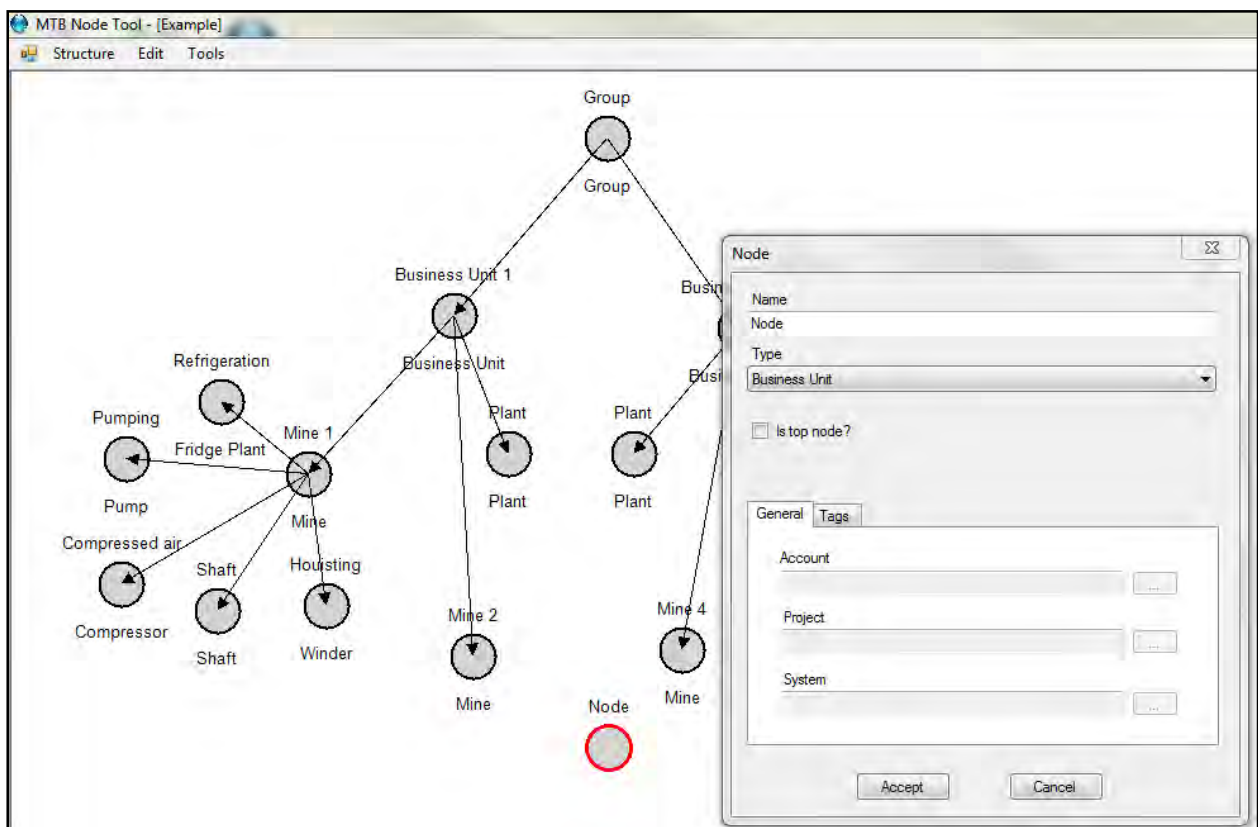


Figure 2-13 Screenshot of MTB node tool application

Process C – Linking tags to nodes

Tags need to be linked to nodes after they are created. This is necessary so that they can be used to create programmable tags, graphs and tables. The node tree structure filters the tags so the user can easily navigate through the data. *Figure 2-14* is a screen shot of the tag linking menu.



Figure 2-14 Screenshot of the tag linking menu

As seen in *Figure 2-14*, the structure is chosen with the drop down menu labelled “Structures”. After the structure is chosen the user can navigate through the node tree. When a node is selected the list box on the right labelled “Tags linked to node” displays the tags already linked to the selected node.

The list box on the left contains the tags that have not yet been linked to a node. These tags cannot be used to create programmable tags, graphs and tables. The node tree display will only display the tags linked to the selected node in the other menus.

Process D.1 – Graph configuration

An interface was developed to create graphs. As shown in *Figure 2-15* the user enters a graph name, graph title, a x-axis title, primary y-axis and if necessary a title for the secondary axis of the graph. The primary y-axis is on the left side and the secondary y-axis is on the right side of the graph.

The graph type and x-axis type are selected from a drop down list populated from the energy management database. The different chart types include the following entries:

- XY plot
 - This is a scatter plot, therefore both axes are numeric axes. Only lines and dots can be plotted using these graphs. The XY plot graphs are used to plot power profiles with vertical trend lines.
- Combo

- With the combo graph only the y-axis are numeric and the values are plotted in the order they are received. The series of the combo chart can be lines, bars or areas and they do not have to be the same.
- Pie
 - A pie graph is a circle divided into sectors; each sector size is determined by the quantity it represents.
- Combo Double Y
 - This graph is the same as the Combo graph except that the secondary axis is enabled.
- Stacked
 - Bars represent the series in this graph. The bars, however, are stacked on top of each other instead of standing next to each other.
- Stacked + Line
 - This graph is the same as the stacked graph, except a secondary axis is added. Every series that uses the secondary axes is represented by a line and is therefore not stacked.

Graph editor - Edit graph

Graph name: (*required)

Graph title:

Graph type:

X-Axis Type:

X-Axis Title:

Y-Axis Title (Primary):

Y-Axis Title (Secondary):

Y-Axis Limit:

Series:

Daily consumption	<input type="button" value="Add"/>
Cumulative consumption	<input type="button" value="Remove"/>
	<input type="button" value="Edit"/>
	<input type="button" value="Up"/>
	<input type="button" value="Down"/>

Figure 2-15 Screenshot of the graph editing menu

If the chart type is a Pie, then the x-axis is irrelevant. With each graph a time period is chosen for display. The x-axis type determines how the data will be displayed using the following entries:

- Hourly
 - There is an x-axis label every hour consisting of the timestamp. With scatter plots the data is not necessarily plotted each hour. The data can be plotted as frequently as available, each entry using its timestamp for its x-axis value.
- Daily
 - There is an x-axis label for each hour consisting of the day of the month as well as the month.
- Monthly
 - There is an x-axis label every month consisting of the month name and year.
- Average profile
 - This option plots a 24-hour profile of the selected time period. The profile is the average value for each hour, for each day, included in the time period. An x-axis label is added every hour.

The list box labelled “*Series*”, displayed all the current series created for the graph. When the “*Remove*” button is clicked the series is deleted. The series can also be moved up or down so the order of how the series data is displayed can be customised. Adding and editing series will be discussed next.

Process D.2 – Series configuration

When clicking on the “*Add*” or “*Edit*” buttons shown in *Figure 2-15*, the series editing menu appears, which is shown in *Figure 2-16*. The user enters the series name and line width. The line width is only relevant if the series is a line. The user can also enter the colour of the series if the option “*Custom*” is selected from the drop down list.

The series tag drop down list is populated from the energy management database and the node tree structure is used as a filter. The tags displayed in the drop-down list are all the tags linked to the selected node and tags linked to the selected node’s descendants.

The series unit can be selected if unit conversion is necessary. This is necessary if the linked tag's unit and the series' unit are different. A conversion table stored in the energy management database was created that converts the data values to the series unit.

Graph editor - Edit series

- Group
 - Business Unit 1
 - Business Unit 2

Series tag: RANDOM TEST TAG

Series name: Daily consumption

Series colour: Red (FF0000)

Series unit: kW

Series type: Bar

Series axis: Primary

Line width: 2

Save changes

Reset changes

Figure 2-16 Screenshot of the series editing menu

The series type drop down list is populated from the energy management database and contains the following entries:

- line,
- bar, and
- area.

The user selects to which axis the series should belong. If the secondary axis is chosen the chart must have that functionality.

Process D.3 – Table configuration

An interface to create custom tables was also created. *Figure 2-17* shows the menu used to add, edit and delete tables. *Figure 2-18* displays the menu loaded when a new table is added. When a table is edited, the menu shown in *Figure 2-19* is loaded.

The user enters the table’s name and the number of rows and columns. The table type property is a drop down list populated from the energy management database. The table type is used when the table has a fixed format or template. When the “Save changes” button is clicked, the menu in *Figure 2-19* is loaded.

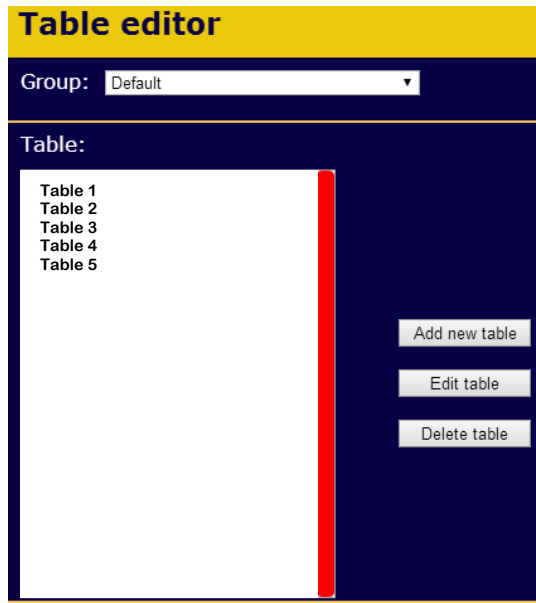


Figure 2-17 Screen shot of table adding and editing menu

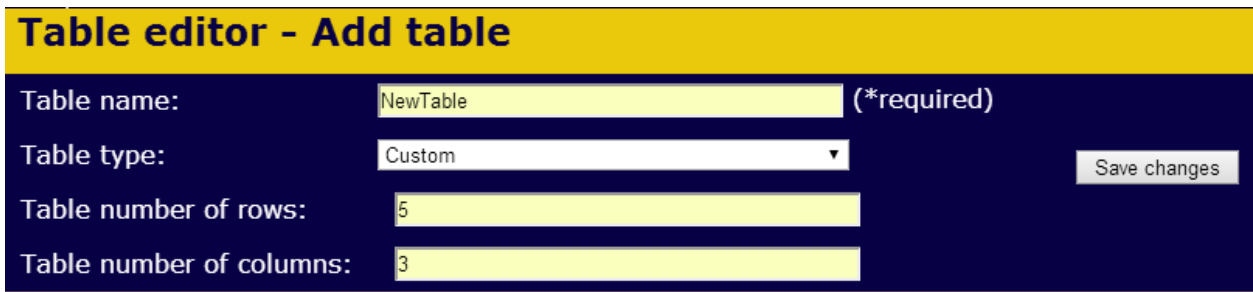


Figure 2-18 Screenshot of table adding menu

The user can add more rows and columns in the menu displayed in *Figure 2-19*. This is done by clicking on the numbered checkboxes on top and on the left. Then if a checkbox is selected, the user can click on the button “Add row or column”. If one of the top checkboxes is selected, a column will be added to the right of the selected tick box column. If one of the left checkboxes is selected a row will be added below the checkbox row.

As seen in *Figure 2-19*, the user must specify the values for each cell. Each cell has a drop-down list populated from the energy management database. The following entries exist in the drop-down list:

- Text/fixed value
 - The user enters a value for the cell in the given text box. The cell value will always stay the same.
- Tag value
 - The user selects a tag from the list box on the left and clicks on the button labelled “*No tags linked*”. After the button is clicked the label will change to the tag’s name. The tag list box is filtered by the node tree structure to its left. The value of the cell will then be the sum of the data period selected by the user.
- Blank
 - This is the default value when the cells are created. This will display nothing.
- Text + tag value
 - The user enters a fixed value in the given text box and links a tag by clicking on the same button as the Tag value option. The cell value will then be the tag value with a space in between.
- Tag value + text
 - This option is the same as Text + tag value except now the tag value is first and the text second. The tag value and text are also separated by a space.
- Tag name
 - This option also displays a button to link a tag. The cell value that will be displayed is the linked tag’s name.
- Tag name + value
 - This option also displays the button to link a tag, but the cell value will be the tag name, then a space and then the tag value.
- Cell calculations
 - This option displays a button labelled “*Create cell*”. When clicked the user is taken to a different menu where calculations can be done with the cells. This cell value is a combination of different cells added, subtracted, multiplied or divided by each other.
- Date: yyyy-mm-dd
 - The cell value will be the selected start date. For example: 2014-02-15.
- Date: MMM-yyyy
 - The cell value will be the selected start date. For example: Feb-2014.

- Date: dd-MMM
 - The cell value will be the selected start date. For example: 15-Feb.
- Date: dd-MMM-yyyy
 - The cell value will be the user selected start date. For example: 15-Feb-2014.

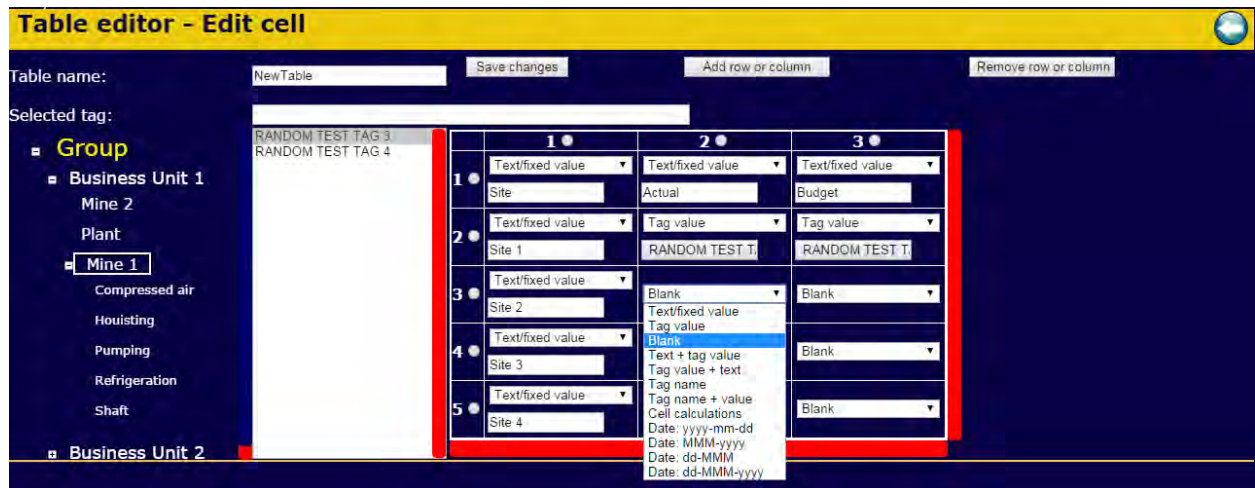


Figure 2-19 Screenshot of table cell editing menu

Process E - View configuration

Views are linked to a user account, and when the user logs into the website they can select between all the different views linked to their account. *Figure 2-20* shows the menu used to add, edit and remove custom views. The user first selects the large energy consumer group the view is created for, using the drop down list labelled “*Group*”. The list is populated using the energy management database.

After the group is selected the user can add, edit and delete custom views belonging to the group by selecting a custom view in the list box labelled “*Custom views*” and clicking on the appropriate buttons on the right. If a view is selected and the “*Copy custom view*” button is clicked, a new view is created with all the same properties as the selected view. A “*Copy*” label is added in brackets to the name of the new view. This can be seen in the list box labelled “*Custom views*” in *Figure 2-20*.

When the “*Add custom view*” or “*Edit custom view*” button is clicked, the menu in *Figure 2-21* appears. The user enters the view’s name and description. The entered name will later be used in a drop down list when the user selects the view on the web site. All the view properties are stored in the energy management database when “*Save changes*” are clicked.



Figure 2-20 Screenshot of the menu to add and edit custom views

Figure 2-21 Screenshot of the custom view editor

When the button labelled “*Link graphs and tables*” in Figure 2-20 is clicked the menu in Figure 2-22 appears. All the graphs linked to the group selected by the user in Figure 2-20 are displayed in the list box labelled “*Available Graphs*”. The tables are displayed in the list box labelled “*Available tables*” in the centre.

When the buttons labelled “*Add new graph link*”, “*Add new table link*” or “*Edit link*” buttons are clicked the menu in Figure 2-23 appears. The user can enter a link description that is displayed above the item on the website. If the description is left blank nothing is displayed. The user can also change the order of the items using the buttons labelled “*Up*” and “*Down*”.

The user chooses the link period from the drop down list labelled “*Link period*”. The drop-down list is populated from the energy management database. The link period is used to pre-set the date pickers on the website. Each view’s tables and graphs has its own date picker on the website. This is so that the user can select the data of different periods to display. The following entries exist:

- Yesterday
 - Both the “*From*” and the “*To*” date are set to the previous day’s date.
- Past week
 - The “*From*” date is set to seven days before the current date. The “*To*” date is set to one day before the current date.
- Past month
 - The “*From*” date is set to current day, from the previous month. For example if it is 2014-09-02, the “*From*” date will be set to 2014-08-02. The “*To*” date is set to one day before the current date.
- Last month
 - The “*From*” date is set to the first day of the previous month. The “*To*” date is set to the last day of the previous month.
- Past year
 - The “*From*” date is set to the first day from the current month, but from the previous year. For example if the current date is 2014-06-15 the “*From*” date will be set to 2013-06-01. The “*To*” date is set to the last day of the previous month.
- Last year
 - The “*From*” date is set to the first day of last year and the “*To*” date is set to the last day of last year.

After the view has been configured, the user can link the view to the appropriate user account. The user account is also linked to the large energy consumer group. *Figure 2-24* shows a screenshot of the menu used to link views to user account. The user is selected from the drop-down list labelled “*Users*”. The drop-down list is populated from the energy management database. When a new user is selected the list box labelled “*Available views*” is populated with views linked to the same group as the user.

When a view is selected in the list box labelled “*Available views*” and the button labelled “*Link view*” is clicked, the view appears in the list box labelled “*Linked views*”. The view is linked to the user account and will display on the website. To unlink a view the user selects a view in the list box labelled “*Linked views*” and clicks on the button labelled “*Unlink view*”.

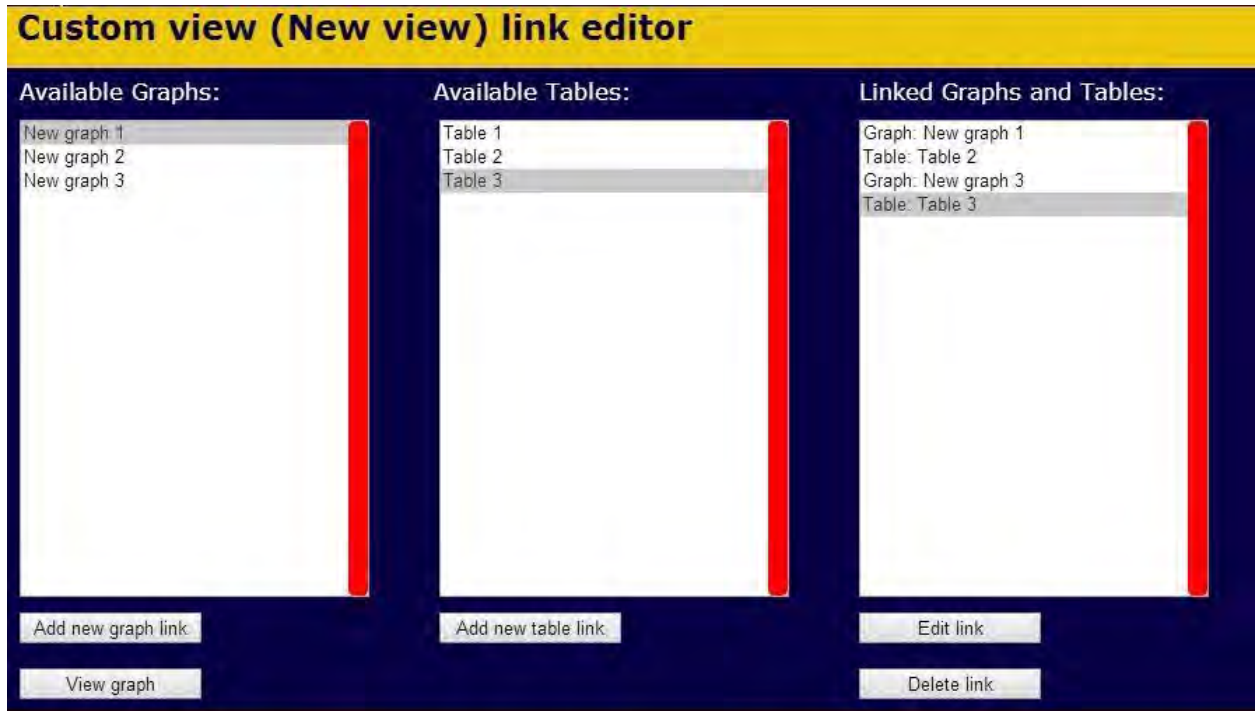


Figure 2-22 Screenshot of the linking menu for custom views

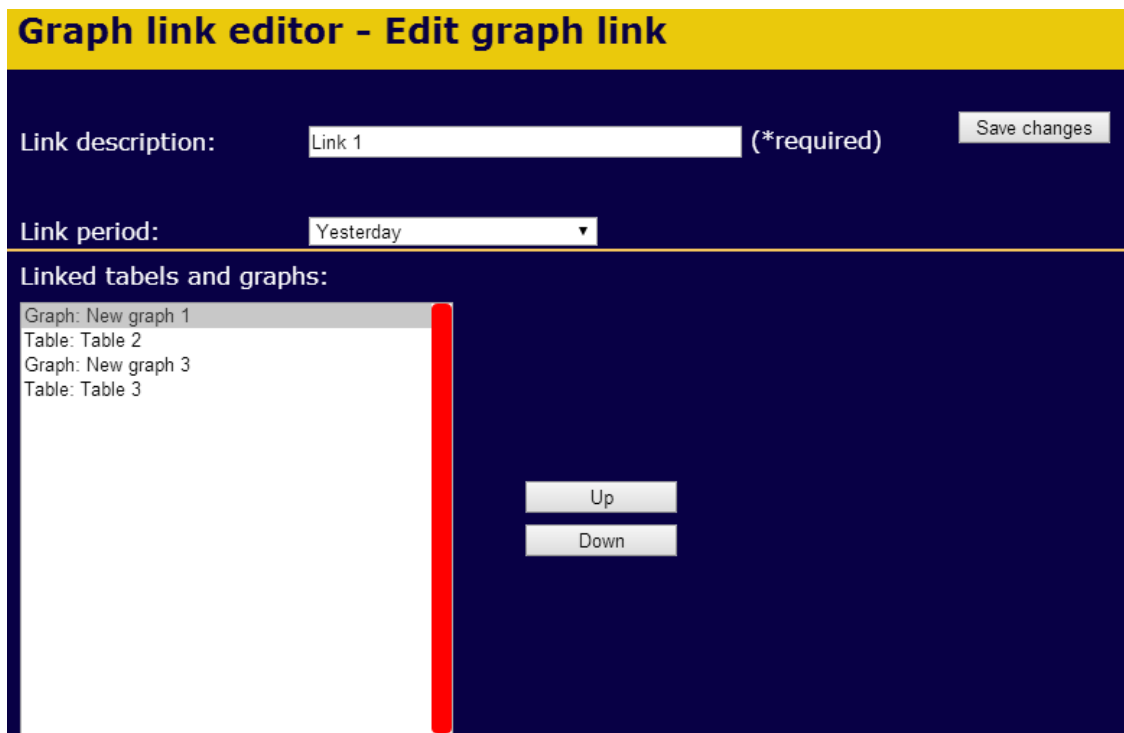


Figure 2-23 Screen shot of the view link editor

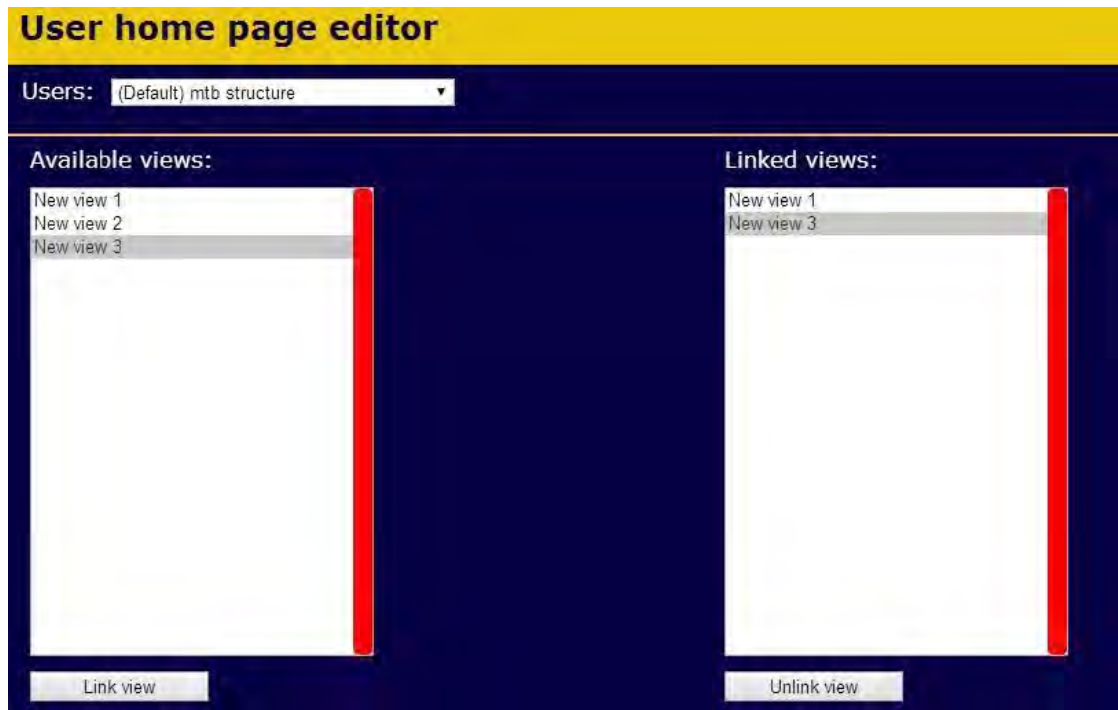


Figure 2-24 Screenshot of linking views to users menu

2.6. Database design

For the database design a relational database management system (RDBMS) was needed. MySQL was used as the RDBMS for the same reasons discussed by Goosen in his thesis “Efficient monitoring of mine compressed air savings” [9].

Tables were created to implement the DAI. The tables will now be explained using figures, which are partial entity relationship diagrams (ERD) of the energy management database. In the following paragraphs the table names are written in *italic*. The tables’ names that start with *tt_* were newly developed for the customisable DAI.

Tables developed for programmable tag configuration

Figure 2-25 shows tables used to store the measurement data and perform calculations with the data. The *tt_GenData_ValueProcessed* table is where all the values are stored. This table’s primary key (PK) is a composite of the date, the tag ID and the value type ID. Each tag in the *tt_GenData_Tag* table can have zero-to-many *tt_GenData_ValueProcessed* entries, but each *tt_GenData_ValueProcessed* entry can only refer to one tag.

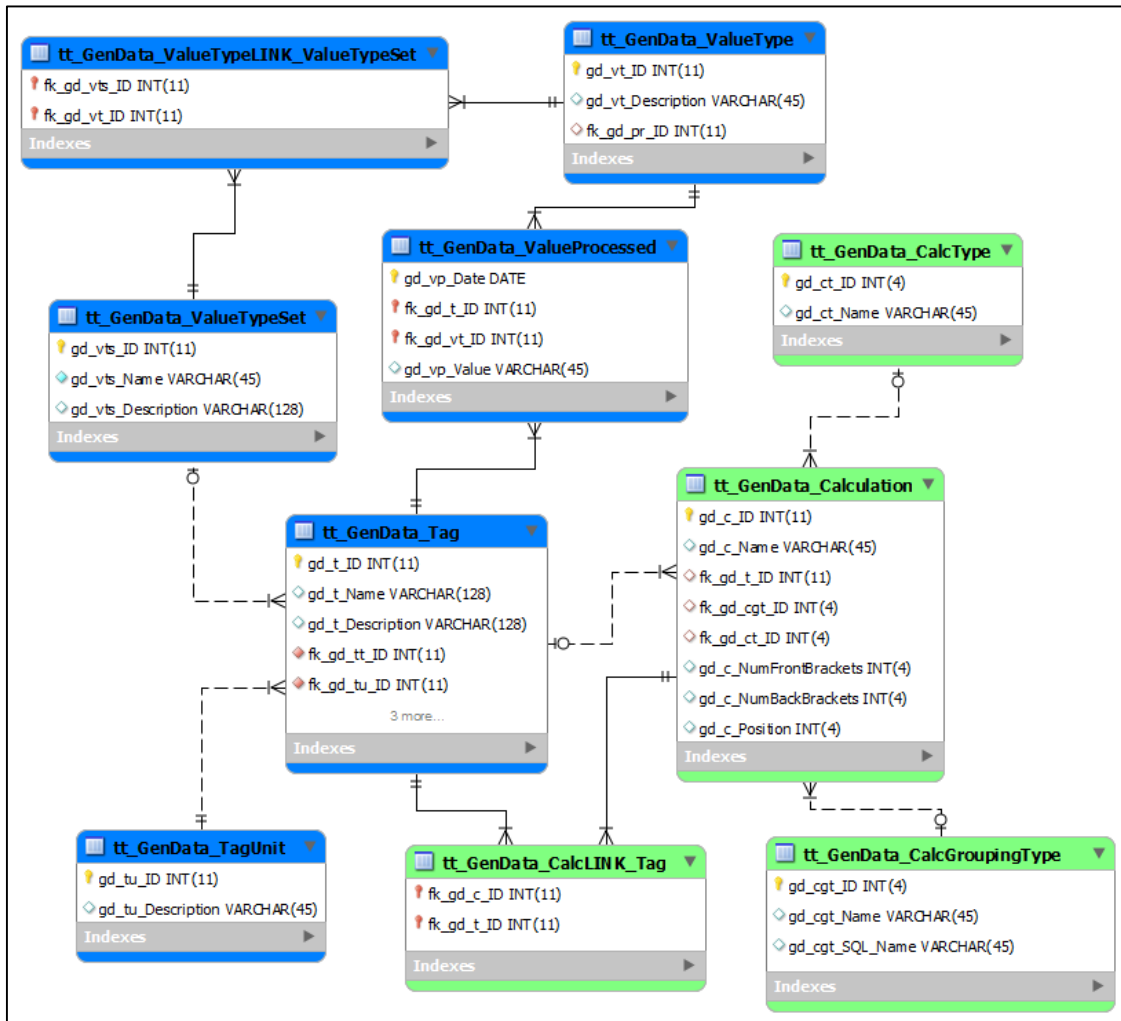


Figure 2-25 Partial ERD of the database including tables needed for programmable tag configuration

Each *tt_GenData_ValueProcessed* entry is also linked to one *tt_GenData_ValueType* entry. Different examples of value types include a month total, or a day total or a total for the first half hour of the day. Then each value type is linked to one value type set using the *tt_GenDataValueTypeLINK_ValueTypeSet* table. The value types and value type sets are configured when the data is processed, consolidated and imported. The *tt_GenData_ValueTypeSet* table contains all the value type sets, for example 48 values per day, 24 values per day, 1 value per day, etc.

The tags in the *tt_GenData_Tag* table are also linked to a value type set. A tag that is linked to energy data, for example energy (kWh) values for every half-hour will be linked to the appropriate value type set. All the values linked to the tag will then also be linked to the value

types that are linked to the tag's value type set. The value types and value type sets are used when the data is retrieved for the graphs and tables.

Every tag is linked to one unit that exists in the *tt_GenData_TagUnit* table. The units are used when values need to be converted to a different unit. Every *tt_GenData_TagUnit* entry therefore has a zero-to-many *tt_GenData_Tag* entries. The *tt_GenData_Tag*, *tt_GenData_TagUnit*, *tt_GenData_ValueType* and *tt_GenData_ValueTypeSet* tables all use an ID as their primary key.

When a programmable tag is configured it is also stored in the *tt_GenData_Tag* table and has all the properties of a normal tag and one additional property calculation. The programmable tag will, however, have no values in the *tt_GenData_ValueProcessed* table. Calculations are stored in the *tt_GenData_Calculation* table. This table's primary key is an ID and stores the following information: the name, number of preceding brackets, number of succeeding brackets and the order of the calculation.

Each *tt_GenData_Calculation* entry is linked to a *tt_GenData_CalcGroupingType* entry, a *tt_GenData_Tag* entry and a *tt_GenData_CalcType* entry. Then *tt_GenData_Tag* entries can also be linked to *tt_GenData_Calculation* entries through the *tt_GenData_CalcLINK_Tag* table. The calculations are performed with the tags in *tt_GenData_CalcLINK_Tag* table using the *tt_GenData_CalcGroupingType* and the *tt_GenData_CalcType* entries as discussed the Process A.1 – Tag creation and data import section.

Tables developed for graph configuration

Figure 2-26 shows tables used to store configured custom graphs. The *tt_CustomGraph_Graph* table has an ID for a primary key and stores the name, description, the x-axis title, the y-axis title and, if necessary, the second y-axis title and y-axis limit. Then a *tt_CustomGraph_GraphType* entry, a *tt_CustomGraph_XaxisType* entry and *mt_et_systems_group* entry are also stored.

The *tt_CustomGraph_GraphType* table contains all the graph types and the *tt_CustomGraph_XaxisType* table contains all the x-axes types. Both of the tables' entries are discussed in the Process D.1 – Graph configuration section and how they are used for graph configuration. These tables have a zero to many entry in the *tt_CustomGraph_Graph* table.

The *tt_CustomGraph_Sieres* table has an ID for a primary key and stores the series name, colour, order, axis and line width. The series name will be displayed in the legend of the graph. The series order determines which series is drawn on top and at the back. The axis value is 0 for the

primary axis and 1 for the secondary axis. The line width is specified in pixels, for example, if the line width has a value of 2, the series line will be two pixels wide. The line width is only applicable if the series type is a line.

Every *tt_CustomGraph_Sieres* entry has one *tt_CustomGraph_Graph* entry so that the series is linked to a specific graph. A *tt_GenData_Tag* entry is necessary in *tt_CustomGraph_Sieres* to link data to the series. The *tt_CustomGraph_SieresType* entry defines the series type, which is used as discussed in the Process D.2 – Series configuration Section. The series are also linked to a tag unit. If the tag unit of the series differs from the tag unit of the linked tag, a conversion will be done with the data values.

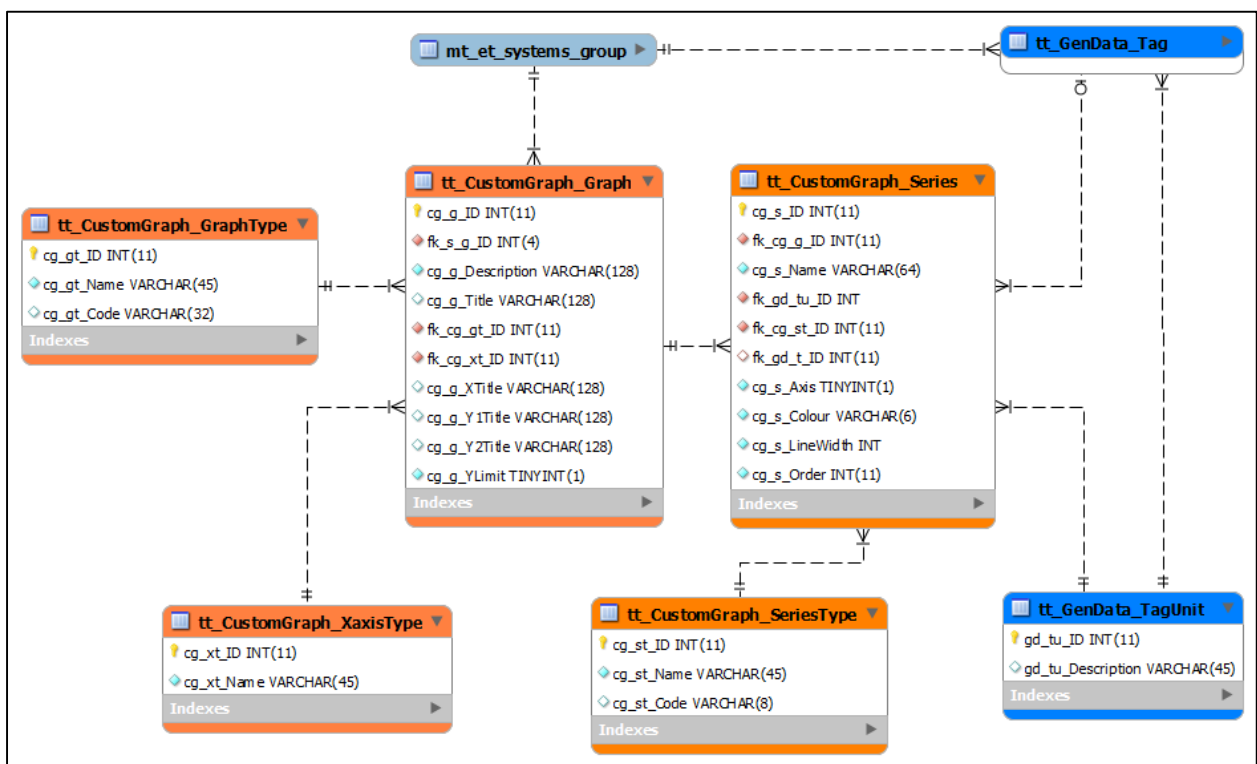


Figure 2-26 Partial ERD of the database including tables needed for custom graph configuration

Tables developed for custom table configuration

Figure 2-27 shows the tables necessary to store configured custom tables. The *tt_CustomTable_Table* table stores the custom table name and the number of rows and columns the custom table has. There is also a foreign key for the custom table type. The *tt_CustomTable_Table* table uses an ID as a primary key.

The *tt_CustomTable_Cell* table has an ID primary key and a *tt_CustomTable_Table* entry so that every cell is linked to a custom table. The cell also has a row and column number for the position in the custom table. Tags can be used for the cell value as discussed in the Process D.3 – Table configuration Section. A *tt_CustomTable_Cell* entry and a *tt_GenData_Tag* entry exist in the *tt_CustomTable_CellLINK_Tag* table.

The *tt_CustomTable_CellType* table contains all the cell type entries and has zero-to-many entries in the *tt_CustomTable_Cell* table. The cell types are used as discussed in the Process D.3 – Table configuration Section. The *tt_CustomTable_CellValues* table contains fixed values for the cell entries in *tt_CustomTable_Cell*. Every *tt_CustomTable_CellValues* entry has a one-to-one relationship with a *tt_CustomTable_Cell* entry.

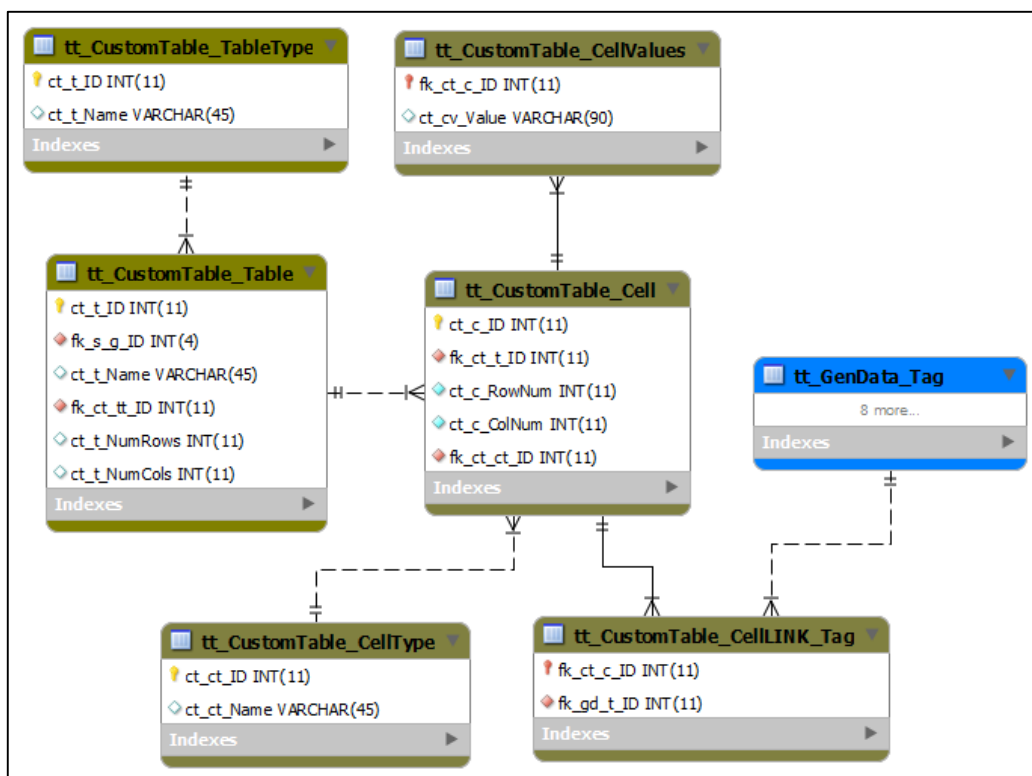


Figure 2-27 Partial ERD of the database including tables needed for custom table configuration

Tables developed for view configuration

Figure 2-28 displays all the tables necessary to link graphs and tables to a view. The *tt_CustomView_View* table has an ID primary key and stores the view’s name and description. The *tt_CustomTableLINK_View* table has a *tt_CustomView_View* and a *tt_CustomTable_Table*

entry to link the table to the view. Then there is a *tt_CustomGraphTable_Period* entry that is used to pre-set the date pickers as explained in the Process E - View configuration Section.

The order of the table is stored, and takes the *tt_CustomGraphLINK_View* entries order for the same view into account. For example the graph or table with the value 0 stored for order will be displayed at the top of the view. The order value with 1 is displayed second, 2 is third and so on. The *tt_CustomGraphLINK_View* entry and the *tt_CustomTableLINK_View* entry can never have the same order for the same view, because the entries are checked before they are stored.

The *tt_CustomGraphLINK_View* table has all the same fields as the *tt_CustomTableLINK_View* table, except it has a *tt_CustomGraph_Graph* entry instead of a *tt_CustomTable_Table* entry. The description is displayed as a heading in the view for both the *tt_CustomGraphLINK_View* entries and the *tt_CustomTableLINK_View* entries.

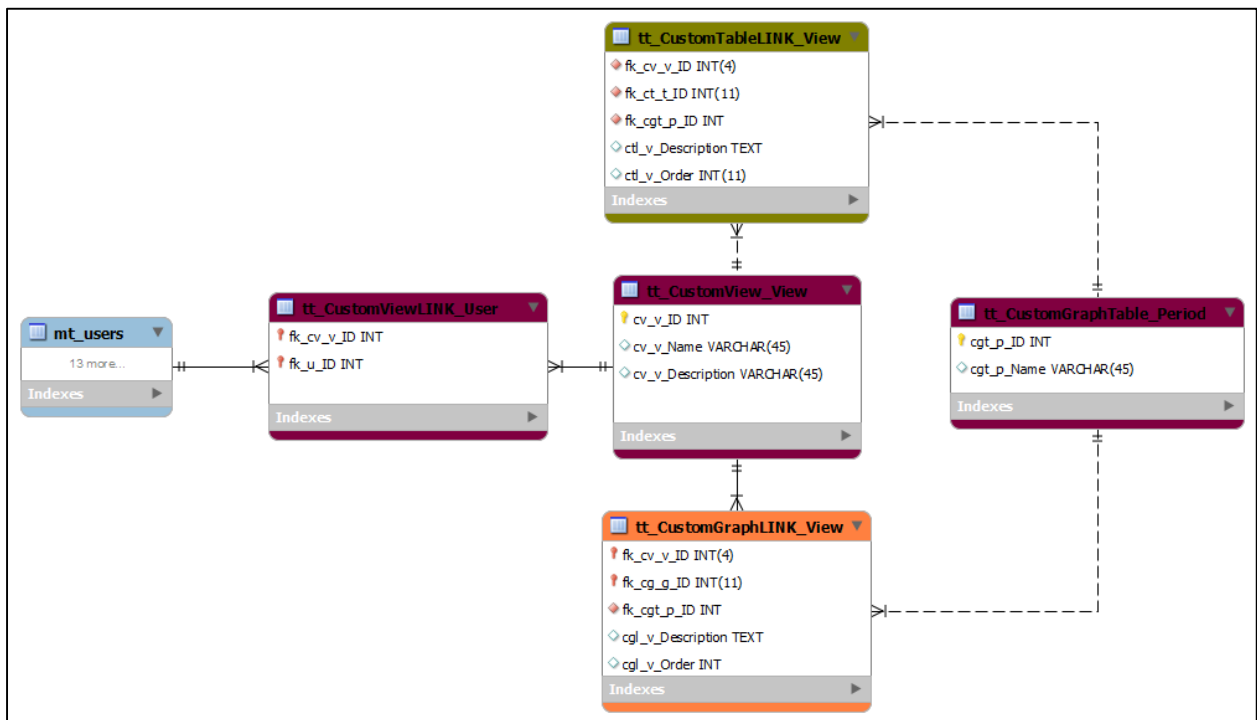


Figure 2-28 Partial ERD of the database including tables needed for custom view configuration

2.7. Summary

A customisable DAI for large energy consumers is developed. The design requirements are identified using the problem statement created in Section 1.6. Specifications of the new data analysis system are defined to ensure that the needs are satisfied by the data analysis system.

An overview of the system is discussed breaking down the data analysis system into five processes. The five processes include tag creation and data import, building node structures, linking tags to nodes, graph and table configuration and finally the view configuration. Each process is discussed in detail and how it contributes to the data analysis system.

Lastly the database design is discussed. Each process discussed in Section 2.4 uses the database to function. The database design for each process is explained with partial ERD diagrams of the database. The ERD contains tables used to store the necessary data. The relationships of these tables are explained and displayed.

CHAPTER 3

RESULTS

3. Results

3.1. Preamble

In 2013, an ESCo started to implement the customisable DAI on different large energy consumers. The energy consumers include two gold mining groups, one platinum mining group, one steel manufacturing group, cement plants and one glass manufacturing group. The data was gathered using data sheets, reports and emails sent automatically using an on-site application connected to the client database. The data was then processed using the PTB system in the short term as well as the automated system mentioned in Section 2.2 for the long term.

Three of the large energy groups were selected as case studies for implementation of the developed system: two gold mining groups and a steel manufacturing group. Data is already available for the energy consumers and graphs are discussed to illustrate the efficiency of the customisable data analyses interface. Due to confidentiality, the large energy consumers are not named and will be referred to as Gold mining group 1, Gold mining group 2 and Steel manufacturing group.

Firstly, the energy management personnel hierarchy of each large energy consumer group is discussed. Then the business structure of the consumer is discussed. How the data is obtained will be looked at and then, finally, the data analysis representation is discussed.

3.2. Case study A: Gold mining group 1

Energy management personnel

Several mining personnel were consulted to gain the information necessary to configure the DAI. The energy personnel supplied the structure of the group and the different sources of data and how the sources can be accessed. After the interface was configured the results were also sent to the mining personnel for feedback and further improvement.

The following personnel received the reports: the Chief Financial Officer, the Engineering Manager of Electrical Audits, the Water and Energy Engineer, Certified Energy Manager, Energy Manager and Shaft Operations Controller. *Figure 3-1* shows the hierarchy of the energy personnel of the gold mining group.

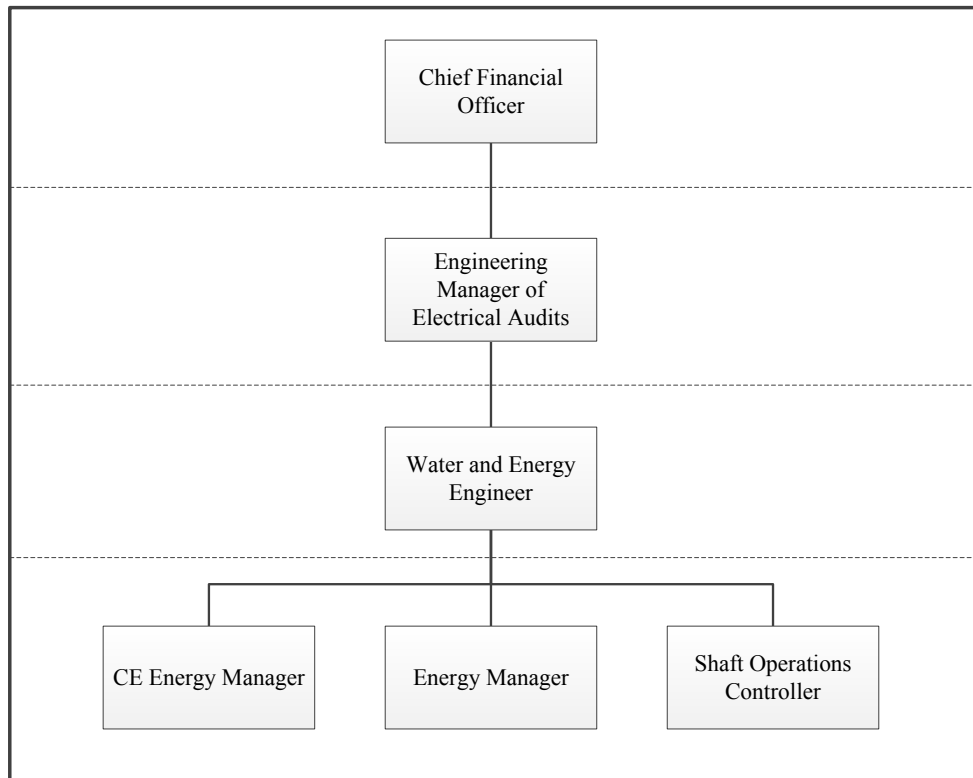


Figure 3-1 Gold mining group 1 energy personnel hierarchy

Business structure

A node structure was built for the mining group. The group consists of two business units which are referred to as Business Unit A and Business Unit B. Business Unit A has three mines and metallurgy, residential and business services nodes. Business Unit B has a business services node, three mine nodes and a metallurgy node. Metallurgy has three plant nodes as well.

Under each mine there are more nodes for example fans, mining, compressors, pumps, winders and refrigeration. *Figure 3-2* shows the node structure of the gold mining group and *Figure 3-3* shows the node descendants of a mine. The energy personnel of the gold mining group wanted to monitor the hourly electricity consumption profiles of each mine's pumping, refrigeration, hoisting and compressed air power and air consumption.

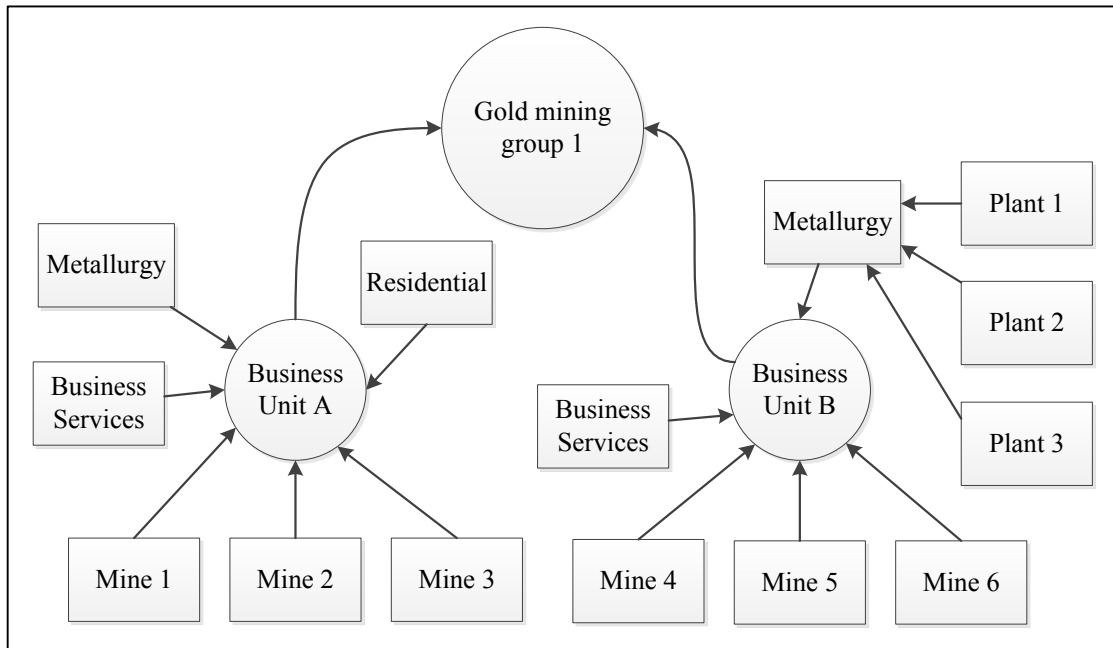


Figure 3-2 Overview of gold mining group 1 structure

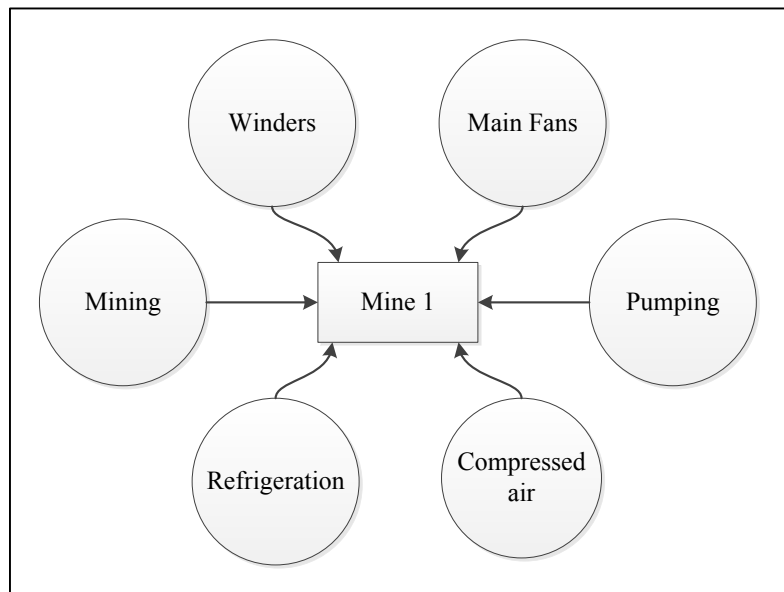


Figure 3-3 Overview of mine and its children nodes

Data collection

The developed interface was implemented for six of the gold mines belonging to the group. Data was collected from the gold mines using the on-site application installed on an ESCo server. Reports currently being made by energy personnel were emailed to the ESCo as well as Eskom accounts. The on-site application sent the data in a format that could be processed and

consolidated. Data is then stored into the energy management database on the hosted web server. *Figure 3-4* is a summary of how the data is stored in the energy management database.

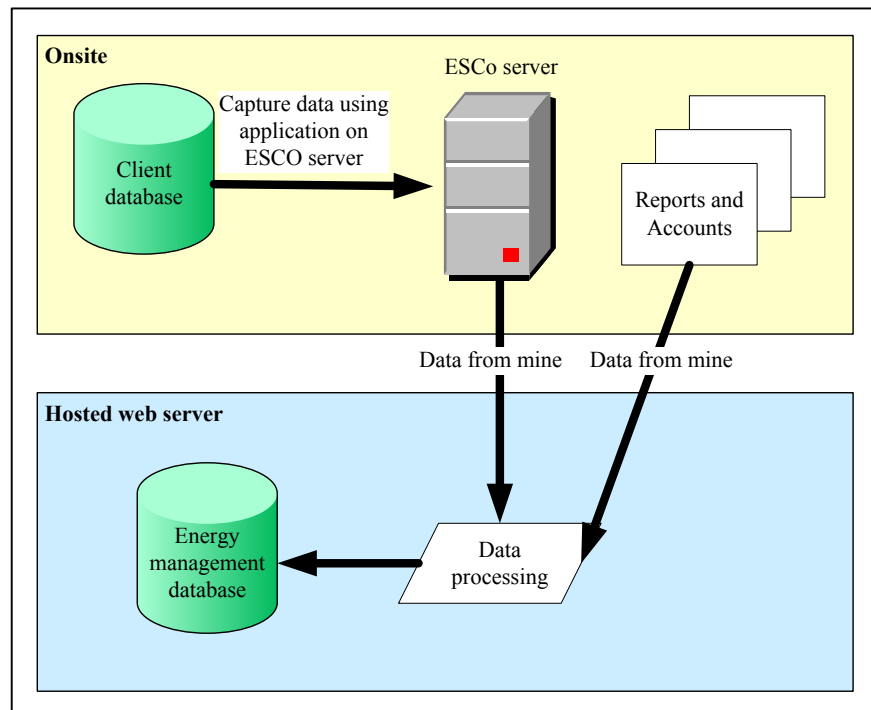


Figure 3-4 Summary of data flow process from gold mine

Data analysis and representation

Views were configured to show power profiles for each mine's pumping demand, refrigeration demand and hoisting demand. Each of the views also had a graph displaying the amount of compressed air consumed, the actual power profile and budget profile. Another view was created to show the hourly profile of each mine's total electricity demand. Reports were successfully generated from each view. *Figure 3-5* and *Figure 3-6* are screenshots of the interface configured for the gold mining group.

Figure 3-5 shows the actual and budget pumping consumption in kW for 28 July 2014. The names of the mine and tags have been removed due to confidentiality. The same graph was implemented for the refrigeration and hoisting as well.

Figure 3-6 shows the same menu with the views selection list box open. The names of the views have been censored to hide the mine names. Six views were configured one for each mine's load management and then a view for all the business units. The graph in the background is the mines refrigeration consumption for 28 July 2014.

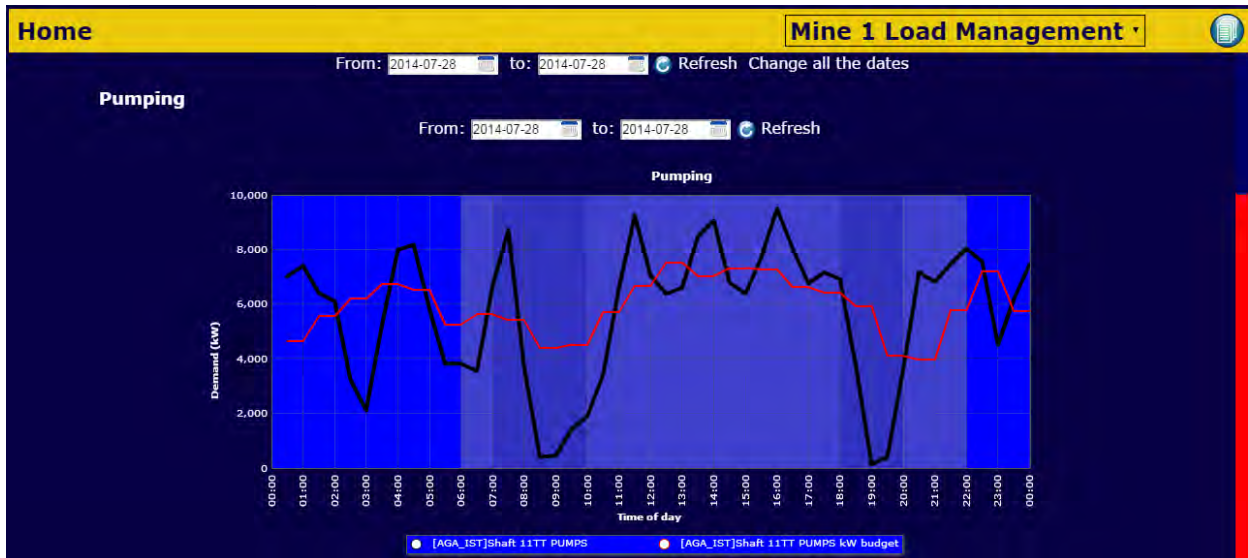


Figure 3-5 Screenshot of the customisable DAI for the Gold mining group 1



Figure 3-6 Screenshot of the customisable DAI with the views list box open

By plotting the mine operations' daily profiles the personnel can confirm whether projects implemented by the ESCo achieved the required results. The ESCo implemented load shifting projects on the pumps and an energy efficiency project on refrigeration. Gold mining group 1 is a relatively new client of the ESCo, therefore more data analysis opportunities can be identified. For example to display the temperature and dam levels of a mine to confirm that the energy projects do not affect the mines' production.

If the dams are empty when water is necessary for operations such as drilling, production is reduced. Or if a mine's temperature rises to hazardous conditions and work must be halted,

production is also reduced. Real-time data can identify risks and problems quickly using the information provided by the data customisable analysis interface, for example when air pressure drops suddenly because of a burst valve or a pump that is overheating.

Tables were also configured for each mine's performance. The tables contained the electricity consumption (kWh) budget usage, the actual electricity consumption (kWh) usage and the over or under budget percentage. The over or under budget percentage is the actual electricity consumption (kWh) subtracted from the budget electricity consumption (kWh) divided by the budgeted amount. Then it is multiplied by a 100 to give the percentage of how far over or under the budget the mine is for the selected period. Programmable tags were used to calculate the over or under budget percentage. *Table 3.1* is an example of the system overview table.

System	Budget (kWh)	Actual (kWh)	Over budget %	R/kWh
Mine 1	45,239,565	41,199,101	-8.9%	0.48
Mine 2	33,446,997	32,929,503	-1.5%	0.46
Mine 3	7,636,086	7,461,295	-2.3%	0.47
Mine 4	11,510,206	11,996,899	4.2%	0.48
Mine 5	27,376,411	27,867,731	1.8%	0.47
Mine 6	15,578,444	14,939,085	-4.1%	0.47
Metallurgy	44,173,735	42,882,400	-2.9%	0.46
Business Services	6,713,909	6,710,538	-0.1%	0.47
Total	191,675,355	185,986,553	-3.0%	0.46

Table 3.1 System overview (1 September 2014 - 26 September 2014)

Previously the CE Energy Manager, Energy Manager and Shaft Operations Controller had to collect the data and compile reports themselves. After the interface was implemented they could log on to a secure site that used the DAI to automate the reports. The mining personnel then generate reports from the site and send it to the necessary personnel.

3.3. Case study B: Gold mining group 2

Energy management personnel

Gold mining group 2 is much bigger than the previous gold mining group therefore they have energy personnel that consult the personnel at different sites. Site personnel are typically shaft

engineers and electricians. Energy personnel included an electrical engineer, a chief electrician and an electrician. The group's electrical engineer was also consulted.

By consulting the energy personnel's reports, reports that could be automated using the customisable DAI, were identified. The group's electrical engineer also gave feedback and instructions on how and to whom the reports should be distributed. *Figure 3-7* shows the hierarchy of Gold mining group 2. A standard report was identified that will be sent to each mine's or site's personnel.

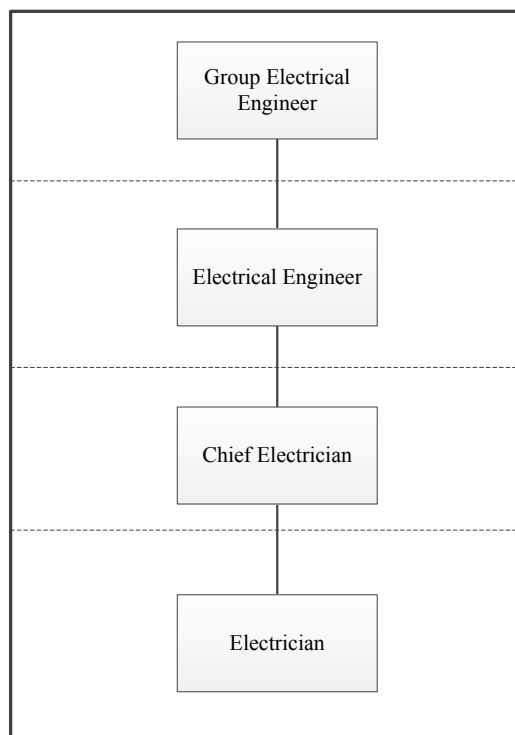


Figure 3-7 Gold mining group 2 energy personnel hierarchy

Business structure

A node structure was built for the mining group. The group consists of eight business units which are referred to as Business Unit A to Business Unit H. Each business unit has its own plant and between one and eight mines. *Figure 3-8* shows a partial node structure of Gold mining group 2. There are four more business units not shown, two with only one mine, one with eight mines and one with six mines. Each business unit has its own plant.

Similar to Gold mining group 1, each mine has nodes that include fans, mining, compressors, pumps, winders and refrigeration. Some mines have additional nodes that include hostels, slime filtration and sub shaft operations.

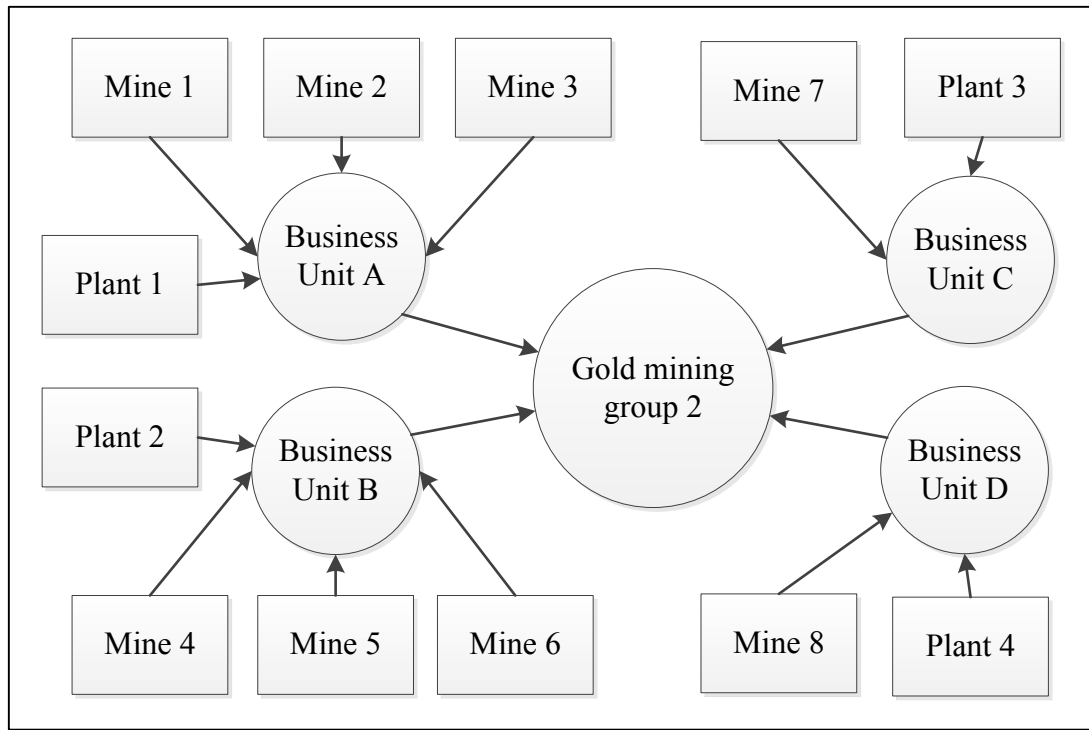


Figure 3-8 Overview of Gold mining group 2 structure

Data collection

Data was also collected similarly as it was collected from Gold mining group 1, because all the sites had ESCo servers installed. The application was therefore installed on the ESCo server that automatically sends the data to the hosted web server where it is processed and stored in the energy management database. Eskom accounts are also received monthly and stored in the database.

The sites have ESCo servers installed, because DSM projects have been implemented on the sites. These DSM projects require measurement and equipment to verify the results achieved. This creates large amounts of data to be analysed.

Data analysis and representation

With the help of the energy management personnel a standard report was identified. This report was duplicated using the interface for each mine. Each business unit could log on to the web

hosted server and view each of their mines' performance with the DAI. Each business unit had its own account and each mine had its own view.

The reports contained a summary table that displayed the following information:

- The first column displayed the actual energy consumption of each operation of the mine and the mine's total energy consumption in kWh.
- The second column displayed the budget energy consumption of each operation of the mine and the mine's total energy consumption in kWh.
- The third column displayed the actual cost of the energy consumption of each operation of the mine and the mine's total cost in Rand
- The last column displayed the amount over or under budget of each operation and the mine's total was shown in Rand.

The report also contained a *Total power consumption* graph for each operation and the mine total, which had a primary and secondary axis. Both axes represented power consumption. The graphs had the following four series:

- A daily budget energy consumption that was represented by grey bars and used the left axis.
- A daily actual energy consumption that was represented by yellow bars and used the left axis.
- A cumulative budget energy consumption that was represented by a red line and used the right axis.
- A cumulative actual energy consumption that was represented by a black line and used the right axis.

A programmable tag was required to configure the cumulative series in the above-mentioned graphs. The programmable tags were also implemented to configure the following two graphs: a time-of-use consumption graphs and a time-of-use cost graph. These two graphs were repeated for each mine operation as well as for the mine's total.

The time of use consumption graph was a pie graph with the following three series:

- A *Peak* series that is red and was the amount of energy consumed during the peak time of use tariff hours.

- A *Standard* series that is yellow and was the amount of energy consumed during the standard time-of-use tariff hours.
- A *Off-peak* series that was green and is the amount of energy consumed during the off-peak time of use tariff hours.

The time-of-use cost graph was also a pie graph with the above-mentioned series, except each series only represented how much the energy cost that was used during the time it was used. When the two graphs are compared it can clearly be seen that although the least energy is consumed during the peak hours it still cost the most. This will help motivate to decrease electricity usage during peak times. *Figure 3-9* is an example of these pie graphs as they appear in the reports.

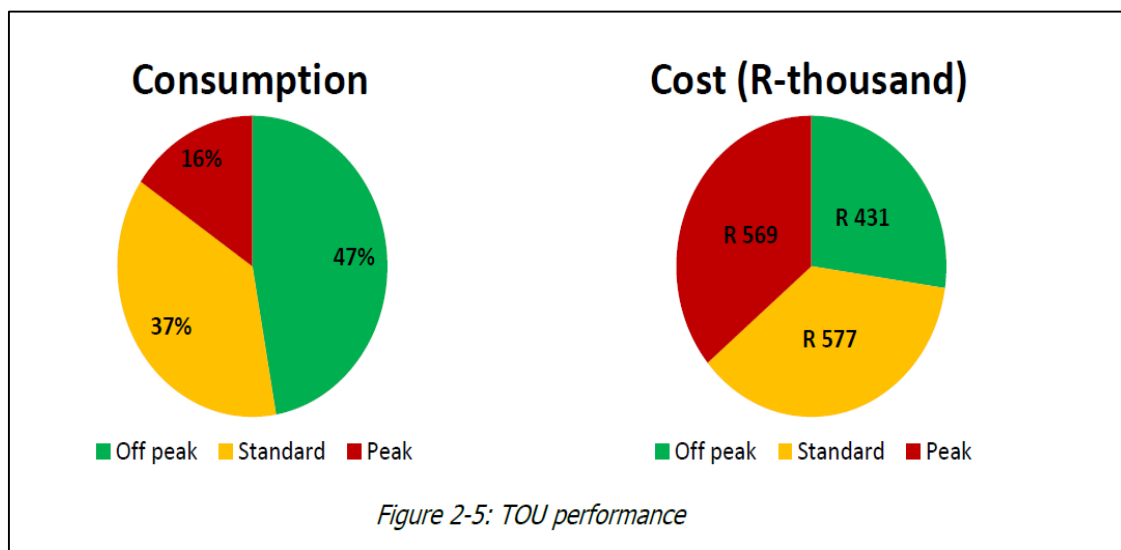
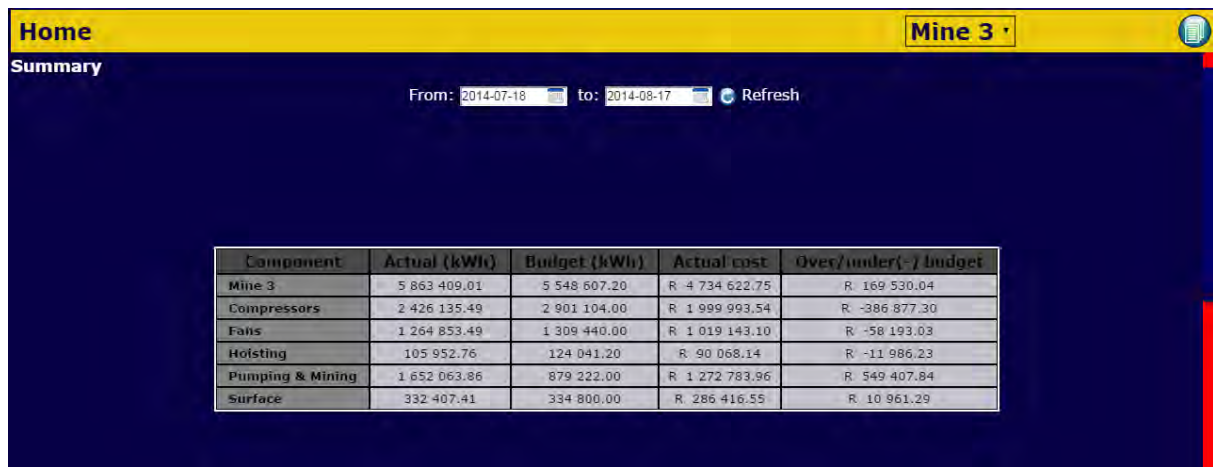


Figure 3-9 Time of use pie graphs

Each operation also had an *Average weekday profile* graph. The *Average weekday profile* graph plots the average budget and the average actual for the selected period. *Figure 3-10* shows a screenshot of one of the views for a business unit of Gold mining group 2. The mines' names have been replaced by Mine 1 to 8 for confidentiality. The summary table discussed earlier can be seen in *Figure 3-10*.

Figure 3-11 is a screenshot with the list box open displaying all the views for each mine. The power consumption graph discussed previously of all the operations consumption added together can be seen in *Figure 3-11*. The report button in the top right corner can be clicked to generate a

PDF report of the view. A report can be generated for each view. An example of a report for Gold mining group 2 is attached in Appendix B.



Component	Actual (kWh)	Budget (kWh)	Actual cost	Over/under(-) budget
Mine 3	5 863 409.01	5 548 607.20	R 4 734 622.75	R 169 530.04
Compressors	2 426 135.49	2 901 104.00	R 1 999 993.54	R -386 877.30
Fans	1 264 853.49	1 309 440.00	R 1 019 143.10	R -58 193.03
Hoisting	105 952.76	124 041.20	R 90 068.14	R -11 986.23
Pumping & Mining	1 652 063.86	879 222.00	R 1 272 783.96	R 549 407.84
Surface	332 407.41	334 800.00	R 286 416.55	R 10 961.29

Figure 3-10 Screenshot of the customisable DAI for the Gold mining group 2

Gold mining group 2 has been a client of the ESCo longer than Gold mining group 1, therefore more data analysis opportunities have been identified. The *Total power consumption* graph helps identify how the mine is performing according to the calculated budget. The day to day actual versus budget can be seen as well as the cumulative performance of the budget versus the actual for the selected period. The *Total power consumption* graph will identify underperformance and then an investigation can be done to determine why. The *Average weekday profile* graphs will help identify whether projects implemented by the ESCo are delivering the expected results.

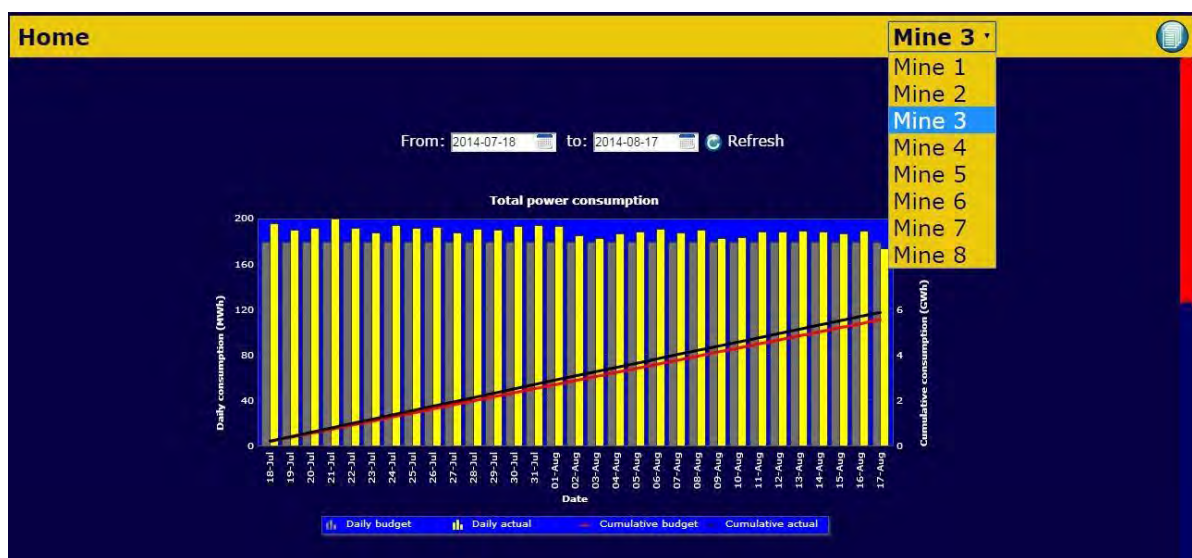


Figure 3-11 Screenshot of the customisable DAI with the views list box open

3.4. Case study C: Steel manufacturing group

Energy management personnel

Energy management personnel of one large business unit of the steel manufacturing group were consulted. *Figure 3-12* shows the hierarchy of the energy personnel from one of the larger business units of the steel manufacturing group. The senior personnel hierarchy is integrated unlike the personnel on the mining groups. Many personnel have more than one superior they can or need to report to. Also personnel on the same level also report to each other. Coal is used to generate energy for many of the processes used on-site. Gas is purchased and also used to generate energy.

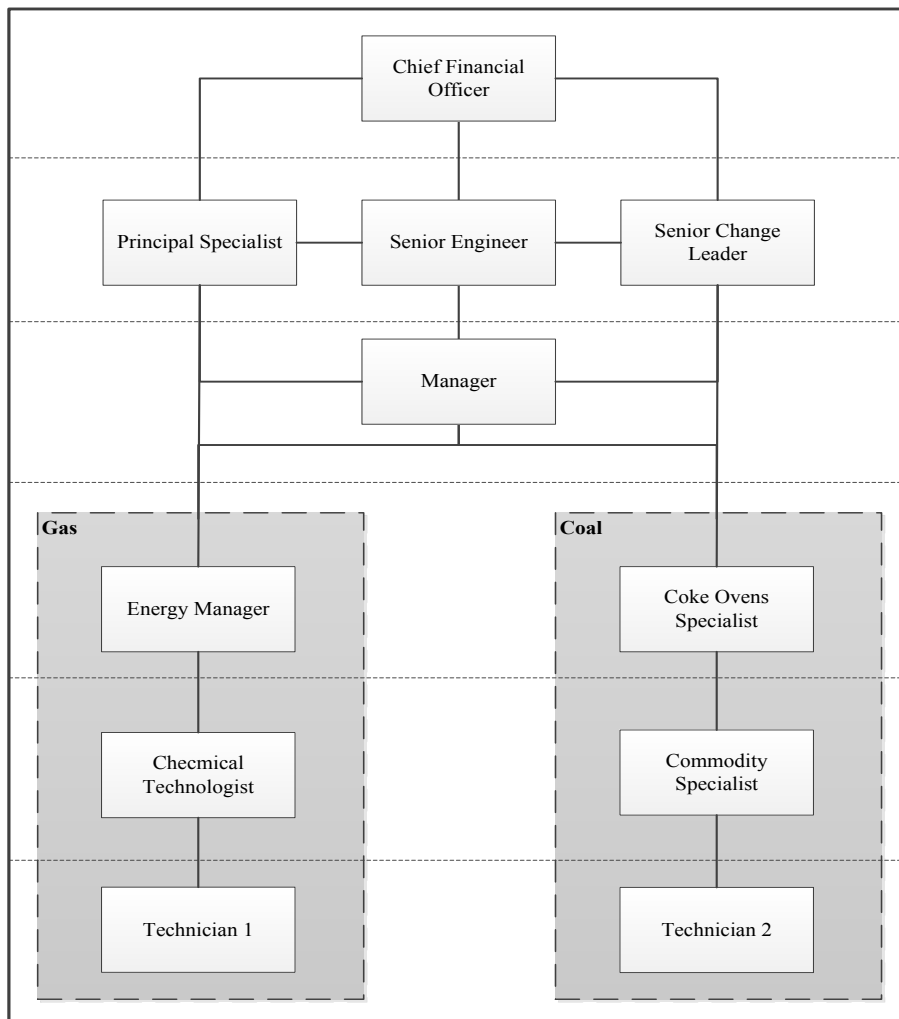


Figure 3-12 Steel manufacturing group energy personnel hierarchy

The energy management personnel requested the analysis of energy regeneration data and gas consumption data. Two reports were sent to the energy personnel, a gas purchased report and a regeneration report. The following personnel received both reports: the Principal Specialist, Senior Engineer, Senior Change Leader and Manager. The following personnel only received the regeneration report: the Coal Manager, Coke Ovens Specialist, Commodity Specialist, and Technician 1. The Energy Manager, Chemical Technologist and Technician 2 only received the gas purchases report.

Business structure

A node structure was built consisting of the group and the four connecting business units. *Figure 3-13* shows the group with the linked business units. Data analysis was not done for the other business units, but the node structure was built to provide for future development.

Figure 3-13 displays the steel manufacturing group and the four connecting business units. *Figure 3-14* displays the node descendants connected to one of the larger business units. Although all the business units have different structures, the interface is currently only implemented for one.

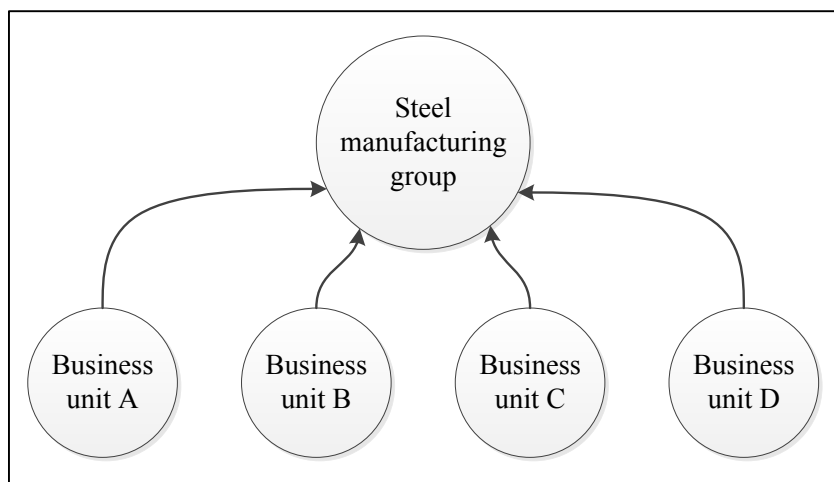


Figure 3-13 Overview of steel manufacturing group structure

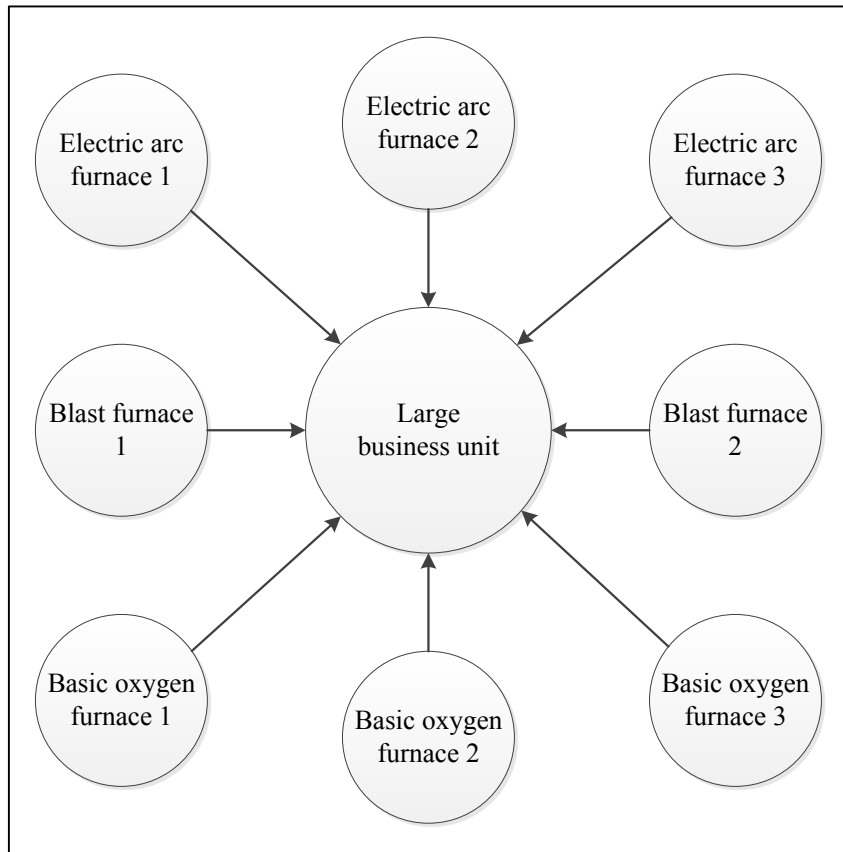


Figure 3-14 Overview of large steel manufacturing business unit

Data collection

The interface was implemented for one large business unit. The data is e-mailed automatically from the client daily. There is no ESCo server on site as there was for gold manufacturing groups. The data is then processed using the PTB software and then imported into the energy management database. *Figure 3-15* displays a summary of how the data was obtained and stored in the energy management database.

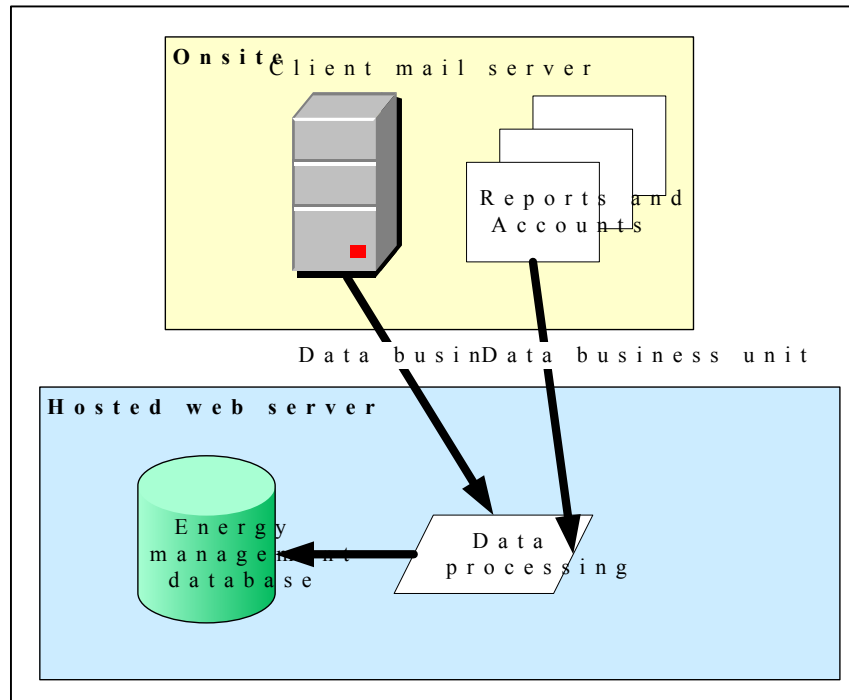


Figure 3-15 Summary of data flow process from steel manufacturing business unit

Data analysis and representation

An energy regeneration and gas purchases report was duplicated for the one large business unit. Views were configured for both reports containing all the graphs and tables included in the reports. The graphs of the energy regeneration report has stacked bars with the lower part of the bar being the amount of energy that was generated per day and the top part the lost opportunity per day. The lost opportunity is the amount that could have been generated minus the amount that was generated that day.

The graphs also contain a black line that represents the cumulative cost savings that have been achieved from the energy generation. The tables in the report are the summary of the average generation and average lost opportunity per day. Tables also displayed the cost savings and lost savings for the selected period. The energy generation report contained three graphs and tables. One graph and table for each plant on site and one with the two plants' values added together. The report button can be clicked to generate the report shown in Appendix C.

Figure 3-16 is a screenshot of the energy regeneration view implemented for the steel manufacturing business unit. The graph of the total daily generation can be seen in the screenshot. The blue part of the stacked bar is the average generation per day in MW and the

white part is the average lost opportunity per day in MW. The reports helped personnel identify unnecessary losses and made it possible to display it visually for their superiors.

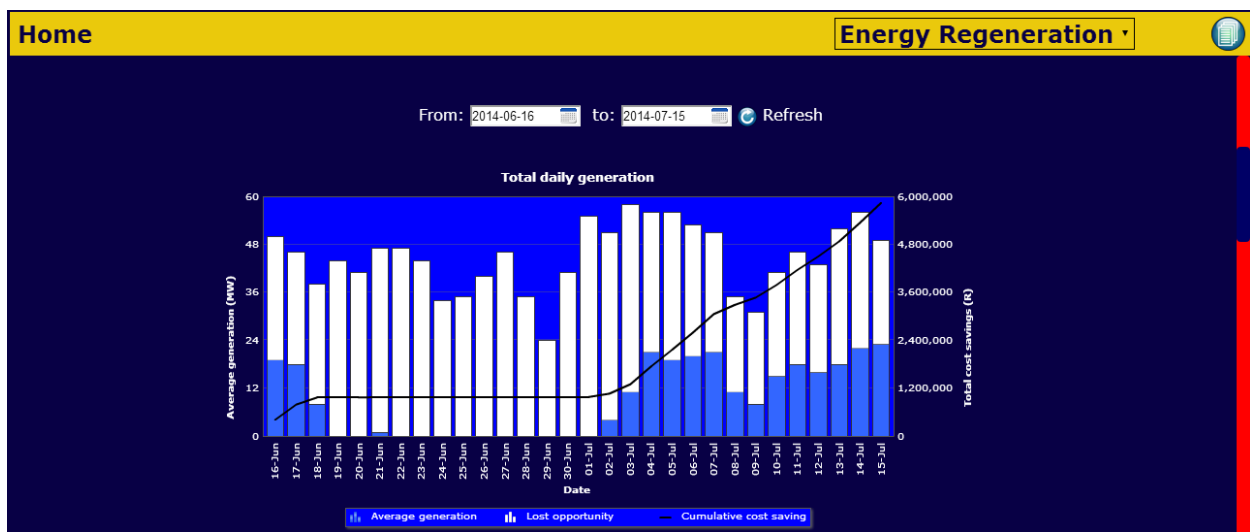


Figure 3-16 Screenshot of the steel manufacturing site interface Energy Regeneration view

The gas purchased view contains one table and six graphs. The table summarises the amount of gas purchased and whether they are over or under budget for the selected period. Then there is a graph for each of the six gases namely argon, oxygen, oxygen vented, nitrogen, hydrogen and natural gas. Each graph has a double y-axis, the left axis using tonnes as a unit and the right using rand (R). The graphs had the following four series:

- An actual consumption of gas per day in tonnes represented by blue bars and using the left axis.
- A budget consumption of gas per day in tonnes represented by light grey bars and using the left axis.
- A cumulative actual cost of the gas that is used per day represented by a black line and using the right axis.
- A cumulative budget cost of the gas that is used per day represented by a light grey line and using the right axis.

The programmable tags were used to configure the cumulative cost series. The natural gas graph also used programmable tags, because the left axis used gigajoule (GJ) as a unit instead of tonnes. The natural gas was used to generate electricity and therefore was charged by the amount in GJ energy they produced by the supplier. Two tags had to be multiplied with each

other to achieve the GJ value. The one was the volume (m^3) of gas and the second a tariff ($\frac{\text{GJ}}{\text{m}^3}$) calculated for the day. The tariff was provided by the gas supplier and varied each day.

Figure 3-17 is a screenshot of the *Gas Purchases* view; the natural gas graph can be seen. When the report button is clicked the full report in Appendix D is generated. The reports help the personnel monitor the gas reserves and improved budgeting for future use.

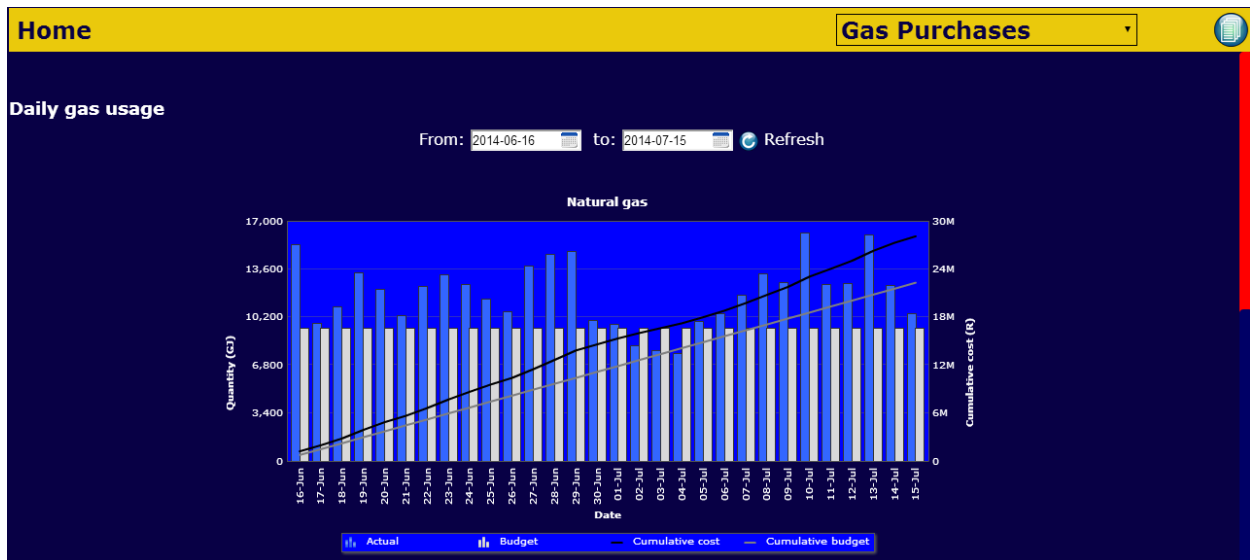


Figure 3-17 Screenshot of the steel manufacturing site interface *Gas Purchases* view

By displaying the energy generation information will help motivate more energy generation and cost saving. The steel manufacturing group is a new client of the ESCo and more data analysis opportunities can be identified. For example, adding the costs saved by the energy generation in the energy regeneration report. The *Gas Purchases* report helps personnel to configure budgets and keep track of stock left.

3.5. Further benefits

The customisable data analysis system was tested by duplicating existing graphs and tables designed for large energy consumers. The graphs and tables were usually found in reports prepared by energy personnel or previous software packages. ESCo engineers use 1 to 4 hours on average to create a daily report and 8 to 16 hours on average to create a monthly report. To create a template for a report using software packages, for example Microsoft Excel®, takes a week on average. Table 3.2 shows summary of the tasks the customisable data analysis can improve.

Activity:	Previous duration:
Validate report	5–10 min per report
Daily report	1–4 hours
Monthly report	8–16 hours
Daily template	20 hours
Monthly template	40 hours

Table 3.2 Summary of repetitive activities

To make sure the template works correctly, the ESCo engineers monitor the reports for a week. Monitoring the reports takes 5 to 10 minutes on average per report; therefore by duplicating the report using the customisable DAI a cumulative amount of man-hours is saved. The customisable DAI can reduce the man-hours spent on reporting by 70% to 80%, by automating the reports. Duplicating a graph with 4 series using the customisable DAI takes 5 minutes on average. Duplicating a table with 12 cells takes 20 minutes on average.

Also incidents are identified where a problem occurs and the DAI can be used to find a solution. For example, a pump from one of the mines of Gold mining group 2 was cycled from 04:50 to 06:53 by a DSM project's control system. This is a problem for the mine, because cycling a pump increases wear. *Figure 3-18* shows how the schedule kept jumping from 1 to 0 between 04:50 and 06:53. When the schedule is set to 1, one pump is started, when the schedule is set to 2 two pumps are started, etc.

A solution would be a graph with the scheduled pump run time versus the actual pump run time as shown in *Figure 3-18*. This solution can be implemented with the DAI using the XY plot mentioned in Section 2.4's sub section Process D.1. The data is already available and can easily be stored in the energy management database.

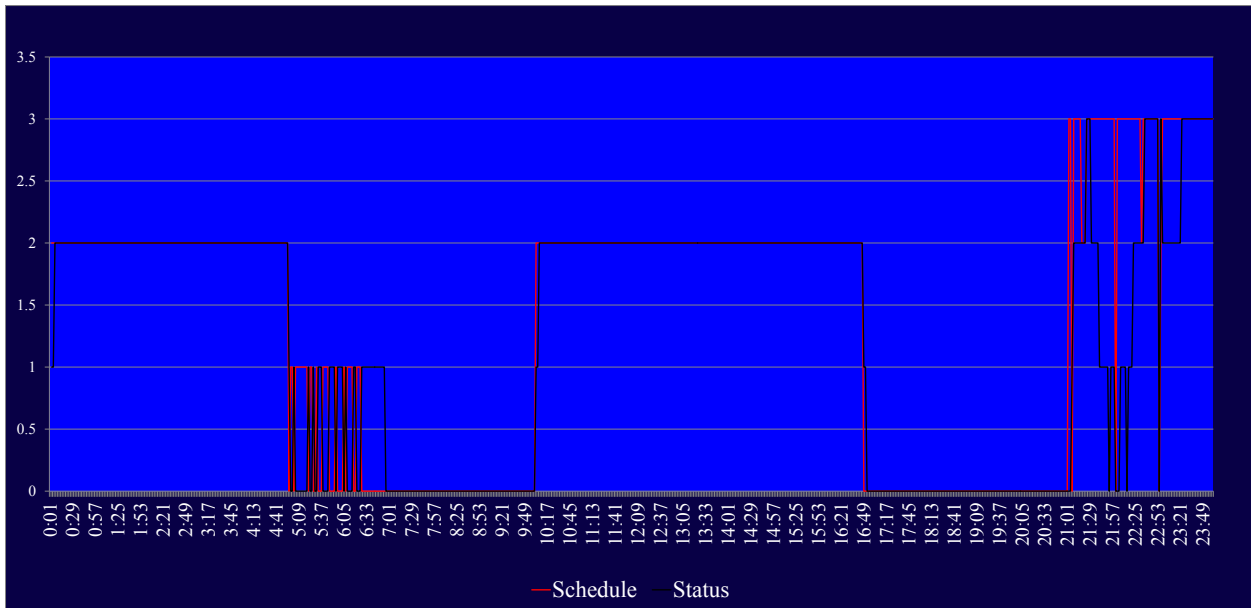


Figure 3-18 Scheduled run time versus actual status of pumps on 25 July 2014

3.6. Summary

Section 2.3 stipulated the specifications for the customisable DAI. *Table 3.3* represents a checklist of all the specifications identified in Section 2.3. All the design specifications were implemented in the customisable DAI.

The customisable DAI was implemented for gold mining groups, platinum mining groups, a steel manufacturing group, a glass manufacturing group and cement plants. Case studies were done on two gold mining groups identifying the different needs between similar industries. Then a case study was done on a steel manufacturing site to display the customisability of the interface.

Further benefits were identified where cumulative man-hours are saved per report automated by the customisable DAI. Also incidents causing problems can be identified where the customisable DAI can be used for a solution in future.

Specification	Accomplished
Raw data was imported on a daily basis	Yes
Raw data was processed on a daily basis	Yes
New data was imported using PTB	Yes
Reports and accounts were available on a monthly basis	Yes
Accounts data was processed automatically	Yes
Reports were duplicated using the interface	Yes
Reports were customisable, without needing to program.	Yes
The customisability did provide for the necessary needs.	Yes
The view configurations were done on a central server from different locations	Yes
Users must gain access to the information using a web interface	Yes
The following graphs could be implemented:	
Bar graph	Yes
Line graph	Yes
Area graph	Yes
Stacked graph	Yes
Pie graph	Yes
Combo graphs	Yes
Tables could be implemented	Yes

Table 3.3 Specification check-list of the customisable DAI

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

4. Conclusion and recommendations

4.1. Conclusion

The objective of this study was to develop a customisable data analysis system for an online energy information system. The need for the system originated from large energy consumers that need to decrease their electricity consumption as well as increase their energy efficiency. This is necessary, because electricity and other resources are becoming increasingly depleted and therefore more expensive.

To implement and sustain the energy projects numerous measurements are stored as data. This data needs to be analysed to show the results of the projects. To analyse the data is a painstaking process, because of the large amounts of data that is stockpiled. There are millions of entries that need to be filtered to obtain the necessary data and information. This is a repetitive exercise that can be automated.

A system was developed that stored the data in a generic format, where the user can easily navigate through the data. The data is stored in a central energy management database using software packages developed to process different data formats. When the data is stored, the user can navigate through a node structure to find the required data.

Each dataset is represented by a data tag. The data tag can be measurements of a pump's electricity consumption, compressor electricity consumption, a whole shaft's total electricity consumption or the total air flow through a valve, etc. When a new tag is created it needs to be linked to a node of the node structure. The node structure represents the operations hierarchy of the large energy consumers.

After the appropriate tag has been selected, by navigating through the node structure, graphs and tables can be configured to display the necessary information. The graphs and tables are then added to views that are linked to an account on the website that is hosted on an on-line server. The clients can log onto their account on the website, where the views display the information contained by graphs and tables. Reports can be generated in a PDF format for each view.

The system was implemented in two gold mining groups, one platinum mining group, one steel manufacturing group, cement plants and one glass manufacturing group. The two gold mining

groups and the steel manufacturing group were used as case studies. Each case study is divided into the following four sub-sections:

- Energy management personnel
 - The large energy consumer personnel hierarchy and the communication between the energy personnel and the ESCo personnel are discussed in this section.
- Business structure
 - The large energy consumer group operations hierarchy is discussed in this section. This hierarchy is used to build the node structure that is used to navigate through the data.
- Data collection
 - The method used to obtain the data is discussed in this section.
- Data analysis and representation
 - The data analysis done for the client is discussed in this section and how the interface is configured.

The case studies in the two mining groups showed, that although their operations and even personnel are very similar, they needed different information. The graphs and tables used in their reports are customised for each group. The steel manufacturing group had totally different operations and personnel; the customisable data analysis system was generic enough to provide the necessary solution.

Finally, further benefits provided by the customisable data analysis system are discussed. These benefits include the man-hours saved by automating the reports for the large energy consumers. Previously the reports were laboriously created by ESCo personnel or energy personnel of the large energy consumer. Depending on the report 8 to 40 man-hours per report are saved.

Also an incident that caused a problem is discussed for which the data analysis can be implemented for the future. The customisable interface can be used as a solution for the problem caused in the incident. After the interface is implemented the problem will be avoided.

4.2. Limitations and recommendations for future research

The energy industry is changing continuously, for example, the new 12L income tax act implemented 1 November 2013 [48]. To plot the income tax savings the x-axis need to be the output production values in tonnes and not date time values. The current system does not

facilitate the 12L income tax requirements. Therefore new development will be needed to provide for the new needs. Another need that has been identified is plotting series with different date ranges in one graph. This is usually done to compare the current year's electricity consumption with the previous year's electricity consumption.

The new development will be achievable by making minor changes, for example adding more grouping types for the programmable tags. Adding more x-axis types for the graphs, for example using tag data for the x-axis instead of the date and time. An extra property can be added to a series to shift the date range etc. With feedback the system can be continuously improved and further developed.

Another functionality that can be developed is conditional tags. Conditional tags are dependent on the values of other tags. For example, if the subtracting of two tags is a positive value the conditional tag value will be 1, if the subtraction is a negative value the conditional tag value is 0 etc. Series or table cells can be modified to use the conditional tags to determine their colour. For example, when the conditional tag is 1 the table cell or series colour is green and red when the conditional tag is 0.

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Appendix A

Brochure of the web interface of
AspenTech's Aspen InfoPlus.21 ®



Elevating Specialty Chemical Performance to World-Class Levels

.....
An Industry White Paper

Marty Moran, Product Marketing Manager, Aspen Technology, Inc.



Introduction

Every day, in specialty chemical manufacturing plants around the world, a process begins where feedstock materials are dispatched, a batch is run, and a product is eventually produced. Then the entire process starts all over again for that same product or a different one. Over the course of this cyclical process, specialty chemical manufacturers are constantly asking themselves these types of questions:

- Was the most recent production run performed as efficiently as possible? If not, why?
- Did we use more ingredients than in previous runs? If so, why?
- Did it take more time than previous runs? If so, why?
- Did we use more energy than previous production runs? If so, why?

In order to be competitive globally, it's not good enough just to produce products. They have to be produced efficiently and profitably. Thus, it's essential to be able to continuously become more efficient. To maintain profitability and manufacturing flexibility, specialty chemical producers want to have predictable and stable batch/transition times for a given product that optimizes material/energy consumption while meeting all product quality specifications. To make this a reality, it's necessary to document and track the materials used during the production run—including exact quantities—as well as the conditions they were subjected to as they traversed the process.

That's why every specialty chemical facility should have a process historian tailored for batch processes. Historians collect data from all the appropriate underlying execution systems and instruments, document that data, calculate and display performance metrics, allow users to visualize the data in a variety of formats, and retrieve data sets for root cause analysis. In this way, data is transformed into “actionable” information—enabling better, faster decisions across the organization. Historians allow you to gain insight into your batch production process around product characteristics, transitions, and also batch production profiles, which can enable you to optimize materials used during a batch and increase product quality.



Mobility opens up new possibilities for specialty chemical manufacturers.



Data Management

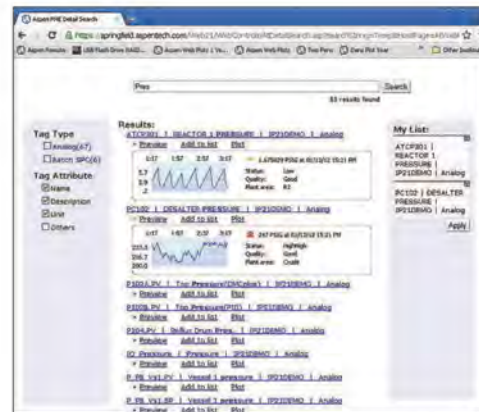
The first requirement for a historian is to seamlessly collect process data from disparate sources, such as from DCS, SCADA, or PLC systems, allowing you to get a more complete view of the manufacturing context. AspenTech's flagship product, Aspen InfoPlus.21™, uses a variety of means to achieve that goal—ODBC, web services, or supporting products such as Aspen Cim-IO, which utilizes industry-standard mechanisms such as OPC.

Data Management also extends to facilitating the initial system setup. Microsoft® Excel add-ins simplify the process of loading data tags into the historian by enabling users to create and configure historian records directly from Excel, thereby reducing installation time.

Intelligent Search

Once the historian is online, you want to be able to quickly locate data within the system. “Google-like” intelligent search capability achieves this goal with virtually no training required. Not only does it make more experienced professionals more efficient, but it also extends the use of the historian to more casual users.

Intelligent search capability within a historian operates in a similar fashion as Google. For example, if you want to find the tagname for the deethanizer reboiler hot oil outlet temperature, you simply start typing ‘Deethan Temperature’. As you are typing, it instantly starts matching what you are typing. In short order, it picks out the best match just as when you search on the web.

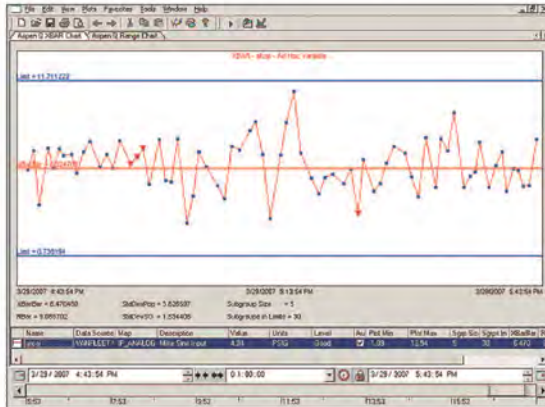


Intelligent search is a “Google-like” method of finding data in the historian.



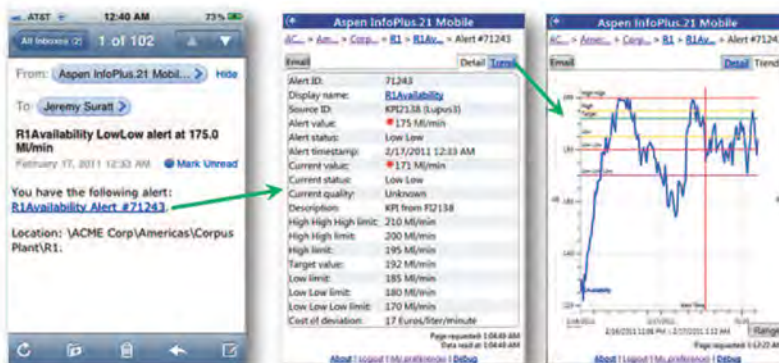
Visualization/Mobility

Once historized, data in the historian can be visualized as process graphics, trends, key performance indicators, SPC charts, and more to aid in the decision-making process.



Track and improve product qualities in real-time using pre-configured SPC charts based on user-defined data with automatic generation of real-time alarms.

In addition to the traditional desktop and web views, new enhancements based on HTML5 technology have now made it possible to view historian data on common mobile devices—smart phones, tablets, etc. Mobile applications allow users to gain access to the same information traditionally only available in the control room—including after hours. What’s also beneficial about mobile applications is that the user can configure email and text alerts for notifications, alerting them to a significant process excursion. After receiving the alert, they can drill down to quickly find more information about a particular issue and continue drilling down until they understand the source of the problem.



Mobile solutions allow the user to drill down using the touchscreen to quickly understand the source of the process issue.



Elevating Specialty Chemical Performance to World-Class Levels

Trends

Specialty chemical operators and engineers will always want to plot variables collected in the historian, either against each other over time or in other formats such as X-Y, in order to gain an understanding of the historical process operation.

The good news is that recent improvements make this easier than ever. High-performance trends allow users to display more than 80 variables over a long historical time period in mere seconds. This gives engineers the ability to connect the dots faster when diagnosing and solving process problems, and is certainly much faster than trying to switch back and forth between a series of much smaller, pre-defined plots or “creating” new trends on the fly.

What’s also ideal about these new trending capabilities is that they can be rendered on whatever device you want—web, smart phone, or tablet—since they are based on HTML5 format.



High performance trends expand data accessibility and provide large amounts of contextualized data quickly, speeding analysis time.

KPIs and Overall Equipment Effectiveness

Another key element of a historian is the performance metrics that allow users to determine how well the plant is achieving its business goals. Key Performance Indicators (KPIs) can be set up in different forms, such as speedometers, so that users can see at a glance how well the plant is performing.

Overall Equipment Effectiveness (OEE) is an industry-standard metric that allows specialty chemical operators to drill down to understand how well the plant is achieving its production, quality, and equipment availability targets. While the ability to measure, compare, and contrast different facilities at a high level is valuable, what’s even more important is the ability to drill down to understand the source of why one of the plants is not achieving its goals. For example, if upon investigation, you discover that availability is only 80%, then you can drill down to look at some possible causes—equipment failure, preventative maintenance, shutdown, etc.



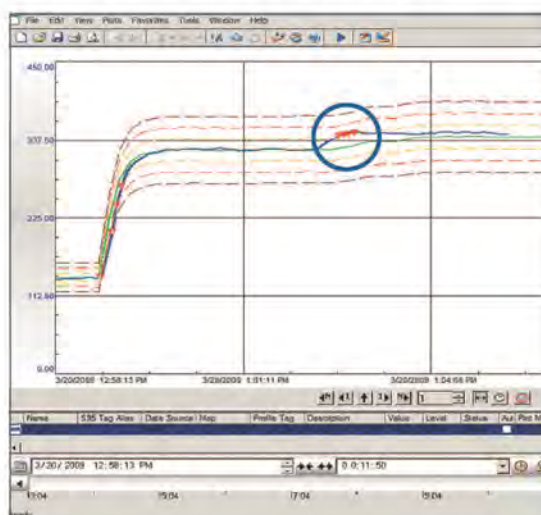
Analyzing Batch Performance

Since the majority of specialty chemical plants are batch, tools must be provided that allow operators and engineers to quickly and easily analyze batch performance. Engineers often have learned that there is one particular production run from the past that they would like to emulate in the future. Some refer to this as their “golden” batch. Historian visualization technology easily allows engineers to visually compare and contrast their “ideal or golden” batch against a current batch or previous batches. This type of analysis allows a manufacturer to quickly understand the nuances and differences between various production runs in order to improve production. Without tools specifically designed for this type of analysis, an engineer would literally have to overlap different batches on top of one another—and consume an enormous amount of time in the process. This innovative technology enables such analysis in a matter of minutes.

In addition, the Aspen InfoPlus.21 family of products provides additional capabilities to compare and contrast batches through the use of “single” and “multiple” batch plots. “Single” plots allow users to dive into all the pertinent values associated with a given batch or portion of a batch (e.g. phase).

On the other hand, the “multiple” plot capability allows users to bring up a variable(s) from multiple batches on one plot. For example, the user might suspect that the max temperature encountered might affect the yield of a certain product during the reactant phase of a batch. Using the “multiple” plot capability, the user might choose to plot the max temperature and product yield of the 50 most recent batches to determine if a discernible pattern emerges. What’s beneficial about this analysis capability is that the user doesn’t need to look up the individual times of the batches. The system understands this through the batch context definition, so this plot can be constructed in a matter of moments.

The bottom line is that all these batch analysis tools allow users to spend their time on analyzing production issues—not on chasing data. This enables increased production and quality, while reducing energy and material costs.



Golden Batch Profiler allows analysis between similar batches.



Root Cause Analysis/Analytics

Plant engineers are routinely faced with having to solve complex process problems. A historian system provides Excel add-ins that allows users to download this data into Excel where they can leverage its full power for deeper analysis. Full integration with Microsoft PowerPivot and Power View makes it possible to create even more powerful analyses and reports, which can be updated automatically and distributed throughout the enterprise with SharePoint 2010.

However, Aspen InfoPlus.21 provides even more sophisticated means of analyzing performance. Using Aspen InfoPlus.21 SQLplus, users with a minimal amount of programming experience can perform sophisticated analyses. The name "SQLplus" is instructive because it is much more than a simple querying tool. Rather, it's a "scripting" language meaning that it's much easier to use than a programming language. The "SQL" portion allows a user to download datasets, while with the "plus" portion a user can perform sophisticated logical and mathematical operations on the resulting datasets. AspenTech clients use Aspen InfoPlus.21 SQLplus heavily to perform a wide variety of analyses.

Conclusion

In order to remain competitive, historians are an essential foundational element for any specialty chemical plant. Historians collect plant and gathering system data so that operators and engineers can view and analyze data. In addition, new visualization tools based on HTML5 technology allow users to view all plant information (tags, trends, graphics, SPC charts) on their favorite mobile device (smart phone, tablet, etc.).

What's especially important is the ability to analyze batch performance. Special tools are provided that allow a user to dive into the particulars for a specific batch or phase of the batch, compare a batch against a "golden batch", or analyze variable(s) from multiple batches. Additional analytical tools allow users to download information to Excel for further analysis or perform mathematical/logical analysis on various result sets.

The bottom line is that a historian allows specialty chemical operators to truly increase manufacturing performance and shareholder ROI.

||||||| About AspenTech

AspenTech is a leading supplier of software that optimizes process manufacturing—for energy, chemicals, engineering and construction, and other industries that manufacture and produce products from a chemical process. With integrated aspenONE® solutions, process manufacturers can implement best practices for optimizing their engineering, manufacturing, and supply chain operations. As a result, AspenTech customers are better able to increase capacity, improve margins, reduce costs, and become more energy efficient. To see how the world's leading process manufacturers rely on AspenTech to achieve their operational excellence goals, visit www.aspentech.com.



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Appendix B

Gold Mining group 2 report

1 Summary

Table 1-1: Power consumption summary

Component	Month to date			
	Actual (kWh)	Budget (kWh)	Actual cost	Over/under(-) budget
	5 855 112	5 548 607	R 4 726 568	R 161 475
-Compressors	2 423 339	2 901 104	R 1 996 812	R -390 059
-Fans	1 265 241	1 309 440	R 1 019 550	R -57 786
-Hoisting	106 222	124 041	R 90 806	R -11 248
-Pumping & Mining	1 646 488	879 222	R 430 911	R -292 465
-Surface	331 662	334 800	R 285 560	R 10 104

2 Section summaries

2.1

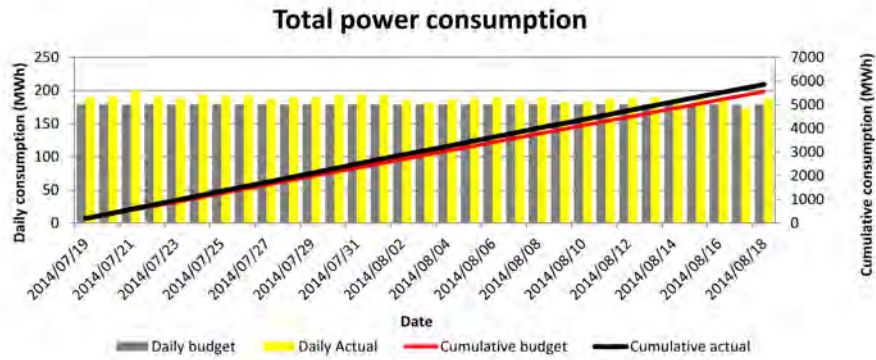


Figure 2-1: Total and daily power consumption



Figure 2-2: TOU performance

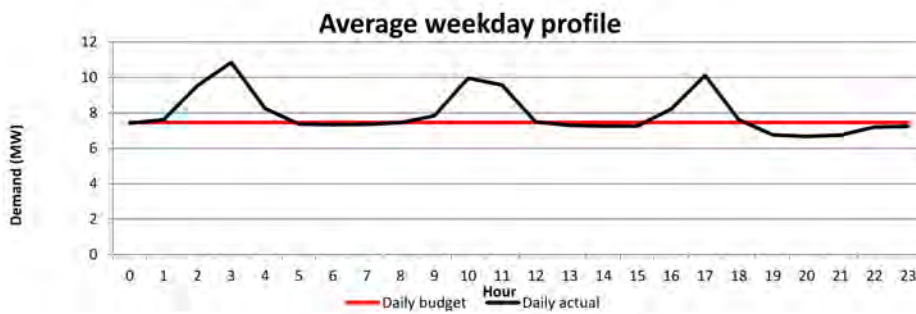


Figure 2-3: Average weekday profile

2.2 Compressors

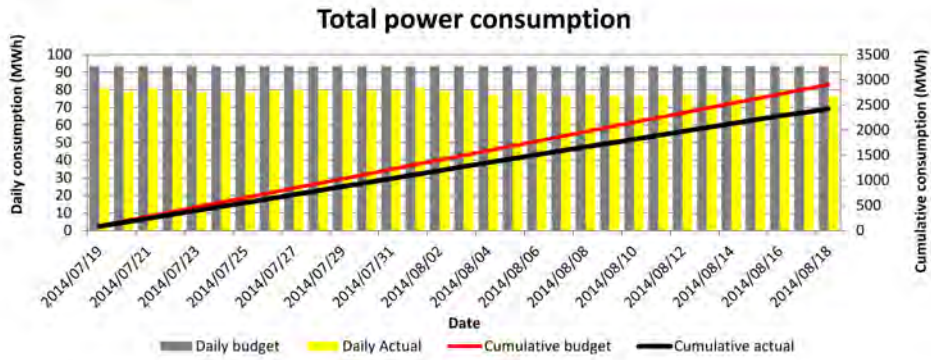


Figure 2-4: Total and daily power consumption



Figure 2-5: TOU performance

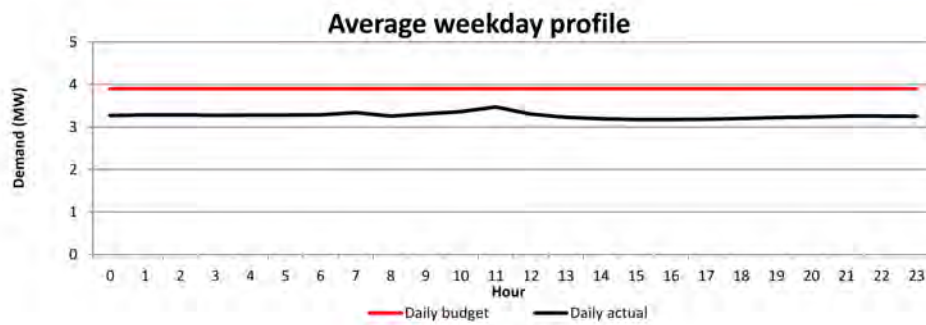


Figure 2-6: Average weekday profile

2.3 Fans

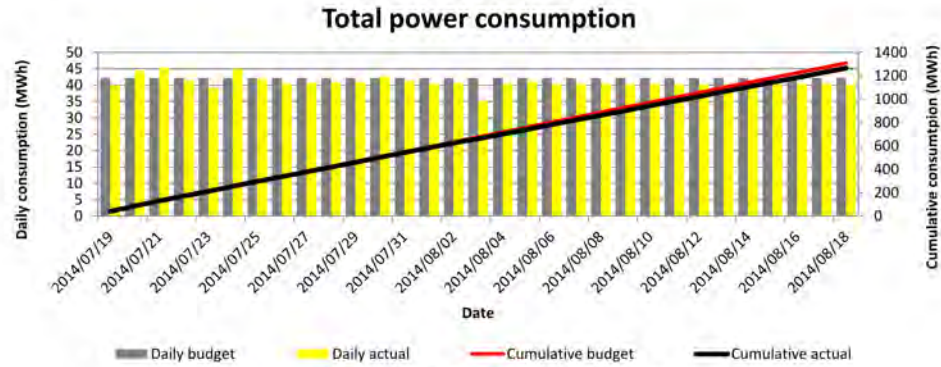


Figure 2-7: Total and daily power consumption



Figure 2-8: TOU performance

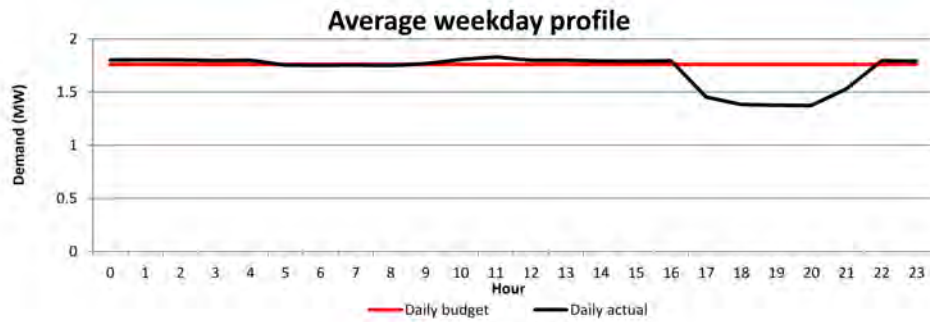


Figure 2-9: Average weekday profile

2.4 Hoisting

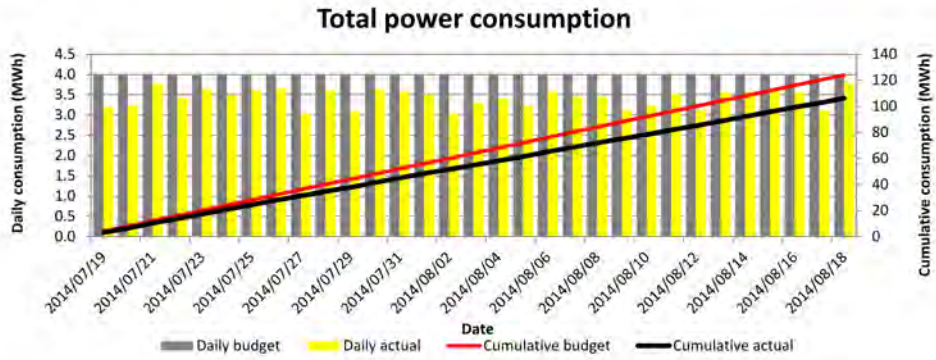


Figure 2-10: Total and daily power consumption



Figure 2-11: TOU performance

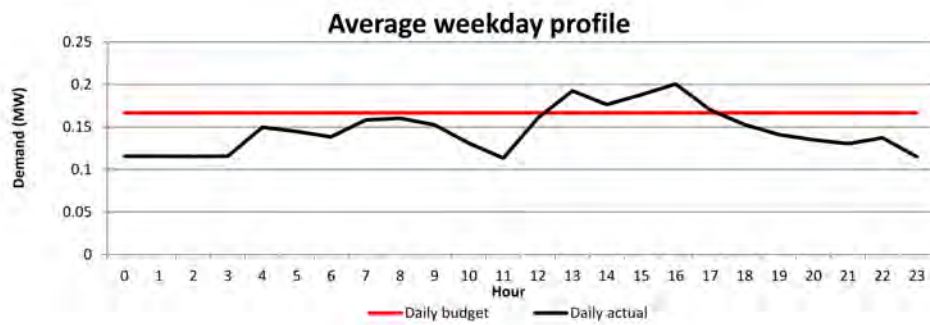


Figure 2-12: Average weekday profile

2.5 Pumping & Mining

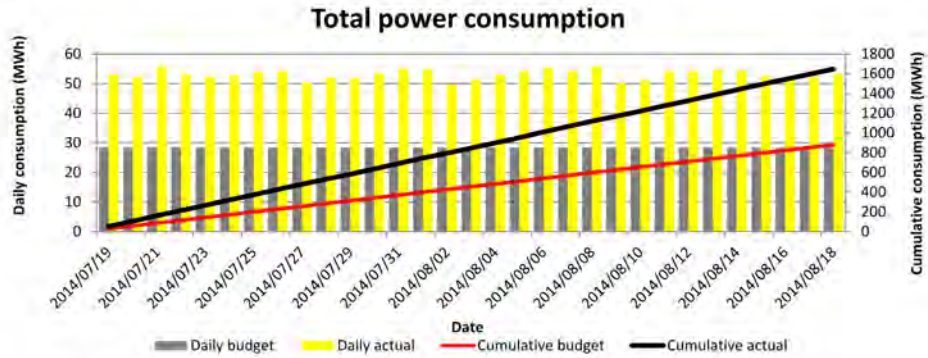


Figure 2-16: Total and daily power consumption



Figure 2-17: TOU performance

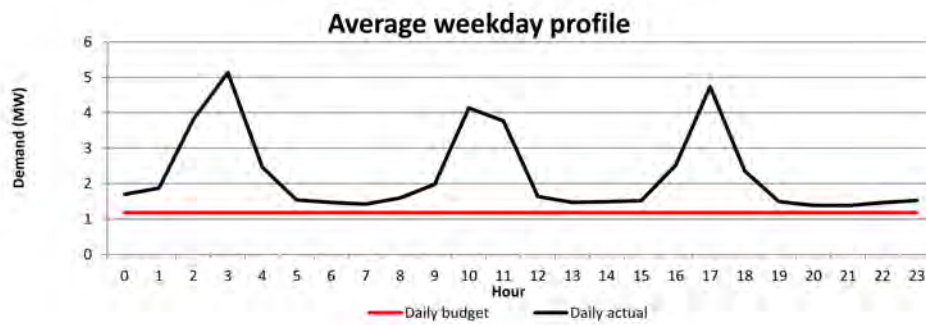


Figure 2-18: Average weekday profile

2.6 Surface

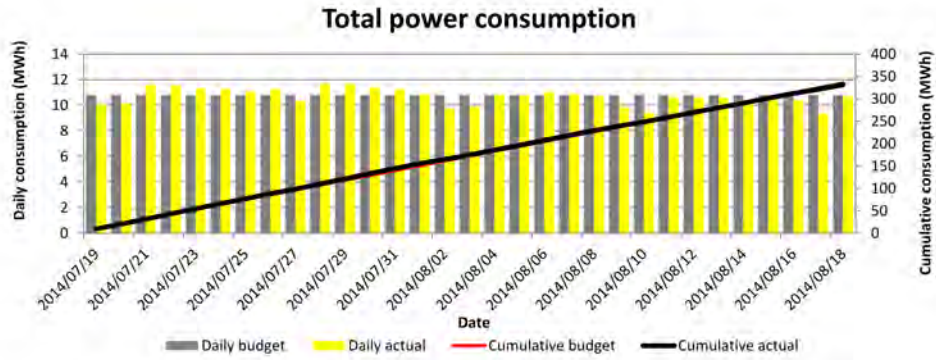


Figure 2-19: Total and daily power consumption



Figure 2-20: TOU performance

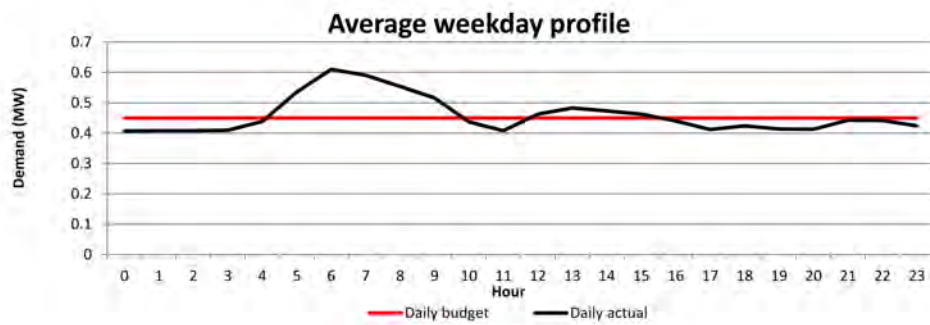


Figure 2-21: Average weekday profile

Appendix C

Steel manufacturing energy regeneration report

Energy regeneration report

1. Summary

Table 1-1: Electricity generation summary

Total daily generation		
	27 October 2014	Month to date
Electricity		
Average generation	26.8 MW	21.36 MW
Lost opportunity	9.16 MW	13.33 MW
Costs		
Avoidance cost saving	R 400 514	R 9 256 660
Lost opportunity	R 136 880	R 5 776 157

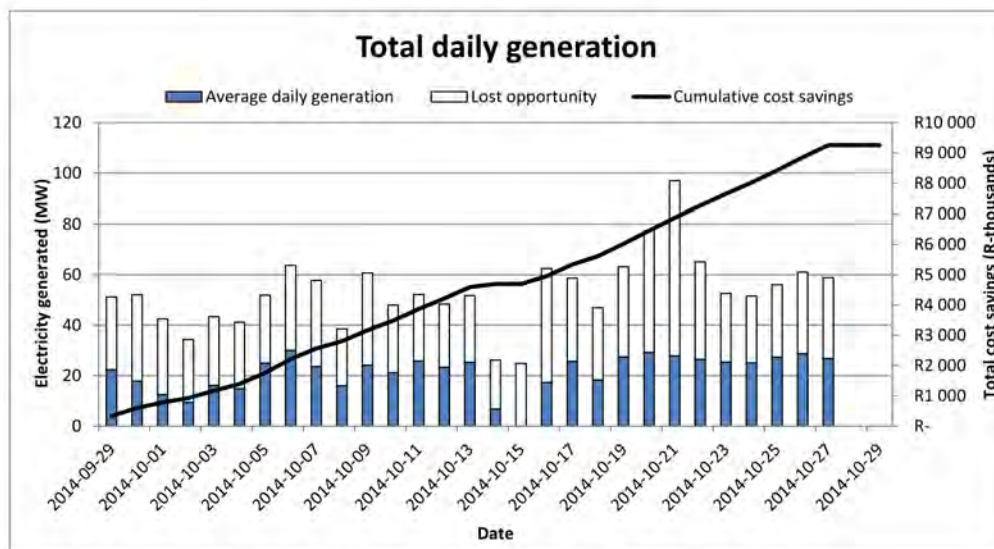


Figure 1-1: Total daily generation

2. Month to date performance

Table 2-1: Electricity generation summary for DR power plant

DR power plant		
	27 October 2014	Month to date
Electricity		
Average generation	0 MW	0.47 MW
Lost opportunity*	5.96 MW	4.64 MW
Costs		
Avoidance cost saving	R -	R 204 740
Lost opportunity	R 89 057	R 2 009 503

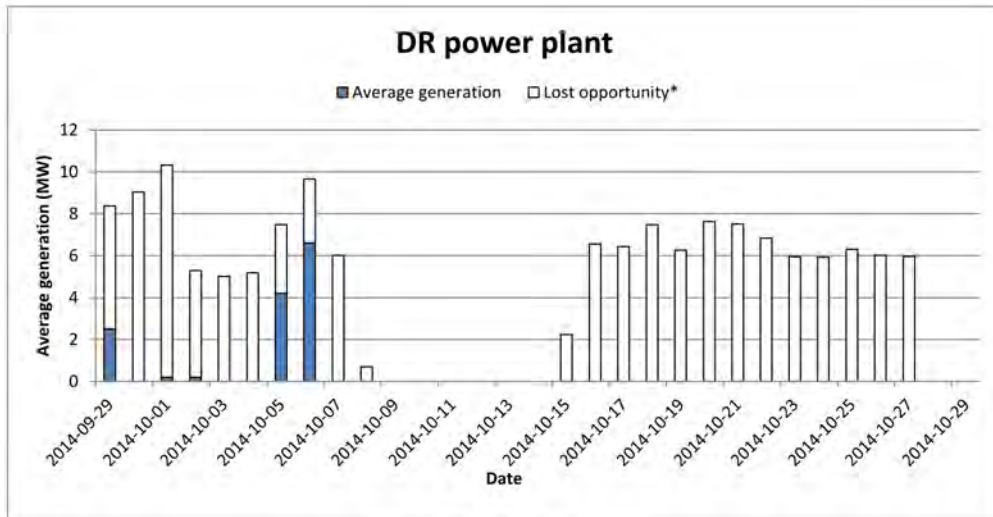


Figure 2-1: DR power plant daily generation

*De-superheated steam is converted to a potential power generation quantity.

2. Month to date performance (Continued)

Table 2-3: Electricity generation summary for 30 MW power plant

30 MW power plant		
	27 October 2014	Month to date
Electricity		
Average generation	26.8 MW	20.89 MW
Lost opportunity*	3.2 MW	8.69 MW
Costs		
Avoidance cost saving	R 400 514	R 9 051 920
Lost opportunity	R 47 823	R 3 766 654

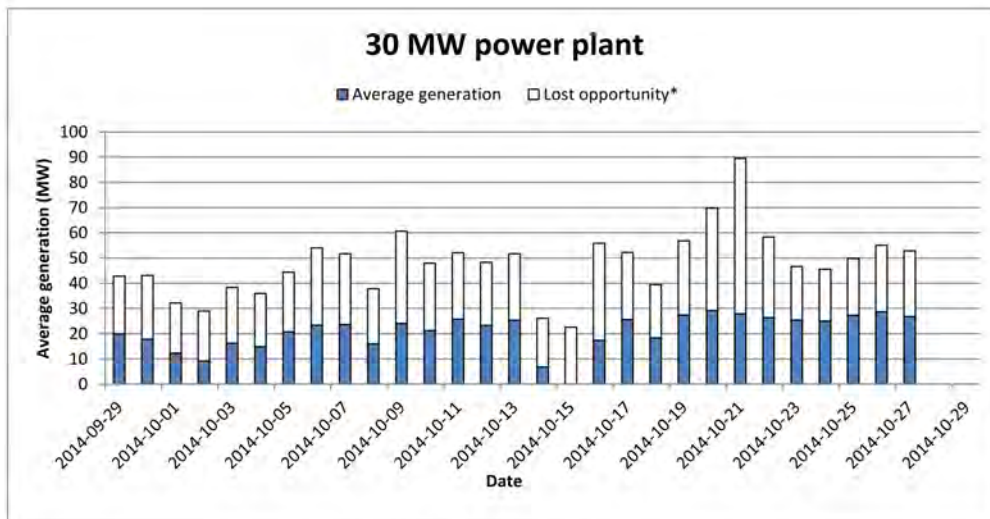


Figure 2-2: 30 MW power plant daily generation

*Blast furnace gas flared is converted to a potential power generation quantity.

Appendix D

Steel manufacturing energy gas purchase report

Gas purchases report

1. Summary

Table 1-1: Gas purchases summary

Total gas purchases				
	27 October 2014		Month to date	
	Quantity	Over/under budget	Quantity	Over/under budget
Argon (t)	7.9	R 33 058	220.2	R 833 045
Oxygen (t)	1 058.0	R -189 864	22 602.2	R 1 574 081
Oxygen vented (t)	0.0	R 16 856	428.5	R -26 452
Nitrogen (t)	1 272.1	R -48 049	27 242.0	R 205 857
Hydrogen (m ³)	19 069.8	R 5 883	382 790.9	R 467 946
Natural gas (NGJ)	13 002.0	R -281 565	336 709.2	R -6 472 509
Total		R -463 680		R -3 418 033

2. Daily gas usage

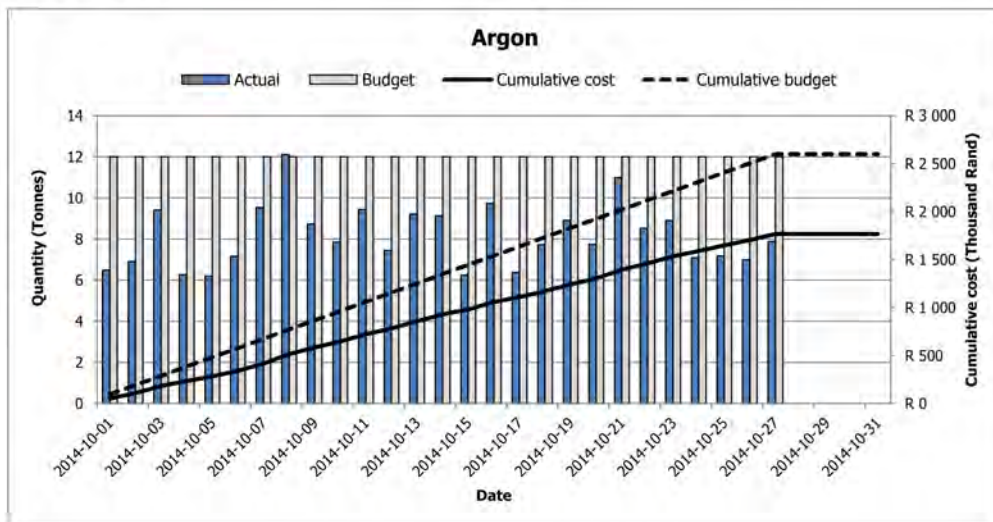


Figure 2-1: Daily argon purchased from Air Products

2. Daily gas usage (Continued)

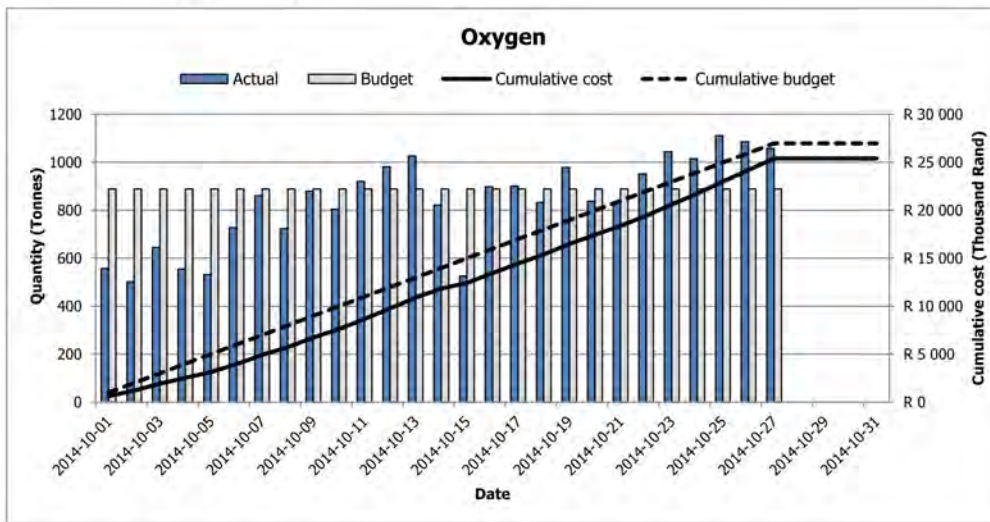


Figure 2-2: Daily oxygen purchased from Air products

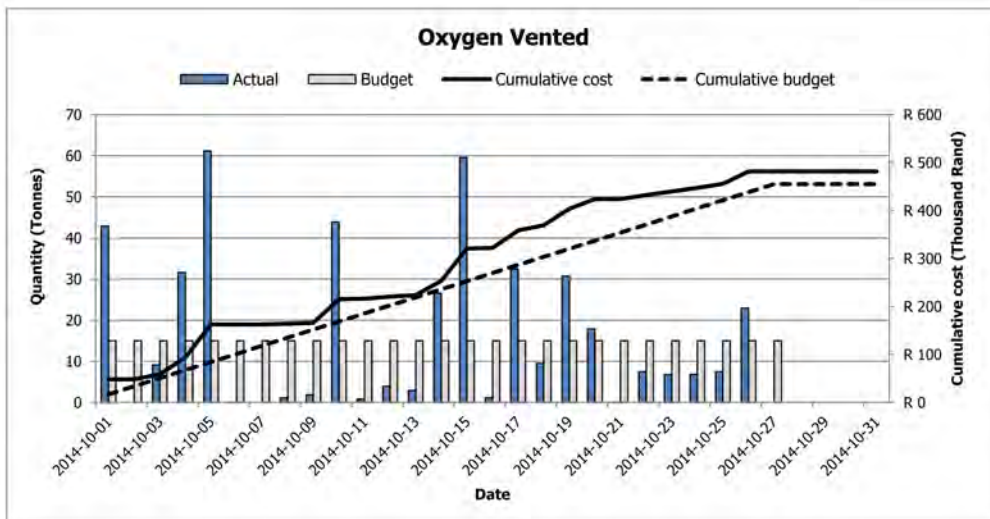


Figure 2-3: Daily oxygen vented

2. Daily gas usage (Continued)

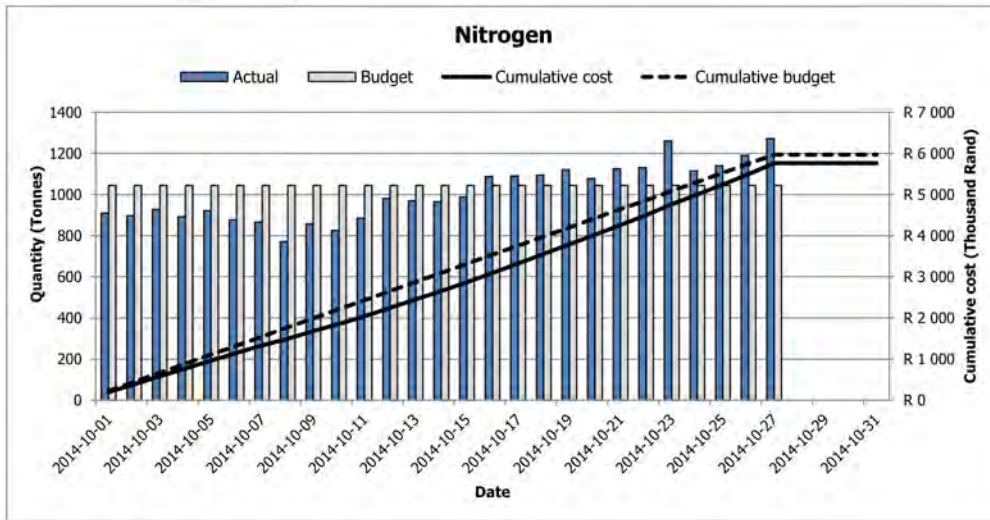


Figure 2-4: Daily nitrogen purchased from Air Products

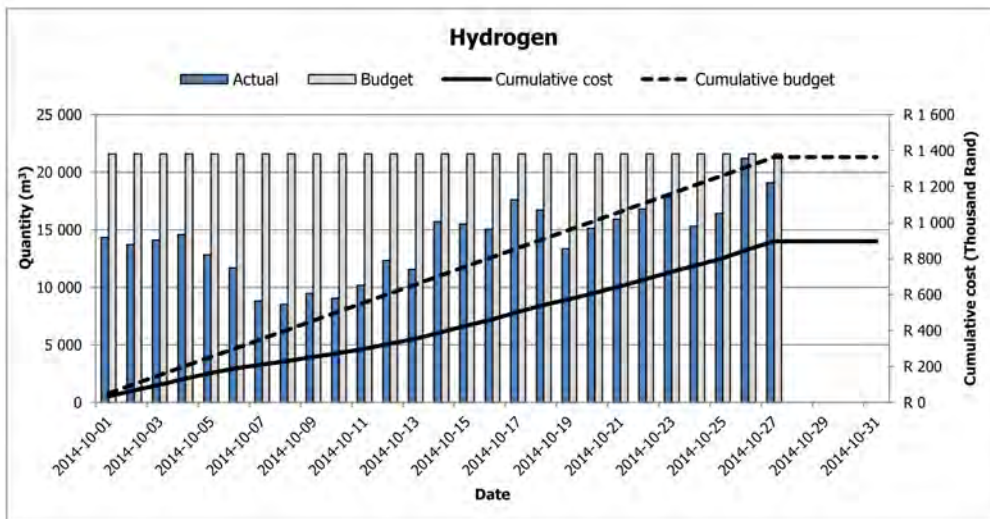


Figure 2-5: Daily hydrogen purchased from Air Products

2. Daily gas usage (Continued)

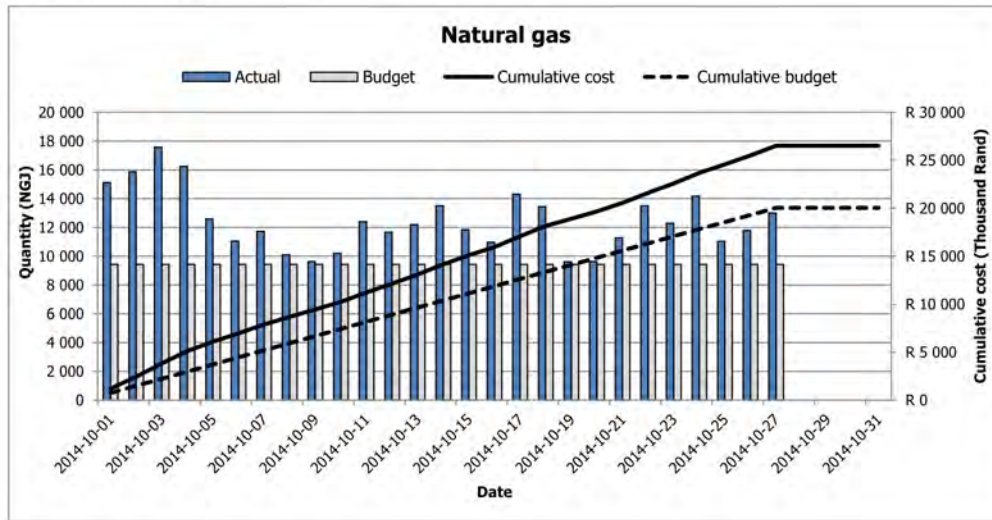


Figure 2-6: Daily natural gas purchased from Sasol