An improved baseline model for a mine surface cooling plant DSM project

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Dissertation submitted in fulfilment of the requirements for the degree Master of Engineering in Mechanical Engineering at the Potchefstroom Campus of the North-West University

Supervisor: Dr JF van Rensburg

May 2017

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Abstract

Title: An improved baseline model for a mine surface cooling plant DSM project

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Several challenges exist for the successful implementation of energy cost reduction projects on industrial systems. Due to the potential large financial impact of these projects, the process of determining and reporting specific project impact is crucial to the ultimate success of the project.

Numerous demand side management (DSM) projects have been implemented worldwide, including South Africa. The success of these projects, and the success of the energy services company industry have ultimately been due to, and testifies to, the large energy savings that DSM projects have delivered. Currently there are detailed measurement and verification frameworks and guidelines that are well developed and widely implemented. The associated energy services industry relies on well-proven standardised methodologies to ensure accountability and sustainability of DSM projects.

Implementation of an actual DSM project on a mine cooling system has highlighted the need for a post-project reassessment of the pre-implementation accepted baseline model, which prompted this investigation. This thesis will focus on developing a baseline model that is suitable for post-project implementation analysis as well as the evaluation of baseline models and reported benefits of DSM projects on mine surface cooling systems.

This study analysed the effect of baseline model selection on a DSM project. It was found that baseline model selection has a major influence on the reported project impact. It was further found that a conservative estimate of an additional unclaimed saving for a specific project on a surface mine cooling system was R835 390.91 with a total unclaimed energy saving of 741.31 MWh over the six-month period from March to August 2016.

Keywords: Mine cooling; refrigeration; energy management; demand side management; measurement and verification; load shifting; peak clipping; energy efficiency

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Nomenclature

Symbol	Description	Unit of measure
°C	Measure of temperature	degrees Celsius
GWh	Measure of energy	gigawatt-hour
h	Measure of time	hour
K	Measure of temperature	kelvin
kg	Measure of weight	kilogram
kJ/kg	Measure of enthalpy	kilojoule per kilogram
kJ/kg.K	Measure of specific heat	
kg/s	Measure of flow rate	kilogram per second
km	Measure of distance	kilometre
kVA	Measure of power	kilovolt-ampere
kW	Measure of power	kilowatt
kWh	Measure of energy	kilowatt-hour
ℓ/s	Measure of flow rate	litre per second
m	Measure of distance	metre
MJ	Measure of power	megajoule
MVA	Measure of power	megavolt-ampere
MW	Measure of energy	megawatt
MWh	Measure of energy	megawatt-hour
rpm	Measure of rotational speed	revolutions per minute
s	Measure of time	second

Abbreviations

Abbreviation	Description
BAC	Bulk air cooler
CCT	Condenser cooling tower
CFCT	Counterflow cooling tower
COP	Coefficient of performance
DSM	Demand side management
EGF	Energy-governing factor
EN (system)	Energy-neutral (system)
EPC	Energy performance contract
ESCO	Energy services company
GDP	Gross domestic product
IPMVP	International Performance Measurement and Verification Protocol
LS (FP) & EN (CA)	Load-shifting (fridge plant) and energy-neutral (cooling auxiliaries)
LS (system)	Load-shifting system
M&V	Measurement and verification
NMD	Notified maximum demand
PA1	Performance Assessment 1
PA2	Performance Assessment 2
PCT	Precooling tower
PLC	Programmable logic controller
SANS	South African National Standard
SCADA	Supervisory control and data acquisition
TOU	Time-of-use
TSM	Theoretical scaled baseline model
VAT	Value added tax
VSD	Variable speed drive

CHAPTER 1: INTRODUCTION



[1]

[1] R.S. van As – personal photo taken of an electrical sub-station at Mine A

1.1. Electricity usage in South Africa

1.1.1. Eskom

Eskom generates approximately 95% of the electricity used in South Africa, and approximately 45% of the electricity used in Africa [1]. Eskom is therefore the foremost generator and distributor of electricity in South Africa. Eskom sold a total of 216 274 GWh during 2015 [2]. Figure 1 indicates that the three top consumers by industry are municipalities (indirect residential), industry and mining.

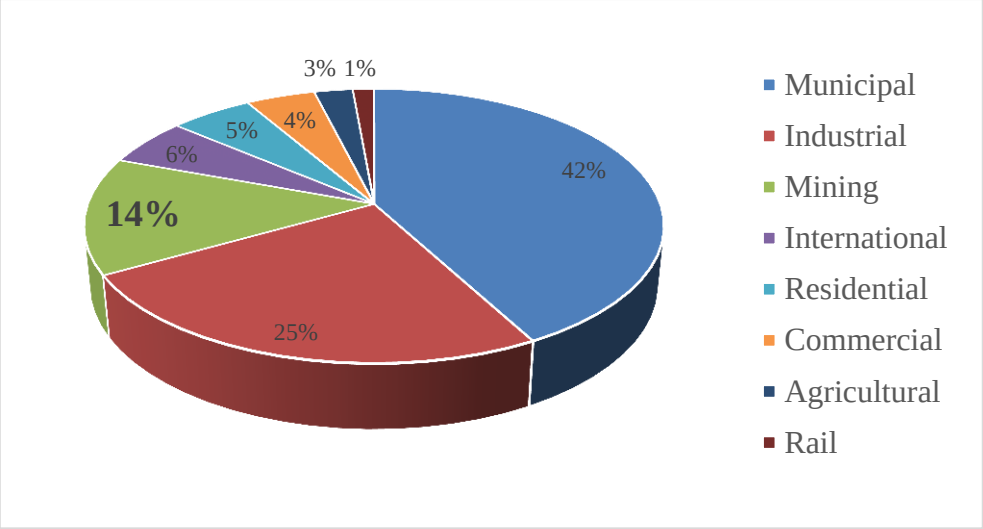


Figure 1: Eskom electricity sales 2015 [2]

1.1.2. Mining as a major electricity consumer

Conventional wisdom views the mining sector as the heart of the South African economy. Although mining is not at the peak it was in 1970 with a 21% contribution to the gross domestic product (GDP); with a contribution of 6% in 2011, the mining sector continues to make a valuable contribution to the South African economy [3].

In 2014, the South African mining industry was responsible for [4]:

- 14% of Eskom electricity sales;
- 7.6% contribution to GDP;
- 1.4 million jobs; and
- 25% of exports.

Therefore, the profitability, sustainability and energy consumption of this sector have a major influence on the South African economy.

Figure 2 illustrates the per-sector contributions to mining mineral exports in South Africa. Gold and platinum group metals comprise 43% of the total mineral exports. The gold and platinum mining industries are therefore of strategic significance to the South African economy and energy sector.

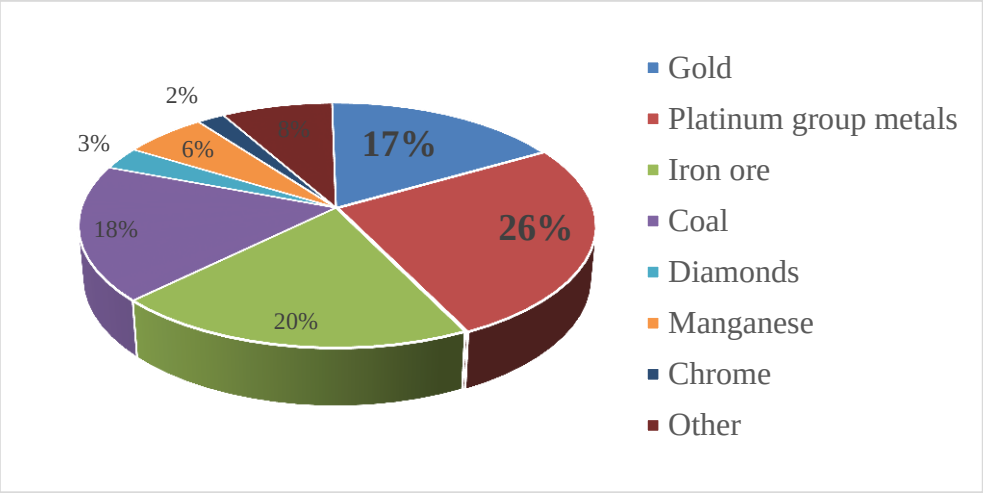


Figure 2: Sector contributions to mining minerals exports in South Africa (2014) [4]

1.1.3. Electricity demand in South Africa

Figure 3 shows the typical winter and summer electrical load profiles experienced by Eskom in South Africa. The electrical load fluctuates with periods of notable increase and peak consumption occurring in the early mornings and early evenings as shown by the shaded blocks.

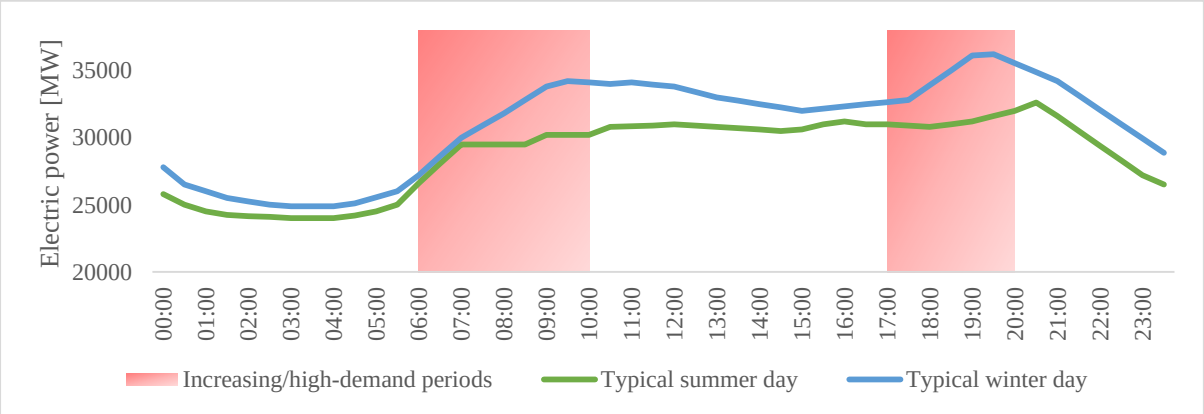


Figure 3: Summer and winter load profiles (adapted from [5])

To achieve adequate supply during the high-demand periods, electrical utilities employ peaking power stations [5]. These power stations generally operate at a higher cost and unavailability and, therefore, there is a direct incentive to minimise their use. In South Africa, Eskom employs hydroelectric, hydro-pumped storage and gas turbine stations as peaking stations [5].

To discourage electricity consumption in the high-demand periods, utility companies typically use time-of-use (TOU) tariff structures whereby consumers are charged based not only on their total energy usage, but also on the associated TOU of energy [6]. Eskom uses different tariff structures for various classes of customer.

Customers are classified per their notified maximum demand (NMD). Their tariff structure is based on this classification [7]. Mines normally have an NMD greater than 1 MVA as well as the ability to shift electrical loads. Therefore, they are typically billed according to the Megaflex tariff structure [8].There are three time periods defined within the Megaflex tariff structure. Depending on the demand season and day of the week, each hour of the day is classified as peak time, standard time or off-peak time. Figure 4 shows the hourly classification of these time periods for each day of the week [9].

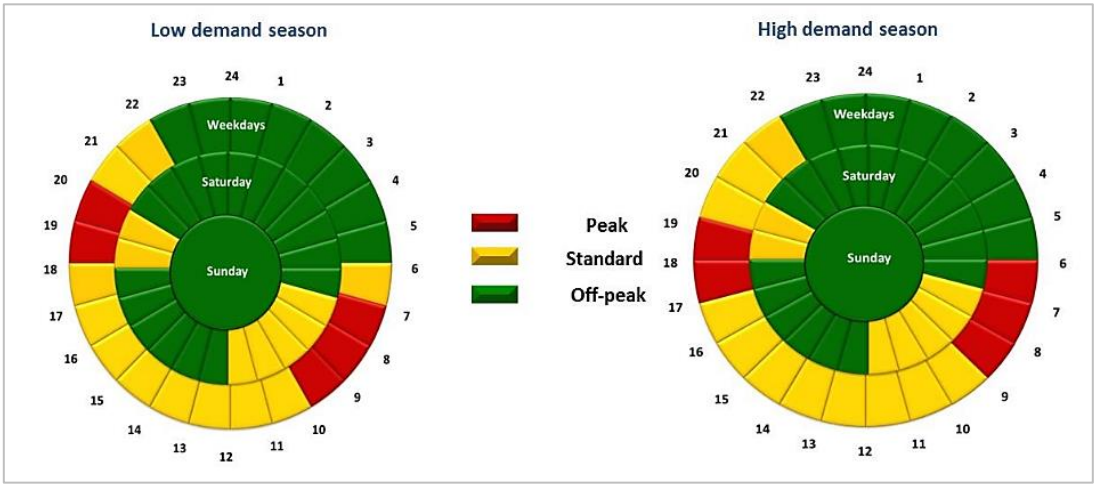


Figure 4: Eskom Megaflex TOU structure [10]

Table 1 shows the Eskom 2016/17 Megaflex tariff structure (excluding VAT) for consumers using more than 132 kVA, and with a transmission zone further than 300 km. As can be seen from Table 1, there is a large incentive for users to optimise their load profiles as the charge during peak time is 230% greater than in off-peak time for low-demand seasons. For high-demand seasons, the charge is 608% more.

Table 1: Eskom 2016/17 Megaflex tariff structure [9]

Time of day	High-demand season June–August [c/kWh]	Low-demand season September–May [c/kWh]
Off-peak	40.25	34.85
Standard	74.11	54.92
Peak	244.65	79.82

1.2. Demand side management

The Electric Power Research Institute implemented the world's first demand side management (DSM) programme in 1980. They define DSM as follows: "The planning, implementation and monitoring of utility activities designed to influence customer use of electricity in ways that will produce desired changes in load shape" [10].

Figure 5 illustrates the concept of supply and demand side. The operations of utility companies are collectively named the supply side, while energy consumption by customers is referred to as the demand side. The customers create the demand for energy which the utility company supplies.

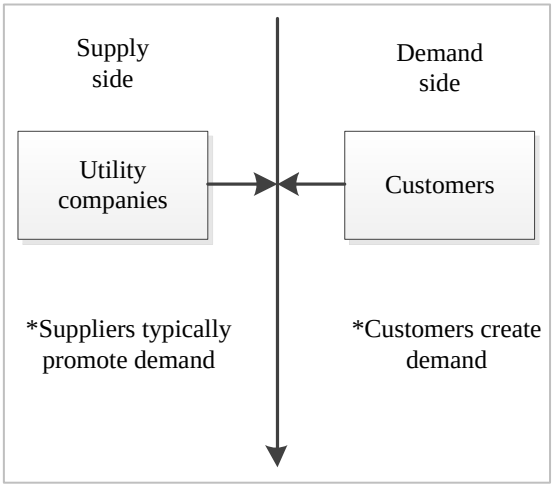


Figure 5: Concept of supply and demand side (adapted from [11]**)**

With DSM, it is possible for a utility company to use its resources efficiently and achieve substantial cost savings. In theory, DSM has the following effects [11]:

- Reduces the amount of fuel burnt at power stations.
- Possibly defers transmission reinforcement associated with both new power plants and increased loads.
- Reduces distribution and transmission losses.
- Leads to a reduction in the emissions of CO_2, SO_2 and NO_2 from power stations.

Ontario Hydro of Canada estimated that meeting its peak demand obligations through supply side measures would cost the utility four times as much as using DSM measures [12]. This cost saving was accredited to the fact that DSM initiatives are generally more economical to implement than the capital- and time-intensive large infrastructure build projects associated with supply side upgrades.

1.3. Typical DSM initiatives

Generally, there are three methods employed to manage electricity consumption in high-demand periods, namely, load shifting, peak clipping and energy efficiency. These methods will be discussed in more detail in the sub-sections that follow. The baseline energy use is the electrical consumption prior to the DSM initiative being implemented.

1.3.1. Load shifting

The first method entails shifting electricity use from high-demand periods to lower demand periods, with an associated lower TOU electricity cost; this is referred to as load shifting. It is important to note that load-shifting is energy neutral – the nett electrical consumption is not reduced.

Figure 6 illustrates the effect of load shifting. This method has both a direct and indirect electrical impact due to the specific DSM intervention in the peak TOU period. The direct electrical impact is attributed to the energy removed from the system during the peak period, represented by the green shaded area from 17:00 to 19:00. The indirect impact, represented by the blue shaded area, is due to the system consuming more energy during the off-peak period.

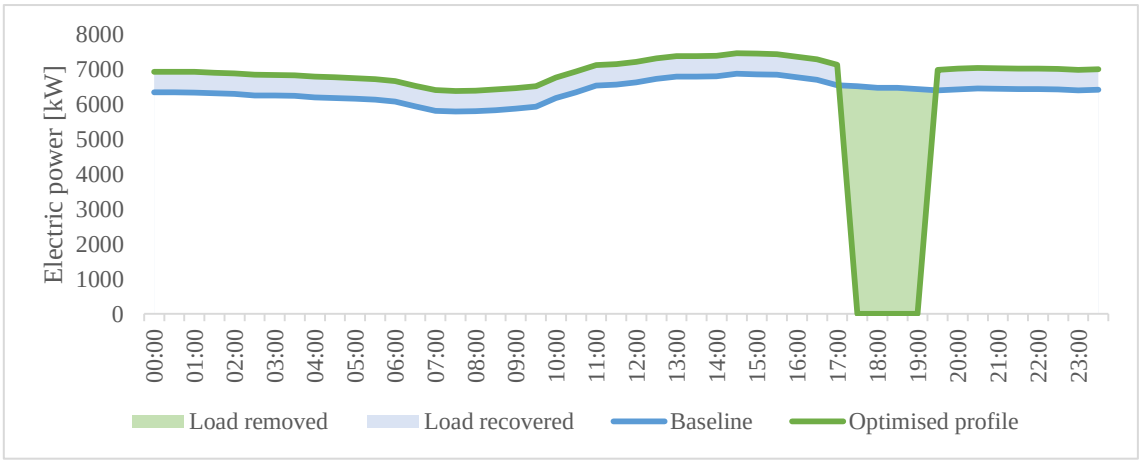


Figure 6: Load shifting

Load shifting has no impact on the total daily nett electricity consumption; it is energy neutral – the total direct impact is equal to the total indirect impact. Load shifting is effectively a method for realising energy cost reductions through a load management programme. Load shifting lowers the amount of electricity that is consumed during the high-energy cost peak demand periods by moving the load to lower energy cost off-peak periods.

1.3.2. Peak clipping

Peak clipping reduces the amount of electricity consumed by limiting high electricity-consuming processes. The effect of an evening peak-clipping intervention is illustrated in Figure 7. The total electrical consumption is reduced, as indicated by the green shaded area from 17:00 to 19:00. The consumption during the rest of the day remains unaltered.

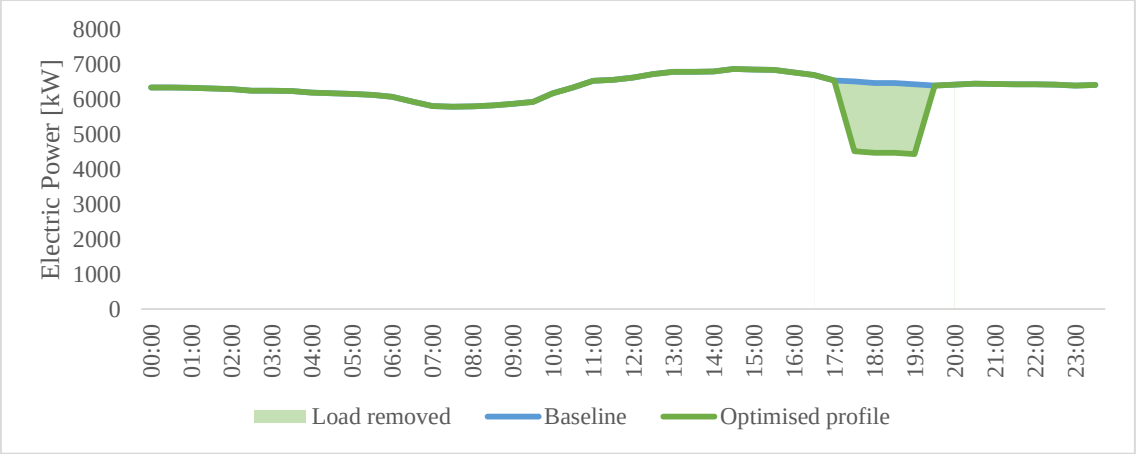


Figure 7: Peak clipping

Peak clipping typically reduces the service delivery of the electricity-consuming device or system during the intervention period. Peak clipping is therefore not energy neutral during the high TOU charge periods since the nett consumption is reduced.

1.3.3. Energy efficiency

Energy efficiency reduces the electrical consumption of end-users or devices, thus resulting in overall energy efficiency. Figure 8 illustrates the effect of an energy efficiency project. The shape of the electrical profile, system outputs and production schedules remain unaltered since existing equipment and processes are optimised without altering system outputs.

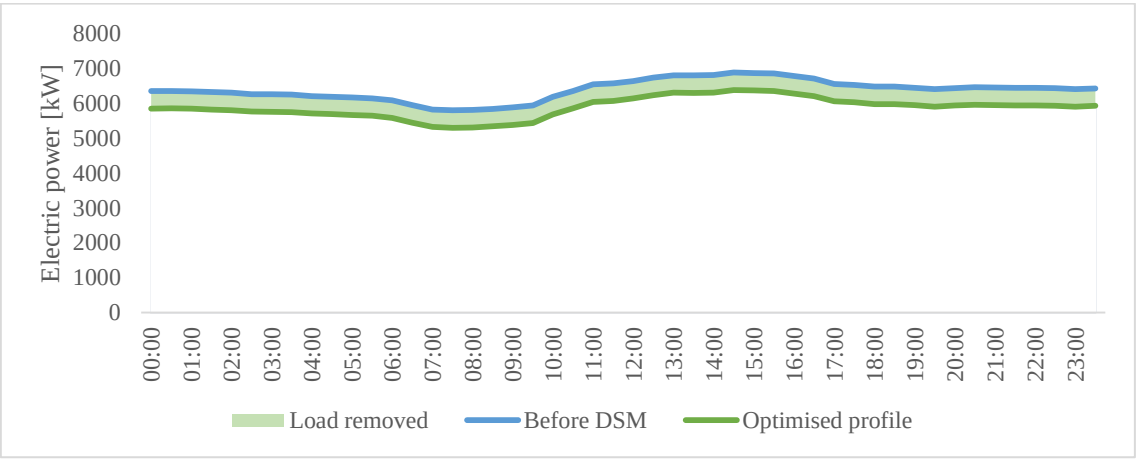


Figure 8: Energy efficiency

1.4. Role players in the South African industrial DSM sector

If a technically and financially feasible energy cost savings opportunity exists, a DSM project can be implemented. All projects, including DSM projects, have associated risks and limitations such as capital and time that have to be managed.

There are various role players involved during the various life cycle stages of a DSM project. In South Africa, these role players typically include Eskom, the energy services company (ESCO), the measurement and verification (M&V) team, and the client. These role players will be discussed in the sub-sections to follow.

1.4.1. Eskom

Eskom, the South African public utility company, is typically the funding party for industrial DSM projects. Eskom ultimately wants to ensure that real impacts are obtained that allow stable and efficient operations of their electrical distribution network during high-demand periods.

To help alleviate supply constraints, Eskom is in the position where it has to consider both supply side and DSM solutions. DSM programmes in South Africa have been directed by Eskom, which have helped reduce their peak demand requirement by approximately 3 000 MW by March 2013 with a further planned 5 000 MW reduction by March 2026 [13].

1.4.2. ESCOs

ESCOs implement DSM projects in the commercial, municipal and industrial sectors. Ultimately, ESCOs want to implement financially and technically feasible DSM projects to receive financial gain for their services.

An ESCO is a company that is involved in developing, installing and financing of comprehensive, performance-based energy efficiency or load-reduction projects [14]. DSM projects are typically complex in nature. An ESCO can offer expertise and resources that guarantee the long-term success of the project [15].

ESCOs have been successfully operating in many countries for a number of years, while in other countries only a few ESCOs have recently started to operate [16]. In South Africa, ESCOs are typically funded through Eskom initiatives. If a DSM project is feasible, it is implemented and maintained at an Eskom consumer site.

1.4.3. M&V teams

The continued success of many DSM projects can often be hampered by the inability of stakeholders to agree on the amount of savings realised [17]. An M&V team is an independent party who is tasked with objectively quantifying the impact of a DSM project.

Implementation of a DSM project, if successful, reduces the energy cost by a certain amount. These reductions, or savings, cannot be measured directly since they represent the absence of energy use. When determining savings under the reporting period conditions, the baseline period energy has to be adjusted to the reporting period conditions such that pre- and post-implementation energy usage can be compared directly.

The adjusted baseline energy is normally found by developing a mathematical model; in this study, it is referred to as the baseline model. The baseline model correlates actual baseline energy data with appropriate independent variables in the baseline period.

1.4.4. Clients

The client is the ultimate end user of electricity. The client wants to leverage DSM project funding and expertise from the utility and the ESCOs to increase their operational profitability by reducing their electricity costs.

Energy management initiatives have proven to be economical in industry. In fact, for most manufacturing, industrial, and other commercial organisations, energy management is one of the most promising profit improvement or cost reduction programmes available today [6].

Utility costs, including electricity and water, represent 10% of total mining operational costs. A year-on-year increase of 13.4% was recorded for 2015 [18]. Electricity cost reduction measures are thus of great importance to mining companies.

1.5. The need for accurate reporting

Common business sense stipulates that any activity is only justifiable if it is cost-effective or has an ultimate nett positive result. The primary questions for all project shareholders therefore are: How much is being saved? Are these savings being maintained?

1.5.1. Necessity of accurate reporting in performance contracting

Energy performance contracting (EPC) represents an innovative form of contracting that leverages future energy savings of a project as a funding source for implementing the project [19]. EPC therefore acts as a tool to deliver infrastructure improvements and energy

savings to customers who lack sufficient energy engineering skills, manpower, capital funding, understanding of risk, or technology information [19]. The ability to accurately determine achieved savings is thus the basis of successfully implementing EPC projects [17].

1.5.2. Other advantages of accurate reporting of energy savings

Many other additional benefits can be realised with accurate reporting of savings beyond that of performance contracting; some of these include:

- **Enhanced financing for other projects:** Increased credibility of achieved savings will lead to enhanced financing options.
- **Realisation of other/more similar projects:** A project with a proven track record has fewer associated risks and a higher likelihood of success and project realisation.
- **Emission-reduction tax incentives:** Section 12L of the South African Income Tax Act came into effect in November 2013 [20]. The 12L tax incentives and penalties for greenhouse gas emissions have given rise to an additional project funding model over direct energy cost savings only [21]. Accurate reporting and accounting of emission reductions thus provide additional value to energy efficiency projects.

1.6. Problem statement

The interaction between various DSM and M&V project stages is shown in Figure 9. It is common practice in industry for baseline models to be developed and accepted prior to final project commissioning [21].

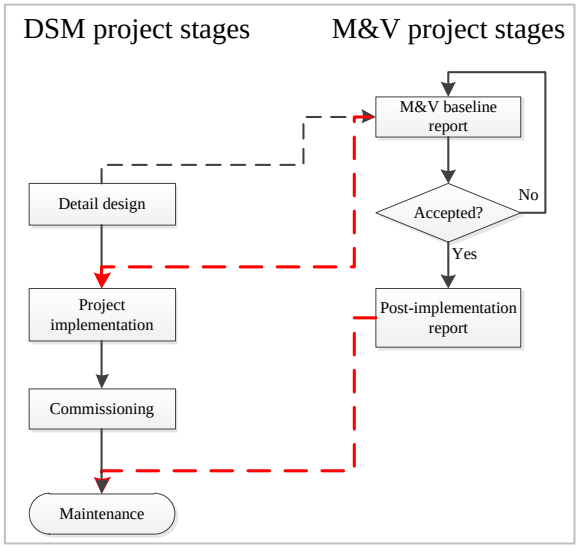


Figure 9: Interaction between selected DSM and M&V project stages (adapted from [21]**)**

Projects are, however, often implemented differently than envisioned in the original detailed design. This is due to many factors such as scope creep, technical and budgetary constraints,

and refinements and improvements to the original design [22]. If the assumptions made for the model in the original baseline report are no longer valid, a new model will be required for the post-implementation report.

Load-shifting and peak-clipping DSM initiatives typically employ baseline models that make fundamental assumptions about the project's recovery energy. It was shown that the load-shifting model recovers all the energy that is removed during the high-cost TOU periods while the ideal peak-clipping model has no associated recovery energy.

During the implementation of an actual DSM project on a mine surface cooling system, the need for a post-implementation reassessment of an initially accepted baseline model for a project that was implemented differently to the original design was highlighted. The specific project will be presented as a case study in Chapter 4. Due to confidentiality agreements, the mine cannot be named and will be referred to only as Mine A.

It was believed that the indirect electrical impact, or recovery energy, of the project was being overestimated by the original pre-project implementation load-shifting baseline model. Figure 10 shows the effect of the calculated recovery energy of two baseline models on the perceived, or calculated, impact of a DSM intervention. The model that calculates a larger recovery energy will report a lower calculated saving; a lower calculated recovery energy will report a larger calculated saving. Therefore, it was believed that the savings reported at Mine A were conservative.

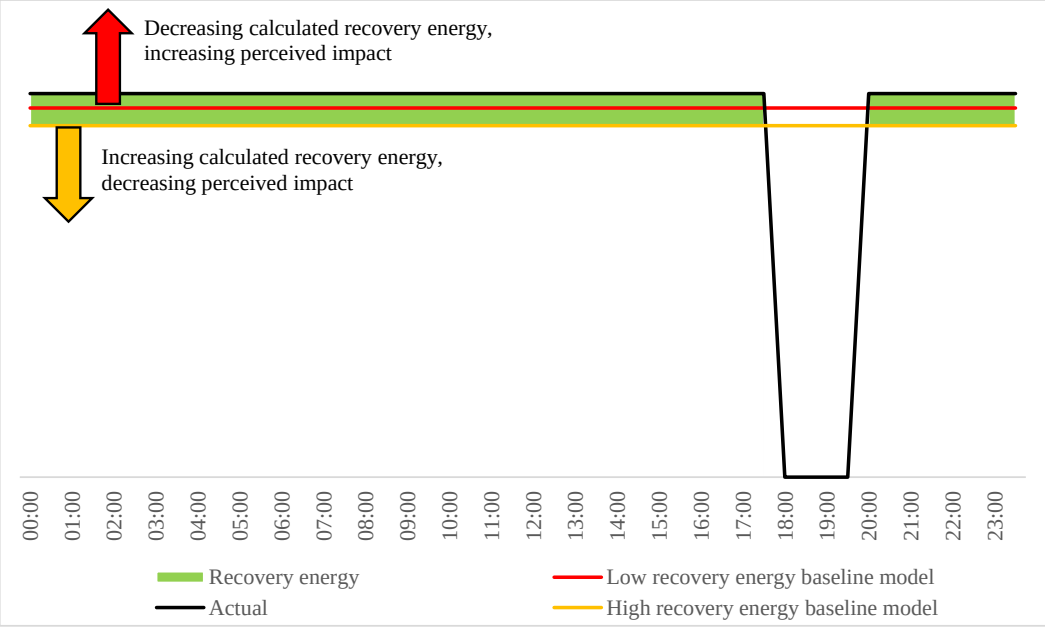


Figure 10: Effect of over- and underestimation of recovery energy

For mine surface cooling plant DSM projects, there will be a minimum required cooling effect or a minimum required service delivery. Industrial systems typically operate with high design margins and the nett reduction in the design margin will be the nett load, or service, removed or clipped by the DSM project.

To ensure that the average or nett specified service level is always maintained for a load-shifting project, it will be required that additional cooling is supplied prior to a particular peak intervention. This additional work will represent the recovery load of a load-shifting project. If there is an adjustment to the nett average service level to a lower energy requirement, the lower work requirement of the cooling equipment will represent the peak clipping or energy removed from a system.

It should be noted that any reduction in service delivery at a specific time has an associated heat energy gain as a direct result of the intervention since the temperature equilibrium is disturbed. Furthermore, cooling equipment typically has a large transient start-up time. This results in higher outlet temperatures until the equipment reaches full operational capacity.

To ensure that the instantaneous service delivery requirement is met after an intervention, it might be required that some additional cooling be supplied to a thermal buffer or storage. This compensates for the heat energy gain during the intervention and the transient start-up time directly after the intervention. Recovery work could be required to ensure that minimum instantaneous service delivery is maintained while still having an overall nett reduction in average daily service delivery.

From the above discussion, it follows that a DSM project on a cooling system can have a hybrid nature with both peak-clipping and load-shifting characteristics. Therefore, a need exists for a baseline model that considers both the recovery load and the load removed for a cooling plant DSM project.

Booysen noted that stricter EPC project funding models in conjunction with increased project complexity are challenges to all stakeholders [21]. The M&V cost of the project will be affected by the complexity of the baseline model development, cost of simulation packages, and the level of professional skills required to operate the model [23].

Project funding will typically be at its lowest just after project implementation. This could result in limited resources being allocated to post-implementation project phase or model reassessment. The post-implementation assessment model must therefore be simple and

accurate enough to be used to assess the pre-implementation model risks. From the post-implementation analysis, risks and opportunities can be identified which could justify allocating more resources towards new model development.

1.7. Objectives of this study

The objectives of this study are to:

- Develop a theoretical baseline model that considers both recovery and removed energy, which is sufficiently accurate and simple enough to be used for post-project implementation analysis.
- Calculate the intervention-associated indirect electrical energy impact, or recovery energy, for DSM projects on cooling and refrigeration systems.
- Evaluate and compare with the various recovery energies predicted by the standard and developed baseline models.
- Investigate the financial implications of applying standard baseline models to the project.
- Evaluate the developed model with actual performance of cooling systems on other mine cooling systems.

1.8. Overview of dissertation

Chapter 1: Introduction – The need for implementing DSM projects in the mining and industrial sectors is given. The need for a newly developed baseline model for a project that is implemented differently to the initial original detailed design is also identified.

Chapter 2: Literature study – The operation and modelling of mine cooling systems are investigated. Emphasis is placed on how the theoretical performance of cooling systems can be incorporated into the M&V baseline model. The M&V process is further investigated with attention to the baseline model and system performance predictions. The chapter also reviews the evaluation of baseline models.

Chapter 3: Baseline model development for mine cooling systems – This chapter provides detail on how baseline models are developed for a specific case study as well as present a model that can be used for cooling systems in the post-implementation project stage. Furthermore, the evaluation procedures for the various baseline models are developed and presented.

Chapter 4: Practical application and evaluation of baseline models – The developed baseline models are implemented and evaluated using a case study at mine A. The possible financial implications of model selection, for the specific case study, are investigated and the project risks exposure associated with model selection is minimised.

Furthermore, the suggested and developed post-implementation model is used and evaluated for other case studies on mine surface cooling systems.

Chapter 5: Conclusions and recommendations – This chapter summarises the key findings and the limits of the study, and provides further recommendations for future studies and/or developments.

CHAPTER 2: LITERATURE REVIEW



[2]

[2] R.S. van As – personal photo taken of condenser cooling towers at Mine A

2.1. Introduction

The accurate measurement and calculation of savings achieved by DSM initiatives were identified in Chapter 1 as the foundation to the success of an energy savings project. In industrial DSM projects, the responsibility for determining and reporting savings achieved ultimately lies with the appointed independent M&V team.

As already noted, energy savings represent an absence of something and therefore it cannot be measured directly. The entire M&V process therefore hinges on the ability to determine what the system operation would have been under current circumstances. The "would have been" can only be estimated by a model that represents the system or makes it possible to predict its performance.

This chapter will commence with an introduction to mine cooling systems and their theoretical operation. This is critical for developing different models that can predict system performance accurately.

Furthermore, some of the typical baseline models used in industry by M&V teams will be identified and investigated. The M&V of DSM projects as per the South African National Standard (SANS) 50010:2011 will also be discussed with specific methodologies presented to apply the standard to industrial-sized projects.

2.2. Mine cooling systems

Eight of the ten deepest mines in the world are located in South Africa [24]. The deeper mining progresses, the more costly and energy intensive the operations become [25]. In deep-level mining operations, mine cooling systems typically consume about 25% of the total electrical energy usage [26].

With increasing depth, there is an increase in the virgin rock temperature which results in an unacceptable hot and humid environment [27]. Due to factors such as worker health, safety, productivity, comfort and legal requirements, mines have to ensure acceptable environmental conditions. This necessitates the need for mechanical ventilation and cooling [28].

As can be seen from Figure 11, the complexity of a mine cooling system is ultimately dependent on the mine's heat load and mining depth [29].

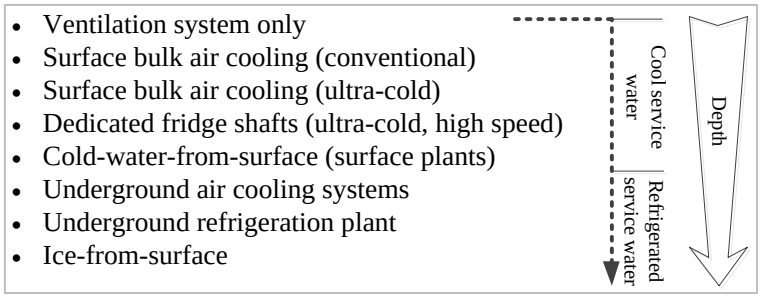


Figure 11: Generic selection of optimum cooling system as a function of mining depth [29]

In deep mines, cooling is typically provided by chilled water from either underground and/or surface refrigeration plants [30]. The chilled water ultimately forms part of the water reticulation system. Using refrigerated cooling water thus affects the water pumping load of the mine [31].

Figure 12 shows a typical mine cooling water circuit with precooling towers (PCTs), surface refrigeration plant, surface bulk air coolers (BACs), and possible underground BACs and fridge plants.

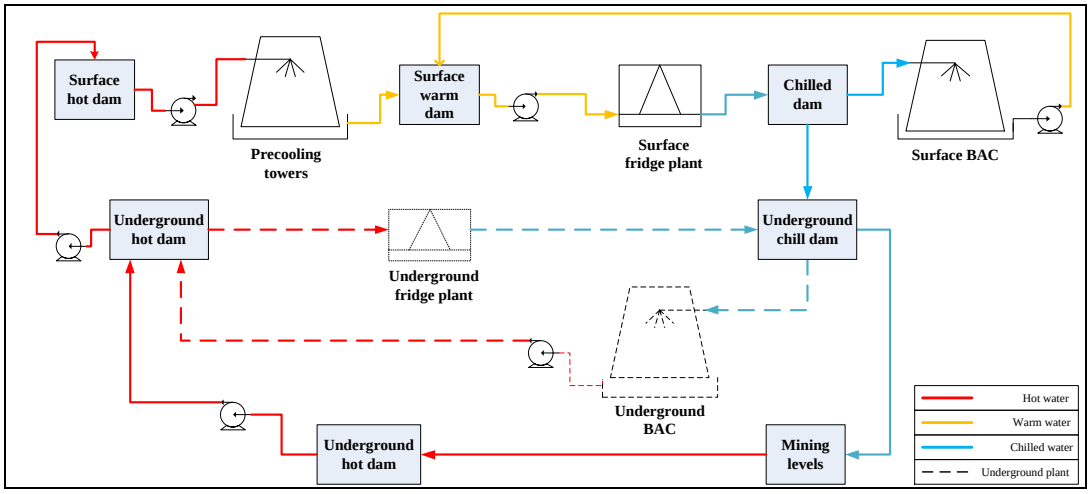


Figure 12: Mine cooling water circuit

Water is heated as it is used by surface and/or underground BACs, as well as in the mining levels. The hot water is pumped from underground to the surface hot dam. From the hot dam, the water is cooled in the PCTs and then pumped to the surface warm dam.

From there, the water is pumped from the surface warm dam to the fridge plant where it is cooled to a low temperature. The chilled water is stored in the cool dam ready for surface BAC or underground use. The cold dam has thermal storage capacity. Typical DSM projects on these systems focus on optimising and utilising this thermal storage capacity.

PCTs form an essential part of the surface cooling system as they have the potential to supply a considerable portion of the total mine cooling – particularly in winter when the ambient wet-bulb temperature is usually much lower than the underground water arriving at the PCTs [32].

The capital required and running costs of a PCT is much lower than a fridge plant which makes it the cheapest form of mechanical cooling available for mines [32]. The cooling provided by underground fridge plant installations has less seasonal variation because of the absence of PCTs preceding the plant.

The mechanical cooling system is made up of various components that ultimately form part or affect the pumping system and ventilation system of the mine. The operation and performance of the various components will subsequently be discussed.

2.2.1. Mine cooling towers

Mine cooling towers can be classified as heat exchangers that dissipate heat from the mine cooling water. This transfer is direct in the case of a PCT, and indirect with a condenser cooling tower (CCT) that exchanges heat from the cooling water to the refrigerant and finally to the CCTs [33]. Figure 13 indicates the heat dissipation from the mine cooling towers.

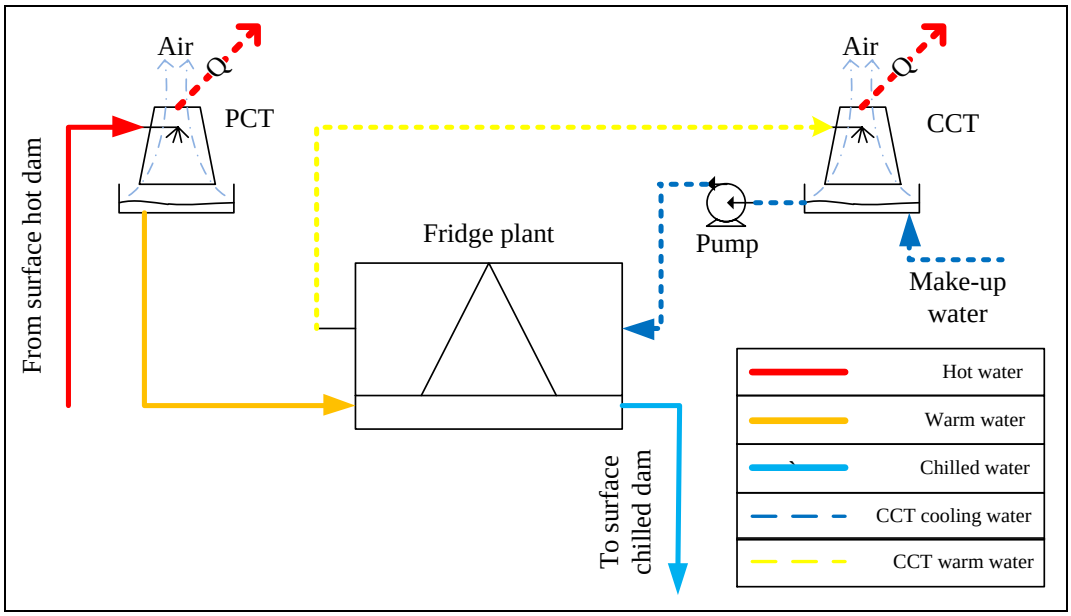


Figure 13: Cooling tower heat rejection

PCTs can cool water to within 2°C to 3°C of the ambient wet-bulb temperature, which is always lower than or equal to the ambient dry-bulb temperature [34]. The overall energy efficiency of the entire cooling system is substantially improved due to the lower temperatures achievable with cooling towers.

Mechanical draft induced counterflow cooling towers (CFCTs) are the most common cooling tower type employed, for PCTs and CCTs, at deep-level mines [35]. In CFCTs, nozzles are used to disperse water droplets throughout the tower [36]. Figure 14 illustrates a schematic drawing of a typical CFCT with the direction of water and air flow, location of the fan, sprays and fill material shown.

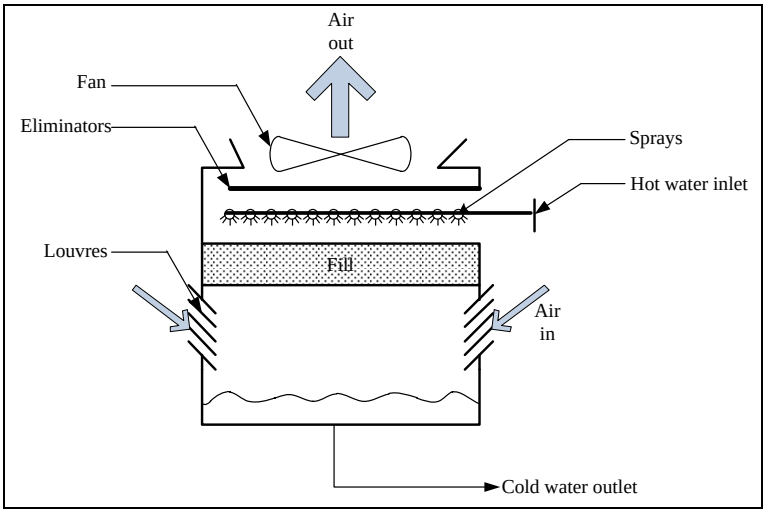


Figure 14: Schematic drawing of a counterflow precooling tower adapted from [34]

A CFCT cools water by a combination of heat and mass transfer [34]. Figure 15 shows the temperature relationship between water and air as the fluids pass through a CFCT. The temperature of the water decreases, while the wet-bulb temperature of air increases.

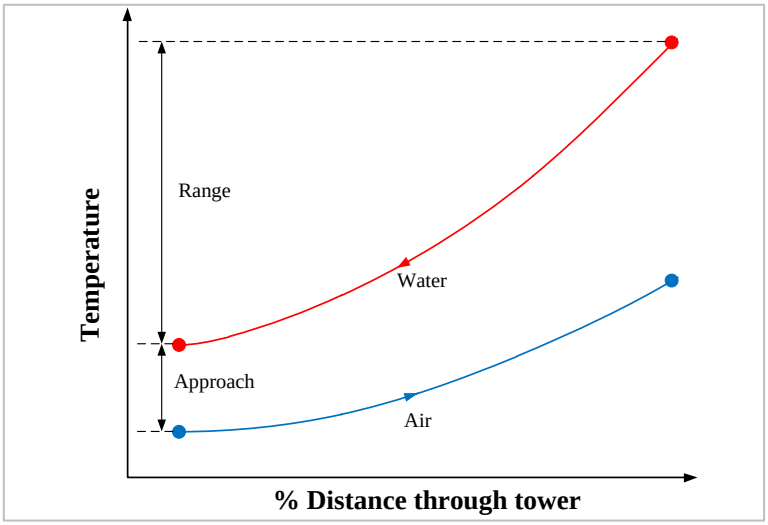


Figure 15: Temperature relationship between air and water in a CFCT [34]

A portion of the water distributed in the CFCT absorbs heat to change from a liquid to a vapour at constant pressure [34]. The heat-transfer area is increased using nozzles and fill material in the CFCT that exposes atmospheric air to water [37]. This latent heat of vapourisation is thus transferred to the airstream. This air and vaporised water mixture is exhausted from the tower.

There is an energy balance between the rate of heat gain by exiting air and the cooling of the water exiting the tower. Thus, using the first law of thermodynamics, the energy balance can be written as [38]:

$$\dot{m}_{air}(h_{airOut} - h_{airIn}) = \dot{m}_{water}(h_{in} - h_{out})$$

Equation 1

Where:

$\dot{m}_{air}$: mass flow rate of air [kg/s]
h_{airOut}: specific enthalpy of outlet air [kJ/kg]
h_{airIn}: specific enthalpy of inlet air [kJ/kg]
$\dot{m}_{water}$: mass flow rate of water [kg/s]
h_{in}: specific enthalpy of inlet water [kJ/kg]
h_{out}: specific enthalpy of outlet water [kJ/kg]

The water-side efficiency of a cooling tower can be calculated using Equation 2 [27].

$$\eta_W = \frac{Range}{Approach} = \frac{T_{wo} - T_{wi}}{T_{ai(WB)} - T_{wi}}$$

Equation 2

Where:

η_W: water-side efficiency [%]
T_{wo}: water outlet temperature [°C]
T_{wi}: water inlet temperature [°C]
$T_{ai(WB)}$: air inlet wet-bulb temperature [°C]

Thermal performance of pre- and condenser cooling towers depends mainly on the wet-bulb temperature of the entering air, while the dry-bulb temperature and relative humidity of the entering air have an insignificant effect when considered independently [34].

The dry-bulb temperature and humidity of the inlet air, however, do have an important effect on the rate of water evaporation in the tower [34]. As can be seen in Figure 13, make-up water has to be supplied to the CCT while some of the water pumped from underground is "lost" to the atmosphere in the PCT.

2.2.2. BACs

BACs can be found on surface and underground and are used to cool ventilation air conveyed through shafts and tunnels. If the surface BACs cannot reduce the temperature of the air sufficiently, secondary underground bulk air cooling is introduced [8].

BACs operate similarly to the pre- and condenser cooling towers except that the heat-transfer direction is reversed [27]. As indicated by Figure 16, BACs use the chilled water from the fridge plant's evaporator circuit, or surface cool dam, to cool air to be conveyed in the mine.

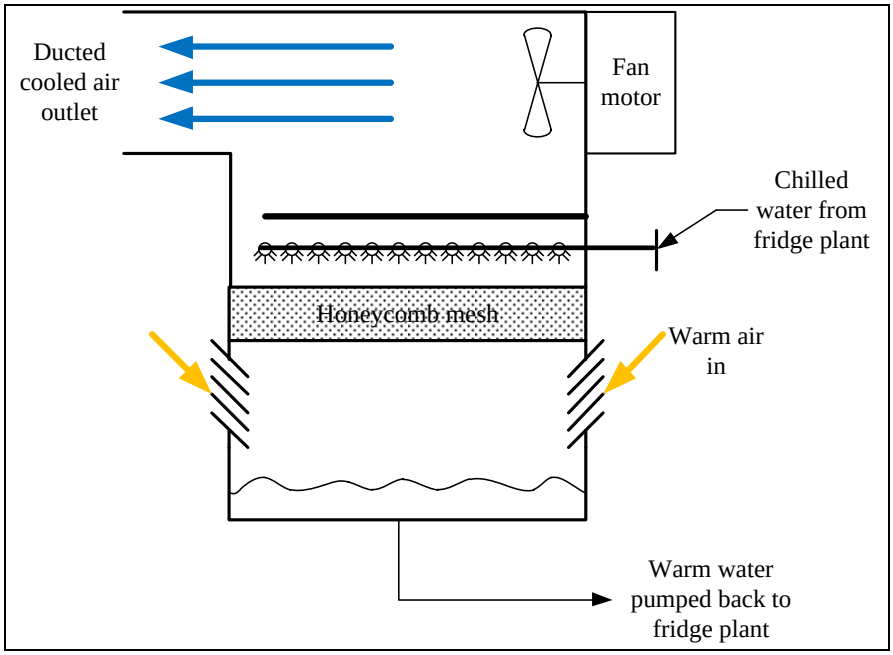


Figure 16: Simplified schematic drawing of a BAC

2.2.3. Vapour-compression fridge plants

Refrigeration cycles transfer thermal energy from low-temperature regions to high-temperature regions. Most surface refrigeration plants used in the mining industry operate on the vapour-compression cycle [25]. For the mine cooling system, there are essentially three working fluid circuits, namely, the mine water circuit, the refrigerant working fluid circuit, and the CCT cooling water circuit. These circuits are only thermally linked through heat exchangers and hence no physical mixing of the fluids takes place (the cycle is shown in Figure 17).

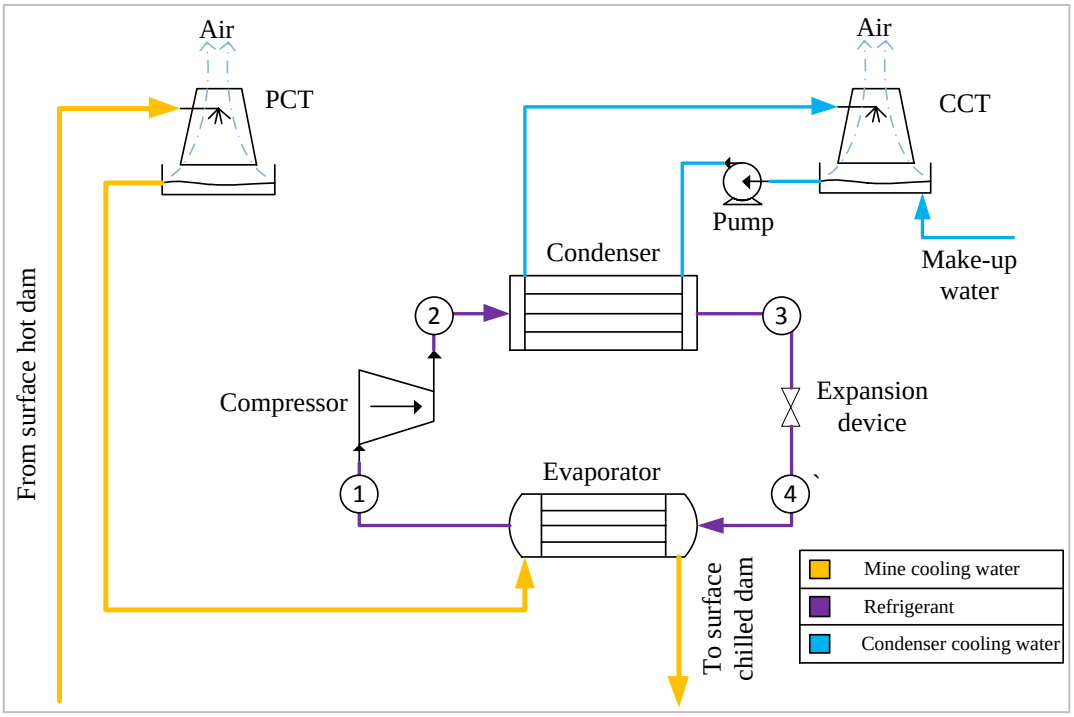


Figure 17: Mine surface cooling system with a vapour-compression fridge plant

The operation of the cycle can be summarised as follows:

- Compression (1–2): The refrigerant undergoes compression and is transformed to a high-temperature high-pressure state.
- Heat rejection (2–3): Heat, mostly latent, is rejected to the environment through the condenser and the refrigerant is transformed from a vapour to a high-pressure liquid. There is a minimal pressure drop in this stage due to frictional fluid resistance present in equipment.
- Expansion or throttling (3–4): The refrigerant is expanded through a throttling process. The temperature decreases and the refrigerant exits in a two-phase form.
- Heat absorption (4–1): Heat is absorbed from the environment by the evaporator and the refrigerant is transformed from a liquid-vapour mixture to a vapour.

Coefficient of performance (COP) is often used to describe the performance of a refrigeration cycle. This is a ratio of the benefit of the cycle (heat removed) to the required energy input to the cycle [38].

$$COP = \frac{Q}{P_{electrical}}$$

Equation 3

Where:

COP:	coefficient of performance
Q:	cooling capacity [kW]
$P_{electrical}$:	electric power input to fridge plant [kW]

The Carnot cycle is an idealised model for a completely reversible cooling cycle operating between two fixed temperatures [38]. The Carnot cycle provides the upper performance level for fridge plants as no refrigeration cycle operating within the same temperatures can have a COP higher than that of the Carnot cycle [38]. The COP of the Carnot is given by Equation 4:

$$COP_C = \frac{T_L}{T_H - T_L}$$

Equation 4

Where:

COP_C:	COP of ideal reversible Carnot cycle
T_L:	absolute temperature of cold reservoir [K]
T_H:	absolute temperature of hot reservoir [K]

In reality, no refrigeration cycle can be completely reversible since irreversibilities are introduced through pressure drops in lines and heat exchangers, heat transfer between fluids at different temperatures, and mechanical friction [39].

Furthermore, it should be noted that these irreversibilities are not constant with time and will change due to factors such as fouling of heat-transfer surfaces, general health of the system, maintenance practices, age of the equipment, and even environmental conditions.

The measure of the departure of the actual cycle from the ideal reversible Carnot cycle is given by the refrigeration efficiency [38]:

$$\eta_R = \frac{COP}{COP_C}$$

Equation 5

Where:

η_R:	second law of refrigeration efficiency
COP:	actual COP of fridge plant
COP_C:	COP of ideal reversible Carnot cycle

The cooling capacity of an actual cycle, which is used in the COP calculation, can be calculated from the cooling water input and output temperatures as follows [38]:

$$Q = \dot{m} c_p (T_{in} - T_{out})$$

Equation 6

Where:

Q:	cooling capacity [kW]
$\dot{m}$:	mass flow rate [kg/s]
c_p:	specific heat at constant pressure [kJ/kg.K]
T_{in}:	temperature of working fluid at inlet [°C]
T_{out}:	temperature of working fluid at outlet [°C]

Control of fridge plants

The compressor is the main component and power consumer on a fridge plant. Compressor capacity control will determine the refrigeration effect (see Equation 6) in the evaporator circuit as well as the power consumption of the plant. Industrial-sized fridge plant chillers typically use screw and centrifugal compressors [40].

Compressor capacity control on large centrifugal machines is typically achieved by prerotation guide vane control, which is also known as inlet guide vane control [41]. The guide vanes alter the direction or swirl of the refrigerant flow entering the impeller relative to the impeller leading blade edge, thus changing the compressor performance without altering the compressor speed [41].

A typical mine cooling system consists of multiple chillers that are arranged in a parallel, series, or a parallel-series configuration [27]. A parallel-series configuration with back-pass control is shown in Figure 18.

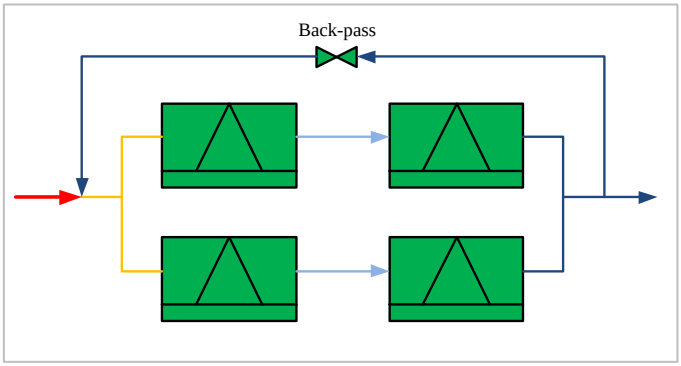


Figure 18: Typical mine surface parallel-series fridge plant configuration with back-pass control

The simplest cooling capacity control is to operate only the fridge plants required to handle the heat load. Capacity control can also be achieved by controlling a back-pass valve which allows fridge plant outlet flow to bypass the terminal heat-load devices and return to the plant, consequently decreasing the inlet temperature and power consumption [42].

2.2.4. Auxiliary cooling equipment

Pumps are employed in mine cooling systems to circulate condenser and evaporator water. For surface mine cooling systems, the pumps, CCTs, BACs, and fans will be termed cooling auxiliaries, as they do not directly form part of the vapour-compression cycle of fridge plant chillers.

Affinity laws govern the effects of parameter variation to the characteristic curves of pumps and fans. The affinity laws are represented from Equation 7 to Equation 10 [43].

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$$

Equation 7

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

Equation 8

$$\frac{H_1}{H_2} = \left(\frac{Q_1}{Q_2}\right)^2$$

Equation 9

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

Equation 10

Where:

Q:	water or air flow rate [ℓ/s]
D:	impeller or blade diameter [m^2]
N:	rotational speed [rpm]
H:	pressure head [m]
P:	pump or fan input power [kW]

Affinity laws indicate that the flow rate (Q) is directly proportional to the rotational speed (N). An increase in pressure head (H) is directly proportional to the square of the flow rate. The input power is proportional to the cube of the rotational speed.

In both pumps and fans, kinetic energy is transferred from rotating blades or impellers to the working fluid, namely, water for pumps and air for fans [43], [44]. The objective of the energy transfer is, however, slightly different for pumps and fans. Pumps convert this kinetic energy to a pressure rise through a decrease in flow velocity in the volute, and a relatively smaller increase in flow rate [44]. In the case of fans, the focus is on increasing the flow rate with a small associated pressure rise [43].

By varying the speed of the rotating element, the performance of cooling auxiliary equipment can thus be altered. This is typically achieved by installing and controlling variable frequency drives or variable speed drives (VSDs) on the electric driving motors of rotating equipment.

2.3. The M&V of energy savings

To aid and standardise the M&V process, several local and international guidelines and standards have been created. These include the International Performance Measurement and Verification Protocol (IPMVP) [45], the Federal Energy Management Program [46] and SANS 50010:2010 [47].

Adherence to local and international standards will ensure that a comprehensive, industry-accepted and logical approach can be used to solve a problem at Mine A. At its core is a re-evaluation of the M&V process used for the specific project [21]. SANS 50010:2011 will serve as the foundation when reviewing the M&V process. In conjunction with the SANS, supplementary practical methodologies will be identified and discussed.

2.3.1. Baseline development

The baseline is the measured energy use of the system prior to the implementation of the DSM project [45]. This “historical record” is a function of certain system parameters. These parameters will impact the energy use during and after the baseline measurement period. These known or measured parameters are often referred to as energy-governing factors (EGFs). They have to be measured and recorded in conjunction with the system’s final energy use [47].

Determine boundary for measurements

A logical first step in the baseline development stage is determining the measurement boundary. Within this boundary, all energy use and EGFs must be measured and recorded. The energy use and ultimate savings shall be determined either for the entire facility, or for a

portion that isolates the sub-systems affected by the DSM project. These options are given in the SANS as follows [47]:

1. Retrofit isolation: Measures the impact of the sub-system by drawing a boundary around the equipment in question. Within this boundary, all significant energy requirements of the contained equipment are determined. This option frequently requires that additional specialised metering be installed. Depending on the characteristics of the particular DSM intervention, one of the following sub-options can be used for isolating equipment energy use [47].
    - Option A: Requires that only key parameters are measured. It is used when the energy quantities have to be derived from a calculation using a combination of measurements of some parameters and estimates of others. This option requires the measurement of at least one parameter and the calculation or estimation of another.
    - Option B: Requires that all parameters in the baseline and baseline model that are needed to quantify energy savings are measured.
2. Whole facility: The measurement boundary is drawn around the facility in its entirety. This option is typically employed when sub-metering is not available or impractical for the specific project. The total invoiced energy use from utility or fuel suppliers can then be used to calculate savings. When whole facility metering is used, this option will include the positive or negative effects of any changes that take place in the facility [47].
3. Calibrated simulation: Energy data from a calibrated simulation programme can take the place of missing or unmeasured data for either part of or the whole facility. The simulation model is calibrated so that it matches meter data to an acceptable degree of accuracy. This option is typically used when there are data issues although its use is not restricted to this case alone [47].

Measure energy quantities

The baseline conditions and energy use data will be confirmed by selecting the measurement boundary. Baseline data must be recorded, stored and documented. The energy use will be determined by measuring the energy flow directly, or by measuring proxies of energy use directly, which gives a direct indication of the energy used [45], [46], [47].

The energy quantities will be measured by one or more of the following techniques:

- Utility invoices: Energy data can be derived from supplier invoices where the invoices are based on actual measured quantities of energy. This is used most often when the whole facility measurement boundary option is selected.
- Isolation metering: Energy meters are placed at the measurement boundary between the equipment affected by the DSM project and the rest of the facility.
- Specific meters: Meters for measuring specific EGFs, such as flow rate, pressure, temperature and others. When the EGFs are used to calculate energy use, the appropriate scientific calculation must be used.

Establish measurement period

The measurement period for which data will be collected is a key EGF and must be established to consider the following [45], [46], [47]:

- Operating modes: The measurement period should span a full operating cycle from maximum to minimum energy use.
- Representative of all operating conditions: To ensure that the baseline does not underrepresent the actual operating conditions, all data must be recorded during the measurement period. In a situation where there is missing data, similar historical data with similar EGFs may be used.
- Completeness of data: Only periods where all EGFs of the facility are known will be included in the measurement period.
- Most recent: The measurement period shall be chosen to coincide with, or represent the period immediately before the implementation of the DSM project.

Baseline data set quality

A crucial part of the M&V process is ensuring the quality of the baseline data set. The collected data is ultimately used to develop the baseline model. A data set free from erroneous data will result in a reliable model. The data set should thus be of high quality and be representative of actual system operation. The quality of the baseline data set is affected by measuring abnormalities and abnormal system operation [21].

Measuring abnormalities

Measuring abnormalities are errors resulting from measuring and recording equipment malfunctioning. There are three main abnormalities that typically occur in the measuring and recording process:

- Data spikes: Occur when metering equipment malfunctions or when communication between recording and measuring equipment is lost. Data spikes are easily identifiable since they are recorded as a sudden and unexplainable change in data, which often fall outside the operational limits of the system.
- Faulty data: Erroneous data is often more difficult to detect since the recorded data can still fall within the operational limits of the system.
- Data loss: Occurs due to communication problems between the measuring and recording equipment.

Abnormal system operation

It can be challenging to identify abnormal system operation since the data set often has to be processed and analysed first. A typical example of abnormal operation is when unscheduled maintenance occurs; this debilitates the performance of the facility. Thus, it has an effect on the project's ability to perform for the period in question.

2.3.2. Evaluating the impact of DSM projects

Energy cost savings are determined by comparing the measured use of energy before and after the implementation of a DSM project [45], [46], [47].

$$E_S = B_{PEU} - R_{PEU}$$

Equation 11

Where:

E_S: electricity savings
B_{PEU}: baseline period electricity usage
R_{PEU}: reporting period electricity usage

If any of the baseline conditions have changed, adjustments are required to the original baseline to bring the baseline and reporting time periods under the same set of operational conditions. The baseline electricity usage combined with the adjustments is known as the adjusted baseline energy, or baseline model energy use. The baseline model is used to determine what the system operation "would have been" under current circumstances. The baseline model predicted energy use enables energy cost savings of a DSM project to be calculated [45], [46], [47].

SANS 50010:2011 provides the methodology for determining the impact of energy savings measures using adjusted baselines. The standard, however, does not specify how these adjustments should be made. Using SANS 50010:2011, the project impact is defined as [47]:

$$E_S = B_{PEU} - R_{PEU} \pm A$$

Equation 12

Where:

E_S: electricity savings

B_{PEU}: baseline period electricity usage

R_{PEU}: reporting period electricity usage

A: adjustments

To bring the baseline and reporting time periods under the same set of operational conditions, there are two adjustment scenarios that have to be considered, namely [45], [46], [47]:

- Routine adjustments: Adjustments that are implemented regularly to compensate for the dynamic nature of typical industrial systems such as changes in production output and environmental conditions.
- Non-routine adjustments: Adjustments that are implemented irregularly or once-off to compensate for changes to the system itself such as physical changes to the facility, changes in equipment type, and fundamental operational changes.

2.3.2 Baseline model development

The adjusted baseline energy is normally determined by developing a mathematical model that correlates actual baseline energy data with appropriate independent variables in the baseline period [47].

$$B_{model} = B_{PEU} \pm Ar$$

Equation 13

Where:

B_{model}: baseline model

B_{PEU}: baseline period electricity usage

Ar: routine adjustments

Subsequently baseline models commonly used in industry to perform the baseline adjustments will be presented.

The constant baseline model

The constant baseline model is the most basic model. It is used to represent systems with steady operational characteristics. The model is never adjusted to compensate for system changes since it is assumed that any change in performance of the system is only due to the DSM intervention that was applied [21].

$$B_{cm} = B_{PEU}$$

Equation 14

Where:

B_{cm}: the constant baseline model

B_{PEU}: baseline period electricity usage

A timer-controlled lighting system or energy efficient light bulb replacement programme are examples of typical projects that successfully use the constant baseline model [21].

The energy-neutral baseline model

The constant baseline model approach discussed in the previous sub-section has the advantage of being simple to develop and implement. However, it lacks the ability to represent more complex systems with fluctuating operational performance.

The energy-neutral baseline model uses energy as reference to adjust the model. In short, it preserves the baseline's profile shape. However, it adjusts the amplitude of the baseline profile to represent the system's operation for a specific scenario. To achieve the required scaling, a ratio is calculated between the baseline and actual performance for a selected time period where the DSM intervention has been determined as having no effect [21].

$$B_{EN} = B_{PEU} \left(\frac{RE_b}{RE_a}\right)$$

Equation 15

Where:

B_{EN}: energy-neutral baseline model

B_{PEU}: baseline period electricity usage

RE_b: reference energy for baseline period

RE_a: reference energy for assessment period

Other baseline models

The energy-neutral baseline model approach has the advantage of being able to predict the performance of a fluctuating system without having to measure any additional parameters over the constant baseline model. When it is difficult or impossible to determine a time period where the DSM intervention has no effect on the system performance, energy cannot be used as a reference for scaling.

Other techniques are therefore required to determine what the system operation "would have been" under current circumstances. Techniques may vary from theoretical adjustments and simple variable linear regression where a single independent system variable is correlated to energy use, to complex multiple parameter non-linear equations that correlate all the independent variables to energy use of the system [21], [47].

Single variable linear regression model

The simple model links an independent system variable to the system power. Many data-processing suites such as Microsoft® Excel already have functionality pre-programmed for easy fitting of models to a data set. Thus, an in-depth analysis of the techniques is omitted.

A linear regression model uses a least-squares approximation that finds the best-fit line by minimising the sum of the square of differences between the values on the approximation line and the data points [48].

The chosen model is linear and therefore has a straight-line equation form:

$$y = a_1 x + a_0$$

Equation 16

Where:

y:	coordinate on the vertical axis
x:	coordinate on the horizontal axis
a_0:	interception coordinate of line on y-axis
a_1:	slope of the line

The error is a function of variables a_0 and a_1.

$$Error \equiv E(a_0, a_1) = \sum_{i=1}^{n} [y_i - (a_1 x_i + a_0)]^2$$

Equation 17

Note: n is the total number of data points; i is the i^{th} data point.

The objective is to minimise the error with respect to parameters a_0 and a_1. The minimum error will exist where the first derivative with respect to both parameters are zero. That is:

$$\frac{\partial Error}{\partial a_0} = 0 \; and \; \frac{\partial Error}{\partial a_1} = 0$$

Equation 18

Substituting for the error term and simplifying yields the following:

$$2\sum_{i-1}^{n}(y_i - a_1 x_i - a_0)(-1) = 0 = \; 2\sum_{i=1}^{n}(y_i - a_1 x_i - a_0)(-x_i)$$

Equation 19

Simultaneous solution of the two equations can be done to solve for a_0 and a_1.

2.3.3. Baseline model evaluation

It is critical that the selected baseline model accurately represents the system as it was prior to any DSM intervention. When using data-processing suites such as Microsoft® Excel to determine the regression model, the value of the coefficient of determination (R^2) can be automatically calculated and reported as well.

The R^2 value is used to illustrate how well the regression model fits the data points and will give the proportion of variance in the y-value that can be attributed to changes in the x-value [48]. Booysen recommends that regression baseline models should have an R^2 value greater than 0.75 [21]. The R^2 evaluation can, however, only be used to evaluate the regression baseline model.

Baseline model evaluation of any baseline model is achieved by comparing predicted values with measured data. By calculating the percentage error between the model and measured data, a quick reference or analysis can be done.

$$Error = \frac{D_{actual} - D_{model}}{D_{actual}}$$

Equation 20

Where:

$Error$: error of a calculated energy data point from a baseline model [%]

D_{actual}: actual measured energy data point [kW]

D_{model}: calculated energy data point from the baseline model [kW]

2.3.4. Uncertainty

SANS 50010:2011 specifies that uncertainty must be managed to ensure that the reported savings are likely to be conservative. The standard does not require an exact quantification of uncertainty; however, it should be ensured that the results cannot be invalidated. Invalidation of the reported results in this case means that lower saving can be calculated by a more accurate or rigorous M&V process.

Generally, the size and complexity of a project will determine the rigour of the risk management process. Project risks can be managed either using a full statistical analysis or using simplified project management methodology. Project management methodology typically uses the probability (P) of the risk occurring and the associated impact (I) of the identified risk to plan risk-mitigation measures [22]. Probability and impact can be combined to determine the risk exposure. A common way to determine risk exposure is to assign levels of between 1 and 5 to both probability and impact, as per Table 2.

Table 2: Assigning levels to probability and impact

Level assigned	Impact (I)	Probability (P)
5	Catastrophic	Very likely
4	Major	Likely
3	Moderate	Occasional
2	Minor	Unlikely
1	Insignificant	Rare

The product of the probability and the impacts levels can then be calculated in a P-I matrix. This allows risks that will affect the project negatively and that are likely to occur to be identified and managed. Typically, combined levels of 15 or greater require urgent risk mitigation. Levels of 5 to 12 require caution. Levels lower than 5 are deemed acceptable [22].

Table 3: P-I matrix

P \ I	Catastrophic	Major	Moderate	Minor	Insignificant
Very Likely	**25**	**20**	**15**	**10**	**5**
Likely	**20**	**16**	**12**	**8**	**4**
Occasional	**15**	**12**	**9**	**6**	**3**
Unlikely	**10**	**8**	**6**	**4**	**2**
Rare	**5**	**4**	**3**	**2**	**1**

2.4. Previous studies on mine surface cooling plant DSM projects

Previous sections presented the theoretical operation of cooling components and an overview of the M&V processes. It was further shown that a baseline model is required to calculate the impact of a DSM project. In this section, a wider literature survey will be presented that specifically focuses on the models used to predict the performance of mine surface cooling components and systems. The survey will be presented in a condensed format in Table 4 to give an overview of the intervention philosophy and the types of model used either for the initial investigation and/or the M&V models used to determine the project impact.

Table 4: Summary of previous studies on mine cooling DSM initiatives

Focus	Control	Investigation	M&V	Variables used	Ref.
BACs	Chilled water flow control to BACs with VSDs and valves, on-off control of BACs	Simulation	Energy neutral	Electric power	[8]
Fridge plants	Fridge plant compressor capacity control	Simulation	Regression model	Electric power, thermal capacity (temperature and flow)	[42]
Fridge plants, cooling auxiliaries, and BACs	Fridge plant capacity control and BAC on/off control	Simulation	Energy neutral	Electric power	[49]
Fridge plants and cooling auxiliaries	Fridge plant flow control with VSDs on evaporator and condenser pumps	Simulation	Regression model	Ambient temperature, supply dam temperature, chilled water storage dam temperature, shaft supply flow and BAC supply flow	[50]
Fridge plants, cooling auxiliaries, and BACs	Flow control with VSDs on all transfer pumps	Simulation	Regression model	Electric power, thermal capacity (temperature and flow)	[27]

As can be seen from Table 4, previous studies on mine cooling systems DSM projects have used either energy-neutral scaling or regression baseline models for M&V of project impact.

Table 4 furthermore shows that regression models are typically employed when a general efficiency is introduced since the energy-neutral scaling method cannot account for these savings. It is important to note that a regression baseline model is project-specific and requires development for each project.

The model for post-project implementation baseline assessment should, however, ideally be general and simple enough to be used without allocating significant resources for M&V

baseline development. The model can therefore be used to identify possible risks and opportunities associated with developing a new or more accurate baseline model.

2.5. Conclusion

The chapter firstly focused on the operation of deep mine cooling systems and on the functioning of the individual system components. This serves as a knowledge base to develop new baseline models in Chapter 3 that accurately describe actual system operation.

The second focus point was M&V of industrial DSM projects. Attention was given to baseline model development and verification methods for developed models. Data set quality was identified as paramount to accurate baseline model development and techniques for data set selection and evaluation were presented.

Common baseline models used in industry for the M&V of industrial DSM projects were identified and development methods of the models were discussed. Baseline model evaluation techniques were presented that can be used to determine the accuracy of these models. Furthermore, a simple risk management methodology was presented that can be used to aid in model selection. Finally, baseline models used in previous studies on DSM projects on surface mine cooling systems were also identified.

CHAPTER 3: BASELINE MODEL DEVELOPMENT AND EVALUATION METHODOLOGY



[3]

[3] R.S. van As – personal photo taken of a BAC at Mine A

3.1. Introduction

As previously noted, this study was initially motivated after the implementation of an actual DSM project on a mine surface cooling plant at Mine A. The accepted pre-project implementation baseline model assumed that the project was a load-shifting project, which implied that the recovery energy is equal to the energy removed during the DSM intervention.

Mine A system description

Hot water from the hot dam is pumped through the PCTs into the warm water dam. The water from the warm well is pumped by the evaporator pumps through four ammonia fridge plants arranged in a parallel-series configuration to provide cold water to the vent shaft BAC, main shaft BAC and cold well dams. Fridge plant cooling water is pumped from the CCTs. This independent water loop acts as the ultimate heat sink of the heat removed from the warm well water by the fridge plants. A schematic layout of the surface cooling system at Mine A is shown in Figure 19 (the cooling plant equipment specifications are provided in Appendix A).

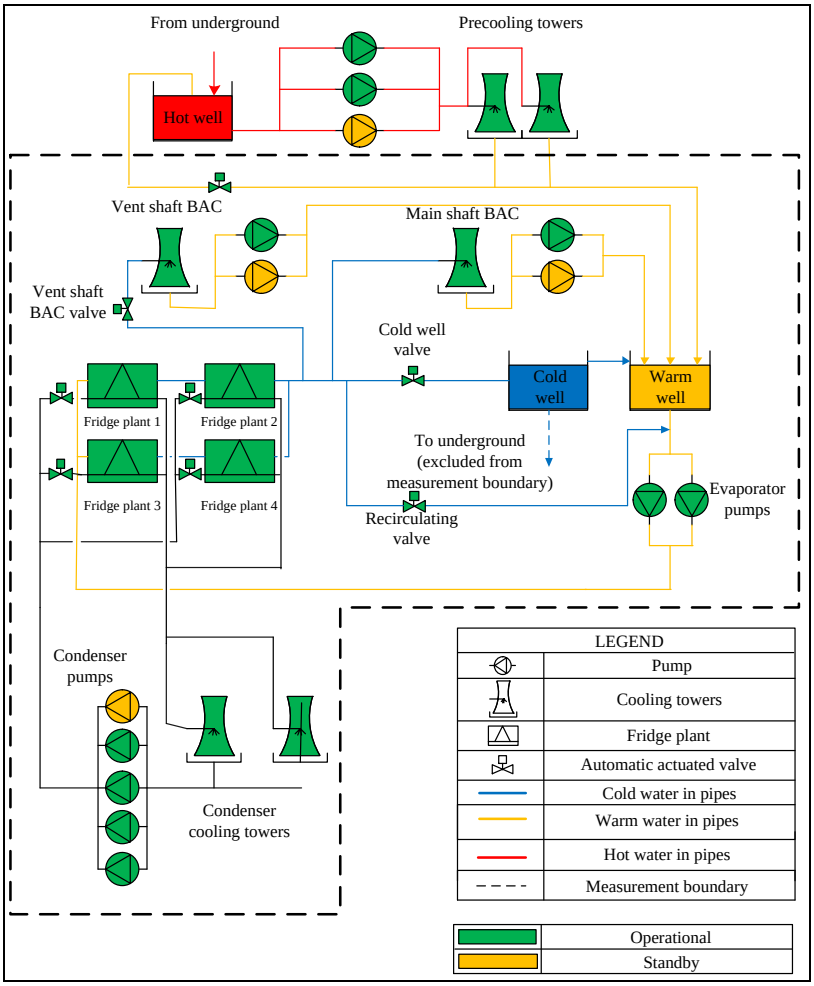


Figure 19: Normal operation and schematic layout of the cooling system at Mine A

The initial and implemented control philosophies during the DSM intervention of the project are summarised in Table 5.

Table 5: Overview of initial and implemented control philosophy

Equipment	Control philosophy	
	Initial	Implemented
PCTs (pumps and fans)	On	On
Fridge plants	Off	Off
Evaporator pumps	On	Off
CCTs (pumps and fans)	Off	Off
Main shaft BAC (pumps and fans)	On	Off
Vent shaft BAC (pumps and fans)	On	Off

The initial project control philosophy

The fridge plants were switched off during the peak period while the BACs remained operational. Water still circulated throughout the system since the evaporator pumps remained operational. This caused the warm well temperature to rise as no chilled recirculation water was received from the fridge plants and warm BAC return water was pumped to the warm well.

Furthermore, the water temperature in the cold well increased since water from the warm well was pumped by the evaporator pumps through the non-operational fridge plants into the cold well. The initial project design intended to use the cold well dam as a thermal reservoir. During the day, the dam temperature was lowered to an adequate temperature to receive the warmer water during the intervention and to remain within operational temperature limits for the water being sent underground during this period.

The project was thus a load-shifting project since more energy was used before and after the peak-time intervention to ensure that the cold well temperatures remained within operational limits. Thus, initially an energy-neutral baseline model with a 24-hour scaling period was selected prior to the project implementation.

The implemented project control philosophy

During project implementation it was, however, found that due to insufficient capacity during non-peak hours, the increase in cold well temperatures during the peak-time intervention was unacceptable. The daily effect of increasing cold well temperatures meant that the project performance could not be reliably maintained since cold well temperatures were too high.

This necessitated an investigation, and a revised control philosophy was implemented to meet the targets set for the project. It was found that underground air temperatures remained within acceptable limits if the BACs were switched off during the peak TOU charge period, without having to change the operational characteristics of the system during the non-peak periods. This allowed for the fridge plants and all the cooling auxiliaries to be switched off as well, since no water was circulated through the system using mechanical means.

Chapter 1 identified the need for accurate reporting and post-implementation reassessment of the baseline model. It was noted that the selected model will have an impact on the calculated recovery energy and that the calculated recovery energy will have a major impact on the reported savings.

The green shaded area in Figure 20 shows the perceived project impact of the original load-shifting model at Mine A. If no recovery energy was assumed (peak clipping), the sum of the green and red shaded areas would represent the removed energy. Therefore it can be seen that there is a potential large unclaimed impact, represented by the red shaded area, if the assumption of recovery energy is incorrect.

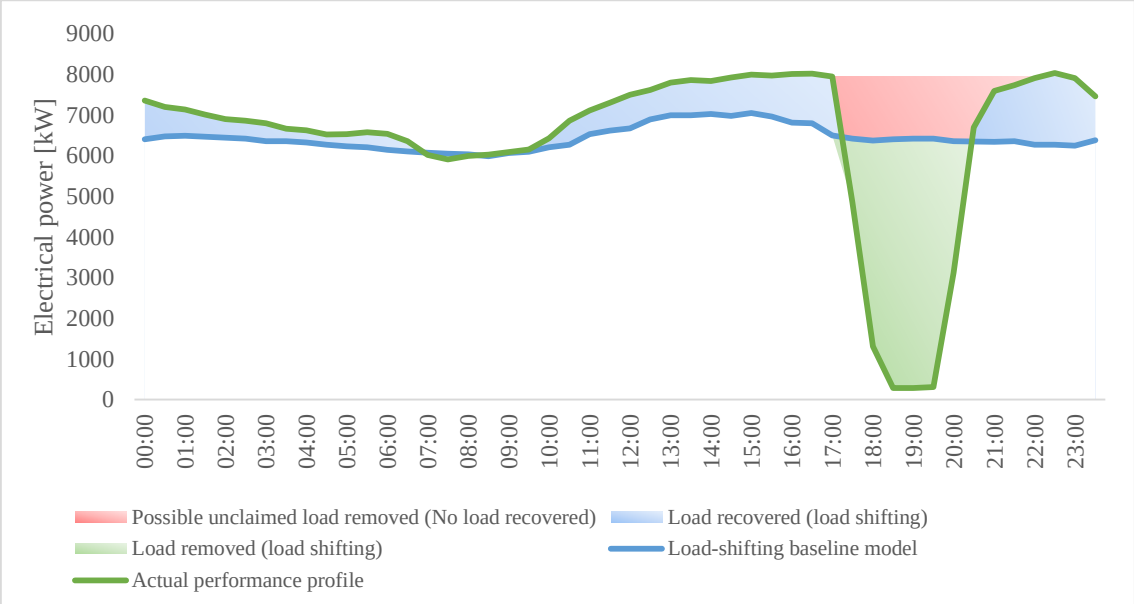


Figure 20: Perceived project impact assuming full and no recovery load at Mine A

For this DSM project at Mine A, it was believed that the original pre-project implementation load-shifting baseline model overestimated the recovery energy. Therefore, a new baseline model was required that could accurately predict the actual removed and recovered energy of the project.

The impact of the implemented project is shown in Figure 21 by comparing the electrical load profiles of two successive days, namely, 1 February 2016 when no DSM intervention took place and 2 February 2016 when the DSM intervention occurred.

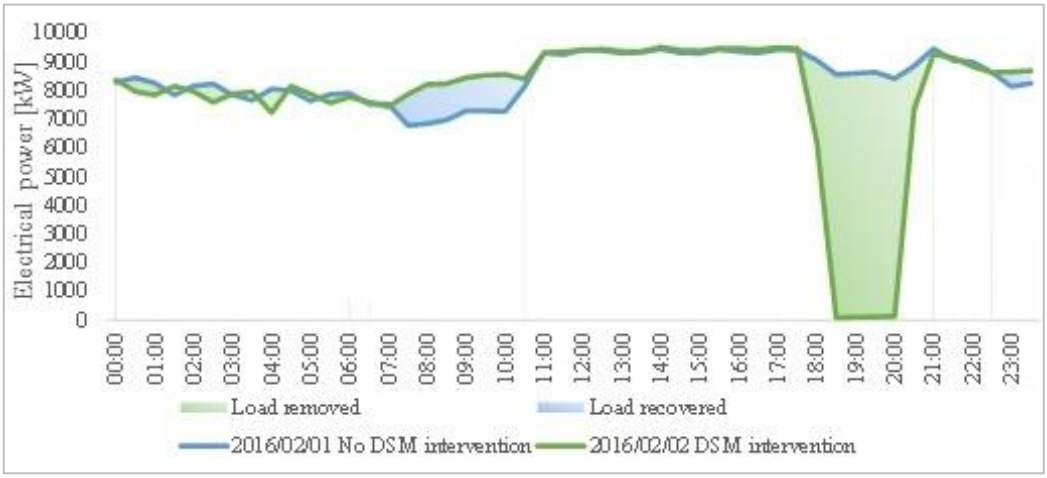


Figure 21: Direct electric power profile comparison

Direct comparison of days with similar environmental conditions allows for a quick and accurate analysis since there is no need for a baseline model to bring the days under the same set of operating conditions. These two successive days were selected for a preliminary assessment because of similar environmental and operational characteristics. For 1 February 2016, the average environmental dry-bulb temperature was 24.4°C with an average wet-bulb temperature of 17.3°C. For 2 February 2016, the average environmental dry-bulb temperature was 24.9°C with an average wet-bulb temperature 17.4°C.

If the original load-shifting model and the assumption of full-load recovery were correct, the recovery load, represented by the blue shaded areas in Figure 21, should have been notably larger. The load removed, represented by the green shaded area, is notably larger than the load recovered. Thus, it can be concluded that the project has a potential recovery load that is less than the load removed.

The focus of this chapter will firstly be on presenting and developing methods that can be used to quantify the recovery energy associated with a DSM project on a cooling system. The implementation of industry standard baseline models as well as the development of a suitable post-implementation assessment model will be presented. Furthermore, baseline evaluation techniques that can be used to calculate the accuracy of the presented models will be discussed and developed. The models will then be used and evaluated in Chapter 4. The purpose of the evaluation is to select the best model and use it for project performance reassessment.

3.2. Calculating the indirect electrical impact of a DSM intervention

As can be seen from the direct comparison in Figure 21, the implemented project has both peak-clipping and load-shifting characteristics since there is some recovery work present. As discussed, the indirect electrical impact of the DSM intervention, or recovery work, is however less than expected for a load-shifting project. To understand the need for additional or recovery work after the particular DSM intervention better, three cases will be considered and methods presented to calculate the possible additional work required.

Case 1: Simple closed-loop system with constant system performance parameters

Figure 22 shows a simple closed-loop cooling circuit with a fridge plant and a chilled dam. The system will be in equilibrium once the temperatures have stabilised, namely, when the natural heat flow from the environment into the chilled dam is equal to the heat removed by the fridge plant.

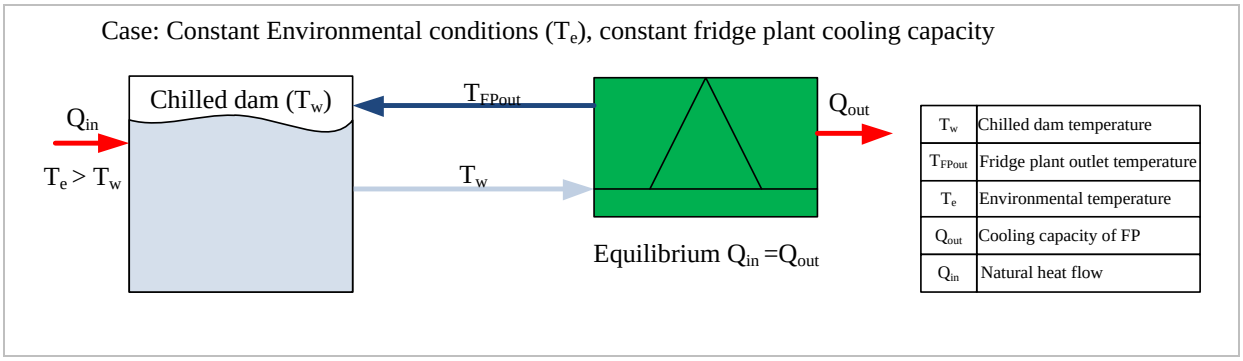


Figure 22: Simple closed-loop cooling circuit with constant capacity

The rate of environmental heat transfer is proportional to the difference between the environmental and chilled dam temperatures. Thus, if the chilled dam and environmental temperatures are the same, heat transfer ceases to occur.

The inlet temperature and cooling capacity of the fridge plant determine the fridge plant outlet temperature. For equilibrium conditions and constant capacity, the fridge plant outlet temperature is constant. The simple cooling capacity equation, Equation 6, can be used to define the water outlet temperature:

$$T_{FPout} = T_w - \frac{Q_{out}}{\dot{m}_{water} \times c_p}$$

Equation 21

Where:

T_{FPout}: fridge plant water outlet temperature [K]

T_w: fridge plant water inlet or chilled dam temperature [K]

Q_{out}: fridge plant maximum cooling capacity [kW]

$\dot{m}_{water}$: mass flow rate of water through fridge plant [kg/s]

c_p: specific heat of water at constant pressure [4.1885 kJ/kg.K]

When a fridge plant is switched off during a DSM intervention, the temperature of the chilled dam increases since $Q_{out} = 0$. This continues until the chilled dam temperature is equal to the environmental temperature, or when the environmental heat flow, shown as Q_{in} in Figure 22, ceases. The rate of the temperature increase depends on factors such as thermal resistance, or insulation level, and the absolute temperature difference between the environmental and cold well temperatures.

Figure 23 shows the effect of the DSM intervention on the fridge plant inlet water temperature by assuming a linear heat-transfer rate. The fridge plant inlet and outlet temperatures are stable at first, which is similar to the temperatures when no DSM intervention occurs. When the fridge plant is switched off, the temperature starts to rise in the chilled dam due to natural heat flow from the environment into the chilled dam. The heat flow continues until the chilled dam reaches the environmental temperature.

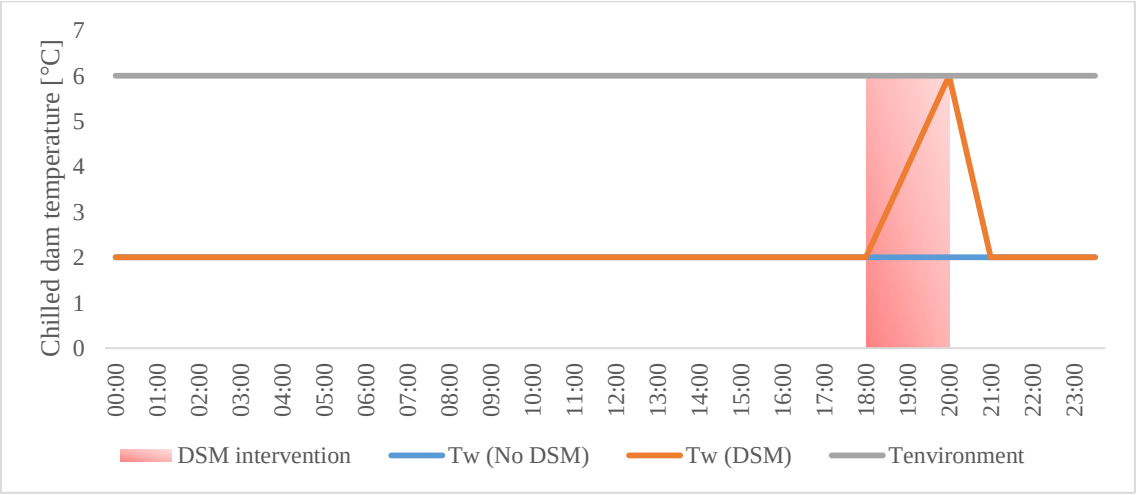


Figure 23: Simplified effect of DSM on fridge plant outlet temperature

Once the fridge plant is switched on again, the inlet temperature will be higher than prior to the intervention since the chilled dam water temperature has increased during the intervention. Since the ultimate cooling capacity of the fridge plant is fixed, the temperature of the chilled dam will not recover to its original temperature instantaneously. Therefore, it can be seen that the DSM intervention will have an effect not only during the intervention but afterwards as well.

The goal of the cooling system as discussed above, is to produce cold water that will be used by cooling auxiliaries such as BACs to produce a cooling effect. The system can be seen as a cold-water service delivery system. As noted, the ultimate water outlet temperature or service delivery of the system is affected not only during the DSM intervention but afterwards as well, as the temperature recovers to the pre-intervention stable value.

Therefore, with a peak-clipping project where the cooling plant is simply switched off with no additional cooling capacity supplied, the service level is lowered during the intervention period and directly afterwards until the thermal equilibrium is restored. The total potential thermal cooling capacity loss of the auxiliary cooling equipment, such as BACs, is therefore determined by the loss of cooling capacity during the intervention. In addition, there is a loss of cooling capacity due to the difference between the fridge plant water outlet temperatures prior to the intervention and up to the point where the temperatures have fully recovered. From the cooling capacity equation that is:

$$Q_{lost} = \dot{m}_{water} c_p (T_{DSM} - T_{NoDSM})$$

Equation 22

Where:

Q_{lost}: lost thermal cooling capacity [kW]
$\dot{m}_{water}$: mass flow rate of water through fridge plant [kg/s]
c_p: specific heat of water at constant pressure [4.1885 kJ/kg.K]
T_{DSM}: fridge plant outlet temperature if no DSM intervention occurred [°C]
T_{DSM}: fridge plant outlet temperature after DSM intervention [°C]

For an intervention that has a zero nett impact on service delivery or total cooling supplied, additional cooling capacity has to be supplied to negate the effect of the lost cooling capacity during and directly after the intervention.

Case 2: Simplified surface mine cooling system with excess capacity

However, a typical mine cooling circuit has excess installed cooling capacity. As discussed in Chapter 2, cooling capacity control is achieved with compressor guide vane and bypass valve control. When additional cooling capacity is available, the system utilises the maximum available cooling capacity to achieve its outlet temperature set point in the shortest possible time. The automated control system controls the compressor guide vane positions to provide maximum cooling capacity, or additional fridge plants can be started.

This implies that additional or recovery work is done by the fridge plant compressor after the DSM intervention, even if the intent of the project design is not to recover all the lost cooling capacity during the DSM intervention. The simplified surface mine cooling circuit in Figure 24 shows that warm water enters the system boundary from the PCT. Not all the cooling water remains in the system boundary as chilled water is delivered to the warm dam through the recirculation valve. The remainder is delivered to the cold dam.

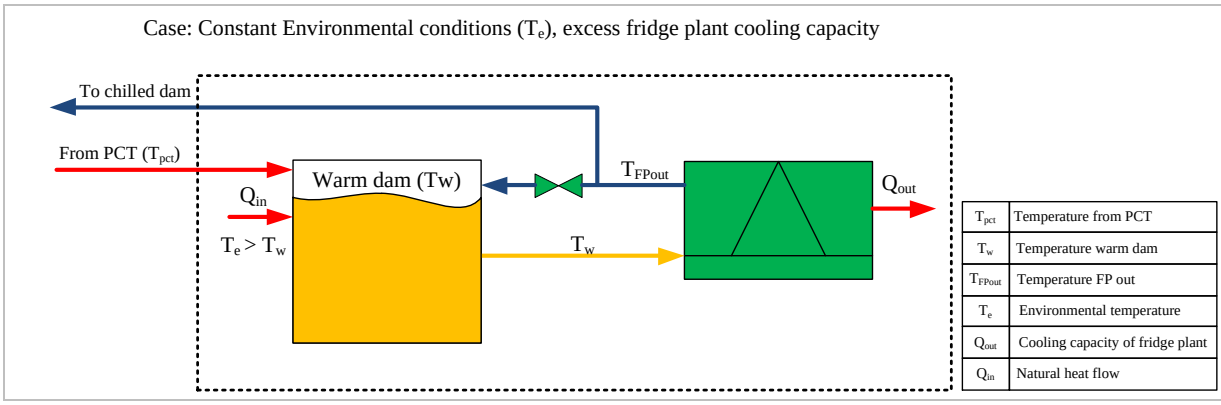


Figure 24: Simplified mine surface cooling cycle

Similar to the case for the cold dam in the simple closed-loop system, the temperature in the warm dam rises. The temperature rise is due to a lack of cold recirculation water being supplied, natural heat flow into the warm dam, and warm water being received from the PCT once the fridge plant is switched off.

The rate of the heat increase of the warm dam depends on the following:

- Temperature prior to the intervention ($T_{W\ (No\ DSM)}$);
- Temperature of water from the PCT (T_{pct});
- Environmental temperature (T_C);
- Water flow rate from the PCT;
- Size of the dam; and
- Thermal resistance of the dam.

Figure 25 shows the effect of a simplified linear heat rate increase in the warm dam, the constant outlet set point temperature, and the cooling capacity of the fridge plant. The blue shaded area represents the baseload thermal capacity required if no DSM intervention occurs. The red shaded area represents the additional capacity required to ensure that the fridge plant outlet temperatures before and after the DSM intervention remain constant.

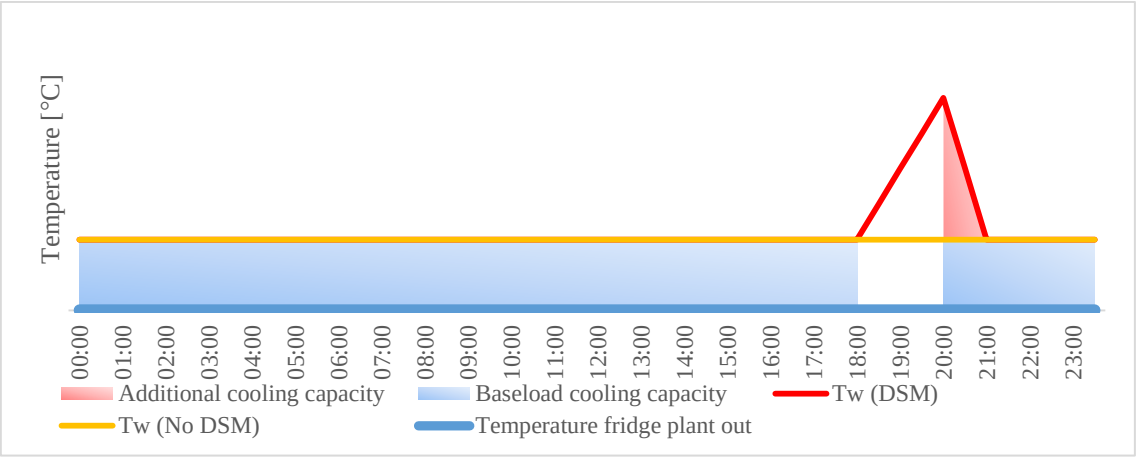


Figure 25: Additional cooling for mine cooling system

The total cooling capacity required can again be calculated with the cooling capacity equation and is dependent on the difference between the inlet and outlet temperatures of the fridge plant. If no DSM intervention occurred, the baseload thermal capacity required will remain constant. It is given by:

$$Q_{baseload} = \dot{m}_{water} \times c_p(T_{FPinlet(No\ DSM)} - T_{FPoutletSP})$$

Equation 23

Where:

$Q_{baseload}$:	thermal cooling capacity required with no DSM intervention [kW]
$\dot{m}_{water}$:	mass flow rate of water through fridge plant [kg/s]
c_p:	specific heat of water at constant pressure [4.1885 kJ/kg.K]
$T_{FPinlet(No\ DSM)}$:	fridge plant inlet temperature if no DSM intervention occurred [°C]
$T_{T_{FPoutletSP}}$:	fridge plant outlet temperature set point [°C]

The total thermal cooling capacity required to reach the set point after the intervention is the sum of the baseload and additional capacity. The additional capacity is given by:

$$Q_{additional} = \dot{m}_{water} \times c_p(T_{FPinlet(No\ DSM)} - T_{FPinlet(after\ DSM)})$$

Equation 24

Where:

$Q_{additional}$:	additional thermal cooling capacity required due to DSM [kW]
$\dot{m}_{water}$:	mass flow rate of water through fridge plant [kg/s]
c_p:	specific heat of water at constant pressure [4.1885 kJ/kg.K]
$T_{FPinlet(No\ DSM)}$:	fridge plant inlet temperature if no DSM intervention occurred [°C]
$T_{FPinlet(after\ DSM)}$:	fridge plant inlet temperature after DSM intervention occurred [°C]

Case 3: Actual surface mine cooling system

The actual mine cooling system with variable EGFs is, however, a dynamic system where the equilibrium fridge plant work and temperatures change throughout the day. The system also has limited excess capacity, and fridge plants have a transient start-up period. During this period, the COP of the plant increases from zero to its stable value. Only then can the fridge plant deliver the maximum cooling effect.

Therefore, during the transient start-up period, the warm dam receives water that is warmer than it was prior to the intervention. The warm water is received from BACs and from the warm fridge plant outlet recirculation valve. Thus, the temperature of the warm well will increase during and after the DSM intervention. The typical actual system response due to the DSM intervention will therefore be different than the fixed conditions in Case 2. The daily inlet temperatures typically decrease during the evening. This is due to cooler water being received from the PCTs and a possible higher COP of the fridge plant due to environmental operating temperatures.

In Figure 26, the blue shaded area represents the actual baseload thermal capacity. The additional cooling requirement therefore would be underestimated if constant inlet conditions were assumed as indicated by the dashed red line.

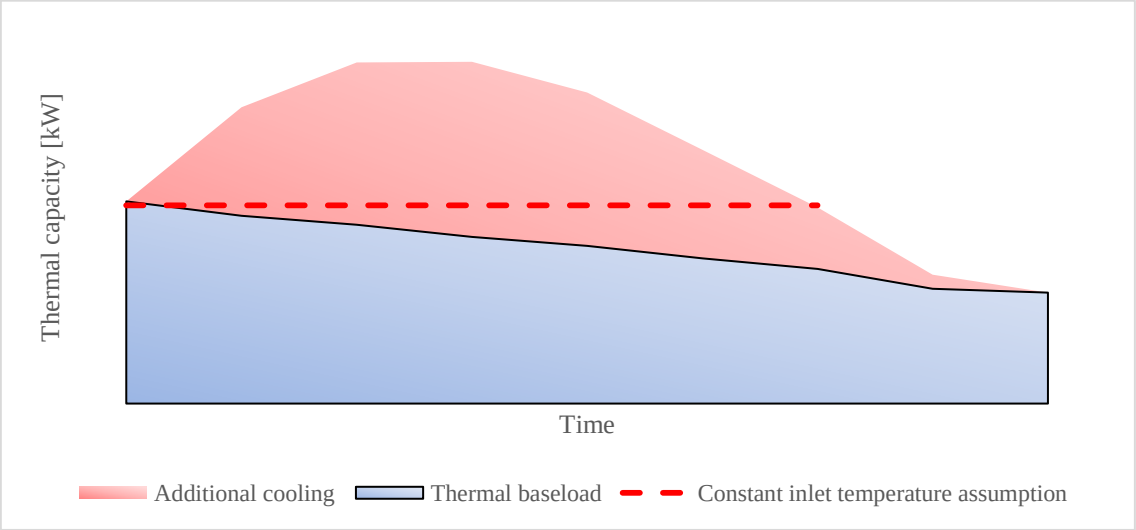


Figure 26: Actual system response due to DSM intervention

To calculate the actual baseload and additional cooling capacities, the fridge plant inlet temperature if no DSM intervention occurred would have to be known. To calculate what the fridge plant inlet temperature "would have been", a cooling system model will be required since the inlet temperature will be dependent on environmental, operational and other

parameters. An overestimation of the additional capacity requirement can, however, be calculated by assuming that the inlet temperature to the fridge plant is equal to the daily minimum. The larger red shaded area above the 'minimum inlet assumption' line in Figure 27 shows the effect of the assumption.

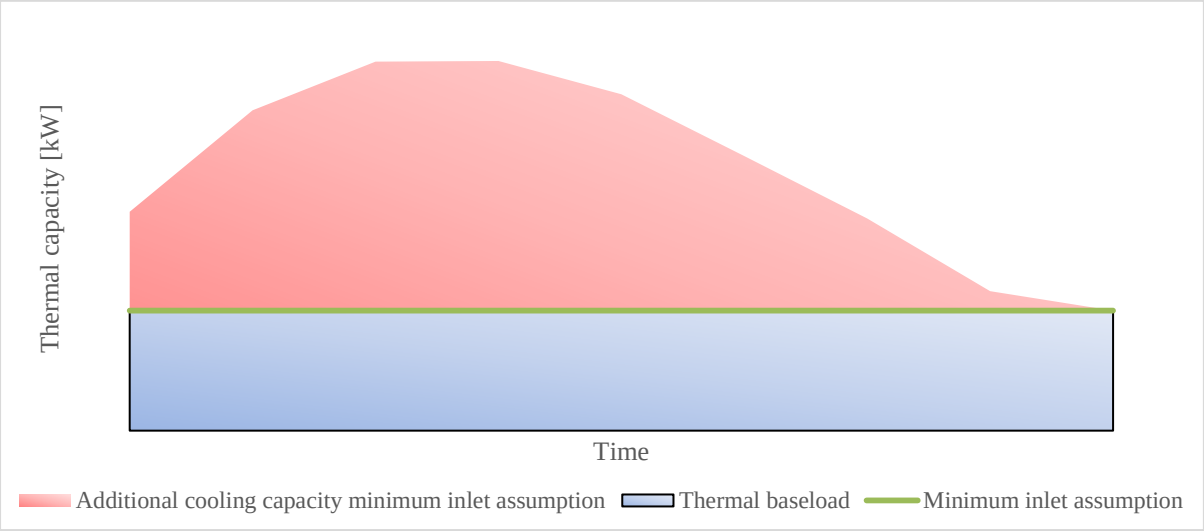


Figure 27: Additional work minimum inlet assumption

The overestimated additional capacity requirement is given by:

$$\boldsymbol{Q_{over} = \dot{m}_{water} \times c_p(T_{inlet} - T_{inletmin})}$$

Equation 25

Where:

Q_{over}:	overestimated additional cooling capacity required due to DSM [kW]
$\dot{m}$:	mass flow rate of water through fridge plant [kg/s]
c_p:	specific heat of water at constant pressure [4.1855 kJ/kg.K]
T_{inlet}:	evaporator water inlet temperature [°C]
$T_{inletmin}$:	minimum evaporator water inlet temperature [°C]

Since power is the rate of doing work, the area underneath the cooling capacity graph will be the cooling work and can be calculated at each point as follows:

$$q_{inst} = Q\ \Delta t$$

Equation 26

Where:

q_{inst}:	instantaneous additional cooling work [kJ]
Q:	additional cooling capacity [kW]
Δt:	data-sampling rate [s]

The total additional work or potential lost cooling work can be obtained by totalling the work at every data point:

$$q_{Total} = \sum q_{inst}$$

Equation 27

The total electrical energy input to perform the recovery work can then be calculated by the COP equation as:

$$E_{AE} = \frac{q_{Total}}{COP}$$

Equation 28

Where:

E_{AE}: total additional electrical energy used due to DSM [kJ]

q_{Total}: total additional thermal energy used due to DSM [kJ]

COP: coefficient of performance of fridge plant

Note: Electrical energy consumption is billed in kWh. To compare the billed data with Equation 28, kJ has to be converted to kWh:

$$1kWh = 3600\ kJ$$

Equation 29

3.3. Measuring the baseline period

The DSM project at Mine A is analysed and classified per the M&V Option B (retrofit isolation with all-parameter measurement) guidelines set in the SANS 50010:2011 and IPMVP. The measurement boundary is drawn around the surface cooling system since the M&V activities focus on a sub-system of the mine, namely, the surface cooling plant.

When selecting baseline measurement periods, care has to be taken to ensure that all pre-implementation operating modes and most recent unaffected data in the measurement period are selected. Baseline development has to consider factors such as project implementation date, evaluation timeline, seasonal cooling requirements, electricity demand season, production days, maintenance days and weekend electricity rate structures.

Baseline period data can be obtained from supervisory control and data acquisition (SCADA) systems, which are typically employed at large industrial sites for real-time data collection and system control. Data can also be obtained from other independent data sources.

Communication with machinery and system components are made through connections with programmable logic controllers (PLCs).

The SCADA system uses the data from the PLCs to monitor the instrumentation, control certain components, display trends and store data from selected data points. Control and monitoring of the entire mining operation can be managed from a single dedicated control room.

3.4. Developing the baseline model

To determine the impact of using different baseline models for the DSM project at Mine A, multiple baselines models are developed, evaluated and compared. The constant, energy-neutral, single-parameter regression, and theoretical scaled baseline models are investigated.

3.4.1. The constant baseline model

The constant baseline model can be developed directly from Equation 14. The model is inadvertently developed in the baseline development phase. The major advantage and disadvantage of the model is its simplicity. The model allows for quick and easy comparisons by directly comparing data. However, this could result in invalid conclusions being drawn regarding the project's performance since no adjustments are made to the baseline period energy use to consider factors such as seasonal variations.

3.4.2. Energy-neutral baseline models

As previously noted, energy-neutral baseline models preserve the baseline shape but adjust the amplitude of the baseline profile using a scaling factor. The scaling factor is calculated by selecting a time period when it is deemed that the particular DSM intervention has no effect. The energy use during this period is represented by the area under the power profile and is used to scale the rest of the baseline power profile.

The first step is selecting a reference energy consumption or area under the system power profile graph. This area can range from one hour to an entire 24-hour day for a "pure load-shifting" project because it is assumed that the nett energy reduction is zero for a load-shifting project. Subsequently three different energy-neutral baselines models will be developed each with different assumptions, and time period selection, for calculating the scaling factor.

Load-shifting (system) baseline model

The load-shifting (system) baseline model, hereafter referred to as the LS (system) baseline model, is an energy-neutral model that uses a 24-hour scaling area for the entire system, including fridge plants and all cooling auxiliaries, to determine the adjusted baseline:

$$LS[h] = BPEU_{SYSTEM}[h] \times \frac{\sum_0^{23} A\,[h]}{\sum_0^{23} B\,[h]}$$

Equation 30

Where:

LS:	LS (system) model adjusted baseline period energy use [kWh]
h:	hour of the day
$BPEU_{SYSTEM}$:	measured baseline period energy use [kWh]
A:	actual hourly average power use [kW]
B:	baseline hourly average power use [kW]

Energy-neutral (system) baseline model

Similarly, the energy-neutral baseline model, hereafter referred to as the EN (system) baseline model, uses a selected scaling area, or time period, where the DSM intervention is deemed to have no effect on the entire system, including fridge plants and all cooling auxiliaries, to determine the adjusted baseline:

$$EN[h] = BPEU[h] \times \frac{\sum_X^Y A_{SYSTEM}\,[h]}{\sum_X^Y B_{SYSTEM}\,[h]}$$

Equation 31

Where:

EN:	EN (system) model adjusted baseline period energy use [kWh]
h:	hour of the day
$BPEU_{SYSTEM}$:	measured baseline period energy use [kWh]
A_{SYSTEM}:	actual hourly average system power use [kW]
B_{SYSTEM}:	baseline hourly average system power use [kW]
X:	initial hour where the DSM intervention has no effect
Y:	final hour where the DSM intervention has no effect

Load-shifting (fridge plant) and energy-neutral (cooling auxiliaries) baseline model

This model, hereafter referred to as LS (FP) & EN (CA), considers some of the physical limitations of the project at Mine A. The LS (system) model assumes that the cooling auxiliaries can somehow recover the work removed during the DSM intervention. This is, however, impossible since there is only a fixed amount of installed cooling auxiliary equipment capacity.

Furthermore, there are no flow-altering devices that can cut backflow during the rest of the day; hence the EGFs for the cooling auxiliaries from Equation 7 to Equation 10 are not altered.

$$EN_2[h] = BPEU_{CA}[h] \times \frac{\sum_X^Y A_{CA}[h]}{\sum_X^Y B_{CA}[h]} + BPEU_{FP} \times \frac{\sum_0^{24} A_{FP}[h]}{\sum_0^{24} B_{FP}[h]}$$

Equation 32

Where:

EN_2:	LS (FP) & EN (CA) model adjusted baseline period energy use [kWh]
h:	hour of the day
$BPEU_{CA}$:	baseline period energy use of all cooling auxiliaries [kWh]
A_{CA}	actual hourly average power use of cooling auxiliary [kW]
B_{CA}	baseline hourly average power use of cooling auxiliary [kW]
$BPEU_{FP}$:	baseline period energy use of the fridge plant [kWh]
A_{FP}	actual hourly average power use of fridge plant [kW]
B_{FP}	baseline hourly average power use of fridge plant [kW]

3.4.3. The single variable regression baseline model

The regression baseline model uses a scaling factor for baseline amplitude adjustment similar to the energy-neutral models. However, the scaling ratio is determined from a regression analysis, and the ratio between the predicted daily average power consumption from a regression analysis to the baseline period average daily consumption, that is:

$$RMPEU_{FP} = \frac{C_{dM}}{C_{dB}} \times B_{PEU}$$

Equation 33

Where:

$RMPEU_{FP}$: regression model adjusted baseline period energy use of fridge plant [kWh]

C_{dM}: predicted average daily consumption [kWh]

C_{dB}: average baseline period daily consumption [kWh]

B_{PEU}: baseline period energy use of fridge plant [kWh]

The regression analysis can now be done between an independent system variable and the daily average power consumption (as per Chapter 2). The analysis will be done with the independent system variable being either the average daily wet-bulb or dry-bulb temperature, with the daily fridge plant power consumption being the dependent variable.

$$C_{dM} = F(T)$$

Equation 34

Where:

C_{dM}: predicted average daily fridge plant consumption [kWh]

F: function determined by regression analysis

T: daily average wet-bulb or dry-bulb temperature [°C]

3.4.4. Theoretical scaled baseline model

In this section, a theoretical scaled baseline model (TSM) is developed that should be simple enough to use for post-project implementation analysis. The TSM uses a scaling factor for baseline amplitude adjustment, similar to the energy-neutral models, however, the scaling ratio is based on the theoretical ideal fridge plant consumption.

$$TSM_{FP} = SR \times BPEU_{FP}$$

Equation 35

Where:

TSM_{FP}: TSM adjusted baseline period energy use of fridge plant [kWh]

SR: theoretical scaling ratio

$BPEU_{FP}$: baseline period energy use of fridge plant [kWh]

According to the second law of thermodynamics there are no other cooling cycles, or a combination of cooling cycles, that can operate at a higher efficiency than the simple Carnot cycle operating between given high and low-temperature reservoirs. The ideal scaling ratio will therefore be defined as the ratio of the actual ideal fridge plant electric power to the baseline period ideal fridge plant power:

$$SR_{ideal} = \frac{APEU_{ELECideal}}{BPEU_{ELECideal}}$$

Equation 36

Where:

SR_{ideal}: ideal scaling ratio

$APEU_{ELECideal}$: actual period fridge plant ideal electric power [kW]

$BPEU_{ELECideal}$: baseline period electric power [kW]

By combining the heat load and Carnot COP equations, the ideal refrigeration compressor electric power is given by:

$$APEU_{ELECideal} = \frac{\dot{m}_{water} \times c_p \times \Delta T}{COP_{CARNOT[SP]}}$$

Equation 37

Where:

$APEU_{ELECideal}$: actual period fridge plant ideal electric power [kW]

$\dot{m}_{water}$: cooling water flow [kg/s]

c_p: specific heat of water at constant pressure [4.1855 kJ/kg.K]

ΔT: difference between outlet and inlet temperature [°C]

$COP_{CARNOT[SP]}$: ideal Carnot fridge plant COP of the specific period

Substituting Equation 36 into Equation 37 gives:

$$SR_{ideal} = \frac{\dot{m}_A \Delta T_A}{\dot{m}_B \Delta T_B} \times \frac{COP_B}{COP_A}$$

Equation 38

The ultimate cooling capacity of the system will be a function of the PCT outlet temperature, fridge plant evaporator outlet temperature, and fridge plant condenser (or CCT inlet) temperature. Equation 38 simplifies to:

$$SR_{ideal} = \frac{\dot{m}_b (T_{evapIN(A)} - T_{evapOUT(A)})}{\dot{m}_a (T_{evapIN(B)} - T_{evapOUT(B)})} \times \frac{T_{evapOUT(B)}}{T_{evapOUT(A)}} \times \frac{(T_{CCT(A)} - T_{evapOUT(A)})}{(T_{CCT(B)} - T_{evapOUT(B)})}$$

Equation 39

Where:

SR_{ideal}: ideal scaling ratio

$\dot{m}_b$: baseline mass flow rate of cooling water through plant [kg/s]

$T_{evapIN(A)}$: actual fridge plant inlet temperature [K]

$T_{evapOUT(A)}$: actual fridge plant outlet temperature [K]

$\dot{m}_a$: actual mass flow rate of cooling water through plant [kg/s]

$T_{evapIN(B)}$: baseline fridge plant inlet temperature [K]

$T_{evapOUT(B)}$: baseline fridge plant outlet temperature [K]

$T_{CCT(A)}$: actual condensing cooling water inlet temperature [K]

$T_{CCT(A)}$: baseline condensing cooling water inlet temperature [K]

When developing a model, it is important to consider which parameters are affected by the intervention. Since the mass flow, temperature of the recirculated water, water from the BACs, and fridge plant outlet water temperatures are affected by this specific DSM intervention, these parameters cannot be used directly in the model.

It is important to use unaffected baseline values in Equation 39. For example, if the mass flow rate is changed as a direct consequence of a particular intervention, it would not help using the mass flow rate in a ratio to calculate the pre-implementation adjusted baseline. Similarly, if the DSM intervention specifically changes the service delivery ($T_{evapOUT}$), then the pre-implemented values have to be used.

3.4.5. Total system power for regression and theoretically scaled fridge plant models

The total system power is the sum of the fridge plants and the cooling auxiliaries (PCT, CCT and BAC pumps and fans, and evaporator pumps):

$$APEU_{system} = ABPEU_{FP} + APEU_{CA}$$

Equation 40

Where:

$APEU_{system}$: adjusted system baseline period energy use [kWh]

$ABPEU_{FP}$: adjusted baseline period energy use predicted by the regression baseline model or the TSM for the fridge plant [kWh]

$APEU_{CA}$: baseline period adjusted cooling auxiliary energy use [kWh]

As was discussed for the LS (FP) & EN (CA) model the performance of the cooling auxiliaries can be estimated by an energy-neutral baseline and is given by:

$$ABPEU_{CA}[h] = BPEU_{CA}[h] \times \frac{\sum_X^Y A_{CA}[h]}{\sum_X^Y B_{CA}[h]}$$

Equation 41

Where:

$APEU_{CA}$:	baseline period adjusted cooling auxiliary energy use [kWh]
h:	hour of the day
$BPEU_{CA}$:	baseline period energy use of all cooling auxiliaries [kWh]
A_{CA}	actual hourly average power use of cooling auxiliary [kW]
B_{CA}	baseline hourly average power use of cooling auxiliary [kW]

3.5. Evaluating the baseline model

The results calculated by the baseline model will never be 100% accurate since each of the models make certain assumptions regarding the operational characteristics of the system in question. The basic baseline model evaluation procedure requires that the power data predicted by the model is compared with the actual baseline period data.

3.5.1. Using recovery energy for baseline model evaluation

If a baseline model estimates a recovery load that is more than the actual recovery load, the baseline model will underestimate the actual impact of the project since the scaled baseline will be shifted down. Similarly, if the model underestimates the recovery load, the impact of the DSM intervention will be overestimated.

If there is a quantifiable model-independent method for determining the recovered or removed energy, then it can be used to evaluate the accuracy of the model:

$$E_m = \frac{RE_{actual} - RE_{model}}{RE_{actual}}$$

Equation 42

Where:

E_m:	percentage error in the model's recovery energy
RE_{actual}:	actual removed energy [kWh]
RE_{model}:	model removed energy [kWh]

Since energy-neutral models use actual power data from the performance assessment period, the baseline and baseline model data cannot be compared directly since they are dependent on each other. In the case of the load-shifting model with a 24-hour scaling area, the error calculated with Equation 16 will always be zero since the model assumes that the nett power consumption is constant.

It has already been noted that SANS 50010:2011 does not require an exact quantification of uncertainty. It only requires that a lower saving cannot be calculated by a more accurate or rigorous M&V process.

It has also been shown that an overestimation of the removed energy for cooling projects can be calculated with the lost-cooling effect. Therefore, the various models' nett removed energy can be directly compared and evaluated.

3.5.2. Evaluating independent models

It is simpler to evaluate models that are not dependent on current energy data than it is to evaluate energy-neutral models. Direct comparison of calculated and actual data during the baseline period thus gives:

$$Error = \frac{D_{actualBP} - D_{modelBP}}{D_{actualBP}} \quad \textbf{(43)}$$

Where:

$Error$: error of a calculated energy data point [%]

$D_{actualBP}$: actual measured energy data point in the baseline period [kW]

$D_{modelBP}$: calculated energy from the baseline model in the baseline period [kW]

Note: For the constant baseline model, there is an error since the model does not consider the effects that varying environmental and operational parameters have on the energy consumption of the system. The calculated error, for the constant baseline, should therefore be interpreted as a potential error obtained rather than an actual error.

3.6. Conclusion

The chapter started by showing that additional work is performed by fridge plants after a DSM intervention at Mine A due to excess capacity and the increase of fridge plant inlet temperatures. Various baseline models and model evaluation techniques were presented for the DSM project at Mine A.

The estimated additional fridge plant work, or temperature recovery work, will be used to evaluate the accuracy of models in the following section. Direct evaluation of the performance-independent models was presented. This can be used to evaluate the accuracy of the constant, single-parameter regression and TSM models.

In the following chapter, these models will be used and evaluated on a specific case study at Mine A where it was suspected that a new post-implementation baseline model was required due to changes in the original project. The financial and M&V risks associated with using different models will be investigated for the specific project. Furthermore, the TSM will be compared with the verified savings achieved by other surface mine cooling DSM projects.

CHAPTER 4: PRACTICAL APPLICATION AND EVALUATION OF DEVELOPED BASELINE MODELS



[4]

[4] R.S. van As – personal photo taken of cold and hot water storage dams at Mine A

4.1. Introduction

In this chapter, the models developed for the case study at Mine A will be implemented. The models adjust the baseline data and hence the baselines are developed first. From the adjusted baselines, the specific model's predicted project impact can be determined by comparing the predicted performance from the various adjusted baselines with the actual recorded performance of the project.

The various baselines models developed for the case study at Mine A will be evaluated and a baseline model will be selected. Furthermore, the newly developed TSM will be applied and evaluated on two different mine surface cooling systems.

4.2. Case Study 1: Mine A

In this chapter, the models developed in Chapter 3 will be used and evaluated for the case study at Mine A, where it was suspected that a new post-implementation baseline model was required due to changes in the original project.

4.2.1. System baselines

The project at Mine A is funded by Eskom using the standard EPC for DSM projects. Performance-based payments are made to the ESCO for weekday reductions in three-month intervals for a total contract duration of three years [51]. The assessment periods will therefore be selected to coincide with the start of the assessment period as per the Eskom EPC. At the time of writing, only two three-month performance assessment periods had been completed – Performance Assessment 1 (PA1) from March to May 2016, and Performance Assessment 2 (PA2) from June to August 2016. Therefore, only these months will be considered in this study. Table 6 shows a summary of the baseline and performance assessment periods.

Table 6: Baseline and performance assessment periods

Period	Eskom demand season	EPC assessment period	Baseline	Performance assessment
March–May	Low	PA1	2015	2016–2018
June–August	High	PA2	2015	2016–2018

Figure 28 shows the two assessment periods in the developed weekday baselines for Mine A. The two baselines show distinct operating modes for the two assessment periods. These operating modes are due to changes in the summer and winter operation of the surface

cooling system (the complete baselines are shown in Figure 41through Figure 44 included in Appendix B).

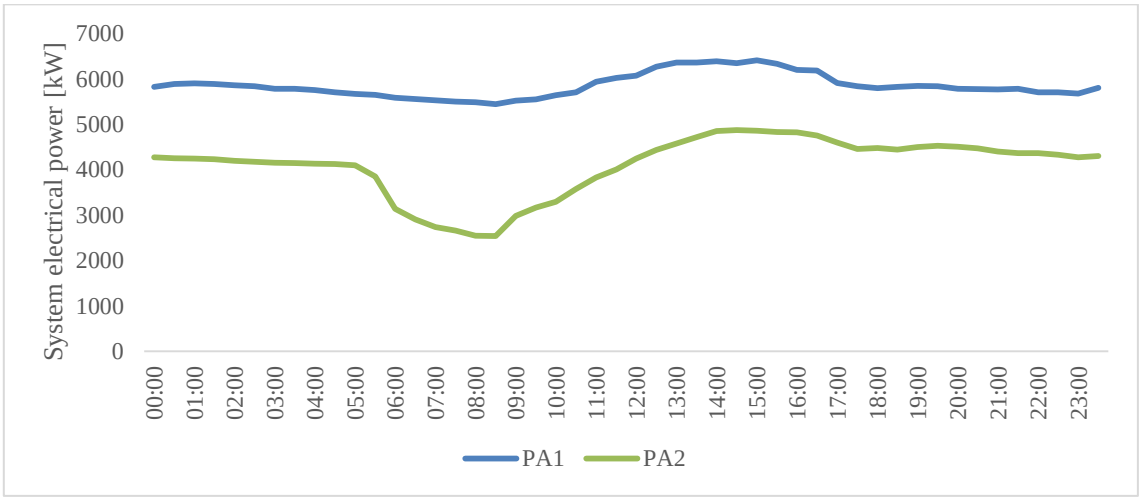


Figure 28: Weekday system baselines for Mine A

4.2.2. System baseline models

The developed baselines can now be adjusted in the baseline model development phase to ultimately determine the project impact. The calculated adjusted baselines for PA1 are shown in Figure 29.

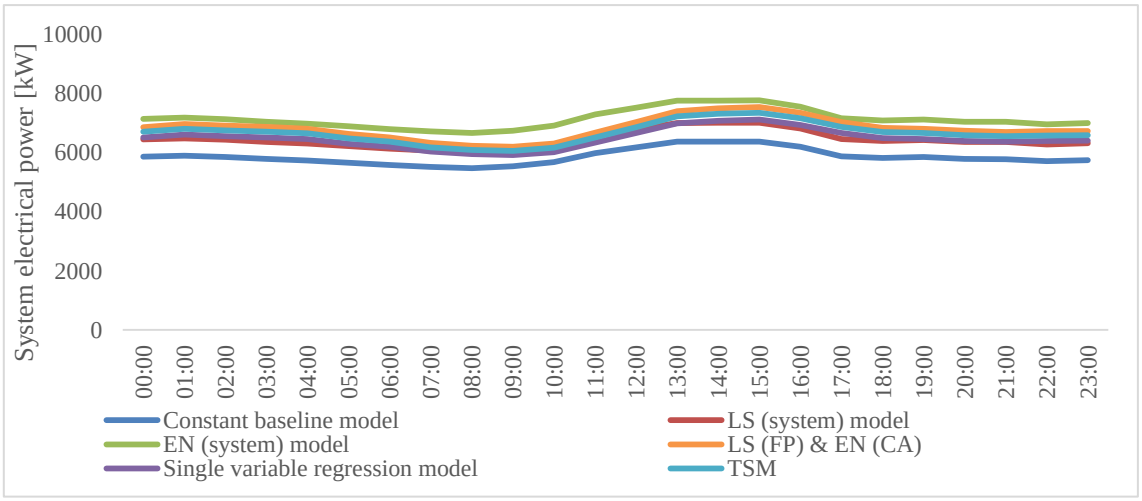


Figure 29: System baseline models for PA1

Figure 29 shows a notable variance in the amplitudes of the calculated models. Thus, baseline model selection will have an associated financial implication when the impact of the project is calculated from the difference between the actual and adjusted baseline profiles.

Similarly, the calculated adjusted baselines for PA2 are shown in Figure 30. The absolute maximum amplitude of the various models is much lower than that for PA2. However, due to the associated high electricity costs during the Eskom high-demand season, there is still a

possible large financial implication associated with model selection, even with the lower cooling demand in winter.

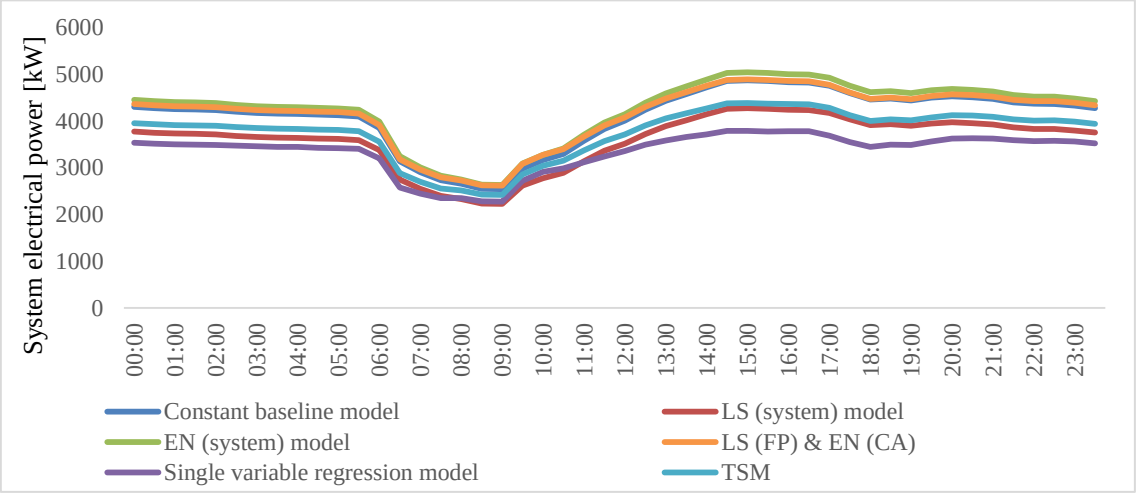


Figure 30: System baseline models for PA2

4.2.3 Actual project performance power profiles

The DSM intervention can clearly be seen from the actual average 24-hour weekday power data for PA1 and PA2 in Figure 31. The evening peak intervention for PA1 corresponds to the Eskom peak TOU electricity cost period during the low-demand season, which is from 18:00 to 20:00. For the PA2 period, both a morning (06:00–09:00) and an evening (17:00–19:00) intervention were carried out due to the high electricity costs and favourable climatic conditions during the high-demand season.

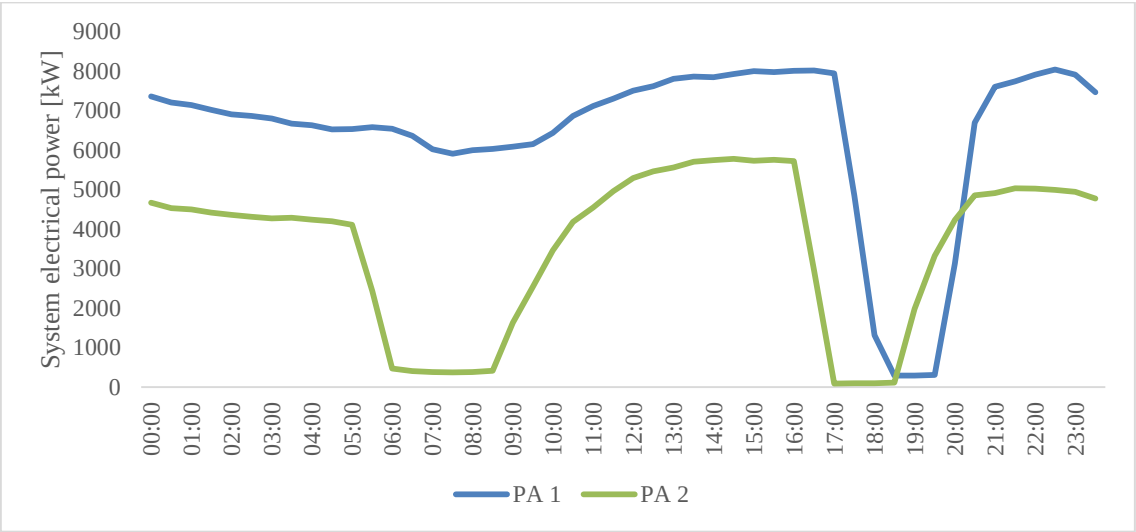


Figure 31: Average power data for PA1 and PA2

4.2.3. Project impact assessment

The performance of the project can now be calculated from the adjusted baselines and the actual performance for PA1 and PA2 (the predicted impact of using the various models are shown in Figure 45 through Figure 58 included in Appendix B).

Summary of project impact for PA1

A summary of PA1 is shown in Table 7. As can be seen, there is a large variation in the average reported values. This will ultimately affect the reported financial impact and continued feasibility and success of the project.

Table 7: PA1 summary

PA1	Average evening peak reduction [kW]	Average daily consumption decrease [kWh]
Constant baseline model	5 281.37	−13 986.50
LS (system) model	5 861.44	N/A
EN (system) model	6 551.60	16 641.30
LS (FP) & EN (CA)	6 274.69	9 135.26
Single variable regression model	5 923.73	766.08
TSM	6 125.68	5 315.65

Summary of project impact for PA2

The summary of PA2 is shown in Table 8. As can be seen, there is a large variation in the average reported values. With the high seasonal electricity costs during PA2, this could ultimately have a large impact on the reported financial impact and continued feasibility and success of the project.

Table 8: PA2 summary

PA2	Average morning peak reduction [kW]	Average evening peak reduction [kW]	Average daily consumption decrease [kWh]
Constant baseline model	2 568.83	4 477.32	12 032.92
LS (system) model	2 204.48	3 916.56	N/A
EN (system) model	2 673.44	4 235.50	15 487.70
LS (FP) & EN (CA)	2 629.55	4 494.96	13 328.59
Single variable regression model	2 131.75	3 446.45	−5 754.39
TSM	2 369.41	4 015.89	2 016.22

Summary of reported financial impact

One of the ultimate goals of the DSM project from the client's perspective is saving money. The continued success of a project and the willingness of all parties involved to maintain a project will be dependent on the perceived nett positive monetary impact of the project. The calculated monetary project impacts for PA1 and PA2 are shown in Figure 32. (the average daily calculated financial savings are shown in Table 24 through Table 35 included in Appendix B).

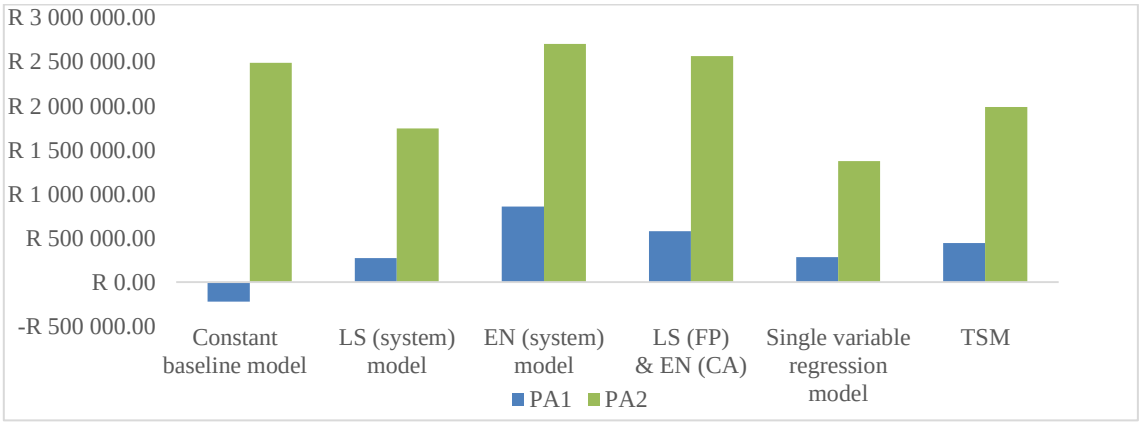


Figure 32: Reported direct financial savings of various models for PA1 and PA2

There is a large disparity in the savings reported with the different models. Furthermore, even with a reduced cooling requirement in the low-demand season, the financial impact of the project is much larger than in the high-demand season due to morning and evening peak interventions and the large variation in seasonal electricity costs.

As was noted the original baseline model accepted for Case Study 1 was the LS (system) model. Table 9 summarises the potential daily difference in the reported project impact for the various developed models for PA1.

Table 9: Daily difference for reported project impact PA1

PA1	Additional daily cost decrease [ZAR]	Unclaimed daily consumption decrease [kWh]
Constant baseline model	-R 7 456.40	−13 986.50
EN (system) model	R 8 871.56	16 641.30
LS (FP) & EN (CA)	R 4 632.41	9 135.26
Single variable regression model	R 203.38	766.08
TSM	R 2 624.30	5 315.65

Similarly Table 10 summarises the potential daily difference in the reported project impact for the various developed models for PA2.

Table 10: Daily difference for reported project impact PA2

PA2	Additional daily cost decrease [ZAR]	Unclaimed daily consumption decrease [kWh]
Constant baseline model	R 11 289.62	12 032.92
EN (system) model	R 14 530.99	15 487.70
LS (FP) & EN (CA)	R 12 454.06	13 328.59
Single variable regression model	-R 5 640.88	−5 754.39
TSM	R 3 669.39	2 016.22

4.2.4. Quantifying the indirect DSM related electrical impact

The additional electrical energy used due to the additional thermal capacity requirement after the DSM intervention will be calculated in this section, as per Section 3.5. The electrical energy removed and recovered predicted by the various models will be compared with the electrical energy used due to the calculated additional thermal capacity requirements to aid in accuracy assessment and model selection.

As was noted in Section 3.5, the additional work calculated with the minimum inlet assumption will be an overestimation. An alternative to the minimum inlet temperature assumption is to use baseline period data for the inlet temperature. The use of baseline period fridge plant inlet temperature data will provide an insight into the possible extent of this overestimation and will also be presented.

The calculated additional work, with the baseline inlet temperature assumption, should however not be used for model evaluation since actual inlet temperature will be dependent on the assessment period EGFs such as environmental conditions, PCT outlet temperature and fridge plant performance (additional details of the thermal performance and additional work calculations are shown in Figure 59 through Figure 64 included in Appendix B).

The additional electrical capacity required, for each of the inlet temperature assumptions, due to the additional cooling requirement for PA1 is shown in Figure 33. The total electrical energy is represented by the area under the corresponding power graph (the calculated additional energy requirement is notably larger for the overestimated minimum inlet assumption).

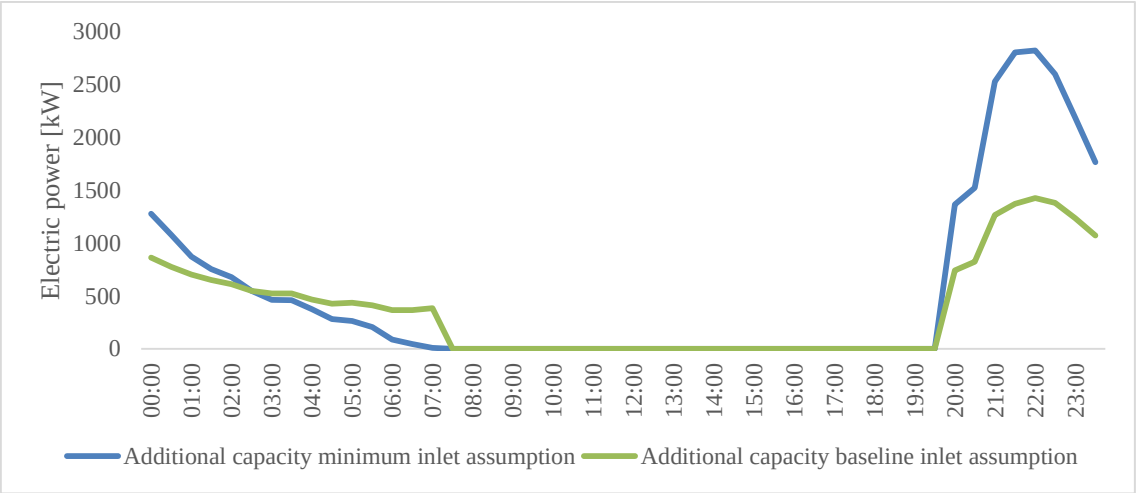


Figure 33: Additional electric power requirement for PA1

Similarly, for PA2, the additional electrical capacity required due to the additional cooling requirement is shown in Figure 34.

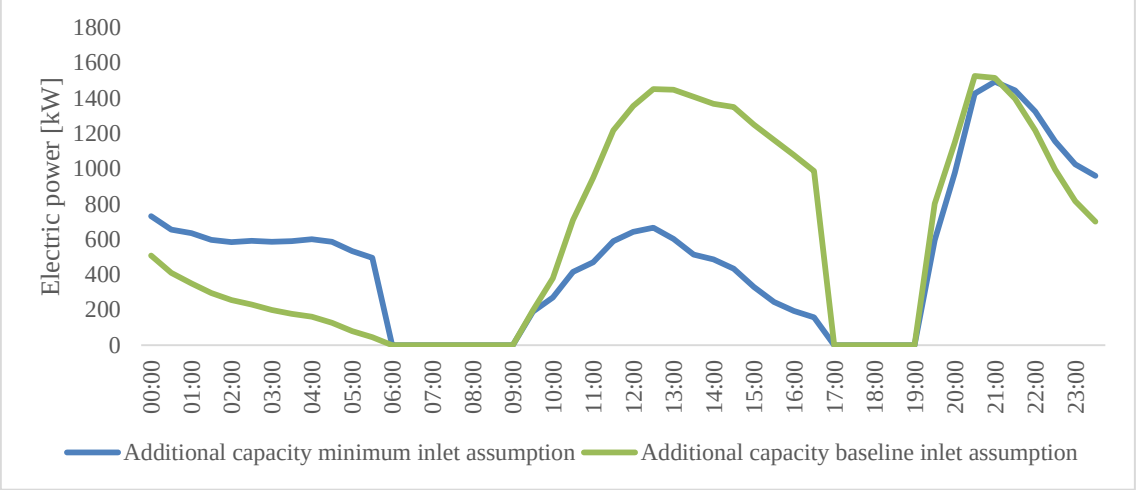


Figure 34: Additional electric power requirement for PA2

The difference in the calculated additional energy with the two assumptions follow the same trends during certain periods of the day. This is because there are two interventions for PA2, therefore the system reaches its minimum temperature for fewer hours per day. In effect, more time is spent in the "temperature recovery" stage in PA2 and the overestimation will be less pronounced since the system reaches its minimum temperature for fewer hours per day.

4.2.5. Recovery energy evaluation of baseline models

Table 11 shows that for PA1, the constant, LS (system) and Single variable regression baseline models overestimate the recovery energy calculated with the minimum daily inlet temperature assumption. It can therefore be concluded that conservative savings reporting will be guaranteed.

Table 11: Baseline model evaluation using calculated recovery energy (minimum inlet temp. assumption) for PA1

Model	Constant Baseline	LS (System)	LS (FP) & EN (CA)	EN (System)	Single variable Regression	TSM
Recovery energy [kWh]	25 547.30	14 248.10	7 426.32	3 825.93	13 090.70	9 980.32
Calculated recovery energy [kWh]	12 444.78	12 444.78	12 444.78	12 444.78	12 444.78	12 444.78
Error [%]	105.29	14.49	−40.33	−69.26	5.19	−19.80
Estimation of recovery energy (minimum inlet assumption)	Over	Over	Under	Under	Over	Under
Possible estimation of impact: under- or overestimation	Under	Under	Over	Over	Under	Over

Although it has been shown that the additional work calculated with the minimum inlet temperature assumption will be an overestimation, it is not guaranteed that the other models will report an overestimated saving.

Table 12 shows that the reported savings of the constant, LS (FP) & EN (CA), EN (system) and TSM baseline models could potentially still be valid. However, when compared with the baseline inlet temperature assumption, there is a greater risk that these models could be invalidated by a more accurate or rigorous M&V processes.

Table 12: Baseline model evaluation using calculated recovery energy (baseline assumption) for PA1

Model	Constant Baseline	LS (System)	LS (FP) & EN (CA)	EN (System)	Single variable Regression	TSM
Recovery energy [kWh]	25 547.30	14 248.10	7 426.32	3 825.93	13 090.70	9 980.32
Baseline calculated recovery energy [kWh]	3 575.09	3 575.09	3 575.09	3 575.09	3 575.09	3 575.09
Error [%]	614.59	298.54	107.72	7.02	266.16	179.16
Estimation of recovery energy (baseline assumption)	Over	Over	Over	Over	Over	Over
Possible estimation of impact: under- or overestimation	Under	Under	Under	Under	Under	Under

Similarly, the estimated additional work using the minimum inlet temperature assumption for PA2 was compared and it was found that the LS (system), Single variable regression, and TSM baseline models overestimated the recovery energy calculated with this assumption (see Table 13). It can therefore be concluded that the reporting of the conservative savings for these models will be guaranteed.

Table 13: Baseline model evaluation using calculated recovery energy (minimum inlet temp. assumption) for PA2

Model	Constant Baseline	LS (System)	LS (FP) & EN (CA)	EN (System)	Single variable regression	TSM
Recovery energy [kWh]	9 048.91	17 277.40	8 188.73	6 929.54	21 230.28	14 436.85
Calculated recovery energy [kWh]	13 386.91	13 386.91	13 386.91	13 386.91	13 386.91	13 386.91
Error [%]	−32.40	29.06	−38.83	−48.24	58.59	7.84
Estimation of recovery energy (minimum inlet assumption)	Under	Over	Under	Under	Over	Over
Possible estimation of impact: under- or overestimation	Over	Under	Over	Over	Under	Under

The reported savings of the TSM baseline model could potentially still be validated if the actual inlet temperatures during the performance assessment periods could be calculated. However, there is a greater risk that these models could be invalidated by a more accurate or rigorous M&V process.

Table 14 shows the recovery energy calculated with the baseline inlet assumption. However, no conclusions can be drawn from this comparison since the actual inlet temperature without the DSM interventions is dependent on the EGFs as noted.

Table 14: Baseline model evaluation using calculated recovery energy (baseline assumption) for PA2

Model	Constant Baseline	LS (System)	LS (FP) & EN (CA)	EN (System)	Single variable regression	TSM
Recovery energy [kWh]	9 048.91	17 277.40	8 188.73	6 929.54	21 230.28	14 436.85
Calculated recovery energy [kWh]	12 078.24	12 078.24	12 078.24	12 078.24	12 078.24	12 078.24
Error [%]	−25.08	43.05	-32.20	-42.63	75.77	19.53%
Estimation of recovery energy (baseline inlet assumption)	Under	Over	Under	Under	Over	Over
Estimation of impact: under- or overestimation	Over	Under	Over	Over	Under	Under

Direct evaluation of constant, single variable regression and TSM baseline models

The direct evaluation of the constant baseline model is done between the daily consumption from March to May 2014, and from March to May 2015. The results of this evaluation are shown in Table 15.

Table 15: Direct evaluation of constant baseline model

	March	April	May
2014 [kWh daily]	129 279.90	82 196.48	54 516.69
2015 [kWh daily]	81 408.50	53 653.25	45 628.87
Error [%]	−58.80	−53.20	−19.48

It should be noted that uncertainty cannot be managed with the constant baseline model since the baseline model can possibly be an over- or underestimation of the actual power consumption depending on the EGFs at the time of evaluation. The evaluation in Table 15 only serves to show the potential error involved in using the constant baseline model.

Evaluation of the TSM is possible since the model is independent of 2016 performance data. The results are shown in Table 16. For the evaluation, one month of each of the three-month assessment cycles will be used as the baseline to be adjusted by the TSM. The model adjusted data will then be compared with the actual power data of the corresponding month.

Table 16: Direct evaluation of the TSM

	PA period	Month used by model	Actual fridge plant average daily consumption [kWh]	Model fridge plant average daily consumption [kWh]	Error [%]
Mar-15	PA1	–	81 408.50	–	–
Apr-15	PA1	Mar-15	53 653.25	54 151.02	0.93
May-15	PA1	Mar-15	45 628.87	45 175.49	−0.99
Jun-14	PA2	–	31 266.83	–	–
Jul-14	PA2	June-14	26 814.26	27 229.67	1.55
Aug-14	PA2	June-14	39 278.80	43 593.47	10.98

Table 16 shows that the TSM predicts the performance of the system with some accuracy. The adjusted baseline model will, however, never be 100% accurate since the model is based on ideal performance.

The single variable regression model was developed with the ambient wet-bulb temperature as the independent variable, and the daily average power consumption of the fridge plant as the dependent variable. A similar approach was used with the environmental dry-bulb temperature (shown in Figure 53 and Figure 54 included in Appendix B).

The wet-bulb model was selected based on higher R^2 values. The results of the regression analysis for PA1 are shown in Figure 35. By observing the actual and model-predicted values of average daily consumption and the model R^2 value, the regression model for PA1 appears to predict the actual performance accurately. The regression model for PA1 has a reported R^2 value of 0.81 which meets the minimum requirement of 0.75 as identified by Booysen [21].

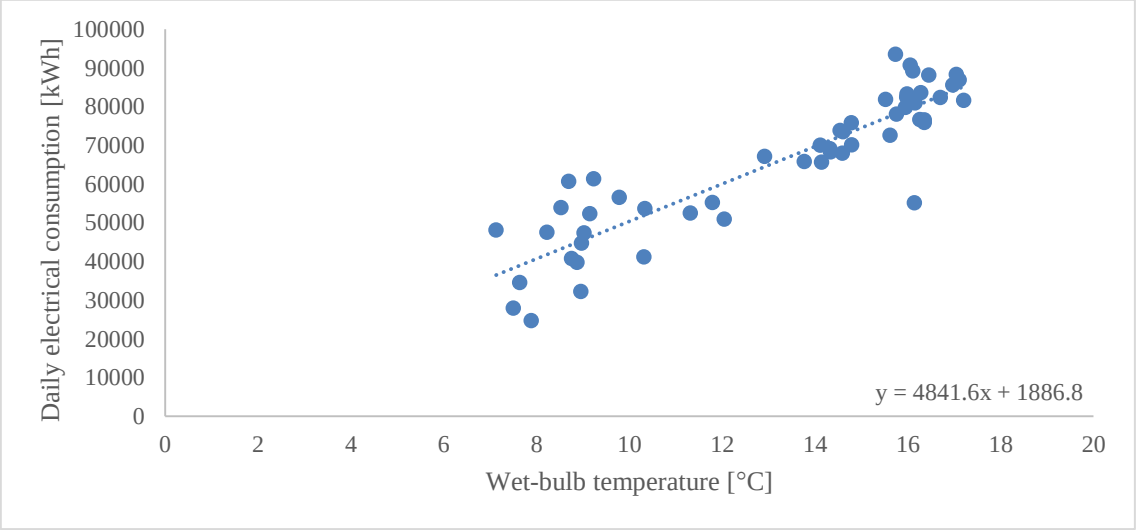


Figure 35: PA1 Single variable regression model

The results of the regression analysis for PA2 are shown in Figure 36. By observing the actual and model predicted values of average daily consumption, it can be seen that the model predicts the performance less accurately than the model developed for PA1. The regression model for PA2 has a reported R^2 value of 0.41 which does not meet the minimum requirement of 0.75 as identified by Booysen [21].

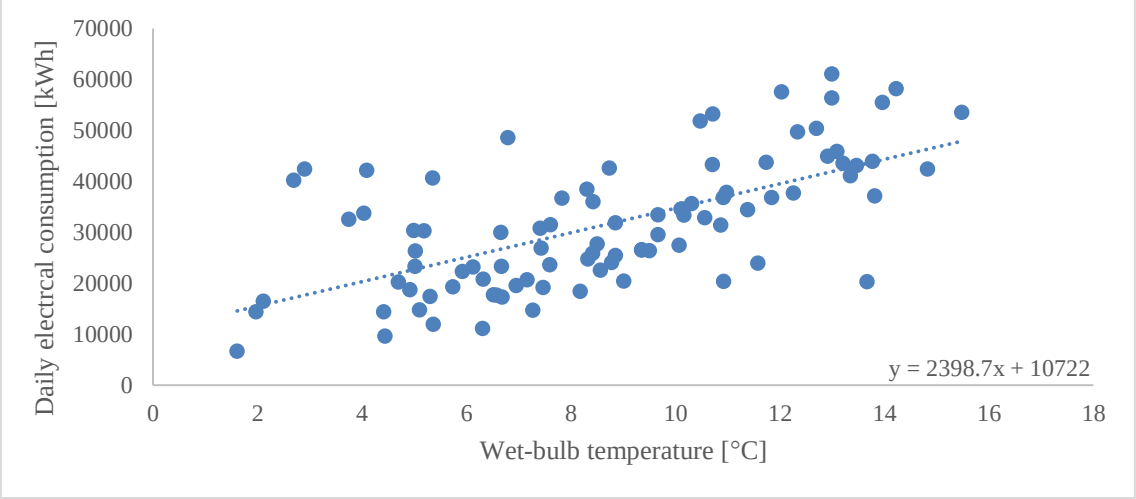


Figure 36: PA2 Single variable regression model

The relatively irregular operation of fridge plants during the winter months can affect the model for PA2. When temperatures are favourable during winter periods, the mine could potentially switch off fridge plants to save energy or do scheduled maintenance (as can be generally noted by the high frequency of actual daily consumption values below the regression line). Furthermore, it was noted that the PCT outlet temperatures do not follow the wet-bulb temperature, as was observed for PA1 (trends shown in Figure 65 and Figure 66 included in Appendix B).

After an investigation and consultation with mine personnel, it was discovered that due to safety concerns a PLC safety interlock bypasses water flow to the PCTs and CCTs. This is due to mine personnel being concerned regarding water freezing and the resultant damage to the fill or packing material that could occur if water in the towers were to freeze.

The previous discussion shows that the winter operation will be more erratic than the summer periods. This is due to higher energy consumption of the fridge plants when the PCTs and CCTs are switched off and lower energy consumption when machines are switched off or when scheduled maintenance occurs. The predicted average daily consumption during the assessment period is compared directly with the actual daily average consumption during the same period.

Table 17 shows that the accuracy for the high-demand season (PA2) is notably lower than for the low-demand season (PA1).

Table 17: Direct evaluation of single variable regression model

	Actual fridge plant [kWh]	Model fridge plant [kWh]	Error [%]
March (PA1 model)	79 892.82	79 011.10	1.10
April (PA1 model)	70 388.44	71 091.79	1.00
May (PA1 model)	47 403.10	47 640.01	0.50
June (PA2 model)	30 678.32	28 929.04	5.70
July (PA2 model)	25 141.24	27 382.89	8.92
August (PA2 model)	38 328.41	36 072.01	5.89

4.2.6. Risk exposure and baseline model selection

In this section, the risks of baseline model selection will be analysed. In the risk assessment, the severity and likelihood of events occurring will be identified and discussed. The two main risks associated with each model is an M&V and a project sustainability risk.

- **M&V risk**: Risk that the savings can be invalidated by a more rigorous and accurate M&V process, or a lower saving can be reported.
- **Project sustainability risk**: Risk associated with lower reporting of savings. The higher the reported savings, the more likely all parties involved will ensure that the sustained performance of the project is maintained.

Constant baseline model risks

The constant baseline model has a high risk for over- and underestimation of savings since no adjustments were made for the EGFs. Depending on weather and operational parameters, the system consumption can vary greatly. This variation can have a positive or negative effect on the perceived “savings”. The constant baseline model thus has a high risk and probability for both risk assessment criteria. The risk assessment is shown in Table 18.

LS (system) baseline model risks

The load-shifting model has a high risk associated with overestimating the recovery load of the fridge plants, since it was shown that a substantial load is removed. It was also noted that it was impossible for the cooling auxiliaries to perform load-shifting because of the inability

to provide additional service delivery – no additional capacity is available for the cooling auxiliary equipment.

The load-shifting model will therefore have a very low associated M&V risk since the recovery energy is vastly overestimated. However, it will have a high project risk since the perceived or reported savings will be low. The risk assessment is shown in Table 18.

EN (system) baseline model risks

The EN (system) model has a high M&V risk associated with underestimating the recovery load since it predicts that little recovery work is done. The recovery energy is associated with additional fridge plant work due to increased inlet temperatures as well.

Furthermore, an incorrect unaffected time period can be selected depending on when additional cooling capacity is available from the fridge plants, and when the additional cooling work is done. This could potentially vary daily. The model also has a high project maintenance risk since trust can be lost between stakeholders if the reported savings are discredited. The risk assessment is shown in Table 18.

LS (FP) & EN (CA) baseline model risks

The LS (FP) & EN (CA) model will be generally more accurate and have fewer risks associated with it than the energy-neutral system models. This is because the LS (FP) & EN (CA) model considers some of the actual physical limitations of the cooling auxiliary equipment. However, the model still potentially overestimates the recovery load of the fridge plants (as was noted in the LS (system) discussion). The risk assessment is shown in Table 18.

Single variable regression baseline model risks

The single variable regression baseline model (WB) has less project risks associated since it considers the actual operation of the fridge plants and is not dependent on the post-implementation system performance data for model predictions. The model has a high reported R^2 value for PA1. However, as discussed, it is less accurate for PA2 due to variable winter operation of the plant. The risk assessment is shown in Table 18.

TSM risks

The TSM appears to have lower risks associated with it. However, the model does make fundamental assumptions regarding the operation of the fridge plants. Furthermore, there are

risks associated with a new model that has only been tested on a limited sample size. The risk assessment is shown in Table 18.

Baseline model risk assessment and model selection

Table 18 shows the baseline model risk assessment for impact reassessment. From the risk assessment performed, the single variable regression model was selected for PA1; the LS (FP) & EN (CA) was selected for PA2. Combined, they had the lowest risk exposure.

Table 18: Baseline model risk assessment

Identification of Hazards				Evaluation of Risks			
Baseline Model	Performance Assessment Period	Hazard	Risk	Impact = I	Likelihood/ Probability = P	Risk = P × I	Combined Risk
Constant baseline model	PA1	M&V	Overestimate savings	4	4	16	16
		Project sustainability	Underestimate performance	4	4	16	
	PA2	M&V	Overestimate savings	4	4	16	16
		Project sustainability	Underestimate performance	4	4	16	
LS (system) model	PA1	M&V	Overestimate savings	4	1	4	12
		Project sustainability	Underestimate performance	4	5	20	
	PA2	M&V	Overestimate savings	4	1	4	12
		Project sustainability	Underestimate performance	4	5	20	
EN (system) model	PA1	M&V	Overestimate savings	4	5	20	12
		Project sustainability	Underestimate performance	4	1	4	
	PA2	M&V	Overestimate savings	4	5	20	12
		Project sustainability	Underestimate performance	4	1	4	
LS (FP) & EN (CA)	PA1	M&V	Overestimate savings	4	1	4	6
		Project sustainability	Underestimate performance	4	2	8	
	PA2	M&V	Overestimate savings	4	1	4	6
		Project sustainability	Underestimate performance	4	2	8	
Single variable regression model	PA1	M&V	Overestimate savings	4	1	4	4
		Project sustainability	Underestimate performance	4	1	4	
	PA2	M&V	Overestimate savings	4	3	12	12
		Project sustainability	Underestimate performance	4	3	12	
TSM	PA1	M&V	Overestimate savings	4	3	12	12
		Project sustainability	Underestimate performance	4	3	12	
	PA2	M&V	Overestimate savings	4	3	12	12
		Project sustainability	Underestimate performance	4	3	12	

4.3. Case Study 2: Mine B

To further assess the accuracy of the TSM baseline model, the model will be applied to the fridge plants at Mine B. The simplified partial layout of the surface cooling plant at Mine B is shown in Figure 37. The measurement boundary has been drawn around the fridge plants.

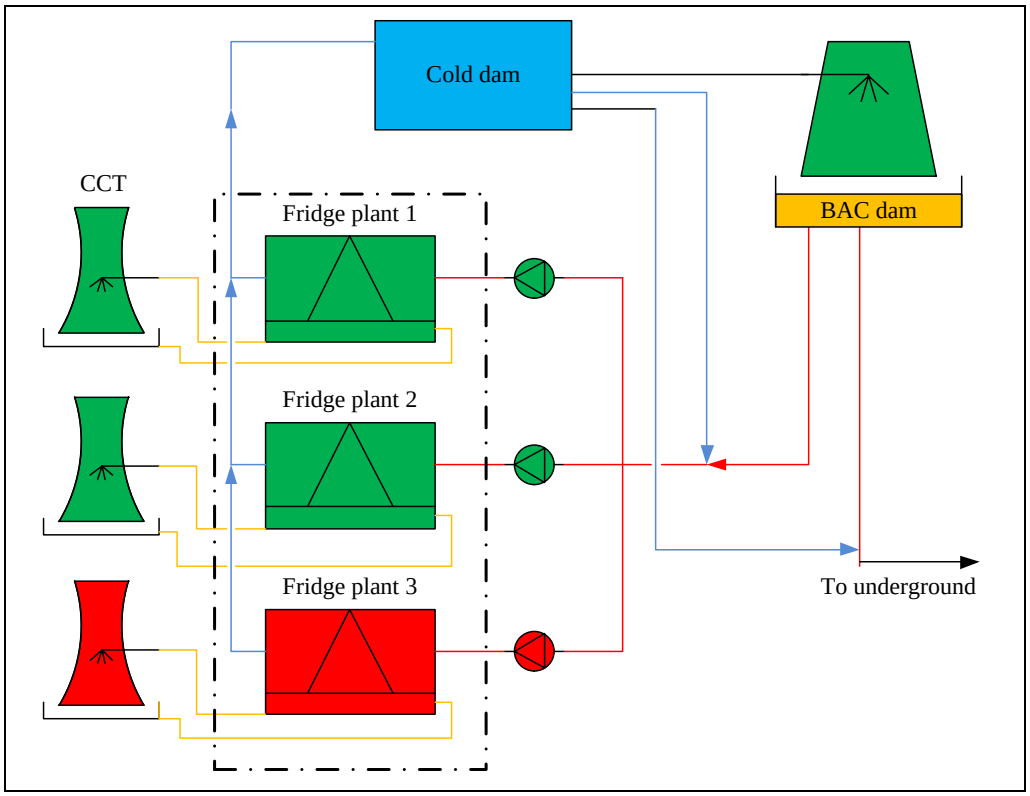


Figure 37: Mine B simplified surface cooling plant layout

The fridge plants at Mine B are only operational in the summer months (September to April) and there is an existing DSM load-shifting project implemented during the evening peak period. Therefore, the model will use January 2016 fridge plant baseline data. The TSM is used to adjust the January data for each successive month. The ideal scaling ratio is applied to the fridge plant compressors with the following weekday average input values:

Table 19: Mine B parameters for the TSM

	Evaporator inlet temperature [K]	Evaporator outlet temperature [K]	Scaling ratio	Model average daily consumption error [%]
Jan-16	282.99	278.76	–	–
Feb-16	282.15	278.38	0.87	13.24%
Mar-16	281.41	277.88	0.89	10.68%
Apr-16	281.27	277.88	0.99	1.34%
Sep-16	285.24	281.39	0.70	−12.76%
Oct-16	281.26	278.10	1.13	0.51%

The results of the TSM baseline adjustments are summarised in Figure 38. The TSM accurately estimates the performance of the fridge plants at Mine B for the 2016 period.

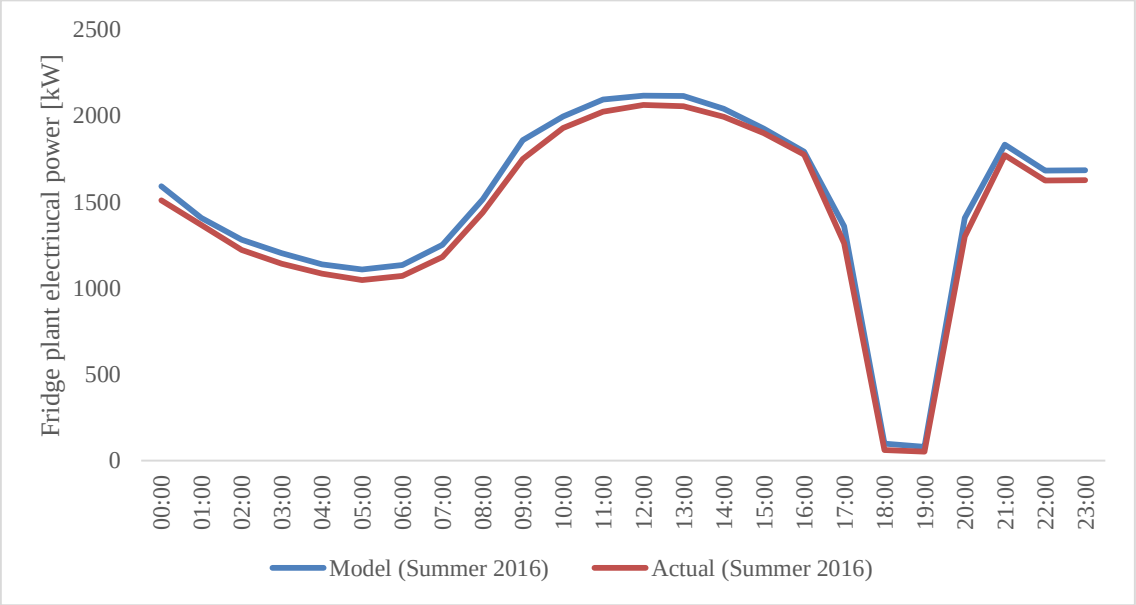


Figure 38: Mine B results of the TSM

The TSM was applied for Case Study 2 to an existing load-shifting project without great difficulty. The accuracy is in part due to sufficient and reliable data being available. Furthermore, no assumptions had to be made about the operational temperatures and flows of the fridge plants.

4.4. Case Study 3: Mine C

To further assess the accuracy of the TSM, it will be applied to the fridge plants at Mine C similar to its application in Case Study 2. The simplified partial layout of the surface cooling plant at Mine C is shown in Figure 39. The indicated measurement boundary has been drawn around the fridge plants.

At Mine C, energy efficiency savings are achieved using VSDs on pump motors. The fridge plants therefore have variable evaporator water flow. Thus, the evaporator flow rate has to be used in the TSM. For the analysis, January 2016 data is used as the baseline and adjustments are made for each successive month until September 2016.

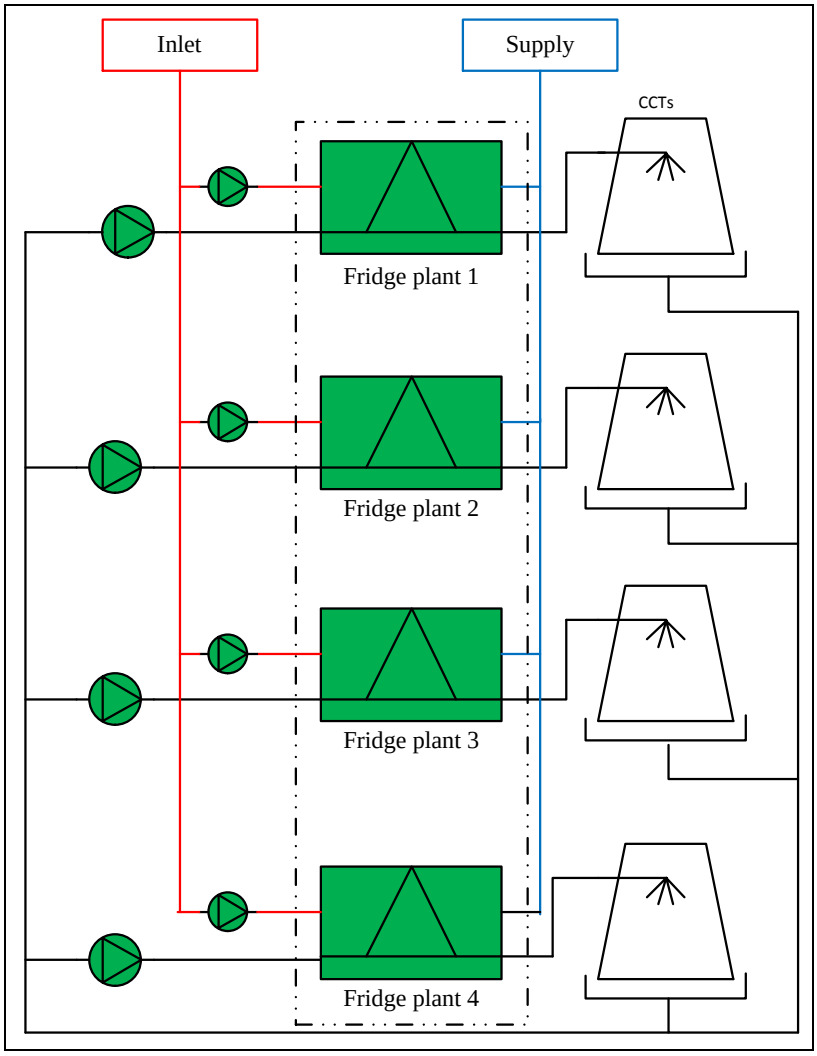


Figure 39: Mine C simplified surface cooling plant layout

The parameters used for the TSM, applied to the total fridge plant compressor power at Mine C, are weekday average input values and are summarised in Table 20.

Table 20: Mine C parameters for the TSM

	Evaporator inlet [K]	Evaporator outlet [K]	Evaporator flow [ℓ/s]	Scaling ratio	Model error [%]
16-Jan	286.26	279.4	735.54	–	–
16-Feb	284.68	278.13	742.73	0.92	6.16
16-Mar	287.00	279.91	671.99	0.87	1.05
16-Apr	285.23	278.81	768.94	0.94	4.20
16-May	285.23	278.81	638.82	0.81	1.92
16-Jun	284.61	279.47	639.66	0.74	9.21
16-Jul	284.83	279.8	628.74	1.00	9.57
16-Aug	285.15	279.71	513.36	0.95	6.75
16-Sep	285.19	279.42	619.36	1.22	5.62
				Average error	5.56

The results of the TSM baseline adjustments are shown in Figure 40. The TSM conservatively estimates the performance of the fridge plants at Mine C for the 2016 period.

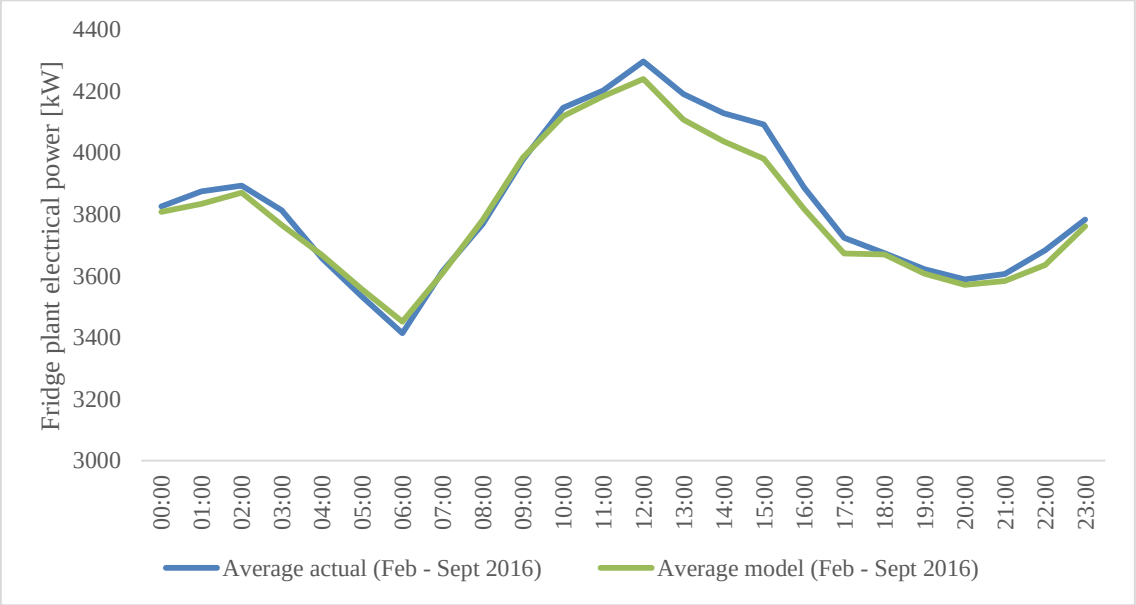


Figure 40: Mine C results of the TSM

4.5. Conclusions

It was shown that baseline model selection has a potentially large financial impact for EPCs. The various models developed for the DSM project at Mine A were further evaluated from which a model was selected. The selection criteria identified were to minimise the risks associated with over- and underestimation of performance.

The selected models reported an additional cost saving of R835 390.91 and a total unclaimed energy saving of 741.31 MWh from March to August 2016 at Mine A when compared with the original load-shifting model.

It was further noted that SANS 50010:2011 does not require an exact quantification of uncertainty. It is only required that a lower saving cannot be calculated by a more accurate or rigorous M&V process. It was shown that a higher calculated recovery energy implies that a lower saving will be reported. Furthermore, it was found that the additional electrical fridge plant work, calculated using assumptions in Section 3.2, can be used to confirm that the results from a specific model cannot be invalidated.

It was further found that the TSM accurately estimated the performance of the fridge plants for two case studies. It was also shown that the model can be used to evaluate various types of DSM intervention – load shifting for Case Study 2 and energy efficiency for Case Study 3 – without the need of redeveloping the model.

The accuracy of the application of the TSM in the case studies is in part due to sufficient and reliable data being available. Furthermore, no assumptions regarding the operational temperatures and flows of the fridge plants had to be made. It can therefore be concluded that the model provides an accurate and simplified estimation of fridge plant power as required for the post-project implementation assessment.

It is also important to note that the developed TSM uses a scaling factor to adjust the baseline amplitudes, somewhat similar to the energy-neutral models. Therefore, it remains important to identify various operating modes and abnormal system operation in the baseline period since the model performs a *power-profile-amplitude adjustment* while it assumes that there is a constant *power-profile-shape* as discussed in Section 3.4.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS



[5]

[5] Google Maps – surface layout of Mine A

5.1. Conclusions

The need for a simplified baseline model assessment method was identified on a specific DSM project that has been implemented differently than the original detailed design. The TSM was suggested for this purpose following a literature study on the operation of mine cooling systems and on the M&V of industrial DSM projects.

It was shown that the under- or overestimation of recovery energy is a major source of error for baseline models. Thus, a simple method, which is independent of the chosen baseline model, was presented to conservatively estimate the recovery energy by considering additional fridge plant work after a specific DSM intervention. Furthermore, it was shown that the additional work is a convenient tool for evaluating baseline models for a DSM intervention on mine surface cooling plants irrespective of the specific model parameters.

The recovery work, as well as the standard baseline model evaluation technique, was used to evaluate the common baseline models used in industry as well as the TSM for the specific case study at Mine A. It was also shown that the overestimated recovery energy can in certain cases be used to ensure that a particular baseline model cannot be invalidated by a more accurate or rigorous M&V process as required by the SANS 50010:2011.

The perceived financial impact of using various baseline models for Case Study 1 at Mine A was presented. It was shown that the selection of a baseline model has a potentially large impact on the reported savings and/or the ultimate life cycle duration of the project. The accuracy and conservativeness of various baseline models were analysed and a model was selected by considering the risks associated with each model.

From the risk assessment, the baseline model was selected. It was found that a conservative estimation of additional unclaimed savings for the DSM project at Mine A over the six-month period from March to August 2016 was R835 390.91 with a total unclaimed energy saving of 741.31 MWh.

Finally, the TSM was applied to two other case studies. It was shown that the model produced favourable results especially regarding ease of application and accuracy, thus making it ideal for post-project implementation. This investigation did not focus on the full validation of the model. This would be needed if it were to be used for the M&V of DSM projects.

5.2. Recommendations for future work

It was shown that by estimating the recovery work more accurately, the accuracy of baseline models can be improved. A recommendation for further work is thus to investigate other methods that could determine the recovery work more accurately. The approach of using recovery work for model evaluation and development can also be investigated for other cooling and non-cooling DSM projects.

It is also recommended that the possible carbon tax incentives of the project be investigated further. The load-shifting model assumes that no energy is removed. Hence, projects that assume load-shifting properties will be carbon-neutral. It was shown that a substantial portion of the total load was removed and hence there are possibilities of carbon-reduction credits.

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APPENDIX A

Table 21 gives the surface fridge plant specifications at Mine A.

Table 21: Surface fridge plant specifications at Mine A

Description	
Number of fridge plants	4
Compressor type	Screw
Refrigerant	Ammonia
Voltage [V]	6 600
Cooling capacity [kW]	10 000
COP	6
Average evaporator temperature [°C]	10.2
Average condenser temperature [°C]	25.8
Evaporator water flow [kg/s]	450
Condenser water flow [kg/s]	325
Evaporator pump motor rating [kW]	650
Number of evaporator pumps	2
Condenser pump motor rating [kW]	350
Number of condenser pumps	5
Number of CCTs	2
CCT water flow [kg/s]	350
Pump motor rating [kW]	100
Number of CCT pumps	3
Number of BACs	2
BAC water flow [kg/s]	200
BAC airflow [kg/s]	200
Number of dams	2
Total cold dam capacity [m^3]	5 000

Table 22 gives the surface fridge plant specifications at Mine B.

Table 22: Surface fridge plant specifications at Mine B

Description	
Number of fridge plants	3
Compressor type	Centrifugal
Refrigerant	R134a
Voltage [V]	6 600
Cooling capacity [kW]	9 600
COP	6
Evaporator outlet temperature [°C]	5
Condenser inlet temperature [°C]	25
Evaporator water flow [kg/s]	290
Evaporator pump motor rating [kW]	90
Number of evaporator pumps	3
Condenser pump motor rating [kW]	55
Number of condenser pumps	3

Table 23 gives the surface fridge plant specifications at Mine C.

Table 23: Surface fridge plant specifications at Mine C

Description	**Type 1**	**Type 2**
Number of fridge plants	3	1
Compressor type	Centrifugal	Centrifugal
Refrigerant	R134a	R134a
Voltage [V]	6 600	6 600
Cooling capacity [kW]	11 000	4 400
COP	6	6
Evaporator outlet temperature [°C]	6	6
Condenser inlet temperature [°C]	23.5	23.5
Evaporator water flow [kg/s]	250	100
Condenser water flow [kg/s]	500	200
Evaporator pump motor rating [kW]	160	55
Number of evaporator pumps	3	1
Condenser pump motor rating [kW]	185	75
Number of condenser pumps	3	1

APPENDIX B

Demand system baseline for performance assessment 1

Figure 41 shows the system baseline for PA1.

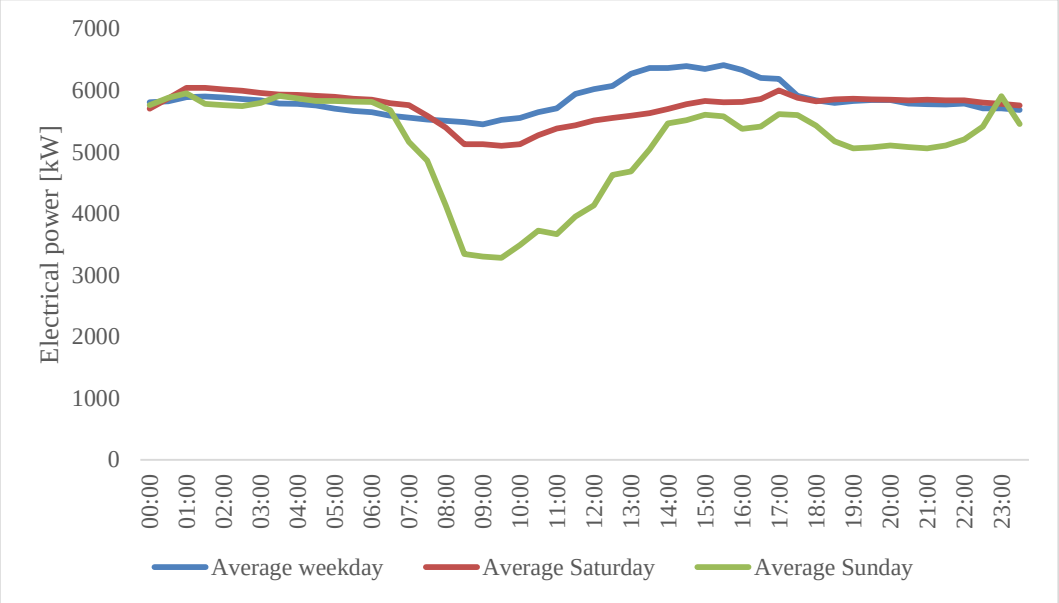


Figure 41: System baseline for PA1

The system demand baseline average summer evening peak period (18:00–20:00) power demand values are:

- Weekday: 5 828.44 kW
- Saturday: 5 855.95 kW
- Sunday: 5 102.07 kW

The daily average energy consumption baseline value is obtained by adding all the hourly kW values over the 24-hour period. The electricity consumption baseline can thus be readily calculated from the demand baseline profile. The average daily electricity consumption values are:

- Weekday: 140 537.04 kWh
- Saturday: 137 493.59 kWh
- Sunday: 123 012.70 kWh

Demand system baseline for PA2

Figure 42 shows the demand system baseline for PA2.

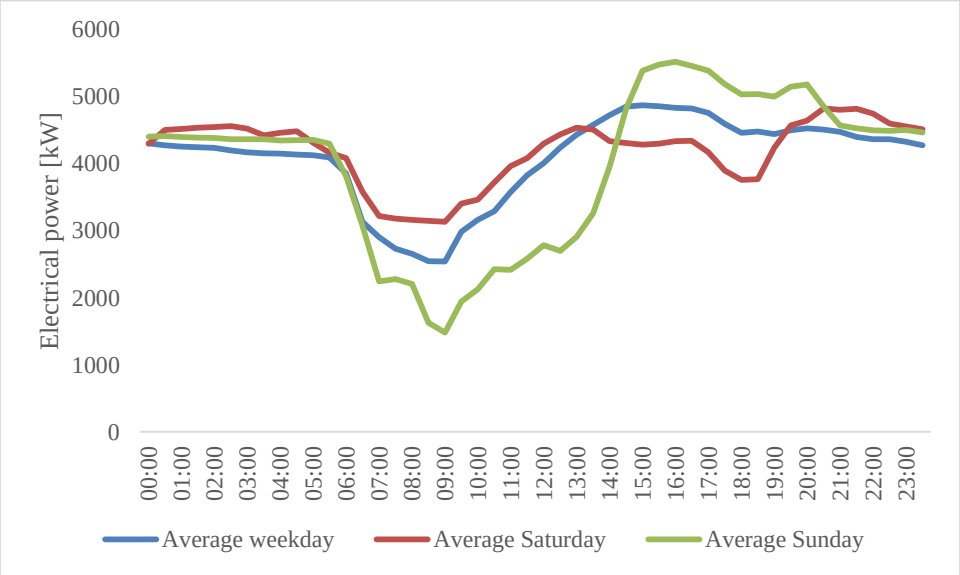


Figure 42: Demand system baseline for PA2

The average winter evening peak period (17:00–19:00) power demand values are:

- Weekday: 4 494.56 kW
- Saturday: 3 917.31 kW
- Sunday: 5 066.36 kW

The average daily electricity consumption values for PA2 are:

- Weekday: 98 133.03 kWh
- Saturday: 100 545.55 kWh
- Sunday: 95 420.45 kWh

Weekday baseline for the fridge plant sub-system

The fridge plant sub-system demand baseline is used to describe the pre-implementation condition of the fridge plant's electricity usage under PA1 and PA2 weekday baseline conditions. Figure 43 shows the weekday baselines for the fridge plant sub-system.

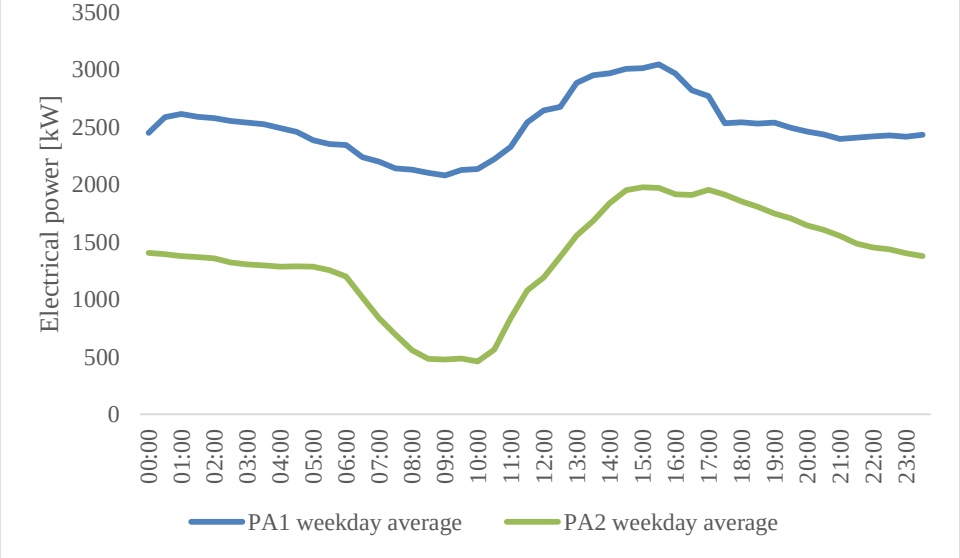


Figure 43: Weekday baselines for the fridge plant sub-system

The average summer evening peak period (18:00–20:00) and average winter evening peak period (17:00–19:00) power demand values are:

- PA1 weekday: 2 505.61 kW
- PA2 weekday: 1 829.01 kW

The average daily electricity consumption values are:

- PA1 weekday: 60 230.27 kWh
- PA2 weekday: 32 450.93 kWh

Weekday baselines for the cooling auxiliary sub-system

The cooling auxiliary sub-system demand baseline profile is used to describe the pre-implementation condition of the auxiliary equipment's electricity usage under PA1 and PA2 weekday baseline conditions. Figure 44 shows the weekday baselines for the cooling auxiliary sub-system.

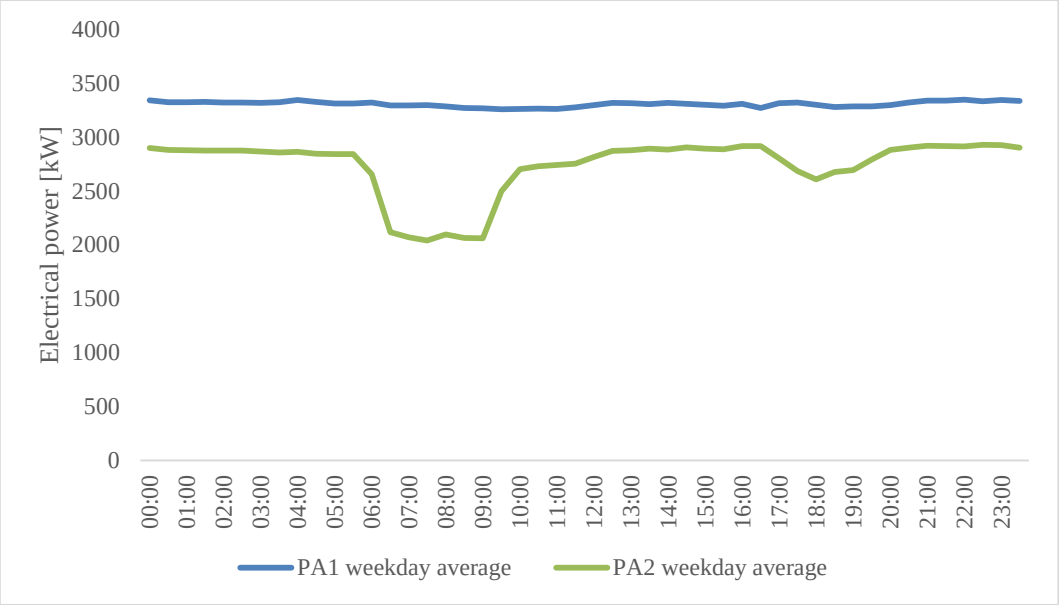


Figure 44: Weekday baselines for the cooling auxiliary sub-system

Based on the pre-implementation data, the average summer evening peak period (18:00–20:00) and average winter evening peak period (17:00–19:00) power demand values are:

- PA1 weekday: 3 287.47 kW
- PA2 weekday: 2 665.55 kW

The average daily electricity consumption values are:

- PA1 weekday: 79 375.00 kWh
- PA2 weekday: 65 682.10 kWh

The constant baseline model was suggested for the cooling auxiliaries in the TSM since none of the main EGFs of the auxiliary equipment can be controlled. As expected, the cooling auxiliary power profile has far less hourly fluctuation in power consumption.

Constant baseline for PA1

Figure 45 shows the constant baseline for PA1.

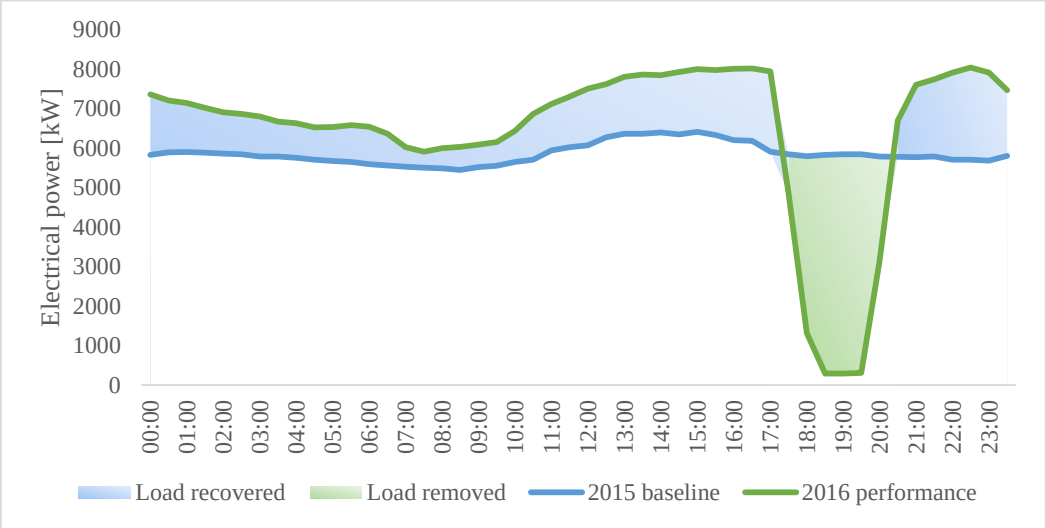


Figure 45: Constant baseline for PA1

The average summer evening peak period (18:00–20:00) reduction and project impact for the for the constant baseline PA1 assessment period are:

- Average daily recovery energy: 25 547.30 kWh
- Average daily evening peak reduction: 5 281.37 kW
- Average daily consumption increase: 13 986.50 kWh

Table 24 shows the calculated average daily cost savings for the Constant baseline model PA1

Table 24: Average daily cost savings Constant baseline model PA1

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	5 894.32	7 078.93	34.85	2 054.17	2 467.01	−412.84
2	5 850.45	6 883.60	34.85	2038.88	2 398.94	−360.06
3	5 784.48	6 733.69	34.85	2015.89	2 346.69	−330.80
4	5 728.92	6 578.17	34.85	1996.53	2 292.49	−295.96
5	5 658.29	6 554.45	34.85	1 971.92	2 284.23	−312.31
6	5 573.02	6 452.46	54.92	3 060.70	3 543.69	−482.99
7	5 516.34	5 963.60	79.82	4 403.14	4 760.15	−357.01
8	5 466.66	6 011.78	79.82	4 363.48	4 798.60	−435.12
9	5 534.91	6 119.81	79.82	4 417.97	4 884.83	−466.87
10	5 676.30	6 646.34	54.92	3 117.42	3 650.17	−532.74
11	5 982.25	7 207.60	54.92	3 285.45	3 958.41	−672.96
12	6 171.17	7 561.57	54.92	3 389.21	4 152.81	−763.61
13	6 364.76	7 831.32	54.92	3 495.52	4 300.96	−805.44
14	6 370.04	7 884.25	54.92	3 498.42	4 330.03	−831.60
15	6 371.57	7 986.98	54.92	3 499.27	4 386.45	−887.18
16	6 193.99	8 014.51	54.92	3 401.74	4 401.57	−999.83
17	5 875.40	6 396.26	54.92	3 226.77	3 512.83	−286.05
18	5 813.60	797.64	79.82	4 640.41	636.67	4 003.74

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
19	5 843.29	296.51	79.82	4 664.11	236.67	4 427.44
20	5 780.17	4 910.51	54.92	3 174.47	2 696.85	477.62
21	5 778.27	7 668.63	54.92	3 173.43	4 211.61	−1 038.18
22	5 707.94	7 975.31	34.85	1989.22	2 779.40	−790.18
23	5 742.93	7 688.55	34.85	2001.41	2 679.46	−678.05
0	5 857.97	7 281.32	34.85	2041.50	2 537.54	−496.04
				R74 921.04	R78 248.06	**−R3 327.02**

Constant baseline for PA2

Figure 46 shows the constant baseline for PA2.

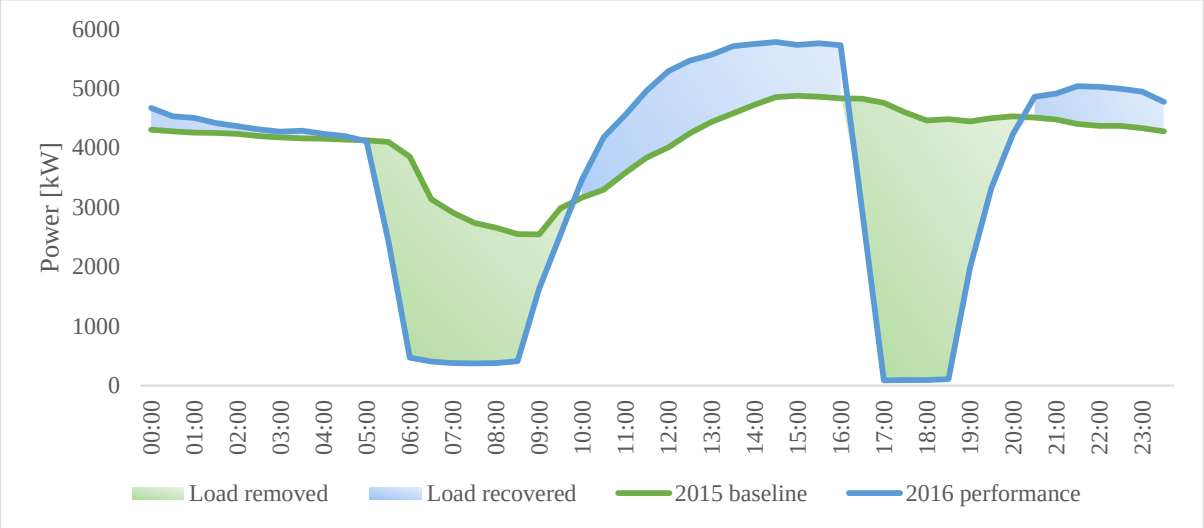


Figure 46: Constant baseline for PA2

The average winter morning peak reduction (06:00–09:00), evening peak reduction (17:00–19:00) and average daily electricity savings for the constant baseline model are:

- Average daily recovery energy: 9 048.91 kWh
- Average daily morning peak reduction: 2 568.83 kW
- Average daily evening peak reduction: 4 477.32 kW
- Average daily consumption reduction: 12 032.92 kWh

Table 25 shows the calculated average daily cost savings for the Constant baseline model PA2

Table 25: Average daily cost savings Constant baseline model PA2

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	4 250.79	4 457.09	40.25	1 710.94	1 793.98	−83.04
2	4 215.60	4 333.09	40.25	1 696.78	1 744.07	−47.29
3	4 163.98	4 278.81	40.25	1 676.00	1 722.22	−46.22
4	4 142.03	4 214.88	40.25	1 667.17	1 696.49	−29.32
5	4 110.52	3 271.91	40.25	1 654.49	1 316.94	337.54
6	3 493.85	438.38	244.68	8 548.76	1 072.63	7 476.14

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
7	2 819.73	376.55	244.68	6 899.33	921.34	5 977.99
8	2 600.68	392.85	244.68	6 363.34	961.22	5 402.12
9	2 761.53	2 085.79	74.11	2046.57	1 545.78	500.79
10	3 228.34	3 819.79	74.11	2 392.53	2 830.85	−438.32
11	3 705.14	4 753.96	74.11	2 745.88	3 523.16	−777.28
12	4 124.90	5 376.30	74.11	3 056.96	3 984.38	−927.42
13	4 506.46	5 634.56	74.11	3 339.74	4 175.77	−836.03
14	4 787.77	5 761.71	74.11	3 548.22	4 270.00	−721.79
15	4 864.05	5 741.94	74.11	3 604.74	4 255.35	−650.61
16	4 828.24	4 338.28	74.11	3 578.21	3 215.10	363.11
17	4 676.07	89.32	244.65	11 440.01	218.52	11 221.49
18	4 470.37	102.48	244.65	10 936.77	250.72	10 686.05
19	4 469.94	2 648.52	74.11	3 312.67	1 962.82	1 349.86
20	4 517.74	4 542.71	74.11	3 348.09	3 366.60	−18.51
21	4 437.02	4 974.24	74.11	3 288.28	3 686.41	−398.13
22	4 366.35	5 009.36	40.25	1 757.46	2016.27	−258.81
23	4 302.87	4 858.69	40.25	1 731.91	1 955.62	−223.72
0	4 289.06	4 598.93	40.25	1 726.35	1 851.07	−124.72
				R92 071.17	R54 337.29	**R37 733.88**

LS (system) for PA1

Figure 47 shows the LS (system) profiles for PA1.

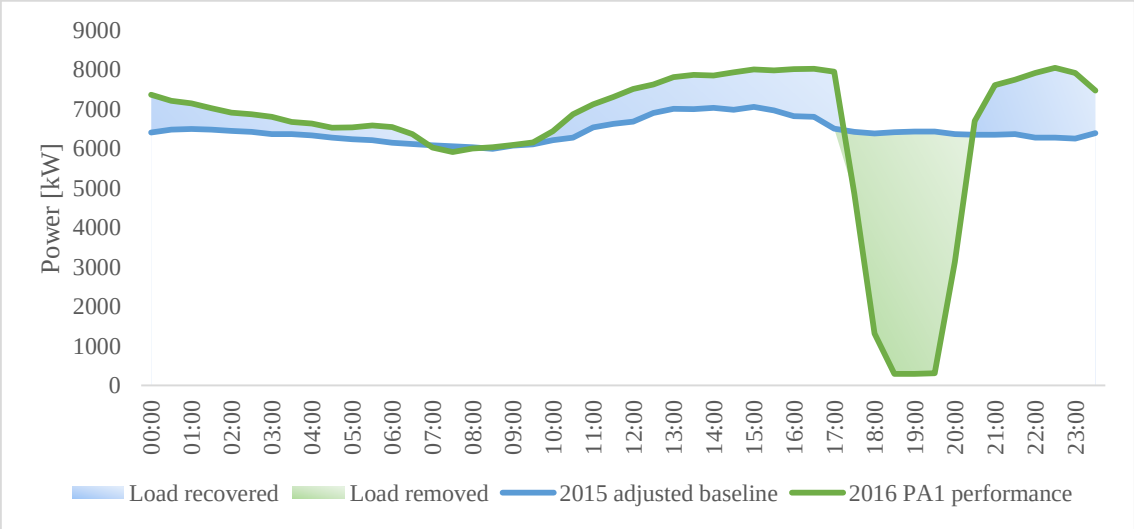


Figure 47: LS (system) profiles for PA1

The average summer evening peak period (18:00–20:00) reduction and project impact for the LS (system) baseline model are:

- Average daily recovery energy: 14 248.10 kWh
- Average daily evening peak reduction: 5 861.44 kW

Table 26 shows the calculated average daily cost savings for the LS (system) baseline model for PA1

Table 26: Average daily cost savings LS (system) baseline model PA1

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	6 480.94	7 078.93	34.85	2 258.61	2 467.01	−208.40
2	6 432.70	6 883.60	34.85	2 241.80	2 398.94	−157.14
3	6 360.17	6 733.69	34.85	2 216.52	2 346.69	−130.17
4	6 299.09	6 578.17	34.85	2 195.23	2 292.49	−97.26
5	6 221.43	6 554.45	34.85	2 168.17	2 284.23	−116.06
6	6 127.67	6 452.46	54.92	3 365.32	3 543.69	−178.37
7	6 065.34	5 963.60	79.82	4 841.36	4 760.15	81.21
8	6 010.72	6 011.78	79.82	4 797.75	4 798.60	−0.85
9	6 085.77	6 119.81	79.82	4 857.66	4 884.83	−27.17
10	6 241.23	6 646.34	54.92	3 427.68	3 650.17	−222.49
11	6 577.63	7 207.60	54.92	3 612.43	3 958.41	−345.98
12	6 785.35	7 561.57	54.92	3 726.51	4 152.81	−426.30
13	6 998.20	7 831.32	54.92	3 843.41	4 300.96	−457.55
14	7 004.01	7 884.25	54.92	3 846.60	4 330.03	−483.43
15	7 005.69	7 986.98	54.92	3 847.53	4 386.45	−538.92
16	6 810.43	8 014.51	54.92	3 740.29	4 401.57	−661.28
17	6 460.15	6 396.26	54.92	3 547.91	3 512.83	35.09
18	6 392.19	797.64	79.82	5 102.24	636.67	4 465.57
19	6 424.83	296.51	79.82	5 128.30	236.67	4 891.63
20	6 355.43	4 910.51	54.92	3 490.40	2 696.85	793.55
21	6 353.35	7 668.63	54.92	3 489.26	4 211.61	−722.35
22	6 276.02	7 975.31	34.85	2 187.19	2 779.40	−592.20
23	6 314.49	7 688.55	34.85	2 200.60	2 679.46	−478.86
0	6 440.98	7 281.32	34.85	2 244.68	2 537.54	−292.86
				R82 377.46	R78 248.06	**R4 129.40**

LS (system) for PA2

Figure 48 shows the LS (system) profiles for PA2.

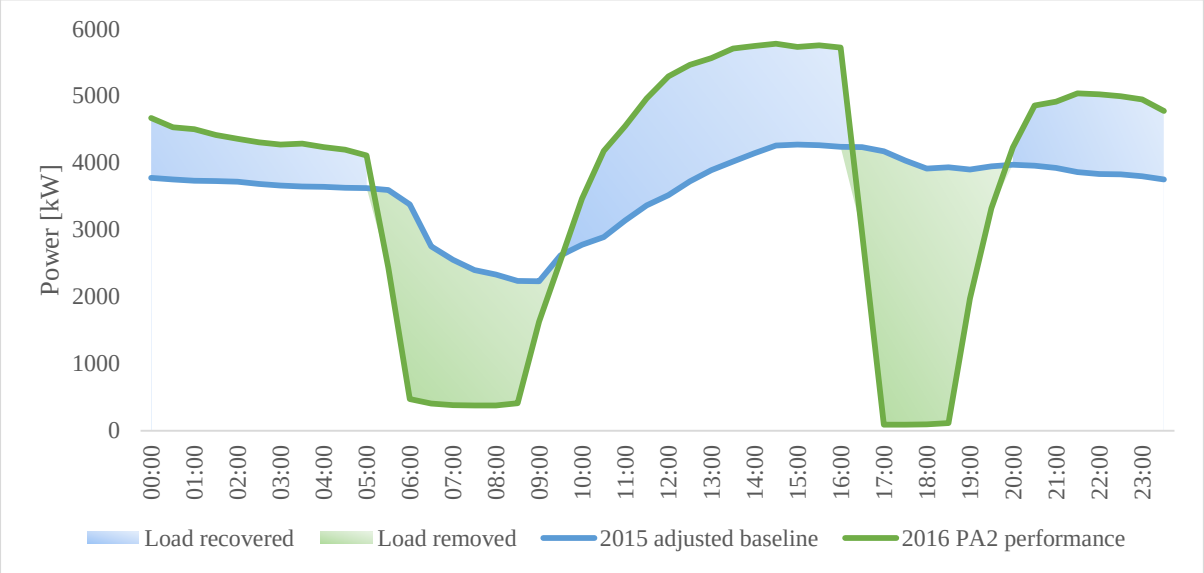


Figure 48: LS (system) profiles for PA2

The average winter morning peak reduction (06:00–09:00), evening peak reduction (17:00–19:00) and average daily electricity savings for the load-shifting baseline model are:

- Average daily recovery energy: 17 277.40 kWh
- Average daily morning peak reduction: 2 204.48 kW
- Average daily evening peak reduction: 3 916.56 kW

Table 27 shows the calculated average daily cost savings for the LS (system) baseline model for PA2

Table 27: Average daily cost savings LS (system) baseline model PA2

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	3 729.56	4 457.09	40.25	1 501.15	1 793.98	−292.83
2	3 698.69	4 333.09	40.25	1 488.72	1 744.07	−255.34
3	3 653.40	4 278.81	40.25	1 470.49	1 722.22	−251.73
4	3 634.14	4 214.88	40.25	1 462.74	1 696.49	−233.75
5	3 606.50	3 271.91	40.25	1 451.62	1 316.94	134.67
6	3 065.44	438.38	244.68	7 500.53	1 072.63	6 427.90
7	2 473.98	376.55	244.68	6 053.34	921.34	5 132.01
8	2 281.79	392.85	244.68	5 583.08	961.22	4 621.86
9	2 422.92	2 085.79	74.11	1 795.62	1 545.78	249.84
10	2 832.49	3 819.79	74.11	2 099.16	2 830.85	−731.69
11	3 250.82	4 753.96	74.11	2 409.18	3 523.16	−1 113.98
12	3 619.11	5 376.30	74.11	2 682.12	3 984.38	−1 302.26
13	3 953.88	5 634.56	74.11	2 930.22	4 175.77	−1 245.55
14	4 200.70	5 761.71	74.11	3 113.14	4 270.00	−1 156.86
15	4 267.62	5 741.94	74.11	3 162.74	4 255.35	−1 092.61
16	4 236.21	4 338.28	74.11	3 139.45	3 215.10	−75.64
17	4 102.70	89.32	244.65	10 037.25	218.52	9 818.74
18	3 922.22	102.48	244.65	9 595.72	250.72	9 345.00
19	3 921.85	2 648.52	74.11	2 906.48	1 962.82	943.66
20	3 963.78	4 542.71	74.11	2 937.56	3 366.60	−429.05
21	3 892.96	4 974.24	74.11	2 885.07	3 686.41	−801.34
22	3 830.96	5 009.36	40.25	1 541.96	2016.27	−474.31
23	3 775.26	4 858.69	40.25	1 519.54	1 955.62	−436.08
0	3 763.14	4 598.93	40.25	1 514.66	1 851.07	−336.40
				R80 781.55	R54 337.29	**R26 444.26**

EN (system) for PA1

Figure 49 shows the EN (system) profiles for PA1.

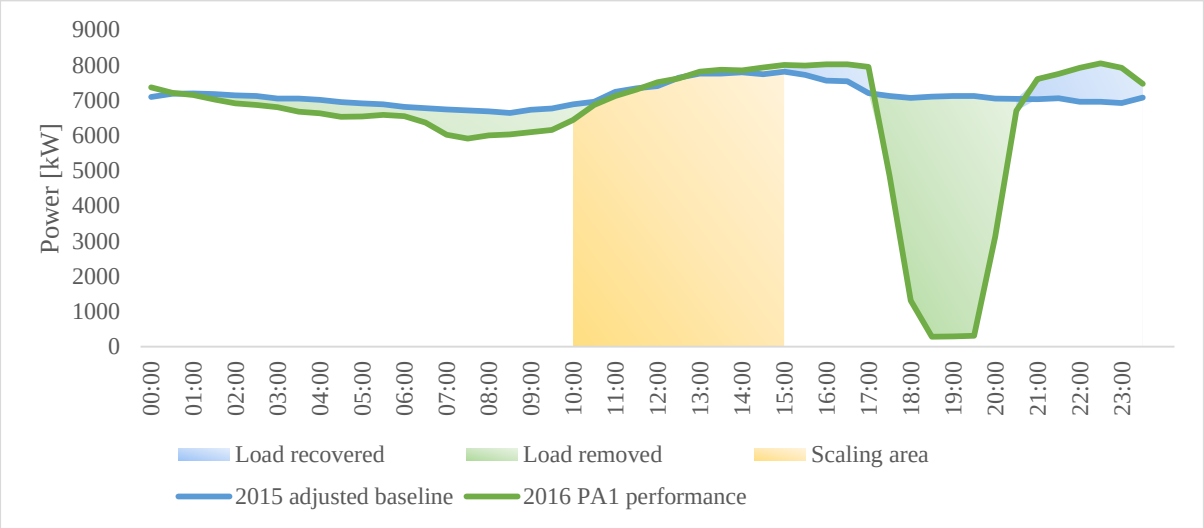


Figure 49: EN (system) profiles for PA1

The average summer evening peak period (18:00–20:00) reduction and project impact for the PC (System) baseline model are:

- Average daily recovery energy: 3 825.93 kWh
- Average daily evening peak reduction: 6 551.60 kW
- Average daily consumption decrease: 16 641.30 kWh

Table 28 shows the calculated average daily cost savings for the EN (system) baseline model for PA1

Table 28: Average daily cost savings EN (system) baseline model PA1

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	7 178.90	7 078.93	34.85	2 501.85	2 467.01	34.84
2	7 125.47	6 883.60	34.85	2 483.22	2 398.94	84.29
3	7 045.13	6 733.69	34.85	2 455.23	2 346.69	108.54
4	6 977.46	6 578.17	34.85	2 431.65	2 292.49	139.15
5	6 891.44	6 554.45	34.85	2 401.67	2 284.23	117.44
6	6 787.58	6 452.46	54.92	3 727.74	3 543.69	184.05
7	6 718.54	5 963.60	79.82	5 362.74	4 760.15	602.59
8	6 658.04	6 011.78	79.82	5 314.44	4 798.60	515.84
9	6 741.17	6 119.81	79.82	5 380.80	4 884.83	495.97
10	6 913.37	6 646.34	54.92	3 796.82	3 650.17	146.65
11	7 286.00	7 207.60	54.92	4 001.47	3 958.41	43.06
12	7 516.09	7 561.57	54.92	4 127.84	4 152.81	−24.98
13	7 751.86	7 831.32	54.92	4 257.32	4 300.96	−43.64
14	7 758.30	7 884.25	54.92	4 260.86	4 330.03	−69.17
15	7 760.16	7 986.98	54.92	4 261.88	4 386.45	−124.57
16	7 543.88	8 014.51	54.92	4 143.10	4 401.57	−258.47
17	7 155.87	6 396.26	54.92	3 930.00	3 512.83	417.18
18	7 080.59	797.64	79.82	5 651.73	636.67	5 015.05

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
19	7 116.75	296.51	79.82	5 680.59	236.67	5 443.92
20	7 039.87	4 910.51	54.92	3 866.30	2 696.85	1 169.45
21	7 037.56	7 668.63	54.92	3 865.03	4 211.61	−346.58
22	6 951.91	7 975.31	34.85	2 422.74	2 779.40	−356.66
23	6 994.52	7 688.55	34.85	2 437.59	2 679.46	−241.87
0	7 134.63	7 281.32	34.85	2 486.42	2 537.54	−51.12
				R91 249.02	R78 248.06	**R13 000.96**

The EN (system) for PA2

Figure 50 shows the EN (system) profiles for PA2.

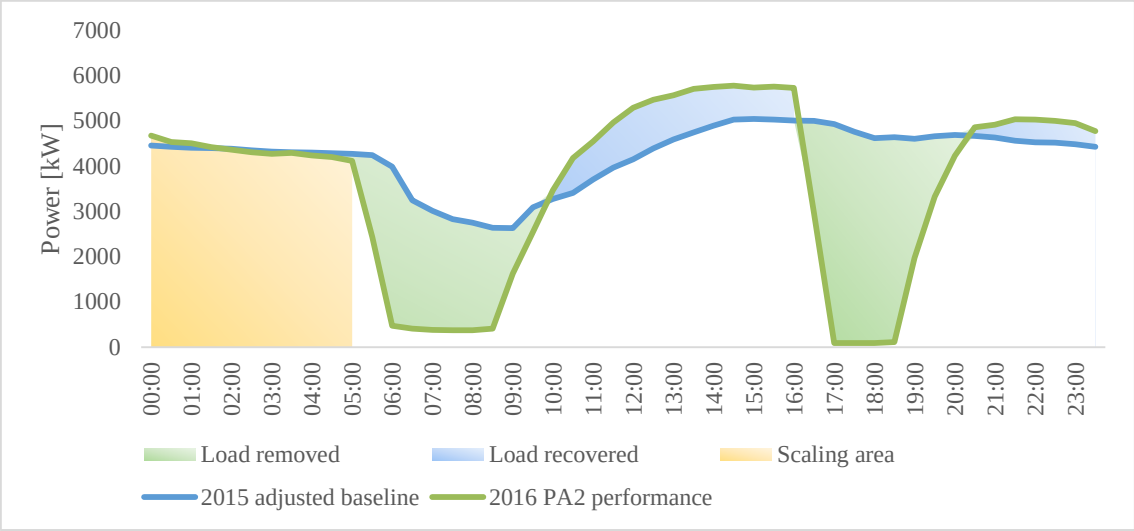


Figure 50: EN (system) profiles for PA2

The average winter morning peak reduction (06:00–09:00), evening peak reduction (17:00–19:00) and average daily electricity savings for the EN (system) model are:

- Average daily recovery energy: 6 929.54 kWh
- Average daily morning peak reduction: 2 673.44 kW
- Average daily evening peak reduction: 4 235.50 kW
- Average daily consumption reduction: 15 487.70 kWh

Table 29 shows the calculated average daily cost savings for the EN (system) baseline model for PA2

Table 29: Average daily cost savings EN (system) baseline model PA2

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	4 400.43	4 457.09	40.25	1 771.18	1 793.98	−22.80
2	4 364.02	4 333.09	40.25	1 756.52	1 744.07	12.45
3	4 310.57	4 278.81	40.25	1 735.00	1 722.22	12.78
4	4 287.85	4 214.88	40.25	1 725.86	1 696.49	29.37

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
5	4 255.23	3 271.91	40.25	1 712.73	1 316.94	395.79
6	3 616.86	438.38	244.68	8 849.72	1 072.63	7 777.10
7	2 919.00	376.55	244.68	7 142.22	921.34	6 220.88
8	2 692.24	392.85	244.68	6 587.36	961.22	5 626.14
9	2 858.75	2 085.79	74.11	2 118.62	1 545.78	572.84
10	3 342.00	3 819.79	74.11	2 476.75	2 830.85	−354.09
11	3 835.58	4 753.96	74.11	2 842.55	3 523.16	−680.61
12	4 270.12	5 376.30	74.11	3 164.58	3 984.38	−819.80
13	4 665.11	5 634.56	74.11	3 457.31	4 175.77	−718.46
14	4 956.33	5 761.71	74.11	3 673.13	4 270.00	−596.87
15	5 035.29	5 741.94	74.11	3 731.65	4 255.35	−523.70
16	4 998.22	4 338.28	74.11	3 704.18	3 215.10	489.08
17	4 840.69	89.32	244.65	11 842.75	218.52	11 624.24
18	4 627.75	102.48	244.65	11 321.79	250.72	11 071.08
19	4 627.31	2 648.52	74.11	3 429.30	1 962.82	1 466.48
20	4 676.78	4 542.71	74.11	3 465.96	3 366.60	99.36
21	4 593.23	4 974.24	74.11	3 404.04	3 686.41	−282.37
22	4 520.07	5 009.36	40.25	1 819.33	2016.27	−196.94
23	4 454.35	4 858.69	40.25	1 792.88	1 955.62	−162.74
0	4 440.06	4 598.93	40.25	1 787.12	1 851.07	−63.95
				R95 312.54	R54 337.29	**R40 975.25**

The LS (FP) & EN (CA) for PA1

Figure 51 shows the profiles of LS (FP) & EN (CA) for PA1.

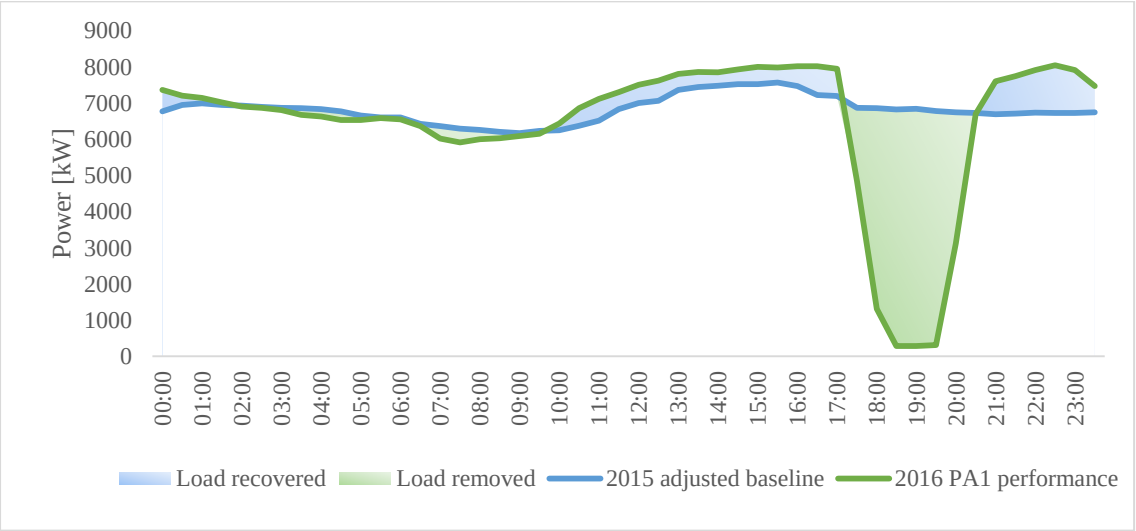


Figure 51: LS (FP) & EN (CA) profiles for PA1

The average summer evening peak period (18:00–20:00) reduction and project impact for the LS (FP) & EN (CA) model are:

- Average daily recovery energy: 7 426.32 kWh
- Average daily evening peak reduction: 6 821.76 kW
- Average daily consumption decrease: 9 125.36 kWh

Table 30 shows the calculated average daily cost savings for the LS (FP) & EN (CA) baseline model for PA1

Table 30: Average daily cost savings LS (FP) & EN (CA) baseline model PA1

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	6 966.86	7 078.93	34.85	2 427.95	2 467.01	−39.06
2	6 910.85	6 883.60	34.85	2 408.43	2 398.94	9.50
3	6 864.05	6 733.69	34.85	2 392.12	2 346.69	45.43
4	6 797.63	6 578.17	34.85	2 368.97	2 292.49	76.48
5	6 623.56	6 554.45	34.85	2 308.31	2 284.23	24.08
6	6 510.55	6 452.46	54.92	3 575.60	3 543.69	31.91
7	6 326.88	5 963.60	79.82	5 050.12	4 760.15	289.97
8	6 231.92	6 011.78	79.82	4 974.32	4 798.60	175.71
9	6 199.76	6 119.81	79.82	4 948.65	4 884.83	63.82
10	6 306.62	6 646.34	54.92	3 463.59	3 650.17	−186.57
11	6 672.22	7 207.60	54.92	3 664.38	3 958.41	−294.03
12	7 029.67	7 561.57	54.92	3 860.70	4 152.81	−292.12
13	7 399.34	7 831.32	54.92	4 063.72	4 300.96	−237.24
14	7 497.99	7 884.25	54.92	4 117.89	4 330.03	−212.13
15	7 541.57	7 986.98	54.92	4 141.83	4 386.45	−244.62
16	7 343.11	8 014.51	54.92	4 032.84	4 401.57	−368.73
17	7 031.87	6 396.26	54.92	3 861.90	3 512.83	349.08
18	6 836.92	797.64	79.82	5 457.23	636.67	4 820.56
19	6 806.60	296.51	79.82	5 433.03	236.67	5 196.36
20	6 734.46	4 910.51	54.92	3 698.57	2 696.85	1 001.71
21	6 698.55	7 668.63	54.92	3 678.84	4 211.61	−532.77
22	6 728.85	7 975.31	34.85	2 345.00	2 779.40	−434.39
23	6 732.34	7 688.55	34.85	2 346.22	2 679.46	−333.24
0	6 856.96	7 281.32	34.85	2 389.65	2 537.54	−147.89
				R87 009.87	R78 248.06	**R8 761.81**

The LS (FP) & EN (CA) PA2

Figure 52 shows the profiles of LS (FP) & EN (CA) for PA2.

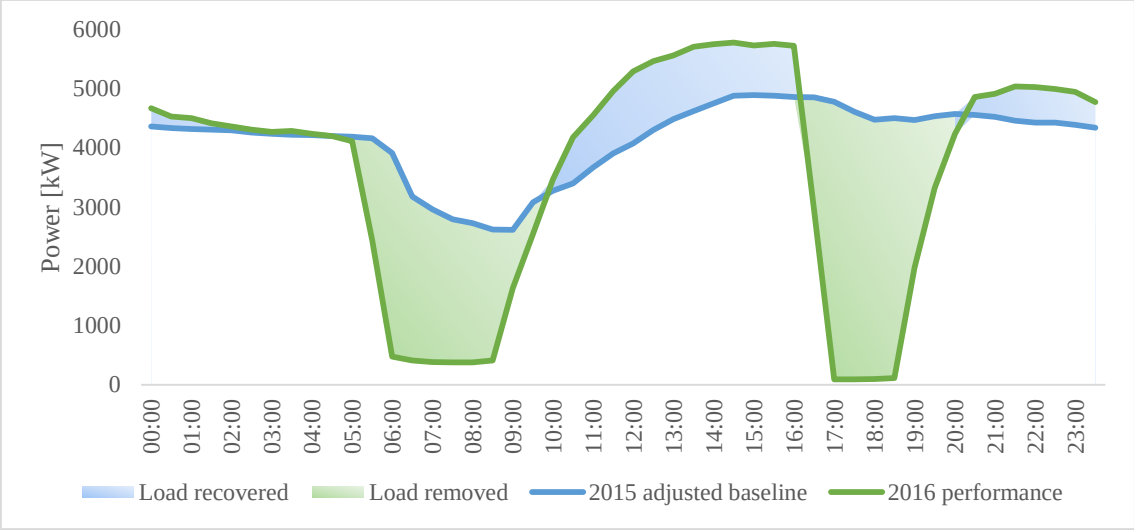


Figure 52: LS (FP) & EN (CA) profiles for PA2

The average winter morning peak reduction (06:00–09:00), evening peak reduction (17:00–19:00) and average daily electricity savings for the LS (FP) & EN (CA) model are:

- Average daily morning peak reduction: 2 673.44 kW
- Average daily evening peak reduction: 4 235.50 kW
- Average daily consumption reduction: 15 487.70 kWh

Table 31 shows the calculated average daily cost savings for the LS (FP) & EN (CA) baseline model for PA2

Table 31: Average daily cost savings LS (FP) & EN (CA) baseline model PA2

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	4 310.65	4 457.09	40.25	1 735.04	1 793.98	−58.94
2	4 277.54	4 333.09	40.25	1 721.71	1 744.07	−22.36
3	4 227.86	4 278.81	40.25	1 701.71	1 722.22	−20.51
4	4 206.42	4 214.88	40.25	1 693.09	1 696.49	−3.40
5	4 175.34	3 271.91	40.25	1 680.58	1 316.94	363.63
6	3 545.61	438.38	244.68	8 675.41	1 072.63	7 602.78
7	2 876.41	376.55	244.68	7 038.00	921.34	6 116.66
8	2 674.39	392.85	244.68	6 543.70	961.22	5 582.48
9	2 848.11	2 085.79	74.11	2 110.73	1 545.78	564.95
10	3 335.49	3 819.79	74.11	2 471.93	2 830.85	−358.91
11	3 785.21	4 753.96	74.11	2 805.22	3 523.16	−717.94
12	4 189.00	5 376.30	74.11	3 104.47	3 984.38	−879.91
13	4 551.03	5 634.56	74.11	3 372.77	4 175.77	−803.00
14	4 815.02	5 761.71	74.11	3 568.41	4 270.00	−701.60
15	4 885.91	5 741.94	74.11	3 620.94	4 255.35	−634.41
16	4 855.44	4 338.28	74.11	3 598.36	3 215.10	383.27
17	4 693.03	89.32	244.65	11 481.50	218.52	11 262.98
18	4 488.70	102.48	244.65	10 981.60	250.72	10 730.88
19	4 500.15	2 648.52	74.11	3 335.06	1 962.82	1 372.25
20	4 562.18	4 542.71	74.11	3 381.03	3 366.60	14.43
21	4 489.66	4 974.24	74.11	3 327.28	3 686.41	−359.13
22	4 423.93	5 009.36	40.25	1 780.63	2016.27	−235.63
23	4 363.58	4 858.69	40.25	1 756.34	1 955.62	−199.28
0	4 348.05	4 598.93	40.25	1 750.09	1 851.07	−100.98
				R93 235.61	R54 337.29	**R38 898.32**

The single variable (dry-bulb) regression baseline model for PA1 and PA2

Figure 53 shows the developed single variable regression model developed, for PA1, with assuming that the independent variable is the daily average environmental dry-bulb temperature. The model does not meet the minimum recommended R^2 value of 0.75 and also has a lower reported R^2 value to the model developed for the daily average environmental wet-bulb temperature.

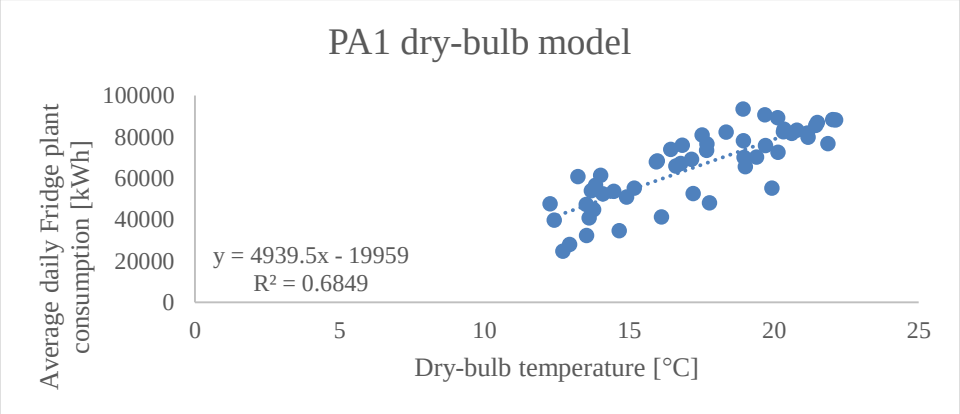


Figure 53: Single variable (dry-bulb) regression baseline model for PA1

Figure 54 shows the developed single variable regression model developed, for PA2, with assuming that the independent variable is the daily average environmental dry-bulb temperature. The model does not meet the minimum recommended R^2 value of 0.75 and also has a lower reported R^2 value to the model developed for the daily average environmental wet-bulb temperature.

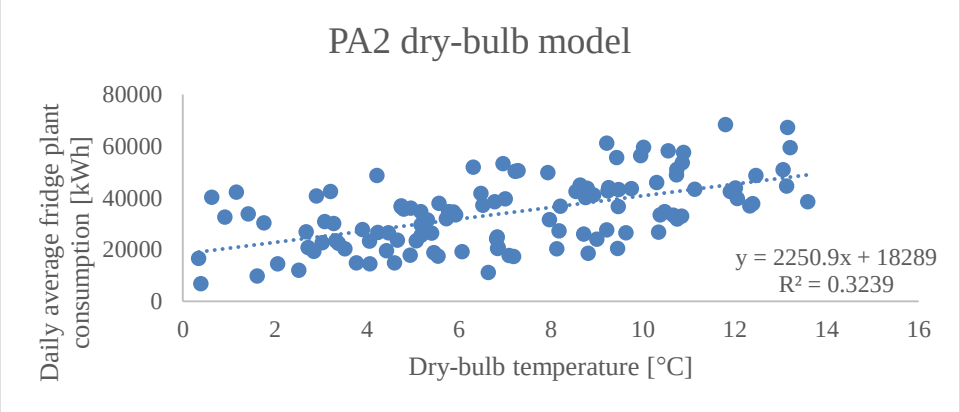


Figure 54: Single variable (dry-bulb) regression baseline model for PA2

The single variable regression model (WB) for PA1

Figure 55 shows the single variable regression baseline model for PA

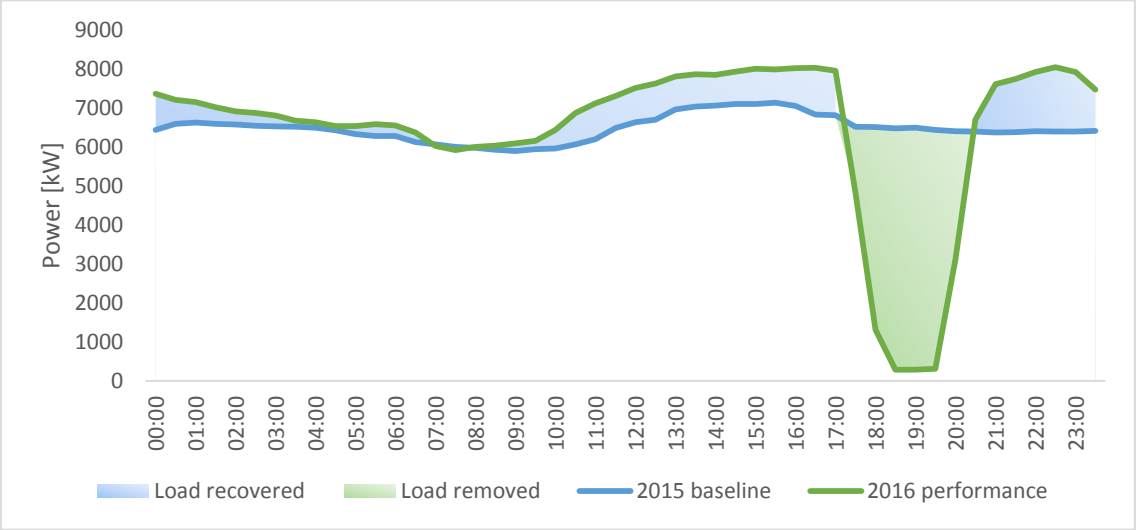


Figure 55: Single variable regression model for PA1

The average summer evening peak period (18:00–20:00) reduction and project impact for the single variable (WB) regression model are:

- Average daily recovery energy: 13 090.70 kWh
- Average daily evening peak reduction: 5 923.73 kW
- Average daily consumption decrease: 766.08 kWh

Table 32 shows the calculated average daily cost savings for the Single variable regression baseline model for PA1

Table 32: Average daily cost savings Single variable regression baseline model PA1

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	6 604.76	7 078.93	34.85	2 301.76	2 467.01	−165.25
2	6 554.32	6 883.60	34.85	2 284.18	2 398.94	−114.75
3	6 512.50	6 733.69	34.85	2 269.60	2 346.69	−77.09
4	6 455.12	6 578.17	34.85	2 249.61	2 292.49	−42.88
5	6 297.07	6 554.45	34.85	2 194.53	2 284.23	−89.70
6	6 195.78	6 452.46	54.92	3 402.72	3 543.69	−140.97
7	6 030.55	5 963.60	79.82	4 813.59	4 760.15	53.44
8	5 943.80	6 011.78	79.82	4 744.34	4 798.60	−54.27
9	5 913.25	6 119.81	79.82	4 719.96	4 884.83	−164.87
10	6 008.54	6 646.34	54.92	3 299.89	3 650.17	−350.28
11	6 335.19	7 207.60	54.92	3 479.28	3 958.41	−479.13
12	6 658.56	7 561.57	54.92	3 656.88	4 152.81	−495.93
13	6 988.65	7 831.32	54.92	3 838.17	4 300.96	−462.79
14	7 076.82	7 884.25	54.92	3 886.59	4 330.03	−443.44
15	7 113.48	7 986.98	54.92	3 906.72	4 386.45	−479.73
16	6 936.04	8 014.51	54.92	3 809.27	4 401.57	−592.30
17	6 661.93	6 396.26	54.92	3 658.73	3 512.83	145.91
18	6 484.54	797.64	79.82	5 175.96	636.67	4 539.29

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
19	6 457.07	296.51	79.82	5 154.03	236.67	4 917.36
20	6 395.55	4 910.51	54.92	3 512.43	2 696.85	815.58
21	6 367.03	7 668.63	54.92	3 496.77	4 211.61	−714.84
22	6 394.26	7 975.31	34.85	2 228.40	2 779.40	−551.00
23	6 397.41	7 688.55	34.85	2 229.50	2 679.46	−449.96
0	6 507.64	7 281.32	34.85	2 267.91	2 537.54	−269.63
				R82 580.85	R78 248.06	**R4 332.78**

The single variable (WB) regression model for PA2

Figure 56 shows the single variable regression baseline model for PA2.

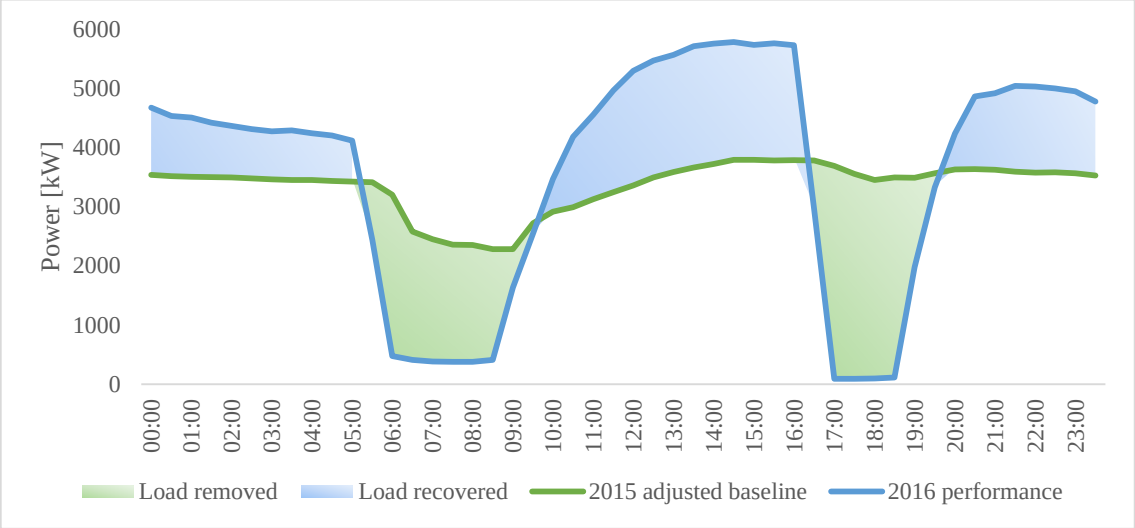


Figure 56: Single variable regression baseline model for PA2

The average winter morning peak reduction (06:00–09:00), evening peak reduction (17:00–19:00) and average daily electricity savings for the single variable (WB) regression model are:

- Average daily morning peak reduction: 2 131.75 kW
- Average daily evening peak reduction: 3 446.45 kW
- Average daily consumption reduction: −5 754.39 kWh
- Average daily recovery energy: 21 230.28 kWh

Table 33 shows the calculated average daily cost savings for the Single variable regression baseline model for PA2

Table 33: Average daily cost savings Single variable regression baseline model PA2

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	3 497.97	4 457.09	40.25	1 407.93	1 793.98	−386.05
2	3 481.16	4 333.09	40.25	1 401.17	1 744.07	−342.90
3	3 451.29	4 278.81	40.25	1 389.14	1 722.22	−333.08
4	3 437.13	4 214.88	40.25	1 383.45	1 696.49	−313.04

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
5	3 415.30	3 271.91	40.25	1 374.66	1 316.94	57.71
6	2 887.17	438.38	244.68	7 064.32	1 072.63	5 991.69
7	2 400.52	376.55	244.68	5 873.59	921.34	4 952.25
8	2 315.33	392.85	244.68	5 665.14	961.22	4 703.92
9	2 497.76	2 085.79	74.11	1 851.09	1 545.78	305.31
10	2 948.06	3 819.79	74.11	2 184.81	2 830.85	−646.04
11	3 180.75	4 753.96	74.11	2 357.26	3 523.16	−1 165.90
12	3 422.79	5 376.30	74.11	2 536.63	3 984.38	−1 447.75
13	3 619.10	5 634.56	74.11	2 682.11	4 175.77	−1 493.66
14	3 749.99	5 761.71	74.11	2 779.12	4 270.00	−1 490.89
15	3 782.24	5 741.94	74.11	2 803.02	4 255.35	−1 452.33
16	3 780.39	4 338.28	74.11	2 801.65	3 215.10	−413.45
17	3 616.91	89.32	244.65	8 848.78	218.52	8 630.26
18	3 467.79	102.48	244.65	8 483.94	250.72	8 233.23
19	3 523.63	2 648.52	74.11	2 611.36	1 962.82	648.55
20	3 627.03	4 542.71	74.11	2 687.99	3 366.60	−678.61
21	3 604.67	4 974.24	74.11	2 671.42	3 686.41	−1 014.99
22	3 574.60	5 009.36	40.25	1 438.77	2016.27	−577.49
23	3 541.37	4 858.69	40.25	1 425.40	1 955.62	−530.22
0	3 522.78	4 598.93	40.25	1 417.92	1 851.07	−433.15
				R75 140.67	R54 337.29	**R20 803.38**

The TSM for PA1

Figure 57 shows the profile of the TSM adjusted baseline model for PA1.

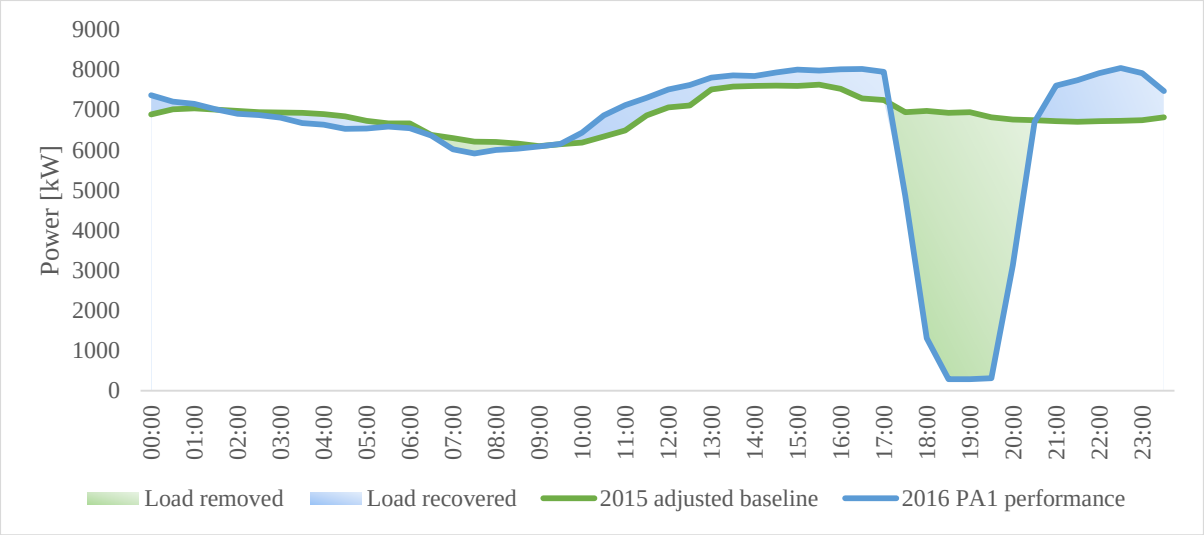


Figure 57: Profile for TSM PA1

The average summer evening peak period (18:00–20:00) reduction and project impact for the TSM are:

- Average daily recovery energy: 9 980.32 kWh
- Average daily evening peak reduction: 6 125.68 kW
- Average daily consumption decrease: 5 315.65 kWh

Table 34 shows the calculated average daily cost savings for the TSM baseline model for PA1

Table 34: Average daily cost savings TSM baseline model PA1

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	6 801.89	7 078.93	34.85	2 370.46	2 467.01	−96.55
2	6 747.55	6 883.60	34.85	2 351.52	2 398.94	−47.42
3	6 706.19	6 733.69	34.85	2 337.11	2 346.69	−9.59
4	6 645.55	6 578.17	34.85	2 315.98	2 292.49	23.48
5	6 481.23	6 554.45	34.85	2 258.71	2 284.23	−25.52
6	6 364.90	6 452.46	54.92	3 495.61	3 543.69	−48.09
7	6 178.83	5 963.60	79.82	4 931.94	4 760.15	171.80
8	6 091.41	6 011.78	79.82	4 862.16	4 798.60	63.56
9	6 056.27	6 119.81	79.82	4 834.11	4 884.83	−50.72
10	6 161.31	6 646.34	54.92	3 383.79	3 650.17	−266.38
11	6 512.68	7 207.60	54.92	3 576.76	3 958.41	−381.65
12	6 859.42	7 561.57	54.92	3 767.19	4 152.81	−385.62
13	7 221.08	7 831.32	54.92	3 965.82	4 300.96	−335.14
14	7 307.81	7 884.25	54.92	4 013.45	4 330.03	−316.58
15	7 343.06	7 986.98	54.92	4 032.81	4 386.45	−353.64
16	7 156.24	8 014.51	54.92	3 930.21	4 401.57	−471.36
17	6 866.61	6 396.26	54.92	3 771.14	3 512.83	258.31
18	6 689.94	797.64	79.82	5 339.91	636.67	4 703.24
19	6 655.57	296.51	79.82	5 312.47	236.67	5 075.80
20	6 580.75	4 910.51	54.92	3 614.15	2 696.85	917.30
21	6 547.98	7 668.63	54.92	3 596.15	4 211.61	−615.46
22	6 573.35	7 975.31	34.85	2 290.81	2 779.40	−488.58
23	6 583.61	7 688.55	34.85	2 294.39	2 679.46	−385.07
0	6 706.22	7 281.32	34.85	2 337.12	2 537.54	−200.42
				R84 983.76	R78 248.06	**R6 735.70**

The TSM for PA2

Figure 58 shows the profiles of TSM for PA2.

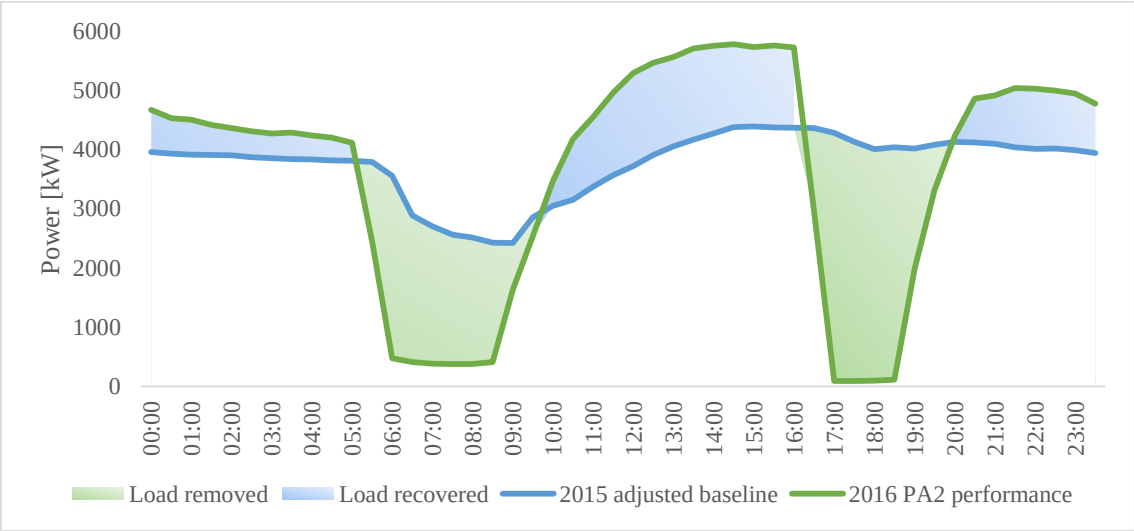


Figure 58: Profile for TSM PA2

The average winter morning peak reduction (06:00–09:00), evening peak reduction (17:00–19:00) and average daily electricity savings for the TSM are:

- Average daily recovery energy: 3 813.29 kWh
- Average daily morning peak reduction: 2 884.13 kW
- Average daily evening peak reduction: 5 032.30 kW
- Average daily consumption decrease: 11 310.46 kWh

Table 35 shows the calculated average daily cost savings for the TSM baseline model for PA2

Table 35: Average daily cost savings TSM baseline model PA2

Hour	Model [kW]	Actual [kW]	Cost [c/kWh]	Model cost [ZAR]	Actual cost [ZAR]	Saving [ZAR]
1	3 910.62	4 457.09	40.25	1 574.02	1 793.98	−219.96
2	3 884.61	4 333.09	40.25	1 563.56	1 744.07	−180.51
3	3 843.03	4 278.81	40.25	1 546.82	1 722.22	−175.40
4	3 823.24	4 214.88	40.25	1 538.85	1 696.49	−157.64
5	3 796.06	3 271.91	40.25	1 527.91	1 316.94	210.97
6	3 219.89	438.38	244.68	7 878.42	1 072.63	6 805.80
7	2 628.31	376.55	244.68	6 430.94	921.34	5 509.60
8	2 467.82	392.85	244.68	6 038.25	961.22	5 077.03
9	2 638.11	2 085.79	74.11	1 955.10	1 545.78	409.32
10	3 097.22	3 819.79	74.11	2 295.35	2 830.85	−535.50
11	3 468.66	4 753.96	74.11	2 570.63	3 523.16	−952.53
12	3 810.80	5 376.30	74.11	2 824.18	3 984.38	−1 160.20
13	4 109.53	5 634.56	74.11	3 045.57	4 175.77	−1 130.20
14	4 323.22	5 761.71	74.11	3 203.94	4 270.00	−1 066.07
15	4 379.71	5 741.94	74.11	3 245.81	4 255.35	−1 009.55
16	4 361.26	4 338.28	74.11	3 232.13	3 215.10	17.04
17	4 202.76	89.32	244.65	10 282.06	218.52	10 063.55
18	4 020.82	102.48	244.65	9 836.94	250.72	9 586.23
19	4 046.38	2 648.52	74.11	2 998.77	1 962.82	1 035.96
20	4 120.23	4 542.71	74.11	3 053.50	3 366.60	−313.10
21	4 064.12	4 974.24	74.11	3 011.92	3 686.41	−674.49
22	4 011.29	5 009.36	40.25	1 614.54	2016.27	−401.72
23	3 962.03	4 858.69	40.25	1 594.72	1 955.62	−360.91
0	3 942.84	4 598.93	40.25	1 586.99	1 851.07	−264.07
				R84 450.94	R54 337.29	**R30 113.65**

Fridge plant performance for PA1

Figure 59 shows the fridge plant performance for PA1.

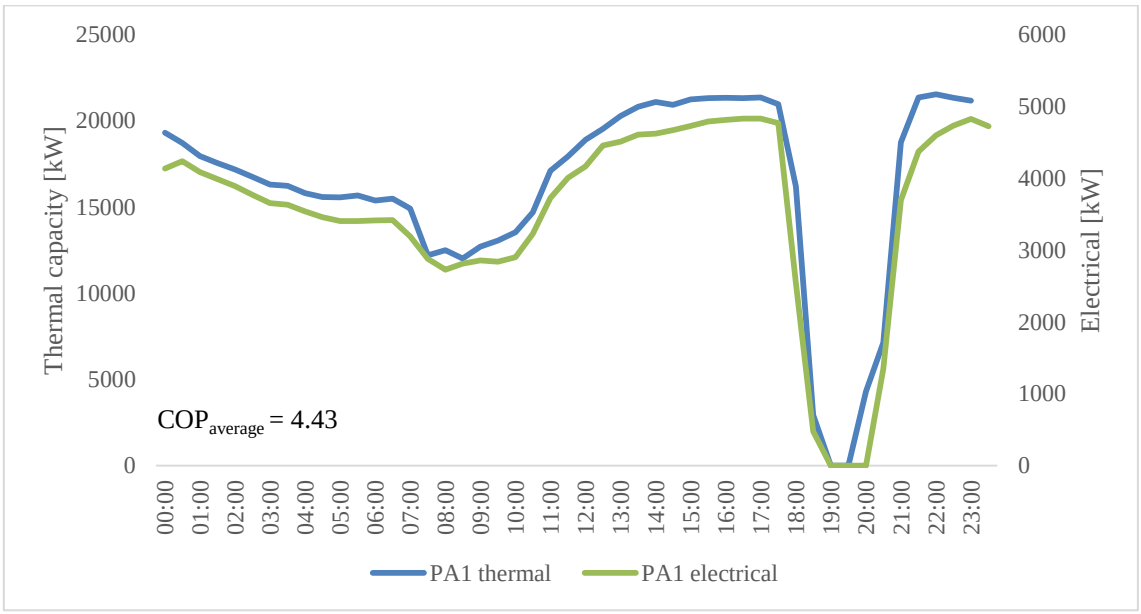


Figure 59: Fridge plant performance for PA1

Fridge plant performance for PA2

Figure 60 shows the fridge plant performance for PA2.

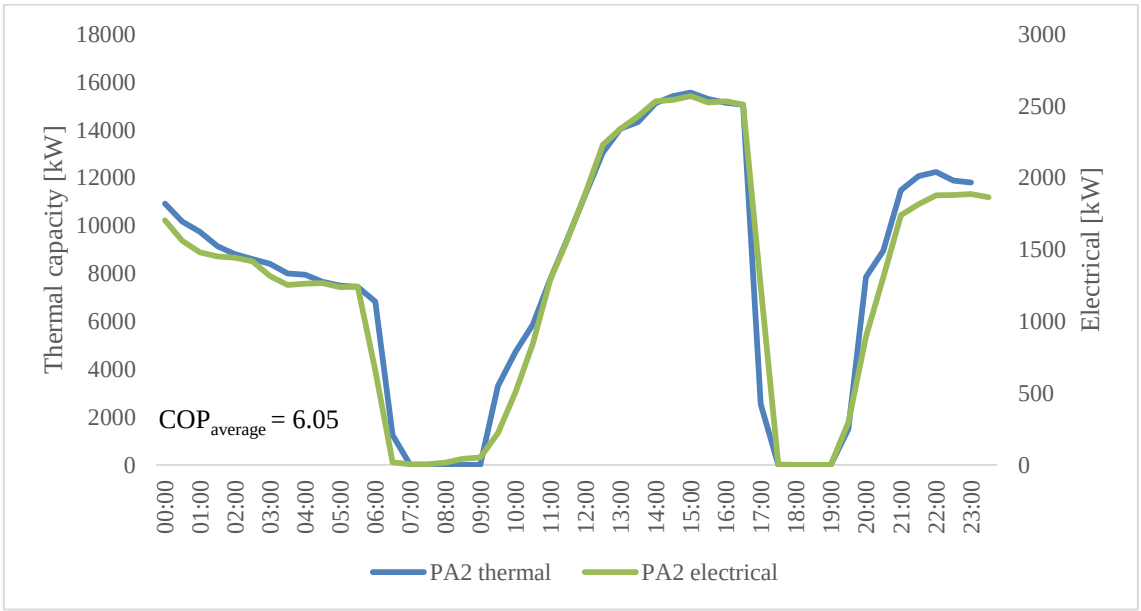


Figure 60: Fridge plant performance for PA2

Constant inlet assumption additional work for PA1

Figure 61 shows the constant inlet assumption for PA1.

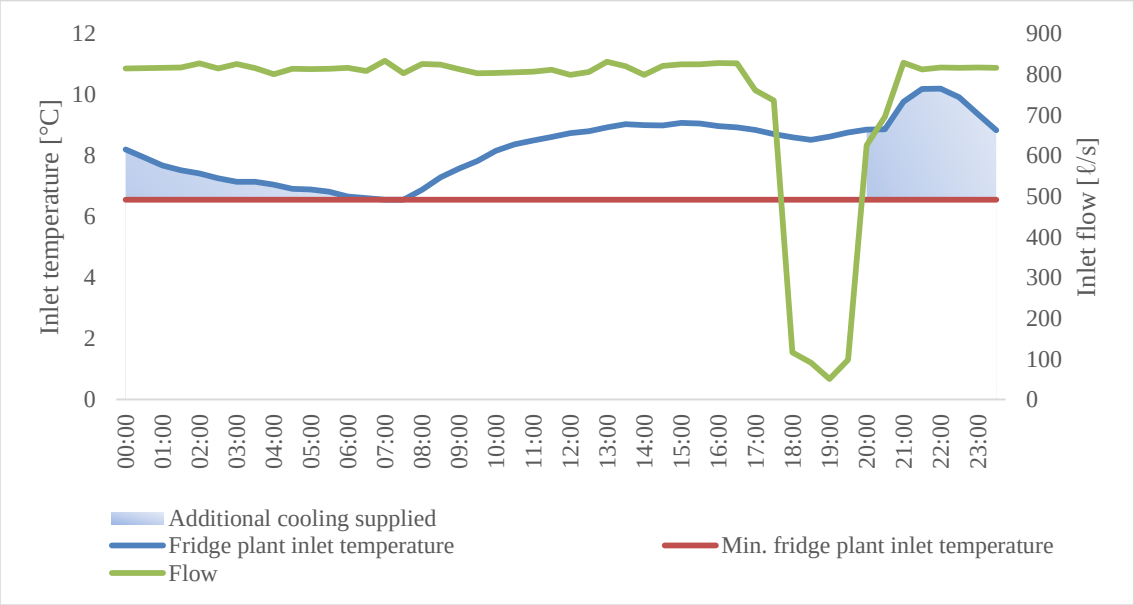


Figure 61: Constant inlet assumption for PA1

Baseline inlet assumption additional work for PA1

Figure 62 shows the baseline inlet assumption for PA1.

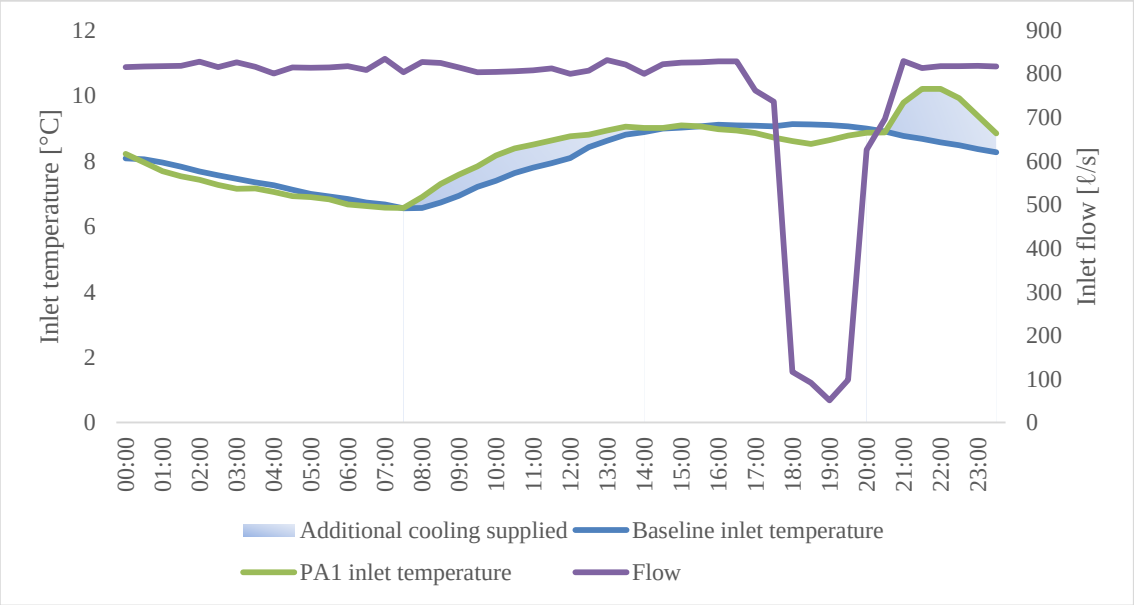


Figure 62: Baseline inlet assumption for PA1

Constant inlet assumption additional work for PA2

Figure 63 shows the constant inlet assumption for PA2.

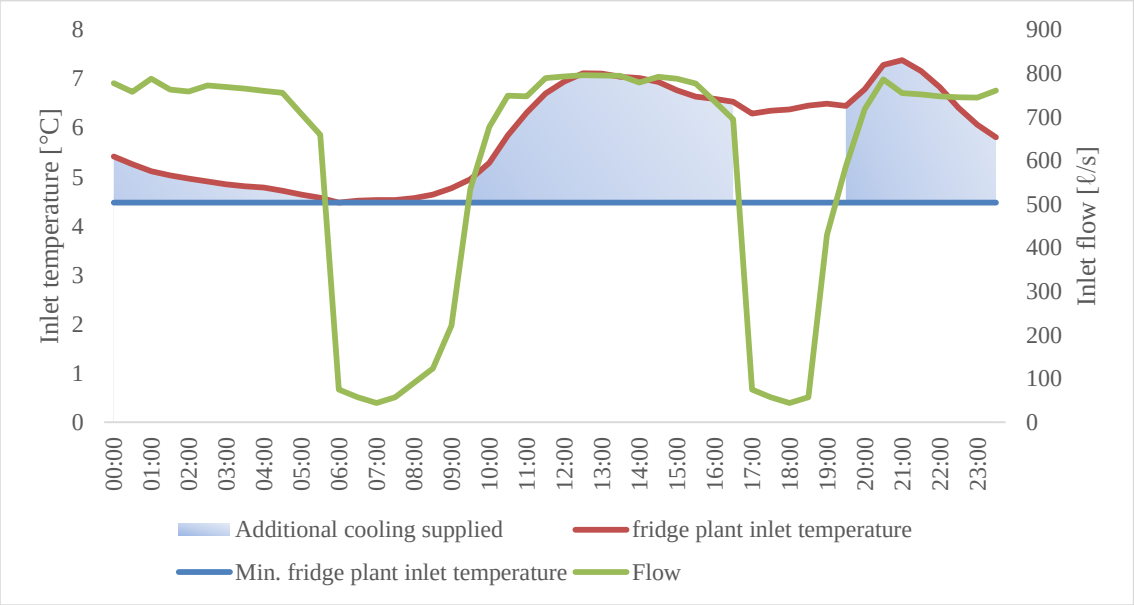


Figure 63: Constant inlet assumption for PA2

Baseline inlet assumption additional work for PA2

Figure 64 shows the baseline inlet assumption for PA2.

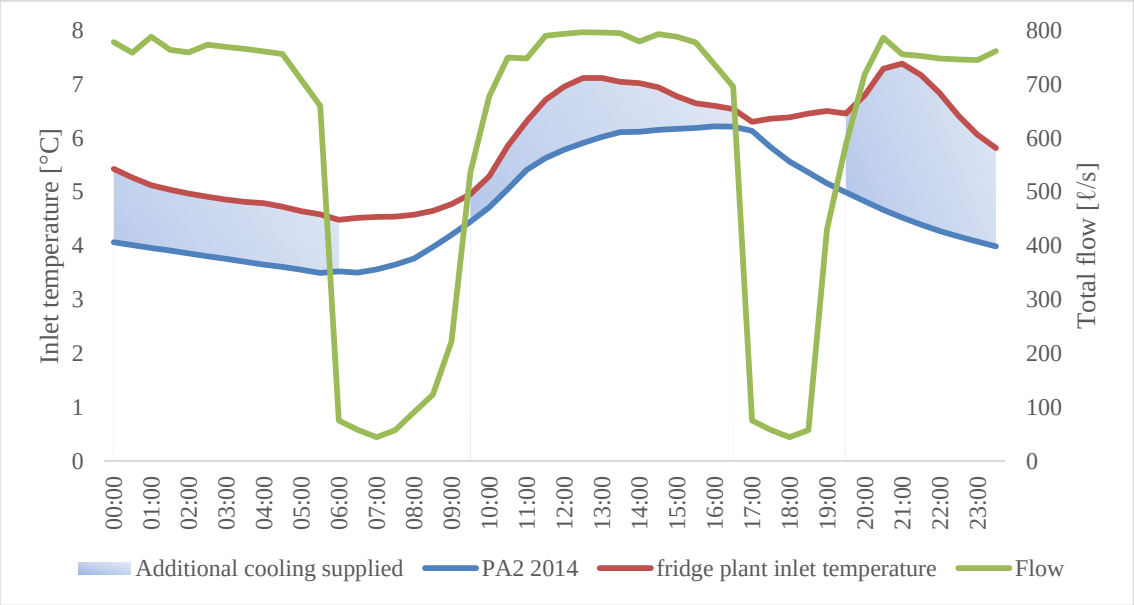


Figure 64: Baseline inlet assumption for PA2

Figure 65 shows the baseline inlet assumption for PA1.

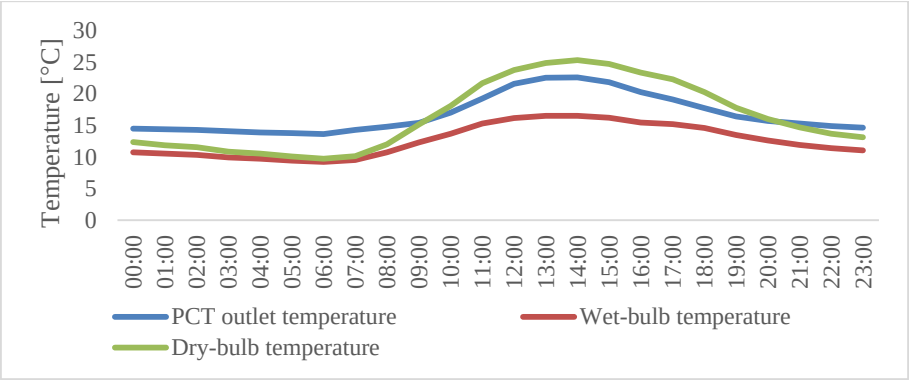


Figure 65: PCT performance during PA1

Figure 65 shows the baseline inlet assumption for PA2.

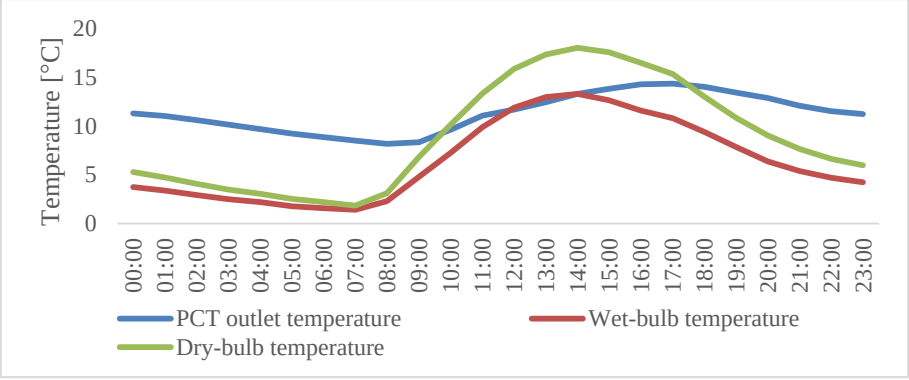


Figure 66: PCT performance during PA2