



Electrical energy cost improvement of platinum concentrator blower systems

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ABSTRACT

Title: Electrical energy cost improvement of platinum concentrator blower systems

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Keywords: Platinum, concentrators, blowers, positive-displacement, centrifugal, DSM, simulation, electricity, methodology development

This research addresses the critical need for electrical energy efficiency within the South African platinum mining industry, where processing plants account for approximately 19% of total electricity consumption. Despite the sector's economic significance, rising Eskom tariffs and declining production have placed operations under severe financial pressure. While demand-side management initiatives have historically focused on mining shafts and cooling systems, auxiliary blower systems in concentrator plants have remained largely underexplored. These systems often operate as significant base-load consumers with substantial inherent inefficiencies, primarily due to a lack of structured methodologies for aligning air supply with the dynamic requirements of continuous flotation processes. Consequently, this study develops and validates a systematic four-phase methodology comprising data acquisition, analysis, simulation modelling, and implementation, to identify and capture electricity cost-saving opportunities in these systems.

The methodology was applied across four distinct case studies encompassing both positive displacement and centrifugal blower configurations. Comprehensive analysis revealed that historical blower operation was characterised by significant oversupply, with air production consistently exceeding flotation cell demand by 20–50%. This resulted in excess air being vented to atmosphere through blow-off valves whilst maintaining full energy consumption, representing substantial electrical energy wastage. According to various literature reviews conducted, the blow-off valve position serves as a valuable indicator of system oversupply, though direct quantification of wasted air volume remained constrained by the absence of accurate compressed air flow instrumentation.

Simulation using Process Toolbox software achieved calibration accuracy within 5% of actual system performance, enabling safe evaluation of operational scenarios without causing a disruption in production. Empirical validation proved to be a critical component of this study. In Case Study A and B, initial theoretical calculations proved inadequate, as subsequent testing revealed that additional blowers were required to maintain the pressure setpoint. This discrepancy

was primarily due to system leaks and the degradation of key components, highlighting the necessity of experimental verification to account for real-world conditions that theory alone cannot predict. Case Study C yielded the highest absolute savings through the discovery that several installed motors differed from their nameplate specifications by up to 75 kW. This discrepancy, identified during the system audit, allowed for the development of a revised, improved sequencing strategy based on actual motor power ratings rather than theoretical data. By prioritising the operation of smaller, more efficient units, the plant successfully reduced energy consumption while meeting all process requirements. Case Study D demonstrated that by restoring the surge control protection to manufacturer specifications, both system stability and efficiency were significantly improved within the centrifugal blower systems.

The methodology achieved combined energy cost savings exceeding R4 million across the four case studies annually, ranging from R160 000 to R2 million per site. These energy cost savings were realised through reduced blower utilisation, improved sequencing based on motor efficiency, pressure setpoint optimisation, and restoration of manufacturer design specifications.

Ultimately, the findings validate that systematic optimisation can mitigate the prevalent air oversupply in platinum concentrators without compromising production stability or recovery. The study establishes a structured framework for identifying inefficiencies that is transferable to broader minerals-processing applications, including gold and copper flotation. Future opportunities identified include the integration of automated control systems with variable frequency drives and the expansion of the methodology to encompass demand-side flotation air optimisation.

PUBLICATIONS

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LIST OF ABBREVIATIONS

DSM	Demand side management
GDP	Gross domestic product
ISO	International organisation for standardisation
KPI	Key performance indicator
kW	kilowatt
MW	Megawatt
MWh	Megawatt hour
NWU	North-West University
OEM	Original equipment manufacturer
PGM	Platinum group metal
PI	Proportional integral
PRV	Pressure relief valve
PTB	Process Toolbox
SCADA	Supervisory control and data acquisition
SP	Setpoint
VFD	Variable frequency drive

NOMENCLATURE

Symbol	Description	Units
P	Power consumption	kW
Δp	Manifold pressure	mbar
Q	Volumetric flow rate	m ³ /min
N	Rotational speed	rpm
m	Slope	-
c	Intercept	-
e_{specific}	Specific electrical energy consumption	kW/(m ³ /min)
η	Efficiency	-

CHAPTER 1 INTRODUCTION

1.1 Context and industry overview

Over 90% of the world's platinum group metal (PGM) reserves are located in South Africa [1], making the country the largest global producer of PGMs, accounting for 70% of the world's refined platinum in 2019 [2]. This industry plays a crucial role in South Africa's economic growth, with PGMs contributing 22% of the country's total mining revenue in 2024 [3].

Despite its critical importance, PGM production declined from 280 tonnes in 2021 following the COVID-19 pandemic, to 240 tonnes in 2024 [4]. The mining sector's contribution to nominal Gross Domestic Product (GDP) has steadily declined since 2022, falling from 7.5% to 6.1% in 2024 [5]. Furthermore, for the first time since 2020, PGMs have been surpassed by coal as the largest contributor to total mining sector sales [4].

Several factors have contributed to this decline, including rising operational expenses, falling mineral prices, and global trade disruptions caused by the COVID-19 pandemic [3-5]. The combination of decreasing production and increasing costs has led to lower profit margins for many mining operations, with some mines being forced to shut down [6].

As price takers, mining companies cannot adjust commodity prices to improve profitability and must instead sell at global market rates. To sustain profitability, PGM mining operations must focus on reducing operational costs [7-9].

A typical South African PGM mining operation's cost breakdown shows that employment benefits and contractor fees are the largest costs due to labour-intensive underground mining methods [7, 10, 11]. The sector employed 471 882 people in Q3 2024, which is a reduction of 9 893 from the start of the same year [4].

South Africa's electricity supply is predominantly provided by Eskom Holdings SOC Ltd, which produces approximately 92% of the country's electricity [12]. The majority of Eskom's generation comes from ageing coal-fired power stations, which constitute the bulk of baseload capacity [13-15]. Reduced plant availability can constrain electricity supply, affecting industrial operations, including platinum processing plants [16-18]. Furthermore, studies report that energy accounts for approximately 15–40% of total operating costs in the mining industry [19]. Energy demand in mining operations is projected to increase by 36% by 2035 relative to 2018 levels due to rising mineral demand and falling ore grades [20]. Eskom tariffs have risen by more than 180% since

2008, emphasising the importance of electricity efficiency to maintain profitability and prevent further job losses [9, 21-23].

1.2 Energy consumption in mining operations

Utilities rank as the third-largest expense in mining operations, following labour and supplies [24]. For platinum mines to maintain financial stability and long-term sustainability, implementing energy-saving measures is essential [25].

Significant efforts have been made to reduce shaft energy consumption through Demand Side Management (DSM) initiatives, such as load shifts and energy efficiency projects [26]. However, processing plants, where approximately 19% of the investigated area's electricity is consumed, have received far less attention in terms of energy cost-saving measures. Despite their substantial contribution to overall energy usage, initiatives aimed at optimising energy efficiency in these facilities remain underexplored [27]. Addressing this gap presents an opportunity to enhance operational efficiency, reduce costs, and improve the sustainability of mining operations. In a typical platinum mining operation, the distribution of electrical energy consumption is dominated by three primary functional areas: materials handling, mineral processing, and compressed air systems. As illustrated in Figure 1-1, these sections represent the most energy-intensive components of the typical mine, collectively accounting for 59% of the total site energy demand.

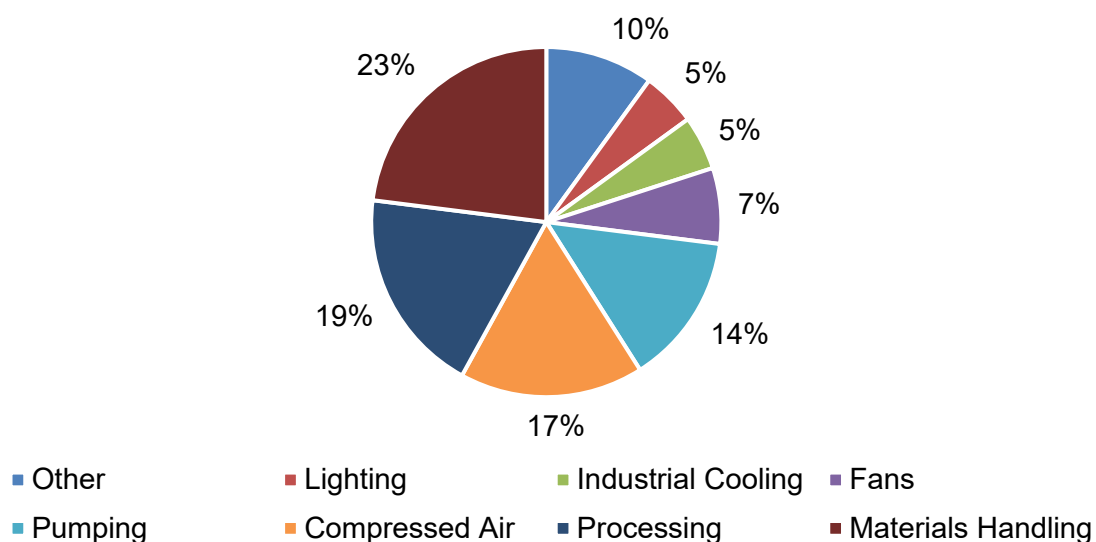


Figure 1-1: Electricity usage breakdown of a typical mining operation [28]

Historically, electricity-saving initiatives have focused on mining operations, including optimisation of pumping schedules and water reticulation systems [29], industrial cooling [30], rock hoisting and material transfer systems [31, 32], and compressed air networks [8, 33].

The reliability and availability of electricity supply from Eskom can impact continuous operations in platinum processing plants. Declining plant availability and ageing baseload infrastructure can result in constrained or less predictable power supply, increasing operational risks and highlighting the importance of internal energy efficiency measures [16-18].

This research gap is likely due to the inherent challenges of implementing energy-saving measures in continuous operations, where process interruptions can lead to production losses and operational inefficiencies [27, 34]. Unlike intermittent processes that allow for flexible energy management strategies, continuous operations require innovative approaches to reduce energy consumption without disrupting production. Addressing this challenge presents a valuable opportunity for the industry to enhance cost efficiency, reduce environmental impact, and improve overall energy management practices in platinum mining.

While the potential is clear, electricity-saving initiatives on processing plants are more complex due to continuous operations, particularly in milling and smelting, which cannot be interrupted without affecting product quality and recovery [27, 34-38]. Auxiliary systems, including agitation, material transfer, compressed air, and pumping systems, do not operate continuously and therefore present opportunities for cost and energy savings [39].

There is significant potential to achieve energy savings by optimising auxiliary systems commonly found in mineral processing plants, including platinum concentrators. Key systems with high energy consumption include compressed air equipment (such as blowers and compressors), material handling systems (e.g. conveyors), and various pumping systems (including sump and tailings pumps) [40]. There have been successful projects on many of these key systems, such as compressors [41, 42].

In addition to compressors, platinum processing plants also utilise blower systems as part of their compressed air infrastructure. One of the primary applications of blowers is in flotation circuits, where they are used to inject air into flotation cells. This aeration promotes the formation of air bubbles, creating the appropriate hydrodynamic conditions for the effective flotation of fine particles [43]. Blowers used in this application typically have motor ratings ranging from 10 kW to 90 kW [34]. A typical blower setup can be seen in Figure 1-2.

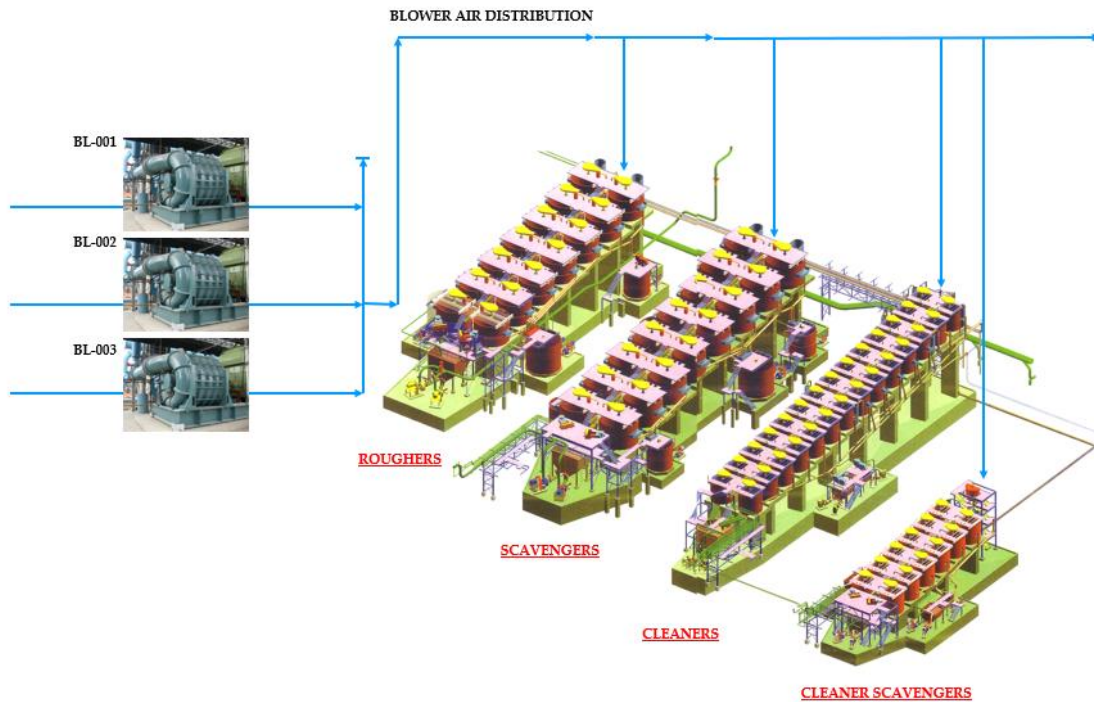


Figure 1-2: Typical flotation air distribution

Blowers are also employed during the matte converting process, where they supply oxygen-enriched air to facilitate the oxidation of sulphur and its removal as sulphur dioxide. The blowers used in this stage are significantly larger than those in flotation circuits, with installed capacities reaching up to 600 kW [44, 45]. Given the critical nature of this process and the severe safety risks associated with matte converting, a thorough investigation is essential before any operational changes are implemented. Owing to their continuous operation and high energy demand, these systems represent a key opportunity for energy savings and performance optimisation in platinum processing operations.

1.3 Literature review

1.3.1 Blowers in platinum concentrators

Literature dedicated specifically to blowers is limited; consequently, they are often discussed in relation to other gas-moving devices such as fans and compressors. Fluid movers are broadly divided into two categories: kinetically driven and positive displacement [46]. Kinetically driven gas-moving devices can be further categorised into single-stage and multi-stage configurations [46]. In kinetically driven devices, energy is imparted to the fluid in the form of velocity, which is subsequently converted into pressure at the outlet. By contrast, positive-displacement devices

trap fixed volumes of low-pressure fluid and forcibly deliver them into a region of higher pressure [47].

Blowers are frequently referred to as fans, although in practice they are more closely aligned with compressors, since both deliver appreciable positive pressure to gases [47]. A device that produces airflow at a moderate pressure is commonly called a blower [48].

For the purposes of this study, two blower types are of primary relevance: the centrifugal blower (a kinetically driven machine) and the rotary lobe blower (a positive-displacement machine). These are considered in greater detail below.

Centrifugal blowers

The operating principle of centrifugal blowers is essentially the same as that of centrifugal compressors [49]. Gas leaving the impeller possesses significant velocity; the casing therefore incorporates a diffuser (static vanes) to convert velocity into static pressure [49], as illustrated in Figure 1-3.

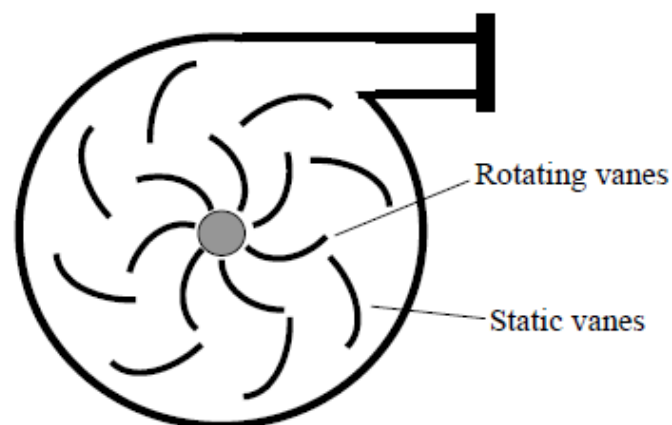


Figure 1-3: Centrifugal compressor/blower with diffuser vanes [47]

Centrifugal machines offer several advantages. They are inherently close to oil-free, can accommodate large capacities, and are often the most economical solution at high flow rates. Indeed, in many high-flow or high-pressure applications, they represent the only practical choice [50]. When other compressors or blowers that can meet the same pressure and flow requirements are available, centrifugal units are usually preferred where a fixed pressure ratio and oil-free gas are essential [50]. Moreover, if centrifugal and reciprocating machines are comparable in capital cost, the centrifugal is generally selected due to its superior reliability and lower life-cycle costs [50].

However, centrifugal blowers are not without limitations. Their initial installed costs are typically higher than those of reciprocating or screw compressors in equivalent pressure–flow ranges. Furthermore, they are less flexible to variations in pressure ratio: capacity decreases significantly if the discharge pressure rises [51].

Multi-stage centrifugal blowers are typically controlled by inlet valve throttling, where the system adjusts the inlet valve to reduce the incoming airflow [52]. In addition to inlet throttling, centrifugal units require surge control to prevent unstable operation. This is achieved by modulating the blow-off valve to maintain motor current at the setpoint, together with guide vane adjustment to ensure constant manifold pressure [53].

Rotary lobe blowers

Rotary lobe blowers are mechanically identical to rotary lobe compressors; the terms are often used interchangeably [47]. While this equivalence might be assumed for centrifugal machines as well, in practice the differences in attainable pressure and flow separate centrifugal blowers from centrifugal compressors.

The discharge flow from a positive displacement blower is generally proportional to its operating speed at a given pressure. For this reason, VFDs and adjustable belts are commonly employed to regulate flow [46, 52]. Positive displacement blowers also offer substantial turndown capability, making them advantageous in plants where initial loads and aeration demands are significantly lower than the design conditions. They are generally most economical for smaller facilities [52].

The operating cycle of a rotary lobe blower is illustrated in Figure 1-4, where the shading intensity of the ellipses represents the pressure magnitude.

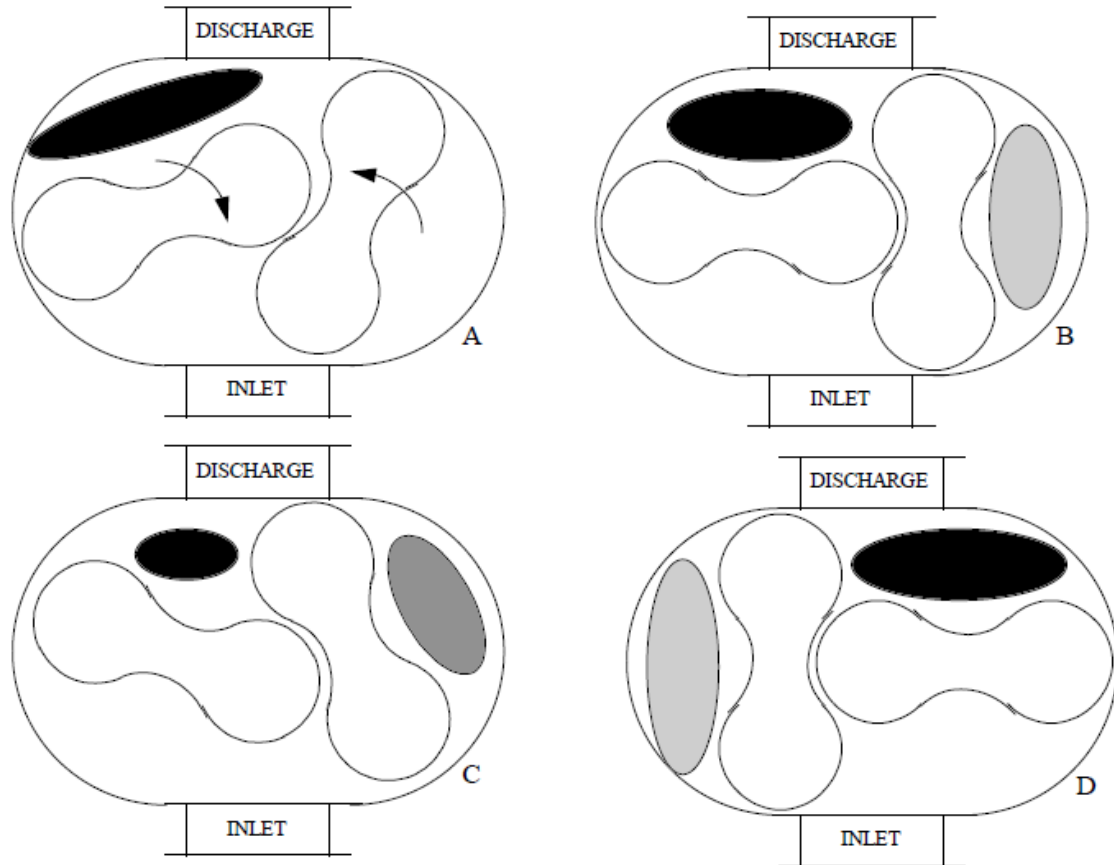


Figure 1-4: Lobe blower/compressor [47]

As the lobes rotate in opposite directions, air is drawn into the inlet (Stage A) and trapped between the lobes and the casing (Stage B). These discrete volumes are transported around the periphery (Stage C) toward the discharge. Unlike internal compression machines, the pressure increases in Stage D when the trapped volume is exposed to the outlet, causing high-pressure air to backflow into the casing before being expelled. This ensures a fixed volume is delivered per revolution regardless of the system pressure. The volume of air within the machine remains constant; the blower simply displaces air from the suction side to the discharge side, working against the resistance of the discharge system [54].

Automated blower control can be achieved through three methods: variable speed drives, maintaining constant airflow, or the use of blow-off valves [46]. While variable speed drives are the preferred technique, the blow-off valve method remains the most common in platinum concentrators. This approach is comparatively simple, with regulation achieved via a blow-off valve on the manifold that maintains line pressure. Without variable speed control, positive displacement blowers operate in a near on–off manner, offering only limited capability for intermediate regulation [55].

Centrifugal and rotary lobe blowers are therefore sufficiently analogous to their compressor counterparts that established air-optimisation strategies can be adapted to their operation [33]. However, the scarcity of published literature specifically addressing energy optimisation in blower systems necessitates this adaptation, as dedicated methodologies for blower operation remain largely undeveloped.

1.3.2 Compressed air energy management in mining operations

Given the similarities between blower air and compressed air systems, and the extensive body of literature available on compressed air systems, this literature was reviewed to identify relevant and applicable information. This approach was taken because there is currently very little literature available specifically focusing on blower systems. Compressed air systems represent one of the most significant energy consumption components in mining operations, with extensive research demonstrating substantial opportunities for operational cost reduction through systematic energy management approaches [56]. The literature reveals consistent potential for annual cost savings ranging from 500 kWh to 86 MWh per annum, depending on the compressed air system, emphasising the economic significance of effective compressed air management strategies in deep-level mining environments [57]. Given the similarities between compressors and blowers, understanding these established energy management principles provides crucial insight for developing a methodology that can assist with optimising and improving the performance of blower systems.

Demand management and wastage reduction approaches

The foundation of compressed air energy management lies in systematic demand reduction and wastage elimination. Benchmarking models have been developed that prioritise mining shafts based on their underground demand reduction potential [8]. These models have demonstrated improvements of up to 57% over alternative benchmarking approaches when integrated with modified leak audit strategies adapted from potable water distribution systems [58]. The methodology encompasses comprehensive leak detection protocols, unauthorised usage identification, and systematic repair prioritisation based on potential savings.

Implementation of such integrated approaches has achieved substantial operational improvements including overall system pressure increases of 17.7 kPa, flow reductions of 1.24 kg/s, and cost savings of R2.7 million per annum, whilst simultaneously reducing auditing time by 65% [8]. This dual benefit of operational improvement and resource efficiency demonstrates the value of systematic approaches to compressed air management.

Low-cost methodologies have been developed that focus specifically on matching compressed air supply to demand through practical, readily implementable initiatives [59, 60]. These approaches emphasise three core components: set-point control optimisation, compressor selection algorithms, and demand prediction using energy management systems that provide operators with optimised compressor running schedules. The methodology avoids the complexities and capital requirements associated with fully automated systems, whilst still achieving significant results.

Such practical approaches have demonstrated annual savings of R1.1 million through relatively simple modifications to existing operational procedures [59]. The emphasis on low-cost solutions is particularly relevant for mining operations during periods of constrained capital expenditure, where operational improvements must be achieved without significant infrastructure investment.

Advanced localised benchmarking methodologies have been developed that can identify 80% of operational improvement opportunities compared to comprehensive manual audits, whilst requiring only 20% of the investigation time [61, 62]. These methodologies employ statistical analysis techniques to identify anomalous consumption patterns and prioritise intervention areas based on potential impact. Implementation across multiple mining operations has resulted in R7.4 million annual electricity cost savings and 19% production increases, highlighting the effectiveness of data-driven approaches to compressed air network optimisation in South African deep-level mines.

The literature consistently identifies multiple sources of system inefficiency that extend far beyond traditional leak management [63]. Comprehensive auditing approaches have demonstrated that energy wastage encompasses improper installation practices, pipe scaling due to inadequate maintenance, sharp bends causing pressure losses, flow restrictions from undersized components, and incorrect pipe sizing throughout distribution networks. These findings emphasise the importance of holistic system evaluation rather than focusing solely on obvious leakage points.

Detailed case studies involving the replacement of 400 metres of incorrectly sized distribution piping have resulted in system pressure increases of 45 kPa and estimated annual production value increases of R11 million [63]. Such improvements demonstrate that infrastructure modifications, whilst requiring initial capital investment, can deliver substantial long-term operational benefits through improved system efficiency and enhanced production capability.

Specialised applications within mining operations have also received attention, particularly refuge bay compressed air consumption [64]. Research has addressed this through the implementation

of check valves modified to use heavier springs, that maintain adequate ventilation during normal operations whilst ensuring full pressurisation during emergency scenarios. These modified ball valves incorporate precision holes that allow limited airflow in the closed position, providing continuous ventilation whilst eliminating the wastage associated with fully open valves during normal operations. Implementation investments of R210 000 over two-month periods have yielded annual savings of R5.1 million, demonstrating exceptional return on investment for targeted improvements [64].

Automated control and dynamic compressor systems

The evolution towards automated control systems represents a significant advancement in compressed air management technology. Dynamic compressor control systems have been developed that continuously evaluate and optimise compressor selection whilst adjusting set points based on real-time network demand and the physical proximity of compressors to consumption points [57]. These systems employ sophisticated algorithms that consider multiple operational parameters including current demand patterns, compressor efficiency curves, energy costs, and system pressure requirements.

Comprehensive case studies have demonstrated the potential for substantial energy savings through dynamic control implementation. Primary installations have achieved energy reductions of 86 MWh per day, equivalent to annual cost savings of R17 million in 2016 [57]. Secondary implementations, whilst more modest in scope, have still achieved meaningful improvements with daily reductions of 500 kWh worth R650 000 annually.

Dynamic compressor selection systems have been extensively researched and implemented across multiple mining operations [65]. These systems achieve average energy savings of 3.3 MW, equivalent to R11 million annually in 2014. The technology employs real-time data analysis to prevent missed savings opportunities that commonly occur with static control strategies. However, implementation experiences have revealed significant challenges related to system stability and reliability.

Field implementation studies have documented stability issues arising from sensor failures and communication problems with existing control infrastructure [66]. Initial deployments have experienced operational periods limited to single days due to these technical challenges. These experiences emphasise the importance of robust sensor networks and reliable communication protocols for successful dynamic control system implementation.

Subsequent research has addressed these limitations through improved system designs that incorporate auto compression considerations, flow loss calculations, and comprehensive pressure drop analysis [67]. Enhanced systems have demonstrated more stable operation whilst achieving significant operational improvements, including 3.3 MW power reductions during evening peak demand periods.

The literature consistently demonstrates that manual operation of compressed air networks typically results in system pressures maintained at levels significantly higher than operationally required [68, 69]. This conservative approach, whilst ensuring adequate supply under all conditions, results in substantial energy wastage through unnecessary compression work. Automatic control systems have proven to be more efficient in maintaining optimal pressure levels that match actual demand requirements whilst providing appropriate safety margins.

Advanced control approaches have incorporated artificial intelligence and machine learning technologies [70]. Hierarchical reinforcement learning systems have been developed for compressed air system optimisation, demonstrating that artificial intelligence can effectively match supply to demand through precise motor speed adjustment. These systems employ adaptive algorithms that continuously learn from operational data and adjust control strategies to optimise energy efficiency whilst maintaining operational reliability.

Additional automated systems have been developed focusing on cost-effective implementation approaches [71]. Research has demonstrated that existing throttle strategies can be successfully modernised by integrating actuators and positioners onto square butterfly valves. This conversion transforms static setups into high-precision, variable throttle control systems capable of dynamic flow adjustment. This approach has resulted in flow reductions achieving energy savings of 650 kWh per weekday.

Benchmarking methodologies for system performance assessment

Benchmarking represents a critical component of systematic energy management, providing quantitative methodologies for identifying inefficiencies and prioritising intervention opportunities. Comprehensive benchmarking models have been developed that evaluate electricity usage patterns across multiple South African mining operations [11]. These models incorporate sophisticated techniques for determining energy-saving initiative priorities based on potential impact, implementation feasibility, and resource requirements.

The benchmarking approach utilises comparative analysis techniques that identify performance variations between similar operational units, highlighting systems operating below optimal

efficiency levels. However, traditional benchmarking methodologies demonstrate significant dependence on production data, which limits their validity during periods of reduced or suspended production activity [11, 62].

Multiple correlation factor approaches have been developed to establish utility benchmarks that can identify relationships between compressed air consumption and various operational parameters [72]. Research has identified strong correlations between compressed air consumption and production tonnage, enabling predictive modelling of energy requirements under different operational scenarios. These relationships have been utilised to identify the least efficient operational units and prioritise them for targeted intervention [72].

Practical applications of benchmarking methodologies have achieved substantial operational improvements. Studies have documented potential annual savings of R2.5 million through systematic valve set-point reductions from 550 kPa to 520 kPa during periods of reduced demand [72]. Further optimisation opportunities have been identified through additional set-point reductions to 400 kPa, contingent upon the replacement of pneumatic equipment with more efficient electro-hydraulic alternatives.

Compressed air cost-saving identification models have been developed specifically to address the resource constraints commonly encountered in mining operations [73]. These models have successfully reduced investigation timeframes by 86 weeks whilst simultaneously reducing personnel requirements from eight to two human resources. This dramatic improvement in resource efficiency enables more frequent system assessments and faster implementation of identified improvements.

Implementation of these streamlined assessment methodologies across multiple case studies has achieved energy consumption reductions of 1.7 MWh and 0.72 MWh per day respectively [73]. The consistent achievement of substantial savings across different operational contexts demonstrates the robustness and transferability of systematic benchmarking approaches.

Integrated energy management strategies have been developed that align with ISO 50001 energy management standards [74]. These methodologies provide structured approaches for effective energy management across various energy consumers in mining operations, including compressed air systems. Sequencing models have been devised to determine the optimal implementation order for energy-saving initiatives based on specific operational criteria.

Specific energy metrics have been employed to characterise compressor system performance based on energy consumption and compressed air flow relationships [68, 69]. These approaches

compare actual performance against baseline values to identify efficiency degradation over time and evaluate the effectiveness of operational improvements. Research has identified oversized compressors operating inefficiently during low-demand periods, with blow-off valves releasing excess compressed air to atmosphere whilst maintaining full energy consumption.

Simulation and modelling techniques for operational optimisation

Simulation-based methodologies have proven invaluable for evaluating operational changes without the risks and costs associated with full-scale implementation trials [75, 76]. Comprehensive simulation methodologies have been developed specifically for compressed air system investigation and calibration, enabling detailed analysis of potential improvements before physical implementation.

These simulation approaches support the implementation of diverse energy-saving initiatives including compressor set-point reduction, automated valve control, refuge bay flow optimisation, and inactive area isolation [76]. The methodology provides quantitative predictions of potential improvements, whilst identifying any operational constraints or safety considerations that might limit implementation feasibility.

Documented case studies have demonstrated the practical value of simulation-based evaluation. Optimised valve set-points, derived from simulation analysis, achieved a 1 MW reduction in power demand during peak operations. This efficiency gain represents an annual cost saving of R900 000 [76]. These results validate the accuracy of simulation predictions, whilst demonstrating the value of virtual evaluation prior to physical implementation.

Accessible simulation methodologies have been developed that balance accuracy with practical usability requirements [75]. These approaches have demonstrated potential system improvements of 51 kPa during peak drilling operations and electricity cost savings reaching R1.5 million annually. The simulation methodologies enable evaluation of complex operational scenarios including shaft interconnection and compressor combination optimisation.

However, comprehensive simulation studies require significant time investment for model development and validation [75]. Documented case studies have required 104 hours for complete evaluation processes, including simulation construction, calibration, and scenario analysis. This time requirement, combined with the need for specialised technical expertise, may limit the applicability of detailed simulation approaches during periods of operational urgency or resource constraints.

The simulation methodologies provide particular value in evaluating the feasibility of the proposed improvements by considering infrastructure costs, potential impacts on service delivery, electricity cost implications, implementation timeframes, and associated advantages or disadvantages [75]. This comprehensive evaluation capability enables informed decision-making regarding improvement prioritisation and resource allocation.

Advanced monitoring approaches have been developed that utilise statistical regression to establish energy consumption baselines for compressed air systems based on historical operational data [77]. These methodologies enable regular comparison of actual consumption data with established baselines to identify system changes or performance degradation. Implementation in industrial applications has identified inefficient compressor activation sequences, resulting in 10% energy consumption reductions [78].

Infrastructure integration and control strategy implementations

Infrastructure-based solutions represent a significant category of energy management approaches, often requiring substantial capital investment delivering long-term operational benefits. Compressed air system integration studies have evaluated the feasibility of interconnecting separate systems to form larger, more efficient networks [79]. These integrated approaches enable the redirection of excess compressed air from over-specified systems to additional consumption points rather than releasing it through blow-off valves.

Implementation of compressed air system integration approaches has demonstrated substantial operational improvements. Case studies involving the interconnection of two mining shafts have achieved daily average power reductions of 1.45 MW and annual cost savings of R11 million [79]. These results were achieved through combination with additional energy-saving initiatives including inactive area isolation and automated valve control systems operated through actuators based on pressure set points and predefined schedules.

Cost-effective infrastructure modification approaches have been developed that maximise existing equipment utilisation [71]. Research has demonstrated successful conversion of standard butterfly valves to variable throttle control systems through strategic installation of actuators and positioners. This approach achieves the benefits of variable control whilst minimising capital investment requirements, with implementations achieving daily energy reductions of 650 kWh.

Control strategy optimisation has focused particularly on modernising existing demand-side management systems [80]. Many mining operations have implemented demand-side management approaches that require regular updates and optimisation to maintain effectiveness.

Research has identified common problems including outdated control valve set-points and inadequate remote monitoring capabilities.

Modernisation of existing systems has achieved operational improvements including 1.2 MW power savings during working days, worth R4.2 million annually [80]. These improvements have been achieved through systematic updates to valve control algorithms, pressure set-point optimisation during low-demand periods, and the implementation of remote adjustment capabilities that enable continuous optimisation as system conditions change.

Actuated control valve systems with pressure-based set-points have been implemented specifically to reduce energy consumption during low production periods [81]. These systems coordinate with Eskom's time-of-use tariff structure to achieve maximum cost savings during high-tariff periods. Implementation has achieved average weekday power reductions of 2.6 MW during evening peak periods [81].

Dedicated compressor approaches have been investigated where systems with differing demand schedules can benefit from separation [82]. Research has demonstrated that isolating gold plant compressed air requirements from broader mine compressed air systems through installation of dedicated standalone compressors can improve performance for both applications. Such implementations have achieved overall electrical cost savings of R3.3 million per annum [83].

Implementation challenges and production continuity considerations

The literature consistently identifies significant implementation challenges that must be addressed for successful energy management initiatives [81, 84]. Many advanced technological solutions require substantial infrastructure investment and extended implementation timeframes, potentially limiting their applicability during periods of operational constraint or financial pressure. These challenges are particularly relevant for mining operations that must maintain continuous production whilst implementing efficiency improvements.

Dynamic control systems demonstrate particular sensitivity to existing infrastructure capabilities [65, 67, 85, 86]. These systems often depend on multiple sensor networks and integration with existing control system interfaces, creating potential failure points that can compromise system reliability. Mining operations lacking comprehensive instrumentation and control infrastructure may be unable to implement advanced dynamic control solutions without substantial initial investment.

The dependence of many benchmarking and optimisation approaches on production data creates additional limitations during periods of reduced or suspended production activity [11, 62, 72].

Traditional benchmarking methodologies that rely on production correlations become ineffective during maintenance shutdowns, extended stoppages, or reduced operational periods. This limitation highlights the need for alternative assessment approaches that can function independently of production metrics.

Several studies have documented specific operational challenges encountered during implementation [81]. Industrial action and unforeseen operational incidents can significantly delay planned energy-saving initiatives, affecting projected savings and return on investment calculations. However, research has demonstrated that substantial savings remain achievable despite implementation difficulties, provided that systematic approaches are maintained throughout the process.

The complexity of implementing energy management initiatives during continuous operations presents ongoing challenges [87]. Unlike batch or intermittent processes that provide natural implementation windows, continuous mining operations require innovative approaches that achieve energy reductions without production disruption. This requirement necessitates careful planning, staged implementation approaches, and comprehensive risk assessment protocols.

Research has specifically addressed the unique challenges associated with energy management during production stoppages [84]. Limited research focuses specifically on energy management strategies optimised for non-production periods, despite the significant opportunities that such periods present for infrastructure modification and system optimisation. Comprehensive methodologies tailored to production stoppage scenarios remain underdeveloped, representing a significant opportunity for future research.

Comprehensive energy management approaches have been developed that encompass multiple electricity consumers within complex industrial facilities [88]. These system-based approaches include methodologies for implementing accurate energy measurement, managing measurement quality to guarantee accuracy, and providing operational energy management feedback that incorporates all relevant stakeholders. Implementation has resulted in total cost savings of R42 million in specific isolated cases, with improved operational control achieving R25 million annual savings.

Decision-making methodologies have been developed to support the selection of compressed air energy-saving initiatives [89]. These methodologies consider multiple criteria including production impact, operational effects, energy implications, cost considerations, complexity requirements, compatibility issues, and implementation observability. Whilst originally developed for industrial sector applications, these decision-making approaches could be adapted for mining applications.

Enhanced compressor efficiency approaches have been investigated, including replacement of aging equipment and inlet air filter upgrades [90]. Research has identified leak repair, pressure set-point adjustment, and valve control as initiatives providing the largest efficiency improvements. Implementation of these combined approaches has achieved total power reductions of 1.35 MW, equivalent to annual cost savings of R8 million.

Safety considerations have been specifically addressed regarding the impact of compressed air system modifications on refuge chamber performance [91]. Research has developed simulation-based methods to evaluate complex compressed air systems, including all refuge chambers, to ensure minimum safety requirements are maintained before implementing system changes. This work provides detailed minimum requirements for refuge chambers and emphasises the importance of safety verification before system modifications are made.

Simplified investigation methodologies have been developed to address resource constraints commonly encountered in mining operations [21]. Single-variable benchmarking models have been created to simplify compressed air system benchmarking based on energy usage data, combined with savings quantification tools to create integrated investigation methodologies. Implementation across case studies has delivered accurate results within brief timeframes whilst achieving combined power reductions of 6.2 MW through stopping compressors during low-demand periods, repairing leaks, ensuring optimal compressor selection, and controlling valves [21].

The literature suggests that future research should prioritise the development of rapid-deployment solutions specifically designed for implementation during production stoppage scenarios. Such approaches should focus on improvements that can be achieved with minimal infrastructure modification whilst delivering immediate operational benefits upon production resumption. Additionally, research should address the development of more reliable automated control systems that can maintain stable operation despite sensor failures or communication interruptions.

Benchmarking methodologies that function independently of production data represent another priority research area. Such approaches would enable continuous system assessment and optimisation regardless of production status, providing more flexible and comprehensive energy management capabilities. The integration of artificial intelligence and machine learning approaches shows considerable promise; however, further development is required to address the specific operational requirements and constraints of practical mining applications.

Relevance to blower systems

The comprehensive body of research on compressed air energy management provides valuable insights for blower system optimisation due to the fundamental similarities between these technologies. Both systems operate on comparable thermodynamic principles, employ similar control strategies, and face analogous operational challenges including supply-side efficiency optimisation and system performance management.

Whilst the documented compressed air methodologies encompass both supply and demand-side interventions, the supply-side approaches are particularly relevant to this research. The established methodologies for compressor selection algorithms, automated control systems, benchmarking techniques based on energy consumption patterns, and simulation-based optimisation demonstrate proven methodologies that can be adapted for blower supply-side applications. The substantial cost savings achieved through supply-side compressed air improvements indicate the potential magnitude of efficiency gains achievable through systematic energy management approaches applied to blower systems.

Particular relevance exists in the areas of equipment sizing optimisation, pressure set-point control, automated compressor selection strategies, and performance monitoring systems, where the operational principles remain consistent between compressed air and blower supply applications. The documented simulation and modelling techniques for operational optimisation provide directly applicable methodologies for evaluating blower system modifications without full-scale implementation trials.

The documented implementation challenges and production continuity considerations also offer valuable guidance for developing practical blower supply-side optimisation methodologies that can be deployed within the constraints of continuous mining operations whilst maintaining operational reliability and safety requirements.

1.3.3 Current compressed air simulation software

As previously discussed, simulation software shall be employed to verify analytical results. Simulation software has become an integral part of the engineering environment, both in design and in operations. Its application offers numerous benefits [92], [93], including:

1. Improved problem understanding – Accurate modelling requires a clear understanding of the underlying process, and the act of simulating a system develops deeper process insight.

2. Evaluation of multiple solutions – Different approaches can be tested virtually, eliminating the need for costly full-scale trials.
3. What-if analysis – Simulation enables the investigation of alternative operational strategies and scenarios which, in practice, would require disruptive and potentially risky real-time adjustments.

In addition, simulation supports decision-making, process prediction, scenario evaluation, and operational optimisation.

1.4 Need for the study

1.4.1 State-of-the-art overview

The review of 48 studies on energy efficiency and DSM in industrial settings reveals a significant research gap regarding blower systems within platinum concentrators. While current literature focuses extensively on core production processes, auxiliary systems, such as blowers, remain largely underexplored. One identified study briefly addresses DSM for a blower system; however, it lacks a comprehensive, systematic methodology. Consequently, most research continues to prioritise primary production, overlooking significant energy-saving opportunities in plant auxiliaries.

To address this deficiency, a comprehensive approach was adopted to identify studies that facilitate the development of targeted energy efficiency solutions. Given the fundamental mechanical, operational, and thermodynamic similarities between blower and compressor systems, particularly regarding flow dynamics and energy consumption patterns, numerous compressed air studies were incorporated into this review. The extensive body of work on compressed air optimisation provides valuable precedents and methodological frameworks that can be adapted for blower systems.

Furthermore, generic methodology development literature and simulation software have been identified as critical requirements. These tools provide the robust framework and verification necessary to validate proposed interventions in environments where empirical blower data is limited.

Table 1-1 provides an overview of the state-of-the-art research related to the proposed study. The studies were assessed according to the following criteria:

1. Develops a systematic methodology for achieving energy savings in industrial settings.

2. Investigates both potential and applied approaches to enhancing energy efficiency in industrial plants.
3. Evaluates energy efficiency improvements in auxiliary systems within industrial plants.
4. Evaluates energy efficiency improvements in compressed air systems within industrial facilities, encompassing both plants and mines.
5. Utilisation of thermodynamic simulation software for the verification of compressed air system performance.
6. Analyses the effectiveness of energy efficiency and other energy-saving measures for blower systems.

Table 1-1: State of the art summary

Source	Saving Methodology Development	Energy Efficiency on Plants	Energy Efficiency on Auxiliaries in Plants	Energy Efficiency on Compressed Air Systems	Utilises Simulation Software	Energy Efficiency on Blower Systems
[40]						
[41]						
[42]						
[26, 60]						
[27]						
[36-38]						
[35]						
[94]						
[33]						
[67]						
[34, 58]						
[21]						
[59]						
[8, 11, 56, 75, 76, 91]						
[57, 61-66, 68-74, 77, 79-82, 84, 86-90]						

Legend	
	Included in the reference
	Excluded in the reference
	Literature gap

A significant literature gap exists regarding the energy efficiency of blower systems. This gap highlights the need for dedicated research to develop a structured approach for improving blower system efficiency, addressing inefficiencies, and adapting existing DSM methodologies. The study categories were selected based on available literature and research objectives, incorporating insights from other industries to develop a cost-saving DSM methodology. Overall, the findings underscore the necessity for further research to bridge the literature gap and establish a systematic approach to energy optimisation in blower systems within platinum concentrators.

1.4.2 Analysis of key research literature

To further delineate the specific technical limitations within current literature, the following ten studies represent the state-of-the-art in energy management and are critically evaluated below. This analysis highlights the specific contributions and operational shortcomings that necessitate the development of a dedicated blower-system methodology.

1. Cordeiro (2022) [40]

- **Contribution:** One of the few contemporary studies explicitly to target auxiliary systems within the platinum industry, shifting the focus away from primary milling circuits.
- **Shortcoming:** While it identifies blowers as a high-impact area, it lacks a comprehensive, systematic methodology for implementation and validation. It functions primarily as an opportunity identification tool.

2. Marais (2012) [33]

- **Contribution:** Established a robust "integrated approach" that successfully combined supply-side technical optimisation with demand-side operational changes.
- **Shortcoming:** The methodology is heavily optimised for high-pressure (500–700 kPa) compressed air in deep-level gold mines and does not account for the lower-pressure, continuous-flow requirements of flotation aeration.

3. Zietsman (2020) [8]

- **Contribution:** Introduced "zero-waste baselining," which uses theoretical minimums to identify inefficiency and prioritise repair interventions.

- **Shortcoming:** Relies heavily on discrete mining activity data (e.g. drilling shifts). In a continuous flotation process, identifying "waste" requires a different baseline logic that accounts for constant supply requirements.

4. Jonker (2016) [67]

- **Contribution:** Demonstrated how automation and digital twins can ensure the sustainability of energy savings over time by preventing set-point drift.
- **Shortcoming:** The control logic is designed specifically for compressor sequencing. The study's control algorithms remain limited to compressor sequencing, neglecting the specialised logic required to synchronise VFD-driven rotary lobe units with centrifugal units utilising guide vane modulation.

5. Taljaard (2019) [59]

- **Contribution:** Validated low-cost methodologies focused on set-point optimisation and operational scheduling, making them attractive for capital-constrained environments.
- **Shortcoming:** Lacks the thermodynamic simulation depth required for centrifugal machine optimisation. Centrifugal blowers are highly sensitive to discharge pressure variations; a purely "operational" approach may overlook inherent equipment safety margins and optimal efficiency zones.

6. Van Heerden (2016) [57]

- **Contribution:** Achieved substantial cost savings through real-time, dynamic optimal control systems.
- **Shortcoming:** The research documented significant implementation stability issues due to sensor failures in harsh mining conditions, highlighting the need for a more robust, simplified control methodology.

7. Maré (2017) [75]

- **Contribution:** Proved that simulation-based evaluations can accurately predict operational savings before physical implementation.
- **Shortcoming:** Focus was primarily on network pressure drops across kilometres of underground piping. In concentrators, primary losses occur at the point of use and within the blower manifold, requiring a different modelling focus.

8. Oosthuizen (2019) [73]

- **Contribution:** Focused on resource efficiency in energy auditing, reducing the time and personnel required to identify savings opportunities.
- **Shortcoming:** Acts as a diagnostic tool rather than an implementation framework; it identifies where the loss is, but not how to re-engineer the supply-side control logic.

9. Read (2025) [56]

- **Contribution:** Developed strategies to prioritise energy initiatives during production stoppages, addressing the "production is king" paradigm.

- **Shortcoming:** Focus remains on leak repairs. In PGM concentrator blower systems, inefficiency is driven more by supply/demand mismatch than by physical leaks.

10. Kunneke (2022) [72]

- **Contribution:** Provided high geographic relevance by applying benchmarking techniques to a South African platinum mine.
- **Shortcoming:** Uses production tonnage as the primary correlation factor. During load curtailment or production instability, these correlations break down, necessitating a benchmarking model that functions independently of production metrics.

1.5 Research gap

While compressed air systems benefit from established optimisation standards and extensive academic scrutiny, blower systems in platinum concentrators exist in a research vacuum. Despite accounting for substantial base-load energy, they lack a dedicated energy-saving methodology. This research bridges that gap by adapting proven compressed air DSM principles to the unique hydrodynamic constraints of continuous flotation processes. This gap presents an opportunity for targeted research and development, to enhance energy performance and reduce operational costs.

Mining companies are often legally or ethically barred from conducting their own primary research because self-performed studies create a fundamental conflict of interest, where corporate profit motives may compromise the objectivity of environmental or social findings [95]. To maintain credibility and legitimacy in the eyes of the public and regulators, research must be conducted by independent third parties to ensure that potential risks are not minimised or overlooked [96]. Furthermore, many jurisdictions mandate independent oversight because mining firms frequently lack the specialised, non-operational expertise required to handle complex ecological assessments or authentic community engagement [97, 98].

1.6 Problem statement

The South African Platinum Group Metal (PGM) industry is currently facing a dual crisis of declining production and rapidly escalating operational costs [3-5]. This downturn is driven primarily by a 180% increase in electricity tariffs since 2008 [9]. To maintain profitability in a "price-taker" market, mining operations must reduce energy consumption. However, while energy-saving initiatives have been widely implemented in underground mining activities (such as pumping and hoisting), the mineral processing plant has remained largely overlooked [26, 30, 32].

Processing plants account for 19% of total site energy demand [28], yet energy interventions are frequently avoided due to the risks associated with interrupting continuous-flow operations [27,

35]. Specifically, high-energy auxiliary systems, such as the blowers used in flotation and matte converting, operate with significant untapped efficiency potential [41, 44].

The core problem is the lack of energy management strategies dedicated to the improvement of energy usage within these continuous auxiliary systems. Without targeted interventions that can reduce consumption without compromising metallurgical recovery or process stability, PGM processing plants will continue to suffer from avoidable energy overheads, further threatening the economic sustainability of the sector.

1.7 Delineation

This research focuses on supply-side efficiency improvements, specifically targeting "low-hanging fruit" opportunities that require minimal capital expenditure and offer short payback periods. The primary objective is to reduce excessive air production and energy wastage by decreasing blow-off valve opening percentages.

However, several critical components are intentionally excluded from the current scope to be addressed in subsequent research:

- **Demand-Side Optimisation:** The study does not evaluate the specific air requirements or consumption patterns of individual flotation cells and cleaner banks.
- **Matte Converting Process:** Despite the high energy demand and 600 kW capacity of these systems, they are excluded due to extreme safety risks and the criticality of the associated processes.
- **Reticulation Network Infrastructure:** Detailed analysis of distribution pipe sizing, scaling, and pressure losses across the broader plant network is reserved for future investigation.
- **Automated Control Hardware:** The implementation of variable frequency drives (VFDs) and fully automated demand-responsive control algorithms is not covered, as the focus remains on optimising existing manual control strategies.

1.8 Aim and objectives

The primary aim of this research is to develop and validate a comprehensive, high-level methodology for improving the electrical cost efficiency of blower systems in South African platinum concentrator operations. This approach must ensure that operational continuity and production output remain uncompromised throughout the assessment process. The methodology will equip practitioners with the capability to:

- Detect the presence and magnitude of energy wastage
- Isolate and characterise the root causes of identified inefficiencies

- Facilitate the development of practicable remedial solutions

To achieve this aim, the study will fulfil the following objectives:

1. Develop a systematic methodology based on criteria identified from the literature for assessing blower system efficiency.
2. Construct simulation models to verify the new method's viability prior to implementation.
3. Apply the new method to industrial case studies to validate the applicability of the study/research.
4. Demonstrate measurable electricity cost savings whilst maintaining uninterrupted plant operations.

1.9 Research methodology

The majority of studies within the literature review concerning energy efficiency projects utilised a case study approach to facilitate an in-depth understanding of specific phenomena within bounded systems. Accordingly, this research adopts a case study methodology to evaluate the proposed solutions.

The developed strategy is applied to four distinct case studies, selected to account for process variations resulting from the unique characteristics of each platinum concentrator. These cases include: a standard implementation where the solution was applied without complication; a scenario requiring auxiliary system modifications external to the blowers; an instance where equipment discrepancies were identified; and a final application involving an alternative category of equipment. The four-phase technical process utilised to execute these case studies is detailed in the following sections, beginning with the protocols for data acquisition. A summary of the research methodology can be found in Figure 1-5.

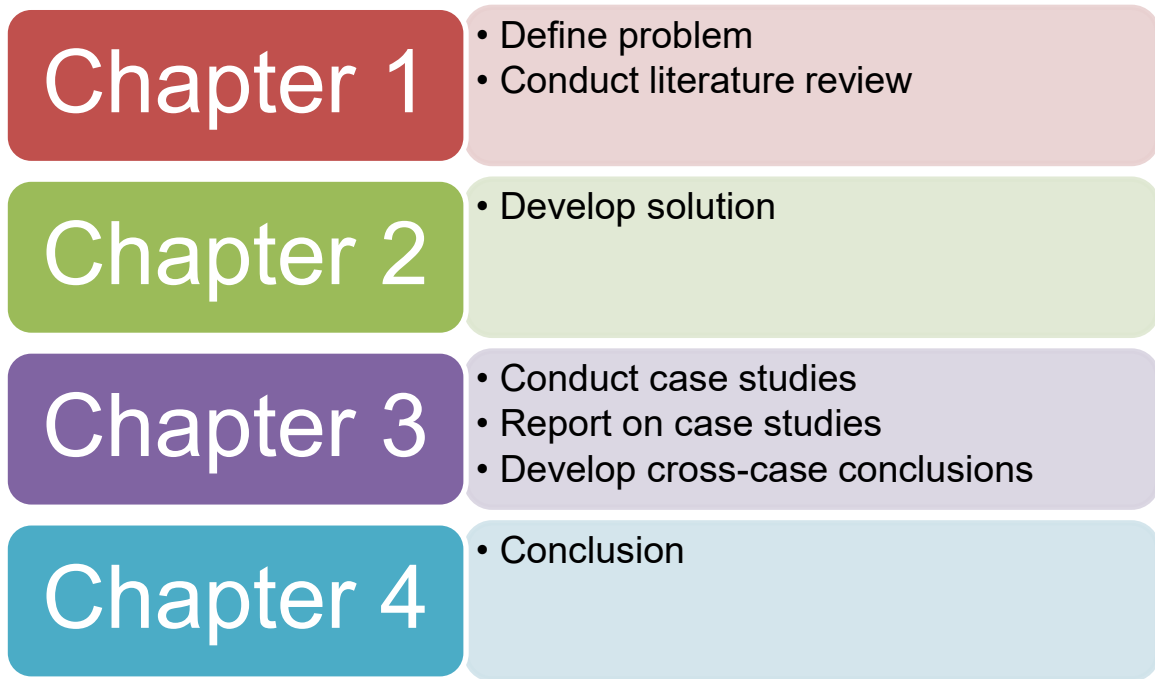


Figure 1-5: Case study methodology [99, 100]

1.10 Dissertation overview

Chapter 1

Establishes the context of South African platinum mining, highlighting declining production and rising energy costs. Reviews blower technologies (centrifugal and rotary lobe) and compressed air energy management literature to identify the research gap—absence of systematic methodology for blower system optimisation in platinum concentrators.

Chapter 2

Presents a four-phase approach: data acquisition (system audits and historical data), analysis (identifying inefficiencies through performance curves), model development (PTB simulation validation), and implementation (testing and continuous monitoring). Includes brief overview of PTB simulation software capabilities.

Chapter 3

Documents four case studies across different platinum operations. Case Studies A-C involve positive displacement blowers with shared air headers and blow-off valves, achieving savings of R80 000 - R750 000 over six months. Case Study D examines centrifugal blowers with guide

vane control, achieving R1 million savings. Demonstrates methodology effectiveness whilst highlighting implementation challenges and system limitations.

Chapter 4

This research demonstrates that the four-phase methodology provides a systematic framework for evaluating and optimising blower configurations. The study examines the 20 to 50 percent air oversupply prevalent in platinum concentrator operations and identifies strategies for alignment. Furthermore, the work evaluates simulation accuracy against actual performance, whilst acknowledging limitations such as the absence of direct flow measurement and the effects of system degradation. Future research opportunities are identified in demand-side optimisation, automated control integration, and plant-wide auxiliary system management. Ultimately, the work establishes the transferability of this methodology to broader minerals processing applications beyond platinum flotation.

CHAPTER 2 DEVELOPMENT OF AN ENERGY COST IMPROVEMENT STRATEGY FOR PGM BLOWER SYSTEMS

2.1 Introduction

To address the lack of standardised methods for improving electrical cost efficiency in platinum concentrator blower systems, this study adopts a tailored approach. This methodology is designed to bridge the gap between theoretical thermodynamic principles and practical industrial application by drawing on the technical similarities between compressed air and blower air systems, utilising established literature as a foundation.

The research design follows a structured, four-phase process: Data Acquisition, System Analysis, Model Development, and Field Implementation. A key feature of this approach is the integration of a PTB simulation, which allows for the de-risking of energy-saving initiatives by testing them in a virtual environment before any physical intervention on-site.

To ensure both academic rigour and industrial relevance, the methods described herein are mapped against the six core evaluation criteria established in Section 1.4. This alignment ensures that the resulting energy-saving strategies are not only technically sound and data-driven but also maintain the operational stability required for platinum production and mineral recovery. The following sections outline the technical constraints, software selection process, and the iterative testing protocols that form the foundation of this study.

2.2 Step 1: Data acquisition

The initial phase of the study involves obtaining site layouts and detailed specifications of the blower systems, including blower performance curves (Appendix A), as this information provides the necessary technical constraints for system modelling [76, 90]. This fulfils Criterion 5 (Section 1.4), regarding the use of thermodynamic simulation for performance verification, a process validated by previous industrial modelling assessments [75, 91]. To validate the received data and identify any discrepancies, a comprehensive system audit was conducted, mirroring the rigorous verification protocols seen in large-scale mine energy assessments [8, 61]. In alignment with the systematic methodology required by Criterion 1 (Section 1.4), this audit followed established verification protocols to ensure data integrity [21, 74, 88].

In accordance with best practices for energy management [59, 77, 84], a clear "Measurement Boundary" was defined to ensure that the study isolated the blower system from external

variables. This complies with Criterion 3 (Section 1.4), which prioritises the evaluation of auxiliary systems to isolate supply-side performance from demand-side fluctuations [11, 87]. Within this boundary, historical operational data was gathered to establish a baseline. Key parameters include:

- Manifold pressure
- Total air flow produced by the blowers
- Blower operation combinations (i.e. which and how many blowers typically run at a given time)
- Power consumption of each blower
- Blow-off air flow and valve position

The audit involved a physical inspection of the blower units and the systematic recording of motor nameplate data. Additionally, the manifold configuration and the quantity of blow-off valves (BOVs) were documented. Primary data regarding the operational logic and functional characteristics of the blow-off system were also collated.

While consumer demand is considered, the focus remains on improving the efficiency of the blower system itself [73], which satisfies Criterion 2 (Section 1.4) regarding the investigation of applied approaches to enhance industrial efficiency

2.3 Step 2: Analysis

The operating parameters of each blower system are determined, using historical data to establish typical performance trends, which is essential for identifying deviations from efficient operation [21, 69]. This analysis complies with Criterion 2 (Section 1.4) by investigating typical performance to identify deviations from efficient operation, a method supported by statistical performance tracking in industrial plants [29, 77]. This assists in identifying energy wastage, particularly unnecessarily vented air [8, 79]. This fulfils Criterion 4 (Section 1.4) by quantifying wastage based on established "Zero-Waste" profiles and demand management strategies [8, 21, 99].

Findings are cross-checked against blower performance curves (Appendix A) to validate savings opportunities [73, 90]. This "Gap Analysis" quantifies the difference between current consumption and system capabilities. This complies with Criterion 4 (Section 1.4), utilising the identification and quantification models developed for deep-level mines [8, 21, 61, 73]. To maximise immediate return on investment, potential initiatives were prioritised based on a "Low-Cost/No-Cost" approach [59, 74]. This satisfies the requirements of Criterion 1 (Section 1.4) for a structured

methodology that prioritises resource-efficient interventions [21, 74, 88]. The improvement strategy may involve [33, 69, 74]:

1. Turning off unnecessary blowers to reduce excess energy consumption [21, 59].
2. Adjusting the manifold pressure setpoint to match actual process demand more efficiently, thereby reducing the overall pressure head required [72, 80, 90].
3. Reconfiguring the default blower operation setup, such as modifying the combination of blowers that run at a given time to improve efficiency [57, 59, 77].
4. The implementation of automated control strategies to maintain these efficiency gains long-term [65, 67, 86].
5. A combination of the above approaches, depending on the specific conditions of each site.

By implementing these targeted adjustments, this study aimed to reduce energy consumption whilst maintaining or improving system performance, leading to measurable cost savings.

2.4 Step 3: Model development

To bridge the gap between theoretical analysis and practical implementation, a simulation model is developed for each blower system to represent accurately its operational behaviour under various conditions [75, 76]. This complies with Criterion 5 (Section 1.4) through the use of thermodynamic simulation software to verify performance. This model is calibrated using historical data to ensure it reflects real-world performance as closely as possible, a step critical for the reliability of any predictive analysis [66, 70].

Verification of the simulation involved cross checking results against actual measured plant values to ensure the "Digital Twin" reacted to variables, such as pressure set point changes, in the same manner as the physical system [75, 76]. This fulfils the systematic verification requirements of Criterion 1 (Section 1.4), confirming that the model can reliably predict system behaviour and energy consumption patterns [88, 91]. This calibration process effectively de-risked the project by providing a virtual environment to test responses before physical intervention

The primary purpose of the simulation was to assess the feasibility of the proposed improvement strategies prior to implementation. This aligns with Criterion 5 (Section 1.4) by using predictive analysis to protect process stability, particularly when changes could impact production [91]. By simulating multiple operational scenarios, the model quantified the potential energy savings and operational impacts of turning off redundant blowers, adjusting manifold pressure, or reconfiguring blower combinations.

Satisfying the methodological rigour of Criterion 1 (Section 1.4), this approach ensured that all recommended test procedures were data driven, technically sound, and practical for real world implementation [21, 75]. This phase was critical for minimising operational risk while maximising potential cost savings through validated, site-specific scenarios.

2.4.1 Evaluation criteria

For this study, available compressed air simulation software was reviewed. Six functional evaluation questions were used to compare packages [94]:

- Training – Is the software primarily intended for personnel training rather than operations?
- Digital twin capability – Does the software generate an accurate digital representation of the real process, even if improvement functionality is limited?
- Scenario investigation – Can the software simulate operational scenarios and explore multiple solutions?
- Optimisation – Does the package enable process efficiency improvements?
- Real-time monitoring – Does the software provide supervisory control and data acquisition (SCADA) functionality for live process monitoring?
- Dynamic analysis – Can the software perform transient (dynamic) simulations to account for varying operating conditions?

2.4.2 Comparison of available software

Several simulation packages were assessed against the above criteria. The results are summarised in Table 2-1.

Table 2-1: Comparison of compressed air simulation software summary

Nr.	Software	Use case					
		Training	Digital twin	Scenario investigation	Optimisation	Real-time monitoring	Dynamic analysis
1	FlowNex		✓	✓	✓		✓
2	Thermoflex		✓	✓	✓		✓
3	Ovation	✓	✓	✓	✓	✓	
4	SimSci	✓	✓	✓	✓		✓
5	SimExec	✓	✓	✓	✓		
6	EES			✓			
7	Excel (IF97)		✓	✓			
8	IPSEpro		✓	✓	✓		
9	3KEYMASTER	✓	✓	✓	✓	✓	
10	PREDIX	✓	✓	✓	✓	✓	
11	ETAPRO		✓	✓	✓	✓	
12	PTB	✓	✓	✓	✓	✓	✓

From Table 2-1, the list of suitable software packages was narrowed down to those capable of simulating operations and supporting scenario investigation. While all packages considered are capable of generating reliable simulation data, the in-house Process Toolbox (PTB) was selected. PTB meets all the required criteria and had the added advantage of being available without additional licensing costs.

2.4.3 The PTB simulation environment

PTB is a semi-empirical thermo-hydraulic modelling tool. It requires detailed system parameters and plant data for initial configuration; however, once the model is established, scenario analysis can be performed with rapid turnaround times benefits [92].

The software's component models are built using a combination of fundamental physical principles and empirical parameters derived from system measurements. This hybrid approach enables accurate component characterisation and enhances predictive capability. Since all models are solved using explicit functions, no iterative calculations are required during component evaluation, which is advantageous for industrial applications where speed and robustness are critical.

In this study, PTB was employed to develop a blower–air system simulation model. The model provided a valuable validation step, enabling proposed modifications to be evaluated in a virtual environment before implementation on the actual system.

The purpose of this document is not to provide an in-depth discussion of compressed air system simulations, as this lies outside the scope of the study. Instead, a brief overview of the selected simulation software, PTB, is presented. PTB is a semi-empirical thermohydraulic platform employed to model the power station. Developing the model required prior knowledge of system parameters as well as comprehensive station data and specifications. By the time the model was constructed, this information had already been gathered. An example of a PTB simulation is shown in Figure 2-1.

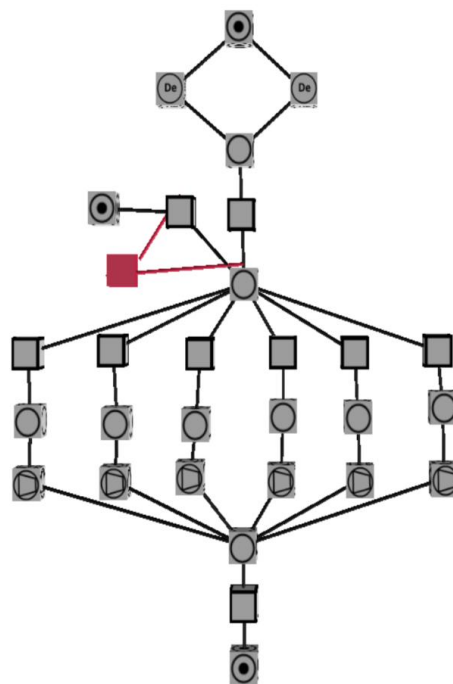


Figure 2-1: Example of PTB simulation

PTB is a component-based software tool with a drag-and-drop interface. Components communicate with one another via links or connections, enabling upstream and downstream relationships to be established, as illustrated in Figure 2-1.

The software provides components across four main categories: water, air, steam, and general. For the purposes of this study, only air and general components are utilised. A breakdown and description of the relevant components are presented in Table 2-2.

Table 2-2: PTB components breakdown

Category	Description	Image	Detail
Air	Air pressure boundary		Control volume boundary
	Air node		Point of calculation and measurement for the air network
	Air demand		Location where air is consumed
	Air pipe		Facilitates airflow between nodes
	Air positive displacement compressor		Pressurised air production unit
	Air dynamic compressor		Pressurised air production unit
General	PI Controller		Takes an input and outputs a control variable to reach a specified setpoint

2.5 Step 4: Implementation

In accordance with Criterion 3 (Section 1.4), which evaluates auxiliary system constraints, tests are conducted during specific low impact windows identified by plant personnel, such as plant stoppages and periods where mass pull and the plant itself was stable [68, 81]. This approach ensured that production was not compromised. A basic overview of the test procedure can be seen in Figure 2-2.

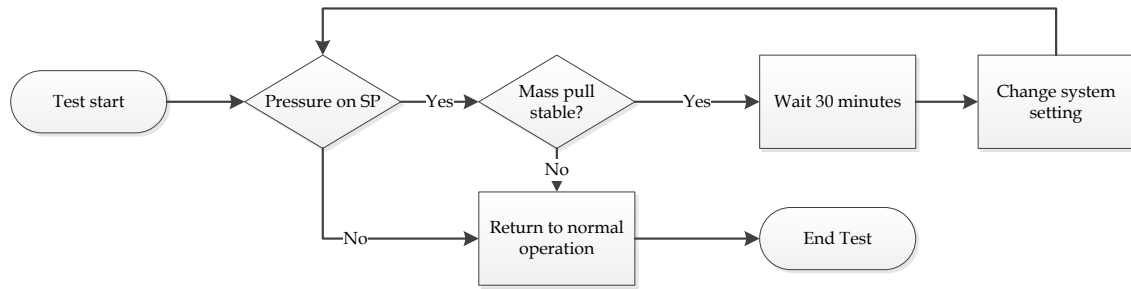


Figure 2-2: Proposed generic test procedure for blower electrical energy cost improvement

The experimental protocol involves verifying the stability of the air blower system, defined by the pressure in the manifold aligning with the specified setpoint. Concurrently, on-site personnel confirm the stability of the mass pull, with both parameters monitored for a duration of up to 30 minutes to ensure a steady-state baseline. Upon establishing stability, the planned system modification is implemented, followed by a repetition of the stability monitoring procedure. This process is iterated until all desired changes are completed. Following the conclusion of all test work, the system is returned to its original state. If, at any stage, the system fails to maintain the required pressure or the mass pull becomes unstable, the system is immediately reverted to its baseline configuration and the test is terminated.

A test procedure was designed, based on the proposed improvement strategy, outlining the exact steps required for implementation and evaluation. The differences between the potential testing procedures for each improvement strategy outlined in Section 2.3 are marginal. Regardless of the chosen strategy, the methodology remains consistent: implementing a modification during a period of system stability and subsequently monitoring for re-stabilisation to determine whether to sustain the change or revert to the baseline configuration.

If the test proves successful, the recommended changes are permanently implemented. However, if unexpected factors emerge during testing, a revised solution is developed based on the new insights gained. This complies with Criterion 2 (Section 1.4) by reflecting the applied and iterative nature of industrial commissioning and real-world problem solving [66, 86]. This approach ensured that all potential challenges were addressed before final implementation and commissioning [81].

Once a solution is in place, the resulting energy savings were verified through continuous energy monitoring and reporting, ensuring that the system did not revert to inefficient habits [77, 84]. Satisfying the systematic requirements of Criterion 1 (Section 1.4), these savings were quantified

using structured measurement and verification protocols established in the baseline phase [84, 88]. These protocols accounted for utility tariff structures and production variances to maintain financial accuracy.

To fulfil Criterion 6 (Section 1.4) regarding the analysis of blower system effectiveness, all improvements were implemented without negatively impacting platinum production or mineral recovery [61, 82]. This was verified by monitoring the mass pull, a key performance indicator used by site personnel to assess flotation efficiency. The system must maintain sufficient pressure to ensure flotation cells remain stable, paralleling safety protocols used in other air pressure systems [82, 91]. The adequacy of air delivery was confirmed by checking that individual cell setpoint requirements were met and through visual inspection of the froth characteristics in the cells. Throughout the implementation phase, the system was required to maintain operational efficiency whilst achieving the targeted energy savings.

Finally, the knowledge and insights gained throughout this study were used to develop a standardised, practical methodology that can be applied to other blower systems in platinum concentrators [21, 88]. This complies with Criterion 1 (Section 1.4) by establishing a structured approach for identifying, testing, and implementing energy-saving measures, enabling wider adoption across the industry.

2.6 Summary of the proposed method

The flowchart in Figure 2-3 summarises the high-level methodology developed during this investigation. This structured approach provides a foundation that can be replicated across various platinum concentrator operations to ensure consistent energy-saving results.

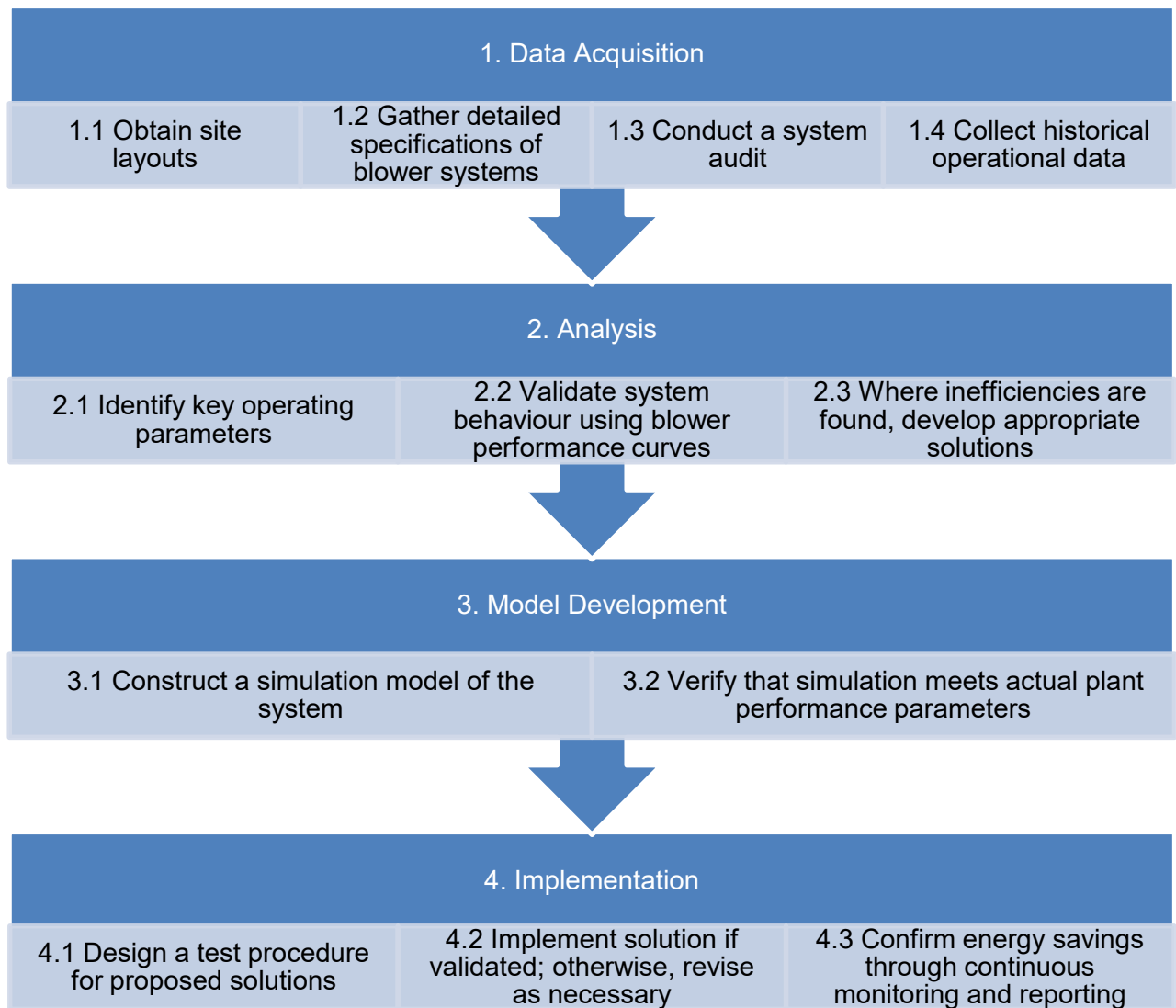


Figure 2-3: Proposed high-level method for blower electrical energy cost improvement

2.7 Verification

The matrix in Table 2-3 provides a mapping between the study's methodological phases and the six core evaluation criteria from Section 1.4.

Table 2-3: Verification of proposed method

Method Step	Criteria 1: Saving Methodology Development	Criteria 2: Energy Efficiency on Plants	Criteria 3: Energy Efficiency on Auxiliaries in Plants	Criteria 4: Energy Efficiency on Compressed Air Systems	Criteria 5: Utilises Simulation Software	Criteria 6: Energy Efficiency on Blower Systems
Data Acquisition	✓	✓	✓	✓	✓	
Analysis	✓	✓		✓		
Model Development	✓				✓	
Implementation	✓	✓	✓			✓

This structured alignment ensures that each step from initial data acquisition and thermodynamic modelling to iterative field implementation directly addresses the technical requirements for systematic energy efficiency. By cross referencing the methodology with these specific criteria, the study maintains a rigorous balance between theoretical simulation and the practical, applied constraints of industrial blower systems.

2.8 Conclusion

The methodology outlined in this chapter provides a systematic and de-risked framework developed for improving the electrical cost efficiency of platinum concentrator blower systems. By integrating traditional industrial auditing with advanced semi-empirical modelling, the study shifts from theoretical "Gap Analysis" to practical, site-specific interventions.

A critical component of this approach was the utilisation of the PTB simulation environment. This ensures that operational changes were validated for energy impact and process safety before physical implementation. Furthermore, the iterative testing protocol conducted during low-impact windows prioritised the maintenance of flotation stability and mass pull, aiming to ensure that energy savings were not achieved at the expense of mineral recovery or production targets.

Ultimately, the alignment of these methodological phases with the six core evaluation criteria ensures that the findings are both technically rigorous and industrially applicable. This structured approach addresses the immediate efficiency needs of the test sites and establishes a standardised, replicable methodology for the broader platinum mining industry.

CHAPTER 3 RESULTS AND DISCUSSION

3.1 Introduction

This chapter presents the findings from the application of the methodology proposed in Chapter 2 across four distinct industrial case studies. To validate the robustness and versatility of the framework, the study evaluates a diverse range of operational environments within the PGM sector, encompassing variations in ore types (Merensky, UG2, and Plat Reef), plant capacities (7 500 to 29 000 t/d), and blower technologies.

The primary objective of this chapter is to demonstrate how the transition from theoretical "Gap Analysis" to empirical site implementation results in measurable electricity cost savings without compromising flotation stability. Each case study follows the structured four-phase process:

- Data Acquisition: Establishing the unique technical constraints and baselines for each site.
- Analysis: Identifying specific inefficiencies, such as excessive atmospheric venting or suboptimal blower sequencing.
- Model Development: Using the PTB simulation environment to create a "Digital Twin" for risk-free scenario testing.
- Implementation: Executing on-site trials to verify the simulation results and finalise operational improvements.

By comparing positive displacement blower systems (Case Studies A, B, and C) with centrifugal blower systems (Case Study D), the discussion highlights the nuanced differences in control logic, ranging from blow-off valve management to surge control optimisation. The results detailed herein provide evidence of the commercial and technical value of the proposed methodology, yielding year-to-date savings after six months of between R80 000 and R1 000 000 per site, while establishing a repeatable standard for industrial energy management.

3.2 Case study background

Four case studies were conducted as part of this research. A summary is provided in Table 3-1 below to highlight the differences and illustrate the unique challenges associated with each case.

Table 3-1: Case study characteristics

Case Study	Reef Processed	Plant Capacity (t/d)	Type	Differentiating System Characteristics	Blower Type	Operating Pressure (kPag)	Installed Blower Load Capacity (kW)
A	Merensky & UG2	7 500	Fresh Ore	Self-aspirating flotation cells retrofitted to work with blowers.	Positive Displacement	30	510
B	Merensky & UG2	16 000	Fresh Ore	Significant leaks, multiple blow-off valves.	Positive Displacement	56	1 120
C	Merensky & UG2	17 000	Tailings	Frequent pressure setpoint changes.	Positive Displacement	53 – 55	801
D	Plat Reef	29 000	Fresh Ore	Centrifugal blowers	Centrifugal	65	2 400

A common feature across Case Studies A – C is their connection to a shared air header. This air header is equipped with one or more blow-off valves. Depending on the pressure setpoints of each valve, one or more of them function as pressure regulators by venting excess air to the atmosphere. The flotation circuits differ across the case studies, comprising various types of flotation cells and operating under varying daily throughput conditions.

Typically, the systems in Case Studies A – C consist of multiple blowers connected to a single manifold. This manifold has a pressure setpoint, which is controlled by a blow-off valve opening and closing as needed to maintain the required pressure. In theory, this configuration allows for flexible operation by running different combinations of blowers to meet varying demand. However, energy wastage frequently occurs when larger blowers than required are operated, or when too many blowers run simultaneously for the actual demand. This inefficiency is characterised by a blow-off valve that remains at a consistently high opening percentage, indicating excess air

generation that must be vented to maintain the setpoint pressure rather than being productively used in the process.

At all case study sites, blower operation is manually controlled to maintain header pressure at its setpoint. The control strategy also permits setpoint adjustment to optimise flotation performance under varying conditions. Increasing the header pressure setpoint raises mass flow to the cells without requiring additional volumetric flow, and vice versa. If the margin required to switch off a blower is sufficiently small, a minor adjustment to the pressure setpoint may be adequate to achieve the desired outcome. However, this should not be pursued due to potential effect on recovery. A 1% reduction in recovery will be significantly more expensive than any potential improvements gained in energy efficiency.

3.3 Case Study A

3.3.1 Step 1: Data acquisition

As part of the proposed method in Figure 2-2, the investigation began by gathering information about the site layout. The system consists of six blowers that supply air to two different streams of rougher flotation circuits. These blowers are connected to a common air header, where the pressure is maintained at a setpoint using a control valve that vents excess air to the atmosphere. A simplified layout of this configuration is shown in Figure 3-1.

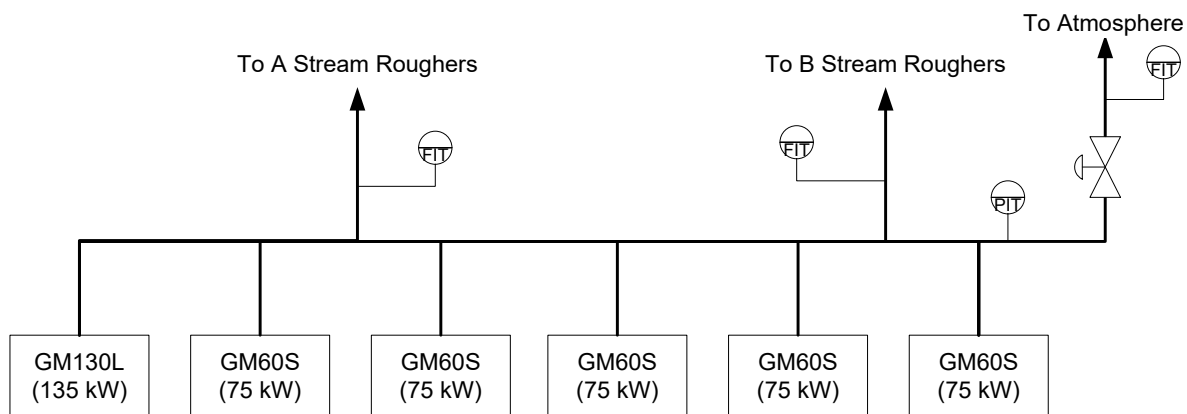


Figure 3-1: Blower air reticulation schematic for Case Study A

The blower configuration includes one GM130L unit operating as the baseload blower, supplemented by five GM60S units acting as trim blowers.

The flotation cells supplied by the blowers are retrofitted self-aspirating units. The existing control philosophy allows for the header pressure to drop to 0 kPag, which would occur if all blowers were

to trip. In such cases, the control valve on the common header is designed to open fully, while non-return valves at the rougher banks open as well, enabling ambient air to flow directly to the cells.

For the initial phase of this investigation, historical data related to blower operation and flotation cell performance was reviewed over a three-month period, from 1 April 2024 to 1 July 2024. During this time, the common header pressure setpoint remained constant at 30 kPag.

3.3.2 Step 2: Analysis

Over the three-month analysis period, the lowest number of blowers were operated during May, where four blowers were active for most of the month. In contrast, six blowers were typically in operation throughout April. Figure 3-2 presents the blower running statuses overlaid with the control valve position. Despite variations in the number of active blowers, the header pressure setpoint remained constant at 30 kPag and was consistently maintained.

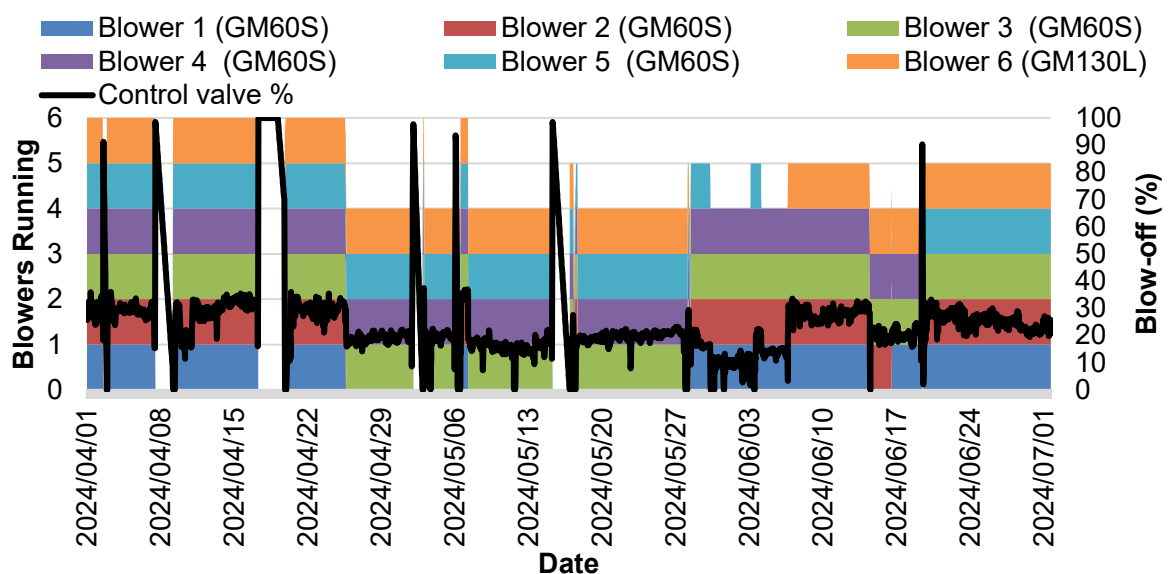


Figure 3-2: Running status and control valve (blow-off) position set to 30 kPag for Case Study A

Figure 3-2 illustrates that the control valve opens further when an additional blower is brought online, maintaining the header pressure at the setpoint by venting the excess air to atmosphere. Since flow is driven by the pressure differential, the amount of air reaching the flotation cells does not significantly increase when an extra blower is added. Instead, the surplus air is diverted, preventing a rise in cell air flow. This imbalance between increased air supply and relatively

unchanged demand is summarised in Table 3-2. An example of the calculation process to determine these values can be found in Appendix B.

Table 3-2: Blown air demand and supply comparison for Case Study A

Month	Average Demand (m ³ /min)	Average Supply (m ³ /min)	Average Over/Undersupply (m ³ /min)
April	206	330	+124 m ³ /min over-supply
May	187	269	+82 m ³ /min over-supply
June	190	299	+109 m ³ /min over-supply

Table 3-2 highlights a significant disparity between the air supplied, estimated using blower performance curves, and the air reaching the flotation cells (average demand), particularly during April when six blowers operated for most of the month before being reduced to four during the final week. Fluctuations in demand can be driven by changes in ore feed density and throughput, as well as the operational status of specific blowers. According to the OEM (Original equipment manufacturer) blower curves (Appendix A), at a header pressure of 30 kPag, the GM130L blower delivers approximately 109 m³/min, while each GM60S unit provides approximately 61 m³/min. These values could not be directly verified due to the absence of flow metering on site; however, they offer a useful estimate for comparison.

Based on these figures, the combined output of the GM130L and two GM60S blowers should be sufficient to meet the observed demand. This suggests a potential inefficiency in the current operation. As a result, the proposed adjustment was to limit blower operation (under similar demand conditions) to three units at a time: one GM130L and two GM60S blowers.

3.3.3 Step 3: Model development

To validate whether three blowers are sufficient, a PTB simulation was developed using the historical data. The simulation can be seen in Figure 3-3.

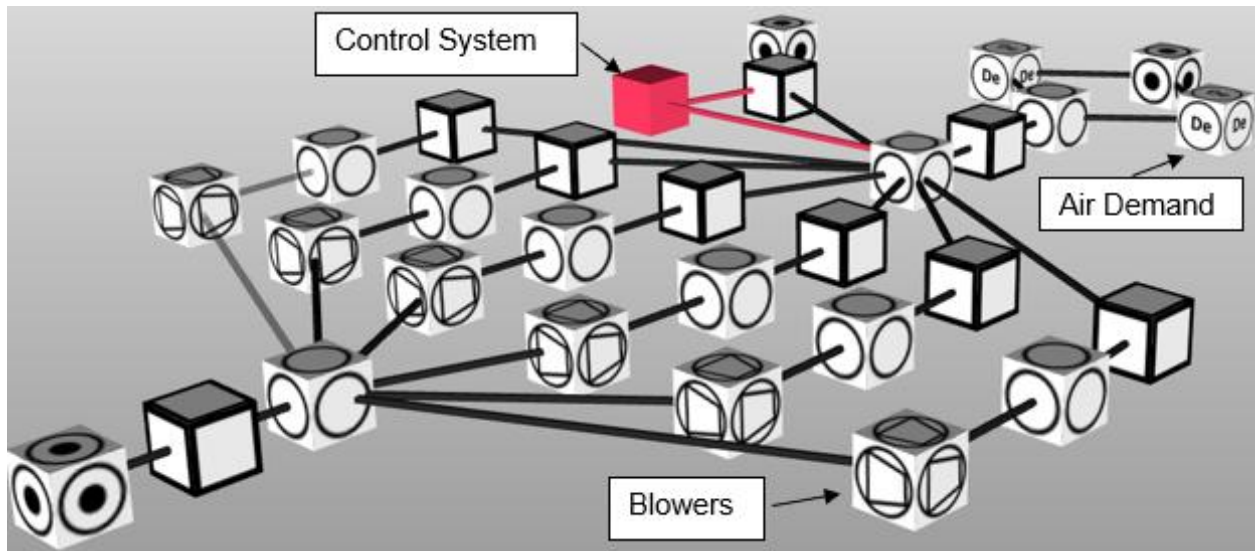


Figure 3-3: Case Study A PTB simulation

The model was calibrated to be within 5% of actual performance, as shown in Table 3-3. A 5% error was deemed acceptable by the stakeholder.

Table 3-3: Model results for Case Study A

Variable	Simulation	Requirement	Error
Stream 1 Roughers Flow Demand	92.52 m ³ /min	93.25 m ³ /min	0.78%
Stream 2 Roughers Flow Demand	124.58 m ³ /min	119.38 m ³ /min	4.36%
Header Pressure	31.39 kPag	30.00 kPag	4.43%

The proposed blower configuration (one GM130L and two GM60S units) was then tested in the simulation by disabling all other blowers. According to the simulation, this configuration could supply sufficient air at the desired header pressure. Additionally, the simulation response can be seen in Figure 3-4.

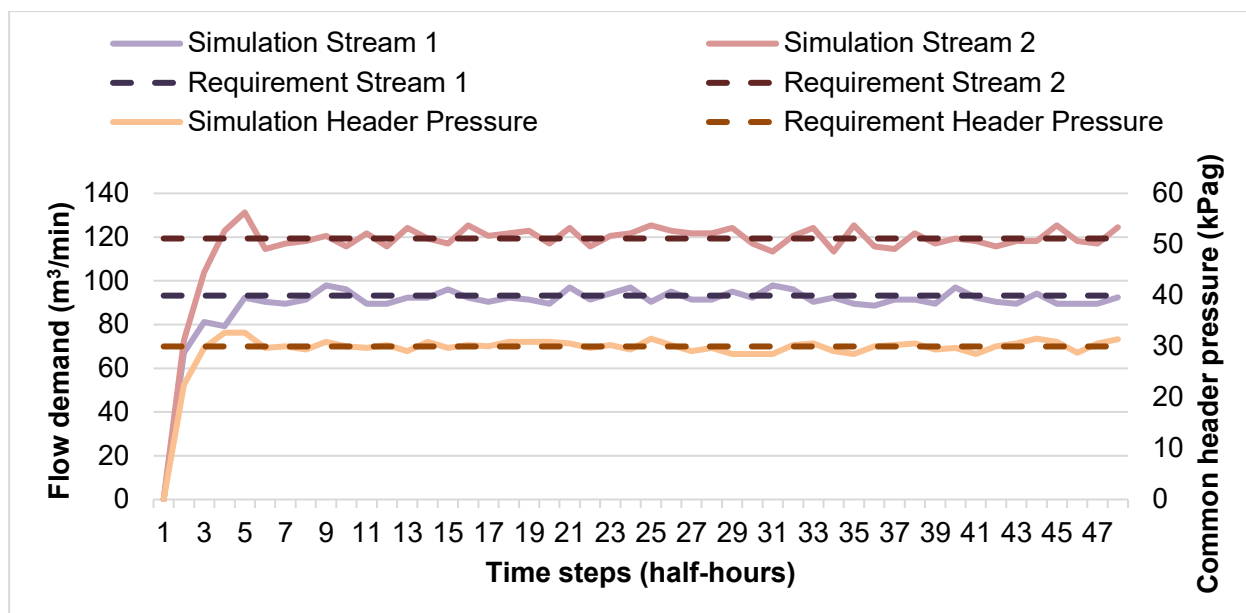


Figure 3-4: Case Study A PTB simulation results

3.3.4 Step 4: Implementation

To test the proposed three blower configuration under real conditions, a site test was conducted. The test involved switching off one or more blowers under stable operation and monitoring pressure, mass pull, and air addition to the flotation cells.

The test procedure:

1. Under stable operation, one GM60S blower was turned off.
2. System response was monitored for at least 10 minutes, up to 30 minutes. System response refers to the observed changes in the blow-off valve position and the manifold pressure.
3. If the blow-off valve percentage was high and SP was maintained, another blower was turned off.
4. If pressure dropped below SP or only three blowers remained, blowers were cycled (one stopped, one started) after the system was given 10 – 30 minutes to respond.
5. The test was repeated across setpoints from 30 kPag up to 35 kPag in 50 mbar increments.
6. The test ended when all blowers were cycled or if operational impacts prompted site personnel to request early termination.

At the start of the test, five blowers were running, with one GM60S on standby. The test data is shown in Figure 3-5.

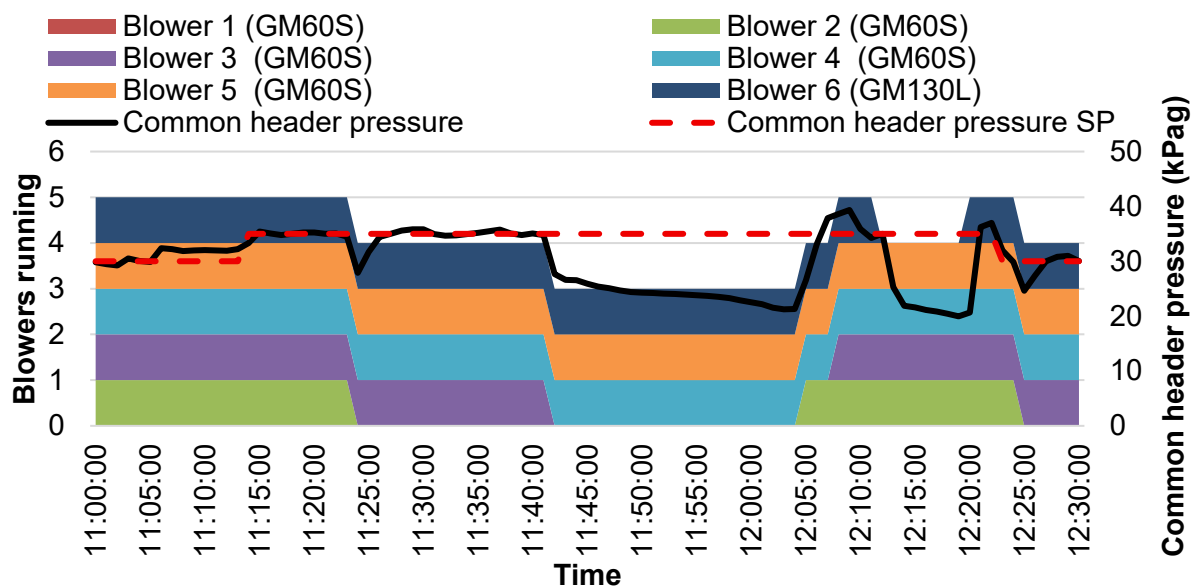


Figure 3-5: Test data for Case Study A

At 11:14, the pressure setpoint was increased from 30 kPag to 35 kPag. This was the first case study, and as such it was desired to confirm the impact of pressure changes on the blow-off valve percentage. In theory, increasing pressure can improve air flow to the flotation cells without requiring an additional blower to be started. However, this affects the flotation cell internal dynamics and should be approached with caution.

At 11:23, a GM60S (blower 2) was stopped. After pressure stabilised, blower 3 was stopped at 11:41. With only the GM130L and two GM60S units running, the SP could not be met—the pressure dropped to 20 kPag. All blowers were restored by 12:09. At 12:11, the GM130L was switched off to test the equivalency of four GM60S units versus the GM130L plus two GM60S units. Pressure again dropped to 20 kPag. At 12:18, the system was restored.

Later, with the SP returned to 30 kPag, another GM60S was switched off, and the system remained stable.

The test confirmed that four blowers can maintain a 35 kPag SP, validating that under standard operating conditions, fewer blowers are required. It also showed that blowers are sometimes added unnecessarily, even when the control valve is already venting excess air.

Test results indicate that the initial proposal of one GM130L and two GM60S units is insufficient to reach the required pressure setpoint. Consequently, the design must be scaled to include one GM130L and three GM60S units to ensure feasibility. Therefore, the proposed solution was insufficient, due to it not being able to reach the required pressure. This could have been due to

a variety of reasons, such as leaks, worn motors, blocked air intakes etc. This highlights the importance of testing before implementing.

More importantly, the project highlighted the importance of considering blow-off valve position when evaluating blower operation. A high blow-off valve percentage indicates an oversupply of air and can serve as a trigger to reduce the number of operating blowers. However, it cannot be directly correlated to a specific volume of air being wasted.

To support long-term optimisation, a baseline operating profile was developed in collaboration with site personnel. This baseline comprises the historical running status and electrical current data of the blowers prior to implementation of the changes. By capturing both running status and electrical current readings, a robust data validation framework was established; where electrical current serves as a safeguard against potential data loss or gaps in the running status logs, and vice versa. This dual-parameter approach ensures data integrity and allows for cross-verification of actual blower operation. By utilising this data, the power consumption of the blowers was determined, and the average operating conditions before intervention were compared with actual post-intervention performance, excluding anomalous periods such as plant shutdowns. This difference in energy consumption was combined with the applicable Eskom Megaflex tariffs to calculate the savings value. Site personnel were instructed to start additional blowers only when the blow-off valve closed completely and were provided with the revised standard operating procedure for blower quantities as determined through testing. Figure 3-6 shows the actual vs. baseline average daily performance.

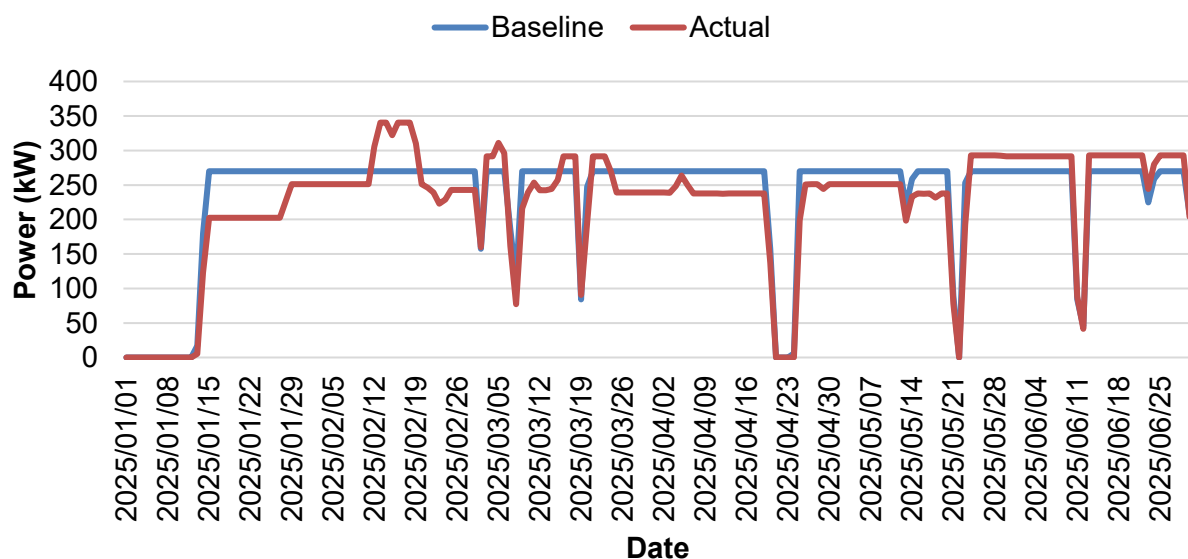


Figure 3-6: Daily profile of project performance for Case Study A

While savings of R80 000 had been achieved in the six-month period up to 1 July 2025, this figure was lower than anticipated. This was primarily due to equipment failures and the unnecessary start-up of blowers at the beginning of shifts.

Based on our on-site experience and observations with the client, it is evident that operator KPIs are not aligned with energy efficiency objectives. Their primary focus remains on maintaining stable plant operations and meeting recovery and production targets, often at the expense of energy performance.

In summary, Case Study A identifies a significant opportunity for energy optimisation by addressing the systemic oversupply of air in flotation circuits. Prior to intervention, the site typically operated with between four and six blowers (with the GM130L unit always running), leading to a substantial oversupply of air that simply vented to the atmosphere. While initial simulations suggested that a three-blower configuration would suffice, empirical site testing proved that four blowers were the practical minimum required to maintain the 30 kPag setpoint. By shifting the operational logic to use the blow-off valve position as a trigger for blower adjustments, the project realised R80 000 in savings after six months by July 2025. Ultimately, the study concludes that technical solutions must be paired with cultural shifts, as operator KPIs currently prioritise production stability over energy performance, often leading to the unnecessary manual startup of redundant equipment.

3.4 Case Study B

3.4.1 Step 1: Data acquisition

This system comprises seven blowers that supply air to the primary and secondary roughers, as well as the primary and secondary cleaners and recleaners. All blowers are connected to a common air header, where pressure is maintained at a setpoint through a control valve that vents excess air to atmosphere. Two atmospheric vent control valves are used, namely one set to 56 kPag and the other to 57 kPag. In practice, blow-off is primarily governed by the valve set to 56 kPag. Only once this valve is fully open does the second valve, set to 57 kPag, begin to operate.

In addition to the atmospheric vents, there is a separate control valve that regulates airflow to the primary and secondary cleaners and recleaners. However, this valve falls outside the scope of the current study, which is focused solely on identifying and reducing air wastage. A simplified layout of the blower configuration is provided in Figure 3-7.

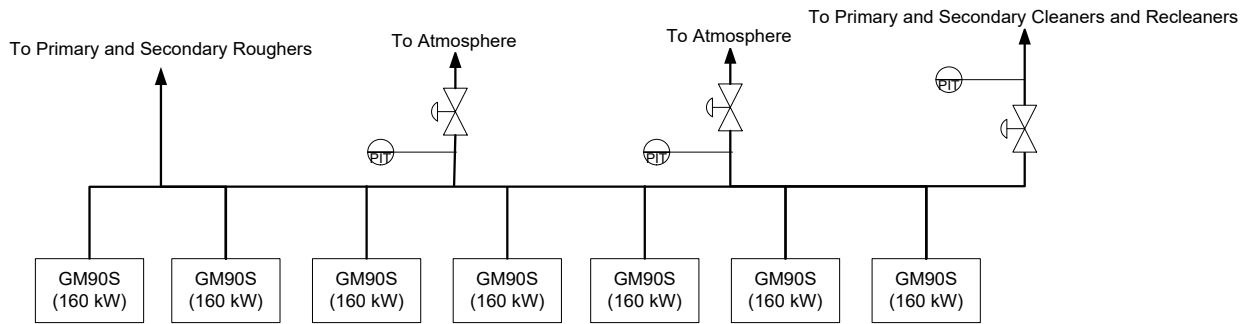


Figure 3-7: Blower air reticulation schematic for Case Study B

The blower configuration consists of seven GM90S units. Under normal operating conditions, six or seven blowers are typically online at any given time. However, this was not always the case; fewer blowers were historically used as part of the standard operating procedure.

Personnel also reported ongoing difficulties in maintaining the required pressure in the common header. This points to the likely presence of significant air leaks within the system, which may have led to the current practice of operating a higher number of blowers.

For the initial phase of this investigation, historical data on blower operation and flotation cell performance was reviewed over a four-month period, from 1 April 2024 to 1 August 2024. During this period, the pressure setpoint for the common header remained constant at 56 kPag.

3.4.2 Step 2: Analysis

Over the four-month analysis period, the minimum number of blowers operating for extended durations was six, although there were also several instances where all seven blowers were running. Figure 3-8 presents the blower running statuses overlaid with the blow-off control valve position. Notably, despite fluctuations in the number of active blowers, the header pressure setpoint remained constant at 56 kPag and was consistently maintained.

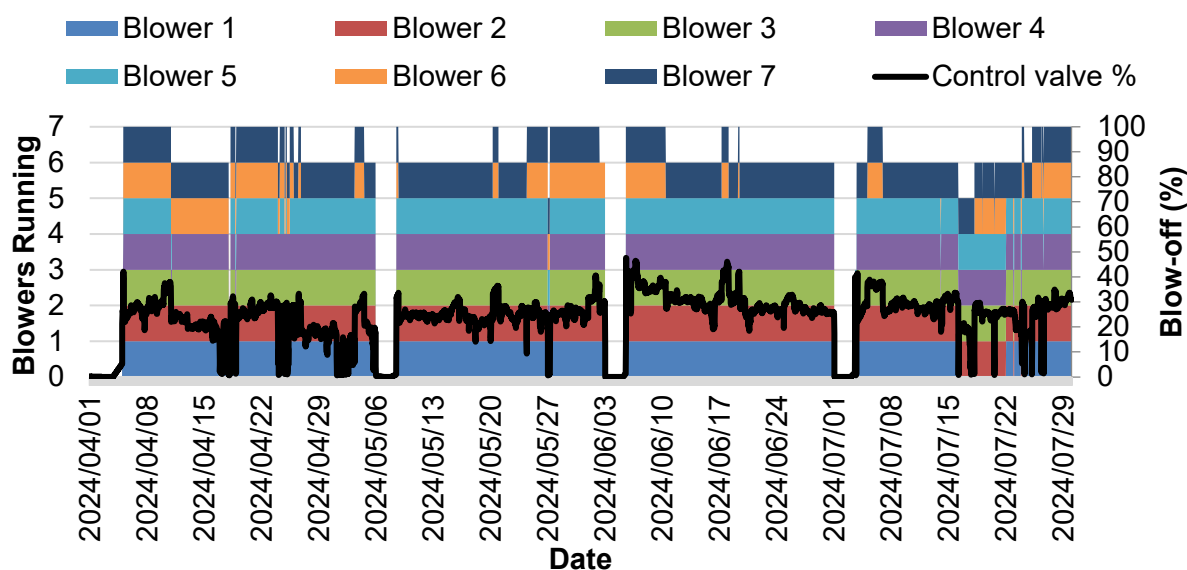


Figure 3-8: Running status and control valve (blow-off) position set to 56 kPag for Case Study B

As illustrated in Figure 3-8 the control valve opens further when an additional blower is brought online, thereby venting the excess air to atmosphere in order to maintain the header pressure at the setpoint. Since airflow to the flotation cells is driven by the pressure differential, the addition of another blower does not result in a significant increase in air delivery to the cells. Instead, the surplus air is diverted, preventing an increase in actual cell airflow. This mismatch between increased air supply and relatively stable demand is summarised in Table 3-4. An example of the calculation process to determine these values can be found in Appendix B.

Table 3-4: Blown air demand and supply comparison for Case Study B

Month	Average Demand (m ³ /min)	Average Supply (m ³ /min)	Average Oversupply (m ³ /min)
April	386	506	120 m ³ /min over-supply
May	402	524	122 m ³ /min over-supply
June	360	521	161 m ³ /min over-supply
July	371	510	139 m ³ /min over-supply

Table 3-4 shows a significant gap between the air supplied, estimated from OEM blower curves, and the air reaching the flotation cells (average demand). According to the blower curve, a GM90S unit delivers approximately 91 m³/min at 56 kPag. While these estimates could not be directly verified due to the absence of flow metering, they provide a useful benchmark.

Based on these figures, five GM90S blowers should have been sufficient to meet the observed demand, suggesting potential inefficiency in the current blower operation.

3.4.3 Step 3: Model development

To validate these findings, a PTB simulation was developed using the historical data. The simulation can be seen in Figure 3-9.

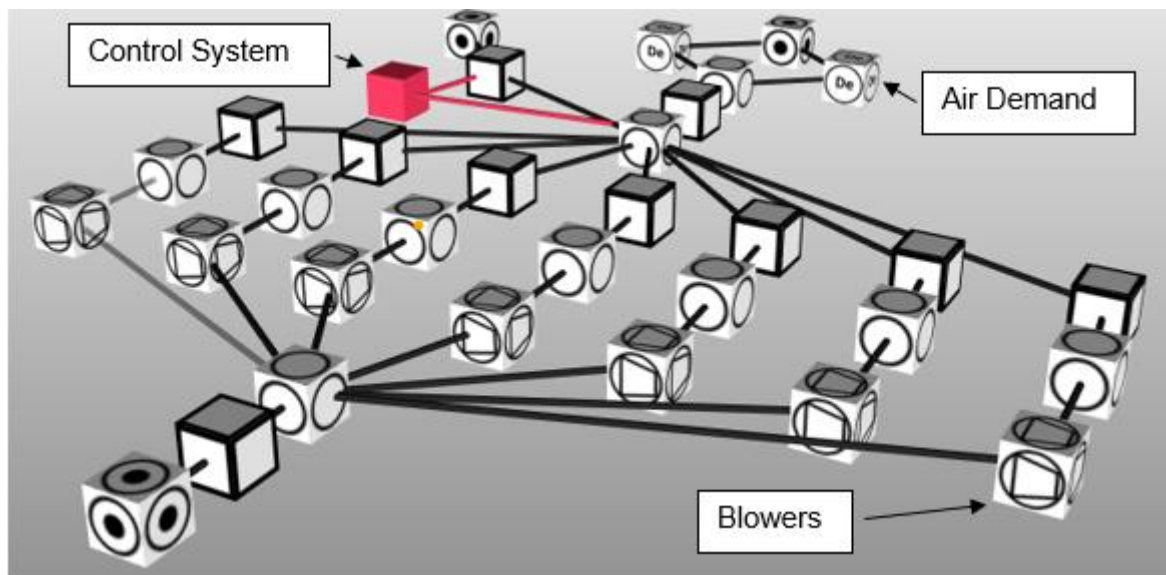


Figure 3-9: Case Study B PTB simulation

The model was calibrated to be within 5% of actual performance, as shown in Table 3-5. A 5% error was deemed acceptable by the stakeholder.

Table 3-5: Model results for Case Study B

Variable	Simulation	Requirement	Error
Primary and Secondary Roughers Flow Demand	332.44 m ³ /min	317.89 m ³ /min	4.58%
Primary Re-cleaners and Secondary Cleaners and Re-cleaners Flow Demand	219.03 m ³ /min	210.05 m ³ /min	4.27%
Header Pressure	58.52 kPag	56.00 kPag	4.63%

The proposed blower configuration (five GM90S units) was tested in the simulation by disabling all other blowers. According to the simulation, this configuration could supply sufficient air at the desired header pressure. Additionally, the simulation response can be seen in Figure 3-10.

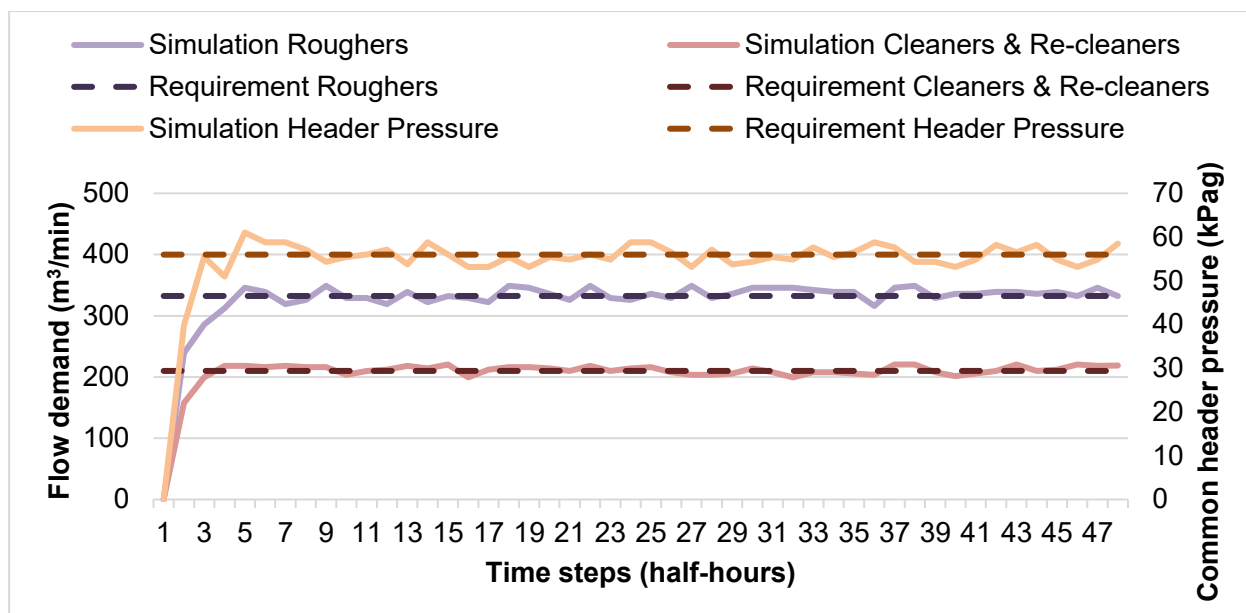


Figure 3-10: Case Study B PTB simulation results

3.4.4 Step 4: Implementation

To test the proposed configuration under real operating conditions, a site test was conducted. The test involved switching off one or more blowers under stable operation and monitoring the effects on common header pressure, mass pull, and air addition to the flotation cells. The use of the blower PRV valves also allowed for testing the effects of raising and lowering the common header pressure setpoint.

The test procedure:

1. Under stable operation, one GM90S blower was turned off.
2. System response was monitored for at least 10 minutes, up to 30 minutes. System response refers to the observed changes in the blow-off valve position and the manifold pressure.
3. If the blow-off valve percentage remained high and the pressure setpoint was maintained, another blower was turned off.
4. If pressure dropped below the setpoint or operational limits were approached, blowers were cycled (one stopped, one started) after the system was given 10 – 30 minutes to respond.
5. The test was repeated across pressure setpoints ranging from 46 kPag up to 56 kPag in defined increments.
6. The test ended when all blower combinations had been cycled or if operational impacts prompted site personnel to request early termination.

At the start of the test, six blowers were running with one GM90S unit on standby. The test data is presented in Figure 3-11.

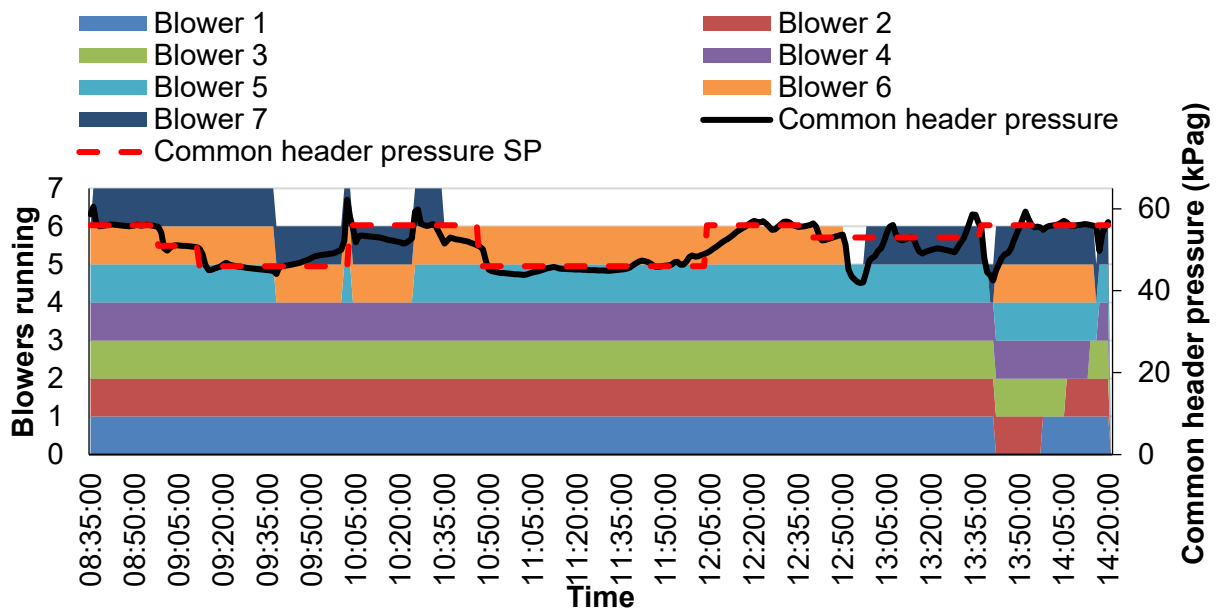


Figure 3-11: Test data for Case Study B

At 08:35, blower 7 was started with the pressure setpoint at 56 kPag. The setpoint was reduced to 51 kPag at 08:58, and then further reduced to 46 kPag at 09:12. The pressure stabilised successfully in all three cases. At 10:03, blower 5 was switched off to begin testing different six-blower combinations, and the setpoint was returned to 56 kPag. Both blow-off control valves closed completely; however, pressure failed to reach the setpoint. At 10:34, blower 5 was restarted and blower 7 turned off. Again, pressure failed to reach the setpoint. At 10:47, the setpoint was lowered to 46 kPag, and pressure stabilised.

Testing was paused due to unrelated issues with the flotation cells, which required intervention by site personnel. At 12:04, the setpoint was restored to 56 kPag, and the six-blower configuration (excluding blower 7) was retested. This time, the pressure setpoint was achieved. At 12:40, the setpoint was reduced to 53 kPag and blower 5 was swapped out for blower 7, without any pressure issues. At 13:14, the setpoint was further reduced to 50 kPag, and blower 6 was replaced by blower 7. Again, no pressure instability was observed. At 13:37, blower 7 was turned off while maintaining a setpoint of 56 kPag. As expected, pressure dropped continuously, and the test was quickly stopped.

From 13:42 onwards, the remaining untested six-blower combinations were evaluated at 56 kPag, all of which successfully maintained the required pressure.

The test took significantly longer than expected due to issues with the flotation cells. Initially, the results suggested that running six blowers was not feasible, despite this being historically common practice. However, once site personnel addressed issues on the flotation cells, system performance improved noticeably.

Although initial modelling indicated that five blowers might be sufficient, the test results showed otherwise. However, as noted, the site reported that the air header is in poor condition. Consequently, a series of audits was initiated to identify and reduce leaks and pressure losses. These audits have already improved pressure stability and allowed the plant to operate more frequently with six blowers instead of seven, resulting in measurable cost savings.

These savings were expected to improve further as additional losses are addressed. To support long term optimisation, a baseline (as discussed in Section 3.3.4) operating profile was developed in collaboration with site personnel. Figure 3-12 shows the actual versus baseline average daily performance.

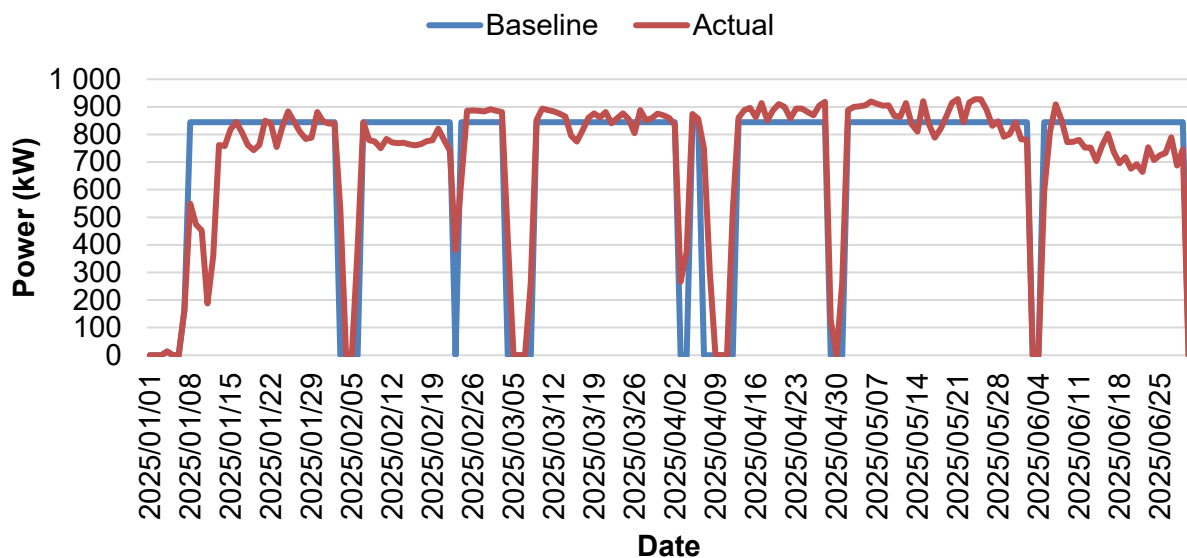


Figure 3-12: Daily profile of project performance for Case Study B

After six months, savings of R170 000 have been achieved (as of 1 July 2025).

In summary, Case Study B identified a significant air oversupply within a seven-blower system (all GM90S units), where operating six or seven units simultaneously resulted in significant wastage through atmospheric venting. Prior to intervention, the site typically operated six or seven blowers to maintain a 56 kPag setpoint, largely due to perceived pressure instabilities and suspected system leaks. While PTB simulations suggested five blowers could meet demand,

empirical testing revealed that six blowers remain the practical minimum until the integrity of the air header is improved. By initiating a series of leak audits and utilising the blow-off valve position as an operational guide, the project successfully transitioned the site toward more frequent six-blower operation, achieving R170 000 in savings after six months by July 2025. The findings underscore that while significant gains were made, further optimisation is contingent upon repairing physical infrastructure to reduce parasitic losses.

3.5 Case Study C

3.5.1 Step 1: Data acquisition

The flotation plant in this case study utilises six GM80L blowers to supply air to both the cleaner and rougher flotation circuits. These blowers are connected to a common air header, where a control valve maintains system pressure by venting excess air to the atmosphere. A simplified diagram of this configuration is provided in Figure 3-13.

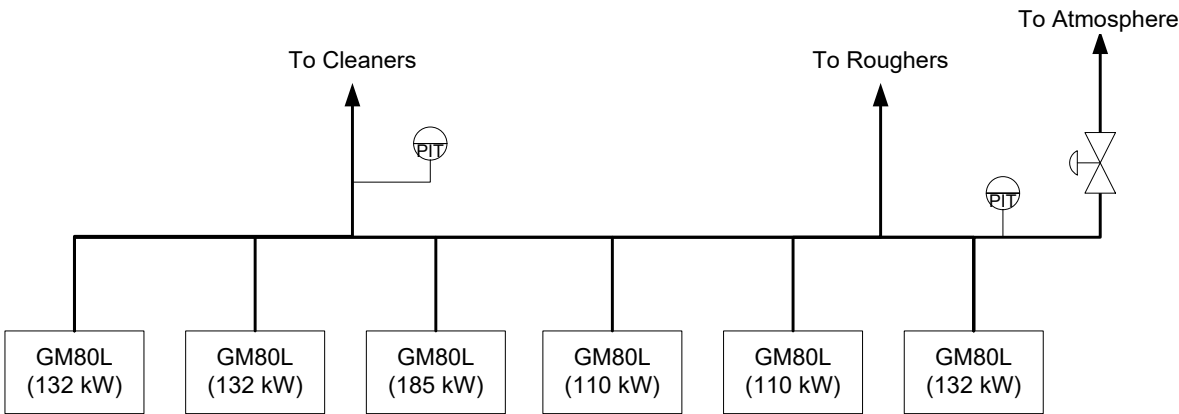


Figure 3-13: Blower air reticulation schematic for Case Study C

The system comprises blowers with varying motor power ratings, as shown in Table 3-6. The manifold pressure has undergone alteration, with site records indicating a change in pressure setpoint from 55 kPag to 53 kPag on 4 January 2024. While this was the only pressure change within the analysed period, site personnel advised that such adjustments are likely to recur.

For the initial phase of the investigation, historical data covering blower operation and flotation cell performance was reviewed for the six-month period from 1 January 2024 to 1 July 2024. Due to the variation in motor sizes, a key opportunity for energy optimisation was identified by developing a priority sequence for blower operation, which is summarised in Table 3-6.

Table 3-6: Blower motor sizes at Case Study C

Blower Number	Motor Power Audited (kW)
1	132
2	132
3	185
4	110
5	110
7	132

3.5.2 Step 2: Analysis

Analysis of the historical dataset revealed that the fewest number of blowers were operated during June, where three blowers were active for most of the month. During the other months, four blowers were typically in operation. Figure 3-14 illustrates the blower running statuses overlaid with the position of the control valve.

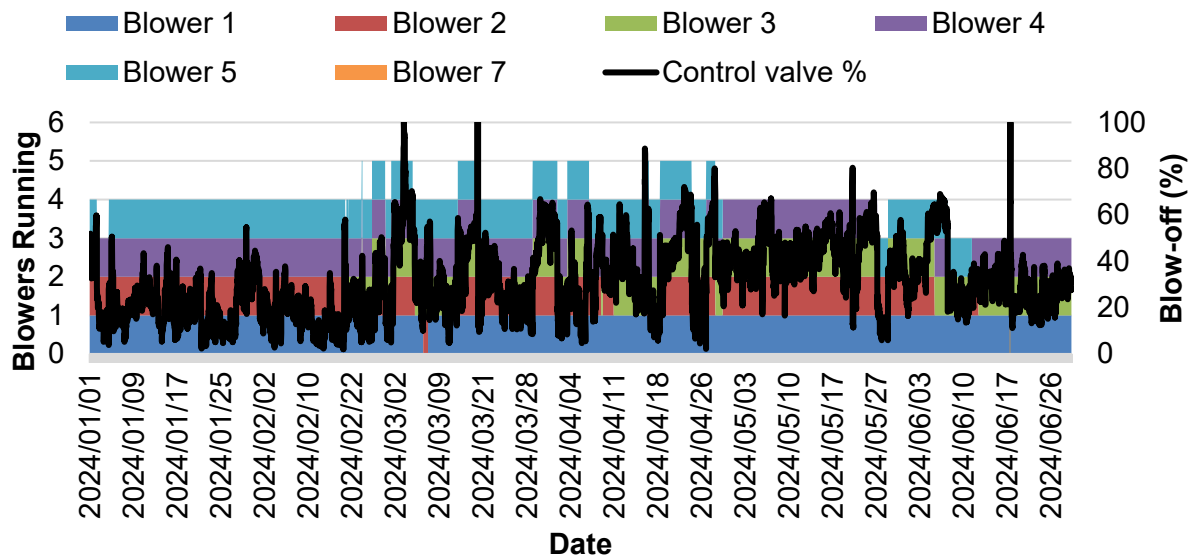


Figure 3-14: Running status and control valve (blow-off) position set to 53 kPag for Case Study C

As illustrated in Figure 3-14, the blow-off valve opens more when an additional blower is brought online. This maintains the header pressure at the setpoint by venting the surplus air to atmosphere. However, since flow is primarily driven by the pressure differential, the addition of another blower does not significantly increase the air delivered to the flotation cells. Rather, the excess air is discharged, resulting in inefficiency. Table 3-7 compares the estimated air supply to

the flotation cells' average demand. An example of the calculation process to determine these values can be found in Appendix B.

Table 3-7: Blown air demand and supply comparison for Case Study C

Month	Average Demand (m ³ /min)	Average Supply (m ³ /min)	Average Over/Undersupply (m ³ /min)
January	256	324	68 m ³ /min over-supply
February	272	338	66 m ³ /min over-supply
March	227	361	134 m ³ /min over-supply
April	231	364	133 m ³ /min over-supply
May	188	325	137 m ³ /min over-supply
June	180	270	90 m ³ /min over-supply

The air supply values were estimated using original equipment manufacturer (OEM) performance curves. At a header pressure of 53 or 55 kPag, each GM80L blower is expected to deliver approximately 82.5 m³/min. Although these values could not be verified due to the absence of flow instrumentation, they provide a reasonable benchmark.

This analysis indicated that the average demand could be satisfied using only three blowers. In particular, the optimal combination would have involved one of the 132 kilowatt blowers (1, 2 or 7) along with both 110-kilowatt units (4 and 5). However, historical data shows that the 185-kilowatt blower (3) was often used in place of a more efficient alternative, contributing to unnecessary energy consumption.

3.5.3 Step 3: Model development

To validate these findings, a PTB simulation was developed using the historical data. The simulation can be seen in Figure 3-15.

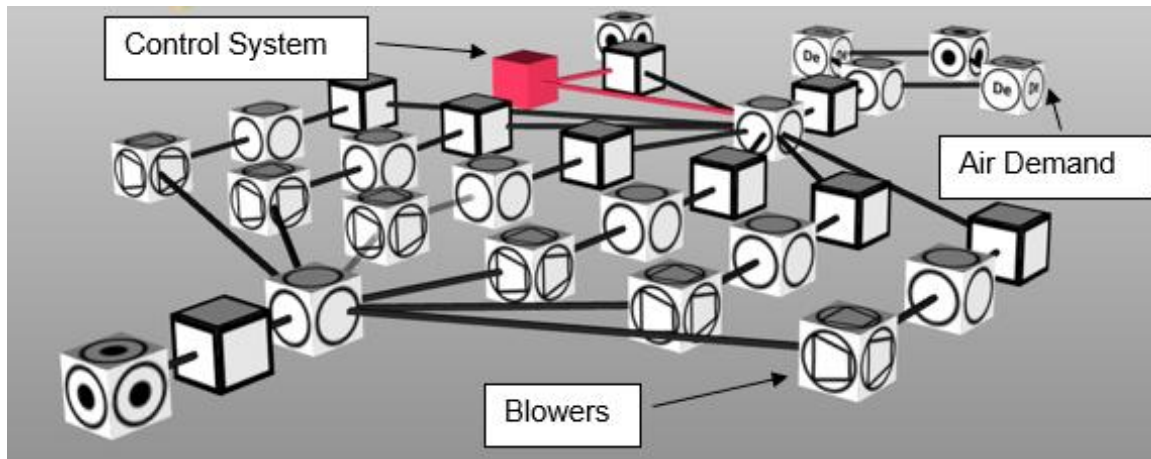


Figure 3-15: Case Study C PTB simulation

The model was calibrated to be within 5% of actual performance, as shown in Table 3-8. A 5% error was deemed acceptable by the stakeholder.

Table 3-8: Model results for Case Study C

Variable	Simulation	Requirement	Error
Roughers Flow Demand	181.47 m ³ /min	174.92 m ³ /min	3.74 %
Cleaners Flow Demand	55.32 m ³ /min	57.58 m ³ /min	-3.92 %
Header Pressure	51.63 kPag	53.00 kPag	-2.58 %

The proposed blower configuration (three GM80L units, consisting of one 132 kilowatt blowers and two 110 kilowatt blowers) was tested in the simulation by disabling all other blowers. According to the simulation, this configuration could supply sufficient air at the desired header pressure. Additionally, the simulation response can be seen in Figure 3-16.

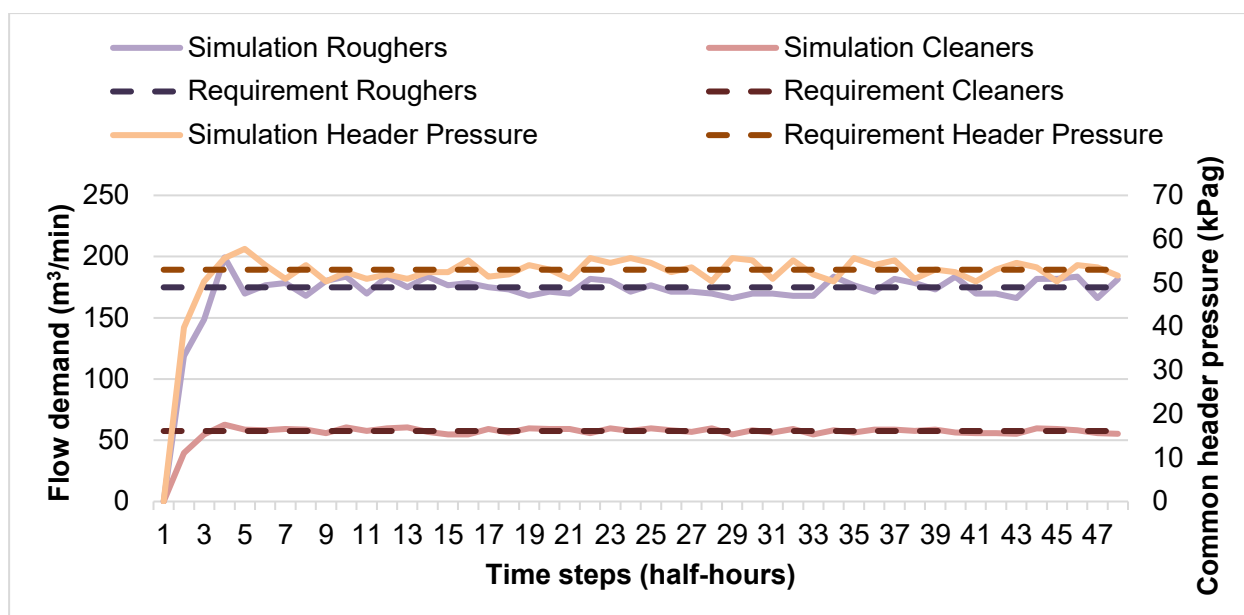


Figure 3-16: Case Study C PTB simulation results

3.5.4 Step 4: Implementation

To validate the proposed configuration, a site test was conducted under controlled operating conditions. The test involved switching off blowers under steady state operation and monitoring key parameters such as pressure, mass pull, and air addition.

The test procedure:

1. Under stable operation, one GM80L blower was turned off.
2. System response was monitored for at least 10 minutes, or until system is stable. System response refers to the observed changes in the blow-off valve position and the manifold pressure.
3. If the blow-off valve percentage was high and SP was maintained, another blower was turned off.
4. If pressure dropped below SP or only two blowers remained, blowers were cycled (one stopped, one started) after the system was given 10 – 30 minutes to respond.
5. The test was repeated across setpoints from 45 kPag up to 55 kPag in 100 mbar increments.
6. The test ended when all blowers were cycled or if operational impacts prompted site personnel to request early termination.

At the beginning of the test, only three blowers were running, as the flotation cells were under low-density conditions due to a planned plant shutdown. Figure 3-17 presents the collected data.

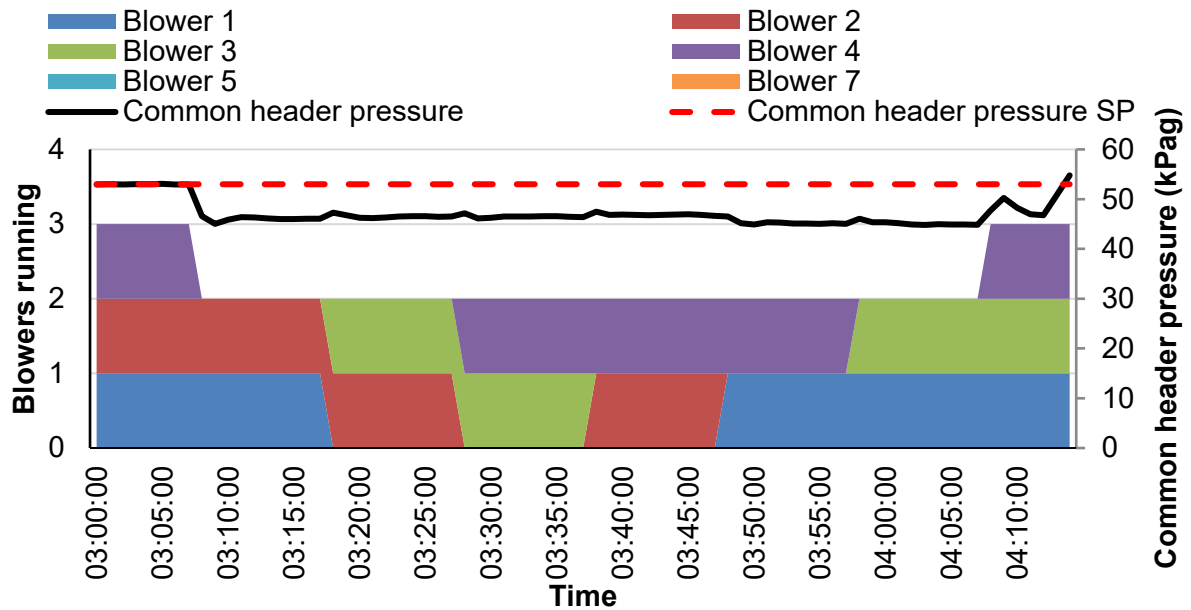


Figure 3-17: Test data for Case Study C

Due to the low-density material present in the flotation cells, resulting from the test being conducted during a planned plant shutdown, it was concluded that further pressure testing would not yield meaningful results. The focus was therefore shifted to evaluating blower combinations. From 03:17 until the conclusion of the test at 04:06, various blower combinations were trialled, as illustrated in Figure 3-17.

The results confirmed that three blowers were sufficient to maintain a pressure setpoint of 53 kPag, providing a strong indication that this configuration could be viable once flotation cell conditions returned to normal operating densities. Subsequent monitoring and engagement with plant personnel resulted in the successful implementation of a three-blower strategy for extended periods. However, due to variability in the characteristics of the processed material, and therefore in the pressure setpoint, there remain instances where four blowers are required.

Importantly, the outcomes of the test also led to a revision of the standard operating procedure, with a new prioritisation sequence implemented for selecting which blowers to operate based on motor size and efficiency.

To facilitate ongoing optimisation, a baseline (as discussed in Section 3.3.4) operating profile was developed collaboratively with site personnel. Figure 3-18 presents a comparison of the actual and baseline average daily performance.

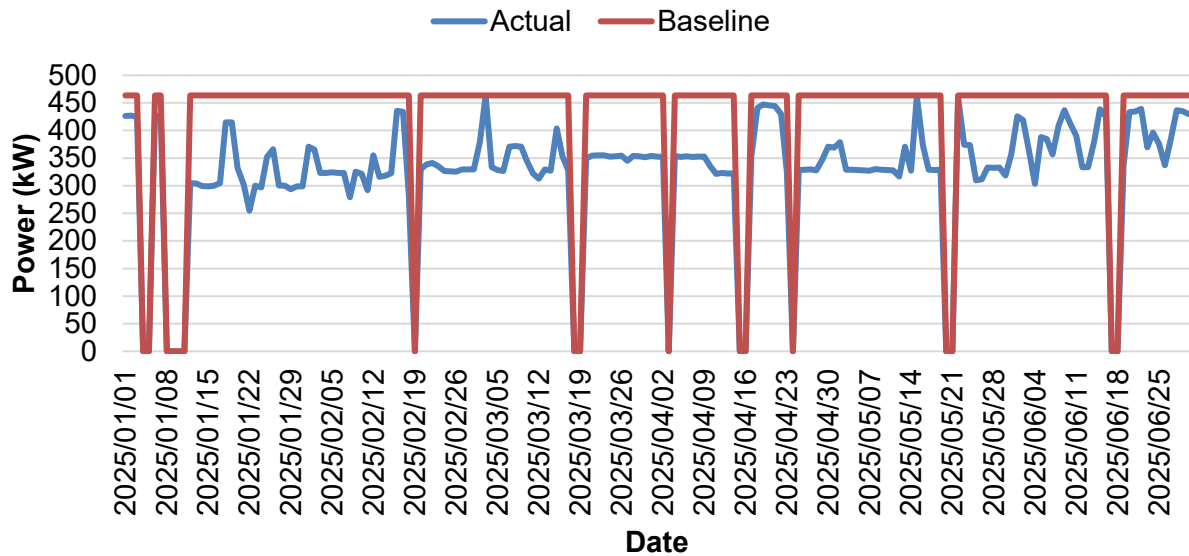


Figure 3-18: Daily profile of project performance for Case Study C

In the six-month period up to 1 July 2025, savings of R750 000 have been achieved. The initial hypothesis that only three blowers would be required under most operating conditions was confirmed. In addition, the discovery that the installed motors differed in size from one another and from what was reported on the nameplates contributed significantly to the improvement in efficiency.

In summary, Case Study C demonstrated that substantial energy savings are achievable by optimising equipment selection based on actual motor efficiency rather than simple unit count. Prior to intervention, the site typically operated between three and four blowers without a priority sequence, frequently utilising the high-consumption 185 kW blower when three smaller units would have been sufficient. This lack of differentiation resulted in an oversupply of air being vented to the atmosphere. An audit of the actual motor sizes revealed discrepancies between the previously assumed specifications and the hardware installed; consequently, a new priority-based selection sequence was implemented to favour the more efficient 110 kW and 132 kW units. Validated by site testing, this shift allowed the plant to maintain the 53 kPag setpoint while operating the same number of blowers more efficiently; by prioritising smaller units over the high-consumption 185 kW blower, the site achieved R750 000 in savings for the six-month period up to 1 of July 2025. This case underscores that when motor sizes vary, the specific selection of equipment is as critical as the total number in operation.

3.6 Case Study D

This case study differs from the previous one due to the use of centrifugal blowers rather than positive displacement blowers. As a result, the system operates on fundamentally different principles. Centrifugal blower systems typically do not use blow-off valves on the common header to regulate pressure. Instead, they rely on adjustable inlet guide vanes installed on each blower to control the discharge pressure across the system.

Although blow-off valves are present, they are fitted directly on the blowers and serve a different purpose. These valves are primarily used to prevent surge conditions and are actuated based on the electrical current drawn by the blower motor, rather than to manage system-wide pressure.

3.6.1 Step 1: Data acquisition

The system comprises three centrifugal blowers, each rated at 800 kW. Typically, only two blowers operate at any given time. All blowers are connected to a common discharge header, where system pressure is maintained using inlet guide vanes. A single control signal is sent to all blowers, meaning the guide vane position is always the same across all units.

The system operates to maintain a constant pressure setpoint of 65 kPag. When the guide vane position reaches 40% open, the blow-off valves on the blowers begin to activate. These valves are not used for pressure control on the common header; rather, they serve as surge protection for the individual machines, responding to parameters such as blower motor current. A simplified diagram of this configuration is provided in Figure 3-19.

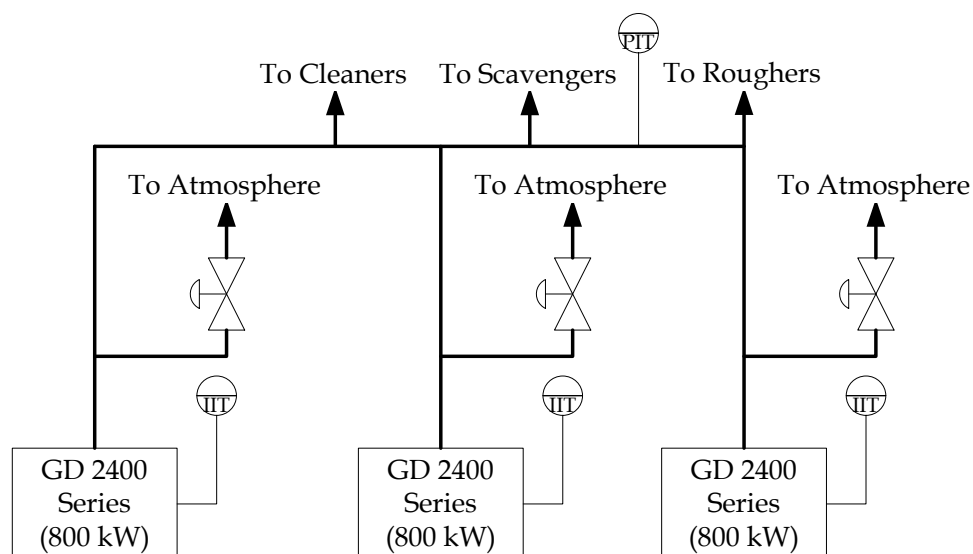


Figure 3-19: Blower air reticulation schematic for Case Study D.

For the initial phase of this investigation, historical data related to blower operation and flotation cell performance was reviewed over a three-month period, from 1 September 2023 to 1 December 2023. During this time, the common header pressure setpoint remained constant at 65 kPag.

3.6.2 Step 2: Analysis

Figure 3-20 illustrates the blower running statuses overlaid with the control valve position.

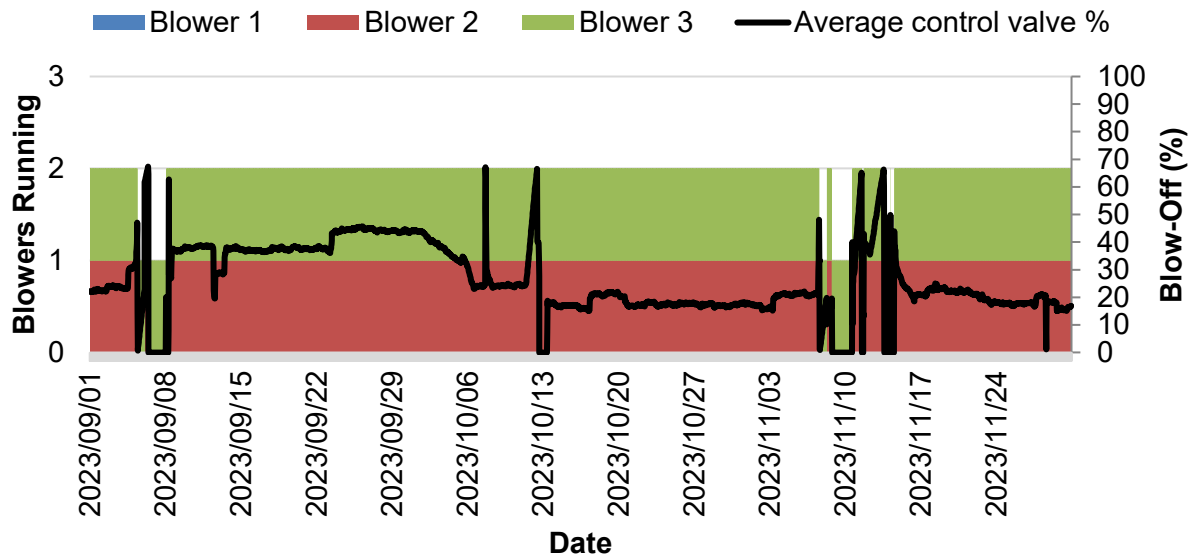


Figure 3-20: Running status and control valve (blow-off) position set to 65 kPag for Case Study D

Over the three-month period, only two blowers were operated at any given time. It is evident that blow-off activity decreases significantly when only a single blower is running. Throughout this period, the common header pressure setpoint was consistently maintained at 65 kPag.

Due to the use of guide vane control, centrifugal blowers inherently offer a degree of air production modulation through pressure control. However, it was identified that the surge protection mechanisms on the individual blowers were not functioning as intended. Figure 3-21 presents the surge control data for blower 2, highlighting these irregularities.

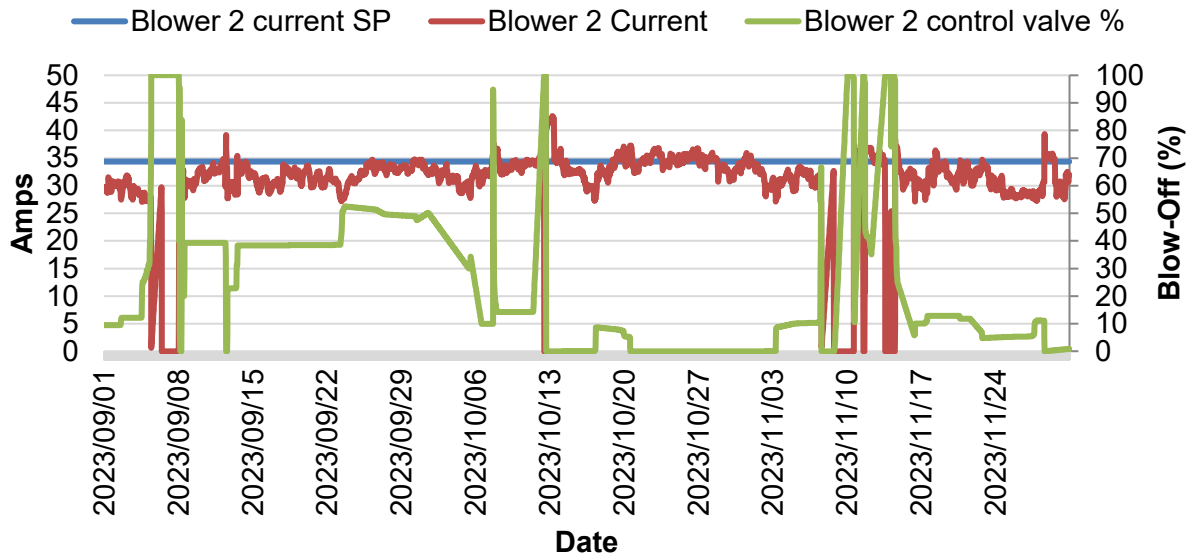


Figure 3-21: Amps data and control valve % for blower from Case Study D

According to site personnel, the surge control system is functional yet currently inactive. If it could be brought online without compromising operational stability, it might enable more effective control of blow-off events. This would, in turn, allow the blowers to reduce output further via the guide vanes, potentially improving system efficiency and stability. Furthermore, it was observed that the surge control setpoint was configured at 34.35 kPag, whereas the blower specifications indicate it should be 29 kPag—suggesting a potential opportunity for optimisation.

3.6.3 Step 3: Model development

To validate these findings, a PTB simulation was developed using the historical data. The simulation can be seen in Figure 3-22.

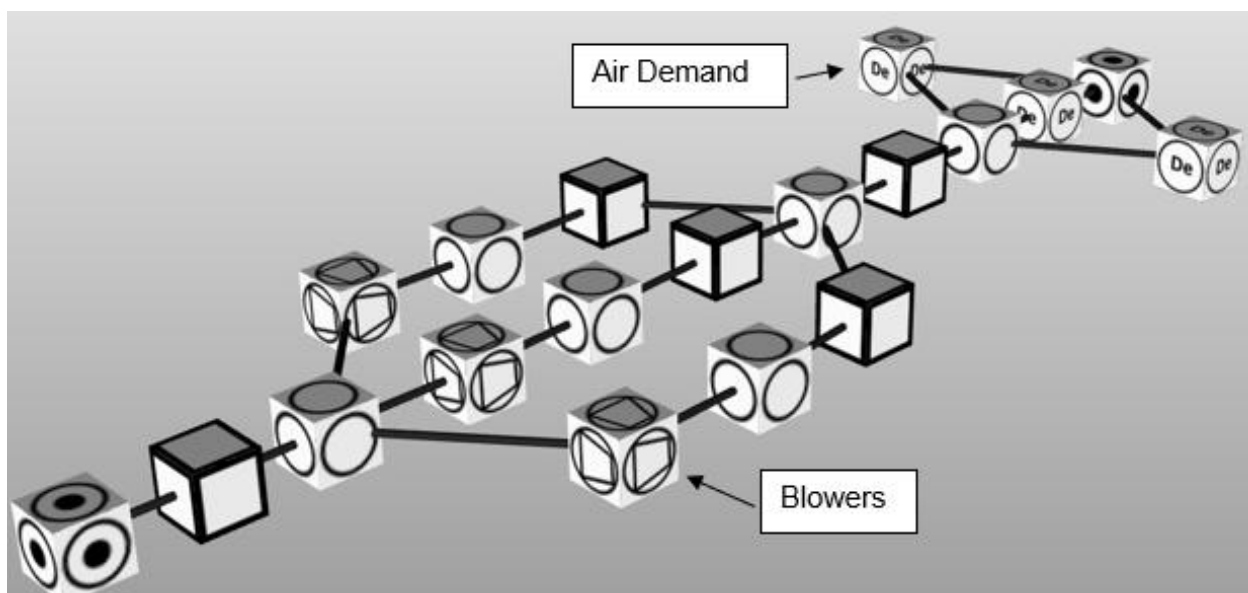


Figure 3-22: Case Study D PTB simulation

The model was calibrated to be within 5% of actual performance, as shown in Table 3-9. A 5% error was deemed acceptable by the stakeholder.

Table 3-9: Model results for Case Study D

Variable	Simulation	Requirement	Error
Roughers Flow Demand	341.21 m ³ /min	325.83 m ³ /min	4.72 %
Scavengers Flow Demand	395.77 m ³ /min	379.92 m ³ /min	4.17 %
Cleaners Flow Demand	844.82 m ³ /min	816.65 m ³ /min	3.45 %
Header Pressure	64.61 kPag	65.00 kPag	-0.60 %

In this case study, the proposed solution focused on optimising control strategies rather than reducing the number of operational blowers. To ensure comprehensive analysis, a model was developed to evaluate whether the system could operate with fewer blowers; however, this investigation demonstrated that maintaining the current blower configuration was necessary for adequate system performance. Additionally, the simulation response can be seen in Figure 3-23.

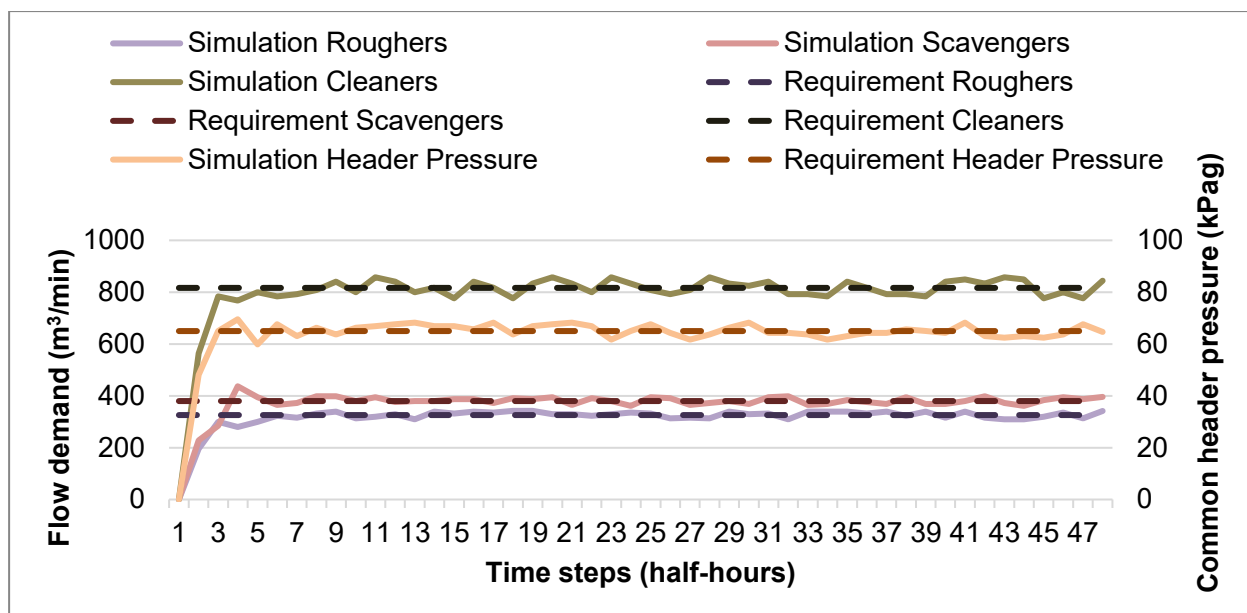


Figure 3-23: Case Study D PTB simulation results

3.6.4 Step 4: Implementation

As a result, the initial test conducted was considerably simpler than those in the other case studies. In collaboration with site personnel, a specific blower was selected for reactivating the surge control. The control was then enabled, and the surge control setpoint was adjusted to align with the original design specification.

The test was carried out with caution. If the system pressure dropped or failed to reach the setpoint, the configuration would be immediately reverted to its original state. The test data is presented in Figure 3-24.

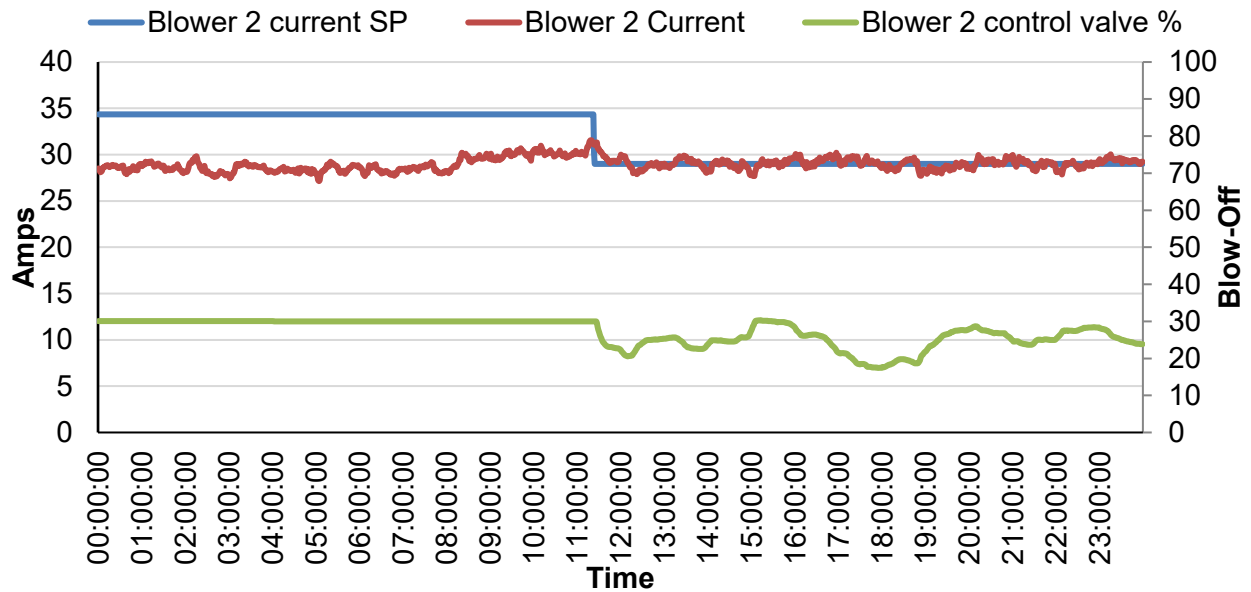


Figure 3-24: Test data for Case Study D

The surge control was activated and the setpoint adjusted at 11:24. Due to interaction with the existing guide vane control, system stabilisation took some time. Once stabilised, no significant shift in surge values was observed; however, the system exhibited noticeably improved control behaviour. Importantly, the activation of the surge control resulted in a reduction in blow-off activity. This improvement in surge control performance contributed directly to a reduction in overall energy consumption. Figure 3-25 presents a comparison of the actual and baseline (as discussed in Section 3.3.4) average daily performance.

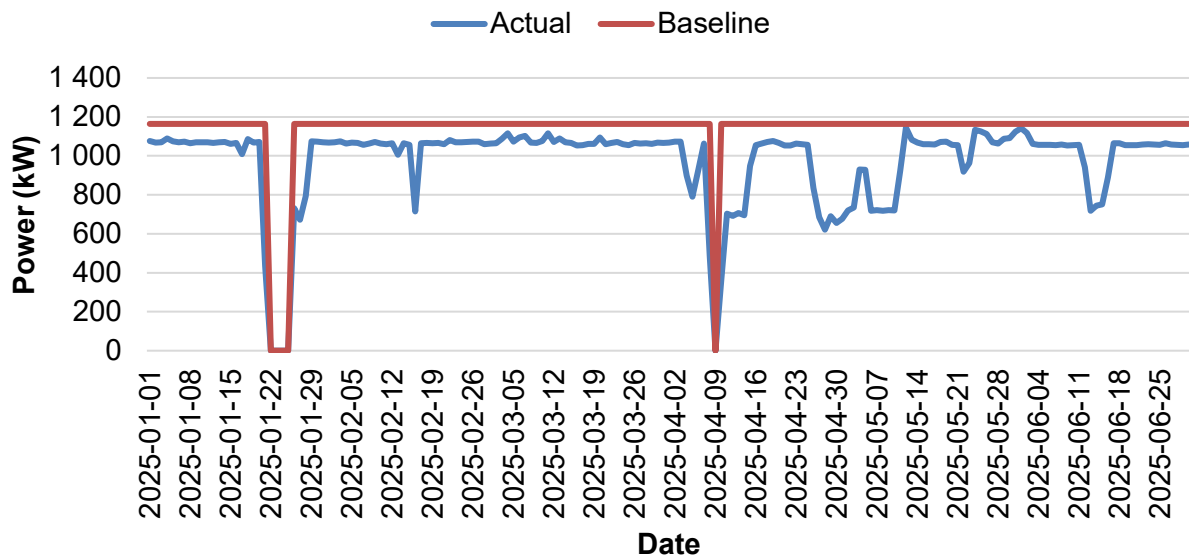


Figure 3-25: Daily profile of project performance for Case Study D

In the six-month period up to 1 July 2025, savings of R1 million have been achieved.

In summary, Case Study D transitioned the focus from volumetric oversupply to control logic optimisation within a centrifugal blower system. Unlike previous cases using positive displacement blowers, this system utilises inlet guide vanes for pressure regulation and dedicated blow-off valves for surge protection. Prior to intervention, the surge control mechanisms were inactive and misconfigured with an incorrect setpoint of 34.35 kPag, causing premature and excessive venting. By reactivating the surge control and aligning the setpoint with the OEM specification of 29 kPag, the system achieved superior modulation of air production and a marked reduction in blow-off activity. While PTB simulations confirmed that a reduction in the number of operational blowers was not feasible, the refinement of existing control strategies resulted in the highest financial impact of the study, yielding R1 million in savings year-to-date as of July 2025. This case highlights that for centrifugal systems, optimising internal machine protection and modulation logic is as vital for energy efficiency as managing system-wide demand.

3.7 Cross-case comparison

The results of the four case studies are consolidated in Table 3-10, which provides an overview of the blower configurations, pressure setpoints, key analytical findings, implementation outcomes, and cost savings achieved. The table also highlights the main lessons learned in each case, offering insights into how different operational strategies and site conditions influence blower system efficiency.

Table 3-10: Cross-case comparison

Case study	Blower configuration	Pressure setpoint (kPag)	Analysis findings	Implementation outcome	six-month savings (as of 1 July 2025)	Key lessons learned
A	1 × GM130L 5 × GM60S	30–35	Historical data showed air supply consistently exceeded demand, with high blow-off valve activity. Based on OEM curves, 1 GM130L + 2 GM60S should theoretically meet demand.	Site tests demonstrated that the proposed combination could not maintain the setpoint; 1 GM130L + 3 GM60S was required instead. A baseline operating profile was developed, although operator behaviour sometimes limited savings.	R80 000	Blow-off valve position is a valuable indicator of oversupply; however, it does not directly quantify air wastage. Operator alignment with efficiency targets is critical.
B	7 × GM90S	56	Average demand was significantly lower than supply; calculations suggested 5 blowers should suffice. However, pressure stability problems and suspected leaks forced higher utilisation.	Tests confirmed 6 blowers could maintain pressure once leaks were partially addressed. Leak audits improved performance and allowed the plant to avoid unnecessary use of all 7 blowers.	R170 000	Air leaks can distort perceptions of demand, leading to excess blower use. Regular audits are essential to enable operation with fewer blowers.
C	6 × GM80L of mixed motor sizes: 3 × 132 kW 1 × 185 kW 2 × 110 kW	53–55	Analysis indicated demand could be met by 3 blowers. The 185 kW unit was often run instead of more efficient options. OEM data showed each blower delivered ~82.5 m³/min.	Site testing confirmed that 3 blowers (preferably 1 × 132 kW + 2 × 110 kW) could meet demand under most conditions. A new prioritisation sequence was introduced to favour smaller units.	R750 000	Proper sequencing of blowers reduces energy use. Nameplate ratings may be inaccurate; auditing installed motor sizes can reveal hidden optimisation opportunities.
D	3 × GD 2400 centrifugal blowers	65	Two blowers normally operated. Blow-off activity was high, and surge control was inactive with the setpoint incorrectly configured (34.35 kPag vs. OEM 29 kPag).	Surge control was re-enabled and reset to OEM specification. This reduced blow-off activity and improved pressure stability. Further optimisation is possible through improved surge management.	R1 000 000	Correct surge control configuration improves both stability and efficiency. Manufacturer design specifications should be verified and restored when deviations are found.

3.8 Limitations

Due to limitations on the instrumentation side, the amount of air wasted was estimated using the blow-off control valve percentage, which proved to be grossly inaccurate. Although simulation models can be refined for greater precision, the same instrumentation constraints make this process extremely time-consuming and may still yield results no more reliable than analytical estimates, due to the simulation being calibrated using inaccurate data. Furthermore, blower specifications provided by the OEM or site personnel were not consistently accurate. In practice, blowers often did not perform to specification due to factors such as open vents, faulty discharge points, and manifold leaks. Additionally, flotation air flow meters do not account for variations in air density.

There exists an equilibrium point that defines the maximum mass flow achievable in a manifold, governed by the manifold design and the duty/standby configuration of the blowers. Therefore, when planning plant modifications to accommodate increased tonnage, it may be more effective to split the manifolds and relocate the blowers, or alternatively resize the manifold, rather than simply bringing an additional blower online.

3.9 Validation

The proposed methodology was evaluated across four industrial case studies to assess its robustness against different blower technologies and operational constraints. Table 3-11 maps the outcomes of these studies against the primary research objectives, outlined in Section 1.8.

Table 3-11: Validation of study objectives

Research Objective	Case Study A	Case Study B	Case Study C	Case Study D
1. Develop a systematic methodology for assessing blower efficiency based on literature criteria.	✓	✓	✓	✓
2. Construct simulation models to verify the viability of the proposed method prior to implementation.	✓	✓	✓	✓
3. Apply the method to industrial case studies to validate research applicability.	✓	✓	✓	✓
4. Demonstrate measurable electricity cost savings whilst maintaining uninterrupted operations.	✓	✓	✓	✓

The validation matrix confirms that the framework is adaptable to diverse metallurgical environments. Despite site-specific variables (such as the air leaks identified in Case Study B or the surge control inaccuracies in Case Study D) the core procedural steps remained effective.

The use of PTB simulations (Objective 2) provided a vital safety margin for testing. While the empirical results in Case Study A required a deviation from the initial model, the iterative process ensured that Objective 3 was met with minimal risk to the plant. Finally, the achievement of Objective 4 is evidenced by the cumulative savings (R80 000 to R1 000 000), proving that technical improvement of blower air supply translates directly into significant commercial value without compromising flotation stability.

3.10 Conclusion

The four case studies demonstrated that significant opportunities exist to improve blower system efficiency in flotation plants through better alignment of supply with demand. Across all sites, historical operation was characterised by oversupply of air, high blow-off valve activity, and reliance on rule-based manual operation rather than systematic optimisation.

The investigations confirmed that simulation and site testing are essential to validate theoretical configurations, as OEM performance data and analytical estimates alone proved insufficient. In Case Studies A and B, inefficiencies were largely driven by oversupply and system leaks, while in Case Study C the key issue was the inefficient use of larger motors due to a lack of prioritisation in blower sequencing. Case Study D highlighted the importance of correct surge control configuration in centrifugal systems, where deviations from manufacturer specifications had compromised both stability and efficiency.

Year-to-date savings achieved after six months ranged from R80 000 to R1 million, underscoring the economic value of targeted optimisation even in the presence of operational and instrumentation constraints. The work also emphasised the importance of regular leak audits, accurate motor auditing, operator engagement, and adherence to OEM design specifications as enabling factors for sustainable improvements.

Overall, the chapter has shown that blower system optimisation is highly site-specific, requiring a combination of analytical assessment, modelling, and empirical validation. While limitations in measurement accuracy remain, the methodologies applied provide a structured methodology for identifying inefficiencies and implementing practical, cost-effective improvements in blower operation.

CHAPTER 4 CONCLUSION

4.1 Summary

This research successfully developed and validated a systematic methodology for improving the electrical cost efficiency of blower systems within platinum concentrator operations. The four-phase approach (comprising data acquisition, analysis, model development, and implementation) demonstrated its effectiveness across four distinct case studies, achieving combined savings exceeding R2 million over six months.

The investigation addressed a significant research gap in the South African platinum mining industry, where processing plants consume approximately 19% of total electricity yet have received limited attention for energy optimisation initiatives. Through comprehensive analysis of blower operations at multiple platinum concentrators, this study established that substantial inefficiencies exist due to oversupply of compressed air, inadequate blower sequencing, and suboptimal control strategies.

The developed methodology proved to be robust across different blower configurations, including both positive displacement (GM60S, GM80L, GM90S, GM130L) and centrifugal systems (GD 2400). Case Studies A through C involved positive displacement blowers connected to shared air headers with blow-off valves, whilst Case Study D examined centrifugal blowers with inlet guide vane control. Despite these technological differences, the systematic approach successfully identified energy-saving opportunities in each application.

Key findings demonstrated that historical blower operation was characterised by significant oversupply, with air production consistently exceeding flotation cell demand by 20-50%. This excess air was vented to atmosphere through blow-off valves whilst maintaining full energy consumption, representing a substantial waste of electrical energy. The research validated that blow-off valve position serves as a valuable indicator of system oversupply, though it cannot directly quantify the volume of wasted air.

4.2 Methodology validation

The four-phase methodology proved essential for systematic optimisation. Data acquisition established baseline performance and identified system inefficiencies, whilst analysis using OEM performance curves quantified potential improvements. Simulation modelling provided crucial validation before implementation, preventing costly operational disruptions. Physical testing

confirmed the practical viability of proposed modifications whilst revealing site-specific constraints not apparent from theoretical analysis.

The iterative nature of the methodology enabled continuous refinement. In Case Study A, initial calculations suggested three blowers would suffice; however, testing revealed four were required due to system leaks and component degradation. This highlighted the critical importance of empirical validation, as theoretical estimates alone proved insufficient for reliable implementation decisions.

Simulation using the PTB software provided valuable predictive capability, achieving calibration accuracy within 5% of actual system performance across all case studies. This enabled safe evaluation of operational scenarios without production disruption, supporting informed decision making regarding blower configuration changes.

4.3 Implementation outcomes

The research achieved substantial cost savings ranging from R80 000 to R1 million per site over six months, demonstrating the significant economic potential of systematic blower optimisation. These savings were realised through various strategies including reduced blower utilisation, improved sequencing based on motor efficiency, pressure setpoint optimisation, and restoration of manufacturer design specifications.

Case Study C yielded the highest absolute savings (R750 000 over six months) through implementation of proper blower prioritisation based on motor power ratings. The discovery that installed motors differed from nameplate specifications by up to 75 kW emphasised the importance of comprehensive system auditing. This finding enabled the development of an optimised operating sequence favouring smaller, more efficient units.

Case Study D demonstrated that centrifugal systems offer different optimisation opportunities compared to positive displacement blowers. Restoration of surge control to manufacturer specifications (29 kPag versus the incorrectly configured 34.35 kPag) improved both system stability and efficiency, achieving R1 million in savings over six months through reduced blow-off activity.

4.4 Industry implications

This research provides the South African platinum mining industry with a structured methodology for addressing energy inefficiencies in blower auxiliary systems. Given that electricity costs constitute a significant portion of operational expenses and are projected to increase further, the

methodology offers a practical approach for maintaining competitiveness without compromising production quality or throughput.

The findings have broader applicability beyond platinum concentrators, as similar blower systems are utilised throughout the minerals processing industry. The established principles of supply-demand alignment, proper equipment sequencing, and systematic performance monitoring are transferable to other flotation applications including gold, copper, and coal processing facilities.

The research also highlighted critical operational considerations for successful implementation. Operator training and alignment with efficiency objectives proved essential, as production personnel naturally prioritise process stability over energy optimisation. Development of baseline operating profiles and key performance indicators helped integrate energy efficiency into standard operating procedures.

4.5 Research limitations

Several limitations affected the precision of energy savings quantification. The absence of accurate flow instrumentation prevented direct measurement of air wastage, requiring reliance on OEM performance curves and blow-off valve position estimates. Whilst simulation models provided improved accuracy, the fundamental measurement constraints limited absolute precision of savings calculations.

System leaks and component degradation significantly affected performance predictions based on manufacturer specifications. Blowers frequently operated below nameplate capacity due to factors including worn impellers, blocked intake filters, and distribution network deterioration. These conditions necessitated conservative implementation approaches and emphasised the importance of regular maintenance.

The complexity of continuous flotation operations constrained testing opportunities and implementation flexibility. Unlike intermittent processes that provide natural windows for system modifications, continuous operations required careful coordination with production personnel and acceptance of suboptimal testing conditions during planned maintenance periods.

4.6 Future research opportunities

This research established a foundation for further investigation into auxiliary system optimisation within mineral processing facilities. Future work should address the development of more sophisticated measurement techniques for accurate air flow quantification, enabling precise determination of energy wastage and improved validation of optimisation initiatives.

This thesis focused exclusively on supply-side optimisation of blower systems within platinum group metal (PGM) concentrators. However, evaluating blower networks utilized in downstream pyrometallurgical operations, such as matte converting projects, represents a high-value avenue for future research. Due to the cyclic, high-pressure nature of converting processes, these systems potentially offer substantially higher energy savings than the steady-state flotation applications studied here. Furthermore, empirical testing should be conducted to determine optimal blower selections across varying operational scales, comprehensively evaluating the respective advantages and disadvantages of different configurations for specific capacities.

Significant opportunities remain for demand-side investigation, including the optimization of flotation cell air requirements and the simultaneous balancing of metallurgical recovery and concentrate grade. Additional areas for study include the analysis of air distribution networks, specifically quantifying the energy losses resulting from pipe bends and compressed air distribution leaks, and the evaluation of alternative aeration technologies. Understanding the actual air consumption patterns of individual flotation cells, cleaners, and other pneumatic equipment could reveal additional energy-saving opportunities through demand reduction rather than supply optimisation.

Investigation of automated control systems represents a significant opportunity for enhanced efficiency. Integration of variable frequency drives with demand-responsive control algorithms could provide continuous optimisation without manual intervention, potentially achieving greater and more consistent energy cost savings than the static improvements demonstrated in this study.

The methodology could be extended to encompass broader auxiliary system optimisation, including pumping networks, material handling systems, and integrated compressed air applications. Development of plant-wide energy management strategies incorporating multiple auxiliary systems may yield synergistic benefits exceeding individual system optimisation.

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Appendix A Blower Curve

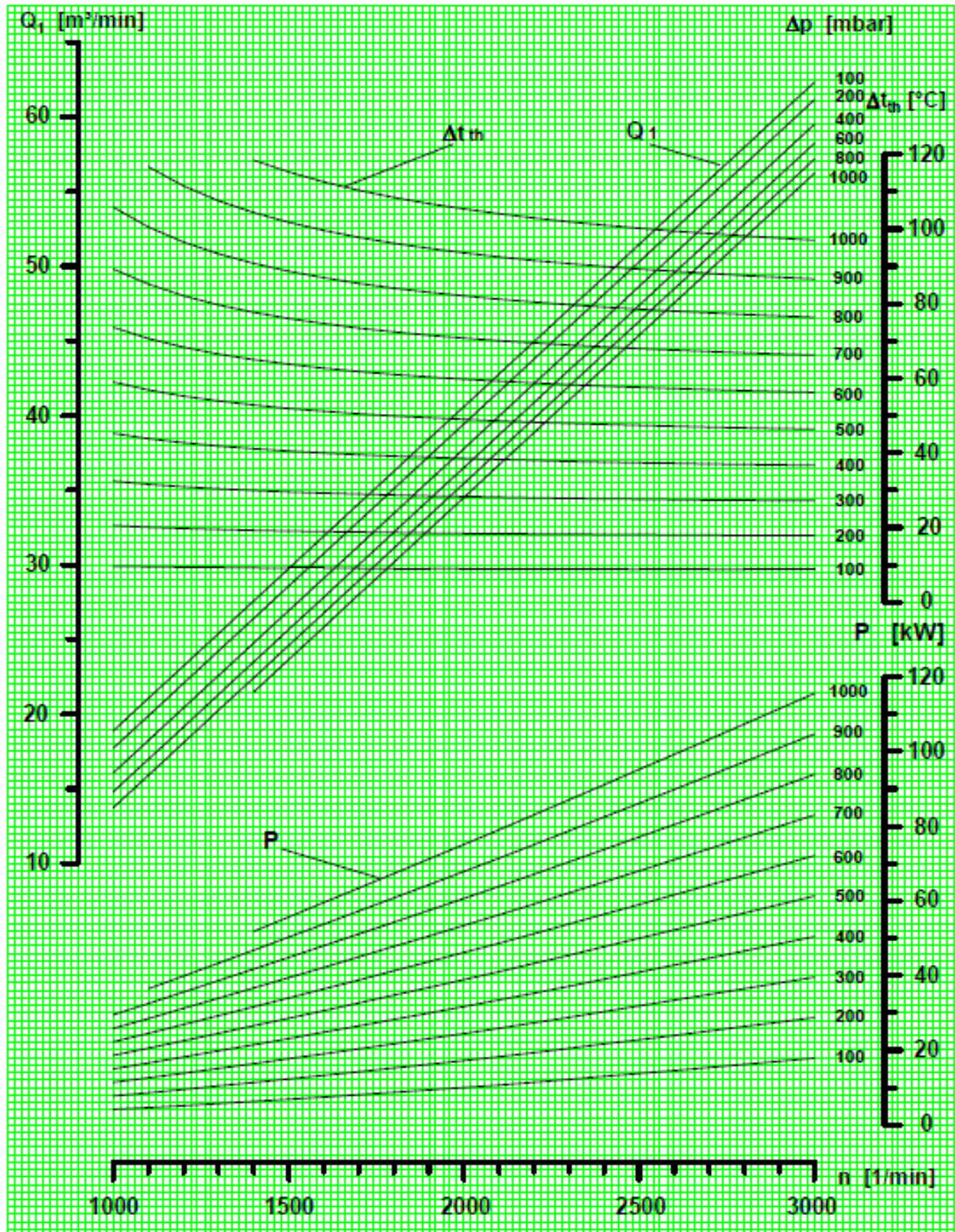


Figure A-1: Example of a blower curve

Appendix B Sample Calculations

This appendix provides a detailed methodology for the calculations performed during the case study analyses. The approach varies between case studies depending on data availability and system characteristics. The primary objective is to quantify unnecessary air production by examining blow-off valve operation and comparing theoretical blower output against actual consumption.

Blower performance is characterised by four interdependent variables: power consumption P (kW), manifold pressure Δp (mbar), volumetric flow rate Q (m³/min), and rotational speed n (rpm). Using manufacturer performance curves (such as the example provided in Appendix A), data points are extracted along constant pressure isobars to establish the relationship between these variables. Table B-1 presents typical data extracted from a blower performance curve:

Table B-1: Extracted flow rate data from manufacturer performance curves

n (rpm)	Q (m ³ /min)			
	100 mbar Isobar	200 mbar Isobar	300 mbar Isobar	400 mbar Isobar
1000	19.0	17.5	16.75	16.0
1500	29.75	28.5	27.75	27.0
2000	40.5	39.5	38.75	38.0
2500	51.5	50.5	49.5	48.5
3000	62.25	61.0	60.25	59.5

For each isobar, a linear relationship between flow rate and rotational speed is established by placing a ruler on the printed curves and determining the slope and intercept in the form $Q = m \cdot n + c$, where m represents the slope and c the intercept. Table B-2 presents the regression parameters for each isobar:

Table B-2: Linear regression parameters for flow-speed relationships

Isobar	Slope (m)	Intercept (c)
100 mbar	0.02165	-2.7
200 mbar	0.02180	-4.2
300 mbar	0.02175	-4.9
400 mbar	0.02170	-5.6

Taking the rotational speed values recorded during the audit process, theoretical flow rate and power consumption can be determined at each isobar using these linear equations. Table B-3 summarises the calculated values for an operating speed of 2700 rpm:

Table B-3: Calculated performance at operating speed ($n = 2700$ rpm)

Operating Speed	$n = 2700$ rpm			
Pressure (mbar)	100	200	300	400
Q (m ³ /min)	55.755	54.66	53.825	52.99
P (kW)	17.25	25.5	35.5	44.0

These values are subsequently converted into generalised straight-line equations through a secondary linear regression performed across the isobars. This yields equations that relate flow and power to manifold pressure at the operating speed, with the values summarised in Table B-4:

$$Q = \Delta p * Q_{slope} + Q_{intercept}$$

$$P = \Delta p * P_{slope} + P_{intercept}$$

Table B-4: Generalised performance equation parameters

Parameter	Slope	Intercept
Q	-0.00913	56.59
P	0.09025	8.0

These equations allow for rapid calculation of theoretical performance at any manifold pressure within the interpolated range, where Δp is expressed in mbar. It should be noted that the power equation becomes redundant when individual blower power metering is available, as measured values provide greater accuracy than theoretical estimates.

The total theoretical air production from all blowers ($Q_{\text{blowers, total}}$) is compared against the measured or estimated consumption by process equipment (Q_{consumed}). The difference represents excess air production:

$$Q_{\text{excess}} = Q_{\text{blowers, total}} - Q_{\text{consumed}}$$

Significant excess air production is indicated when Q_{excess} exceeds zero and is greater than the capacity of any single blower in the system. These conditions suggest that unnecessary air is

being produced and subsequently vented through blow-off valves, representing a clear opportunity for energy savings.

The specific electrical energy consumption provides a normalised metric for assessing system efficiency and is calculated as:

$$e_{specific} = P_{electrical,total} / Q_{blowers,total}$$

where $e_{specific}$ is expressed in kW/(m³/min) and $P_{electrical,total}$ accounts for blower shaft power, belt transmission losses, and motor efficiency. When individual blower power measurements are unavailable, the total electrical power is estimated from theoretical calculations:

$$P_{electrical,total} = P_{blowers,total} / (\eta_{elt} \times \eta_{motor})$$

where η_{belt} is the belt transmission efficiency (typically 0.95–0.98) and η_{motor} is the motor efficiency obtained from nameplate data or assumed based on motor class.

The electrical power wasted through blow-off is quantified using the specific energy consumption:

$$P_{waste} = e_{specific} \times Q_{blow-off}$$

This metric is crucial for building the business case and securing site approval for testing and implementation. The wasted electrical energy value demonstrates the financial impact of excess air production and provides justification for proceeding with optimisation measures.

It must be emphasised that this interpolation methodology introduces inherent inaccuracies due to reading errors from graphical data, assumptions of linear behaviour between data points, neglect of compressibility effects at higher pressures, and variations in actual versus theoretical performance due to wear and installation factors. For this reason, all preliminary calculations are subsequently validated using Process Toolbox (PTB) simulations, which provide dynamic system modelling and account for interactions between multiple blowers, pressure losses, and control strategies. The PTB simulations serve as a verification tool before proceeding to field testing and implementation.

Testing and implementation proceed only when the following conditions are satisfied: clear evidence of excess air production where Q_{excess} exceeds single blower capacity; a viable proposed solution has been identified such as blower shutdown, speed reduction, or control optimisation; PTB simulation validates theoretical calculations and confirms energy savings potential; and the calculated energy waste justifies project costs and site disruption. This systematic approach

ensures that resources are allocated to projects with demonstrable energy savings potential and minimises the risk of unsuccessful interventions.

Appendix C PTB Simulation Inputs

Table C-1: Case Study A simulation inputs

Parameter		Value	Units
GM130L	Air Flow	2.78	kg/s
	Inlet Pressure	0	kPag
	Inlet Temperature	25	°C
	Compressor Efficiency	0.75	-
	Compressor Motor Efficiency	0.94	-
	Polytropic Coefficient	1.4	-
GM60S	Air Flow	1.55	kg/s
	Inlet Pressure	0	kPag
	Inlet Temperature	25	°C
	Compressor Efficiency	0.75	-
	Compressor Motor Efficiency	0.94	-
	Polytropic Coefficient	1.4	-
PI Controller	Control Limit 1	0	-
	Control Limit 2	1000	-
	Integral Gain	0	-
	Setpoint	30	kPag

Table C-2: Case Study B simulation inputs

Parameter		Value	Units
GM90S	Air Flow	2.77	kg/s
	Inlet Pressure	0	kPag
	Inlet Temperature	25	°C
	Compressor Efficiency	0.75	-
	Compressor Motor Efficiency	0.94	-
	Polytropic Coefficient	1.4	-
PI Controller	Control Limit 1	0	-
	Control Limit 2	1000	-
	Integral Gain	0	-
	Setpoint	56	kPag

Table C-3: Case Study C simulation inputs

Parameter		Value	Units
GM80L	Air Flow	2.53	kg/s
	Inlet Pressure	0	kPag
	Inlet Temperature	25	°C
	Compressor Efficiency	0.75	-
	Compressor Motor Efficiency	0.94	-
	Polytropic Coefficient	1.4	-
PI Controller	Control Limit 1	0	-
	Control Limit 2	1000	-
	Integral Gain	0	-
	Setpoint	53	kPag

Table C-4: Case Study D simulation inputs

Parameter		Value	Units
GD 2400 Series	Air Flow	9200	Nm³/hr
	Air Inlet Pressure	0	kPag
	Air Inlet Temperature	25	°C
	Air Outlet Pressure	157	kPag
	Air Outlet Temperature	95.7	°C
	Compressor Motor Electrical Power	2400	kW
	Compressor Motor Efficiency	0.94	-
	Surge Pressure	29	kPag