

Design and assessment of an energy efficient office building utilising a building management system. A study of a use case in Cape Town.

by

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Declaration

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Abstract

Design and assessment of an energy efficient office building utilising a building management system. A study of a use case in Cape Town.

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According to the WWF, food, water and energy security form the basis of any self-sufficient economy. A crisis in any of the three systems will directly affect the other two. The WWF believes that effectively averting such a crisis requires enhanced information, coordinated planning and adapting to a resource-scarce future. As a result of a global movement toward “green” or sustainable living and possibly boosted by the recently experienced crises in two of these systems, businesses in South Africa have adapted by investing in “green” or resource efficient facilities. The Green Building Council of South Africa, through their rating system, provides a certification process to acknowledge market leaders in this movement. With the development of modern buildings, electronic building systems and controls become increasingly complex, necessitating the use of a building management system.

The V&A Waterfront’s No. 5 Silo building in Cape Town is no different. It is one of a number of buildings in the Silo district that makes use of a seawater district cooling system as an alternative source, primarily for air conditioning purposes. It also utilises a central air conditioning system that incorporates a number of energy saving features. All of its air conditioning systems are also monitored and controlled by a building management system.

This research focusses on the design and assessment of an energy efficient office building, concentrating specifically on the role that a building management system plays in achieving energy efficiency. Various methods of reducing resource consumption or improving system efficiencies are investigated and discussed based on implementation, achievable savings, costs and other complexities. Focus areas include the use of alternative, more sustainable sources, various optimisation methods as well as closely monitoring and reporting of consumption data. The impact of a building management system and the green building rating system on a building project and specifically on its resource efficiency is also evaluated. This information gathered from existing literature is used to assess savings methods that are applied to the No. 5 Silo building. The design, construction and operation of its air conditioning systems are described in depth, focussing

on energy saving practices and ways of quantifying the potential savings. The No. 5 Silo building management system is practically tested for its functionality and is used to gather operational data from the building to investigate potential energy savings. The data is processed, presented graphically and interpreted in terms of its usefulness, visible savings and other trends or events that are identified. The results confirm that substantial savings are achieved through the use of the district cooling system. It also quantifies and proves the previously unknown amount of energy saved through the economy cycle feature of central air handling units. The combined effect of the results and preceding tests also proves the building management system to be an invaluable tool for the monitoring and controlling of building systems from a central point. Transferability to other scenarios (buildings, regions) will be evaluated, and key lessons learned will be captured for the benefit of future ventures.

Uittreksel

Ontwerp en assesering van 'n energie-doeltreffende kantoor gebou met die aanwending van 'n gebou beheerstelsel. 'n Gevallestudie in Kaapstad

(“Design and assessment of an energy efficient office building utilising a building management system. A study of a use case in Cape Town.”)

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Volgens die WWF word voedsel, water en energie sekuriteit geïdentifiseer as die fondasie van enige selfonderhoudende ekonomie. In die geval van 'n ernstige tekort in die verskaffing van enige een van die drie hulpbronne, sal dit 'n direkte uitwerking op die ander hulpbronne hê. Die WWF beweer dat verbeterde inligting, gekoördineerde beplanning en aanpassing tot 'n toekoms met geringe hulpbronne noodsaaklik is om so 'n ramp te voorkom. As gevolg van die huidige beweging in die rigting van 'n meer “groen” of volhoubare lewenstyl asook die onlangse ernstige tekort in die beskikbaarheid van twee van die bogenoemde hulpbronne, begin Suid-Afrikaanse besighede aanpas deur te belê in “groen” geboue asook geboue waar hulpbronne op doeltreffende maniere ingespan word. Die Green Building Council of South Africa bied, deur hulle graderingstelsel, 'n sertifiseringsproses wat daarop ingestel is om erkenning te gee aan voorlopers in die “groen” beweging. Met die ontwikkeling van moderne geboue word elektroniese gebou sisteme en beheerstelsels al meer kompleks en gevolglik het die gebruik van gebou beheerstelsels noodsaaklik geraak.

Die V&A Waterfront se No. 5 Silo gebou ervaar dieselfde tendens. Dit is een van 'n paar geboue in die Silo kompleks wat gebruik maak van 'n seewater distrik verkoeling stelsel as 'n alternatiewe hulpbron gebruik, hoofsaaklik vir lugversorging doeleindes. Die gebou benut ook 'n sentrale lugversorging stelsel wat verskeie funksies gebruik om energie te bespaar. Alle lugversorging stelsels word ook gemonitor en beheer deur 'n gebou beheerstelsel.

Hierdie navorsing fokus op die ontwerp en analisering van 'n energie doeltreffende kantoor gebou. Aandag word spesifiek gerig op die rol wat 'n gebou beheerstelsel speel in die energie doeltreffendheid van so 'n gebou. Verskeie metodes word ondersoek en bespreek rakende die vermindering van die gebruik van hulpbronne asook die verbetering van die doeltreffendheid van sisteme. Die evaluasie word baseer op implimentering, moontlike besparings, kostes en ander faktore. Die metodes word gekategoriseer onder

drie area naamlik, die gebruik van alternatiewe, volhoubare hulpbronne, optimering van sisteme asook die monitor en rapportering van die gebruik van hulpbronne. Die impak van 'n gebou beheerstelsel asook die groen gebou graderingstelsel op 'n gebou en meer spesifiek op die effektiewe gebruik van hulpbronne in die gebou, sal ook deeglik ondersoek word in die navorsing. Bestaande literatuur word verder gebruik om metodes wat op die No. 5 Silo gebou toegepas is te evalueer. Die ontwerp, konstruksie en werking van die gebou se lug versorging stelsels word in diepte verduidelik met betrekking tot energie besparings tegnieke en metodes om moontlike besparings te kwantifiseer. Die gebou beheerstelsel van die NO. 5 Silo gebou word breedvoerig getoets om die funksionaliteit daarvan te beproef asook om operasionele data in te samel wat verder gebruik word om moontlike energie besparings te ondersoek. Data word verwerk, visueel voorgestel asook geïnterpreteer ten opsigte van gebruikswaarde en sigbare besparings. Ander tendense en spesifieke gebeurtenisse word ook geïdentifiseer en bespreek. Die uitslae van die navorsing bevestig dat aansienlike besparings behaal word deur die gebruik van distrik verkoeling stelsel. Dit bevestig en kwantifiseer ook die voorheen onbekende hoeveelheid energie wat bespaar word deur die "economy cycle" kenmerk van sentrale lugversorging eenhede. Die oorhoofse effek van die uitslae en die voorafgaande toetse bevestig gebou beheerstelsels as 'n as 'n uiters waardevolle hulpmiddel vir die monitor en beheer van gebou stelsels vanaf 'n sentrale punt. Die oordraagbaarheid na ander scenario's (verskillende geboue en omgewings) sal geëvalueer word en waardevolle ondervindings sal bespreek word ter voordeel van toekomstige ondernemings.

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Nomenclature

Abbreviations and acronyms

AC	Air Conditioning
ADX	Extended Applications and Data Server
AHU	Air Handling Unit
AMR	Automatic Meter Reading
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BACnet	Building Automation and Control networks
BMS	Building Management System
CAS	Cape Automation Systems
CHW	Chilled Water
DB	Distribution Board
DHW	Domestic Hot Water
ESCo	Energy Services Company
FA	Fresh Air
FAC	Advanced Application Field Equipment Controller
FEC	Field Equipment Controller
GBCSA	Green Building Council of South Africa
GDP	Gross Domestic Product
GLA	Gross Leasable Area
GSSA	Green Star SA
HAP	Hourly Analysis Program
HHW	Heating Hot Water
HVAC	Heating Ventilation Air Conditioning
IEQ	Indoor Environment Quality
IOM	Input Output Module
IP	Internet Protocol
IRP	Integrated Resource Plan
ISO	International Organisation for Standardisation
MED	Metasys Energy Dashboard
MCU	Master Communications Unit
MLM	Multi-loop Modular
NDP	National Development Plan

NIE	Network Integration Engine
NTS	Not To Scale
PCW	Precooling Water
PV	Photovoltaic
PSU	Power Supply Unit
RA	Return Air
SA	Supply Air
SAC	Southern Air Conditioning
SANS	South African National Standards
SMP	Site Management Portal
UI	User Interface
VAV	Variable Air Volume
VDU	Vertical Discharge Unit
VSD	Variable Speed Drive
WWF	World Wide Fund for Nature

List of symbols used

ΔT	Temperature difference (K)
ε_{tenant}	Central AC energy cost of a tenant (R)
ε_{total}	Total central AC energy cost (R)
α_{GLA}	GLA of building floors served by central AC (m^2)
α_{tenant}	Area leased by a tenant (m^2)
ρ	Density (kg/m^3)
c_p	Specific heat ($kJ/kg \cdot K$)
COP	Coefficient of performance
h	Enthalpy (kJ/kg)
\dot{m}	Mass flow rate (kg/s)
P_S	Static pressure (Pa)
P_T	Total pressure (Pa)
P_V	Velocity pressure (Pa)
v	Velocity (m/s)
q	Airflow rate (m^3/s or ℓ/s)
q_{peak}	System peak load supply air airflow rate (m^3/s or ℓ/s)
Q	Sensible heat flow (W)
r_{FA}	Ratio of fresh air airflow rate over supply air airflow rate
FSP	Fan speed as a percentage of maximum fan speed
W	Work (W)

Chapter 1

Introduction

A global movement towards more sustainable living combined with the recent energy and water crises in South Africa have caused businesses and individuals alike to reassess their use of basic resources. This trend has forced businesses to invest in green or alternative solutions to remain competitive in a market where a “green” rating or label can provide an edge over competitors. The movement has also highlighted numerous areas where cost savings are achievable through reducing wastage or increasing efficiencies. This research focusses on some of these areas in a new office building where savings are achieved by making use of seawater as an alternative energy source, increasing building system efficiencies through optimisation and reducing consumption through extensive monitoring of resource usage. The influence that a comprehensive building management system has in achieving these savings is also investigated.

1.1 Resources in South Africa

Modern human survival depends on the constant availability of three basic needs, food, water and energy. The World Wide Fund for Nature (WWF) believes that a crisis in any one of these three sectors will directly affect the other two. [1] With global population figures continually reaching new highs and technological development moving faster than ever before, immense pressure is being placed on our planet to keep providing these resources to all of its inhabitants. South Africa is considered a resource scarce country in this regard. Attention will be given to water and energy resources as these are applicable to this study.

1.1.1 Water

Rainfall in the country is inconsistent in its distribution and annual figures amount to only 60% of the global average. Groundwater accounts for only 13% of its supply. Dam water levels have also reached record lows in 2016 [2]. Water can be seen as the most significant resource constraint with only 1000m³ available per capita per annum.

Governmental planning around the allocation of water resources is also not in line with the reality of availability. From Figure 1.1 it can be seen that the bulk of South Africa’s water is being used for irrigation. The National Development Plan (NDP) for 2030 aims to increase irrigated land in the country by 50% in order to create more job opportunities in the agricultural sector, a sector which only contributes around 3% to the GDP. This

is particularly concerning as it is estimated that, to date, 98% of South Africa's water resources have already been allocated [3].

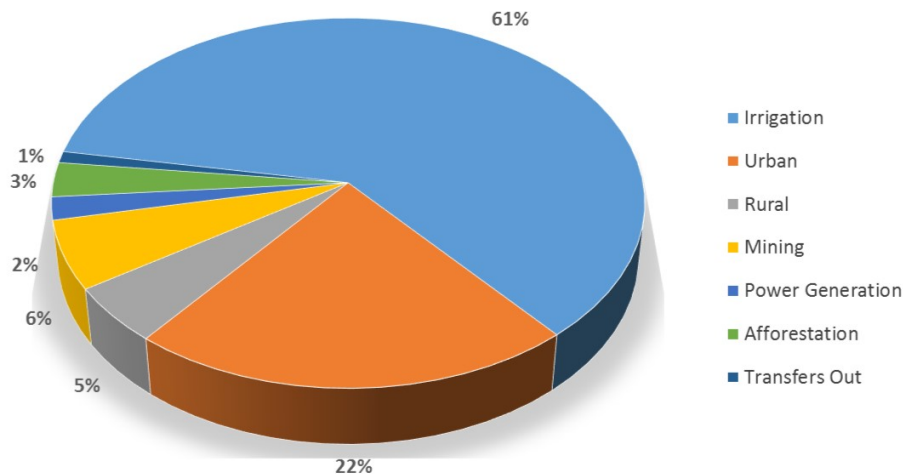


Figure 1.1: South Africa water demand per sector [3]

1.1.2 Energy

Owing to the scope of this study the term energy will collectively refer to electricity supplied from the national grid as well energy supplied to equipment through heat transfer principles. Around 92% of South Africa's electricity is generated by Eskom, a parastatal power utility [1]. Electricity supply in the country is extremely volatile and regularly in a state of emergency with shortages causing nationwide load shedding to be applied. Mismanagement, poor planning and a lack of proper maintenance all combined to cause an electricity crisis in 2008. This is clearly visible through the increase in the price of electricity when compared to the national inflation rate (Figure 1.2). The abnormal price increases place a great amount of strain on all businesses and hence, the country's economy. This is understandable as it is estimated that energy accounts for approximately 30% of an office building's operating costs [4].

From a sustainability perspective it is important to take note of the main source of the country's electricity supply, namely fossil fuels. From Figure 1.3, 92% of electricity is being generated by coal-fired plants. Without lingering on the damaging effects of the CO₂ emissions produced by these plants or the adverse effects on water quality, it is important to consider that this is a finite source of energy that is also dependent on the constant supply of water as well as a struggling mining industry.

Although the Department of Energy recognises the need for transformation in its Integrated Resource Plan (IRP) for 2010 to 2030, it still committed to building two coal-fired plants (Medupi and Kusile) that are each larger in generating capacity than any of the existing plants. There is also the possibility of a third major plant (Coal 3) to be built after the completion of the aforementioned. The IRP does however commit to lowering the stake of fossil fuels to 61.2% by 2030 [1] [6].

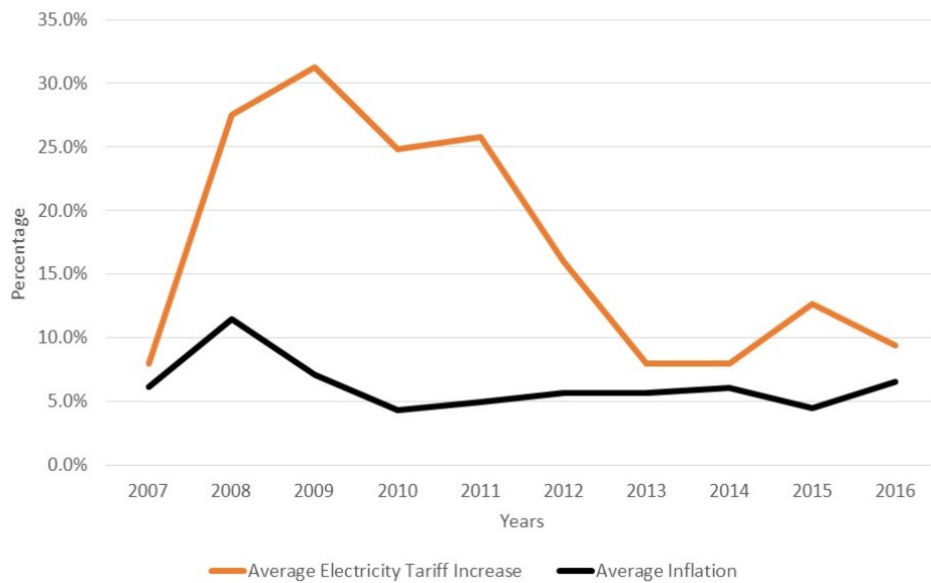


Figure 1.2: South Africa average annual electricity tariff increase compared to average inflation rate [5]

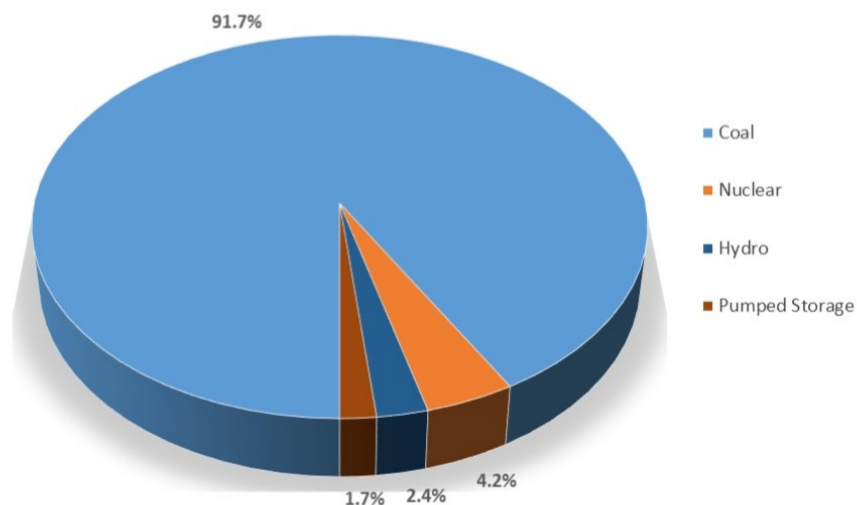


Figure 1.3: South Africa electricity capacity generation by energy source [1]

1.2 Proposed solution

The state of essential resources in this country is a cause for distress for businesses of all sizes and in all industries as well as for individuals. Government has a responsibility to supply sufficient energy and clean water to its people and manage the use thereof in a responsible way. Even though it is clear from documents such as the NDP and the IRP that planning is being done around these resources and that policies are being put in place, the implementation thereof seems to be lacking.

However, the responsibility does not fall exclusively on government, the solution starts with a mind shift from the end-user. Effectively managing their own use of these resources on an everyday basis, as well as making use of alternative more sustainable sources where

possible, will not only provide monetary savings for the user, but it would also help to lighten the load that mankind is placing on the planet.

An unstable supply of energy and water combined with drastically increasing prices of these resources force businesses and individuals alike to reassess their use of resources and their dependency on the suppliers thereof. Focussing on businesses there are at least three ways to adapt to these challenges. The first is to investigate the use of alternative sources such as solar or wind energy, rain water harvesting, water recycling or even thermal storage. Another way to cut costs is to continuously assess and where possible, improve the efficiencies of systems or equipment that consume these resources, specifically air conditioning and lighting equipment as well as the types water fixtures. Regular maintenance is critical to ensure that all equipment is operating at optimum efficiency. Modern technology and globalisation have made it possible, even for small businesses, to gain access to the latest advances in technology. Equipment with vastly improved efficiency is readily available at competitive prices. The final way to improve on resource usage is by proper monitoring of usage. By using smart metering technology, real-time or close to real-time usage data can be used to identify wastage areas, simplify fault finding, and actively manage the use of resources by setting achievable goals. These practices need not be an additional laborious burden on a business. Through the use of a comprehensive building management system, these practices and all building systems can be monitored and / or controlled from one central point, providing a host of additional benefits to businesses or building owners.

This study speaks to a number of these approaches of adapting in new and innovative ways that are applicable to the particular location, type of business and available funds.

1.3 No. 5 Silo building

The study was carried out in collaboration with WorleyParsons RSA, the mechanical consultants for the construction of the No. 5 Silo building.

The No. 5 Silo building, also known as Silo 5, forms part of the Silo district (see Figure 1.4) which is a development by the V&A Waterfront group located in the Cape Town harbour area. The R2.5 billion development comprises of Silo buildings 1 through 6 and the Grain Silo building, which includes office space, retail space, apartments, a hotel, a gym and a museum – all focusing on sustainability and luxury.

The Silo 5 building offers approximately $3000m^2$ of retail space on its ground floor as well as $13500m^2$ of multiple-tenanted office space over the upper five floors. The building also aims to achieve an as-built green star rating from the Green Building Council of South Africa (GBCSA) [7]. Construction started in March 2015 and was completed in June 2016 (see Figure 1.5).

PricewaterhouseCoopers (PwC) is the main tenant in the building, taking up levels 3 to 5 as well as part of level 2. They have their own reception on the ground floor and two rooms on the roof level are also leased out to the company. Werksmans Attorneys is the other office tenant, taking up level 1. Tenants for the rest of level 2 as well as for the retail areas were still to be confirmed at the time of writing.

Both PwC and Werksmans use the majority of their space for offices, open plan office space and meeting rooms. The floor layouts and occupant density of the two companies vary significantly. PwC uses approximately half of level 5 for meeting rooms and the other half for a kitchen, canteen area and training rooms.



Figure 1.4: V&A Silo district artist's impression



Figure 1.5: No. 5 Silo construction

All office and retail areas are served by generators in the case of power outages. The building is also sprinkler protected, has smoke extraction systems and escape routes are pressurised for smoke control in the case of a fire.

The building makes use of the Silo district cooling system which supplies pre-cooling, chilled and hot water to the building for the purpose of air conditioning (AC) and partly for domestic hot water. The district cooling system utilises seawater from the harbour area

as a sustainable alternative to conventional methods. The Silo 5 building is also served by a centralised AC system which aims to optimise energy efficiency by subdividing air conditioned areas into thermal zones and serving these zones with a variable air volume (VAV) system.

The AC system is monitored and controlled by a building management system (BMS). This system is accessible to all stakeholders from a network based software package. Facility operators use the BMS for monitoring of system health, adjusting system controls, fault finding and keeping track of maintenance schedules. Managers and financial staff use the system for real-time reporting of usage information and for the billing of building tenants.

1.4 Thesis statement

This research will focus on different methods used in a new office building to reduce resource consumption or improve system efficiencies in order to reduce costs and to reduce the impact that businesses have on the environment.

Different methods will be conceptually evaluated and compared for implementation. The cost and complexities of implementing such methods in a new construction will be explored, and the benefits (financial and otherwise) will be considered.

The effect of aiming to achieve a green building certification on a building's resource efficiency will be evaluated.

The impact of using a building management system to assist in this goal will also be investigated. Its capabilities will be judged against its potential to assist in reducing consumption or improving efficiencies. The system will be tested for the use of reporting on actual resource consumption and savings. BMS data will be used to test the savings effect of certain incorporated methods.

Transferability to other scenarios (buildings, regions) will be considered, and key lessons learned will be captured for the benefit of future ventures.

1.5 Research objectives

The following objectives aim to achieve the purpose of this research:

Objective 1: Provide a consolidated view of different methods of improving an office building's resource efficiency, analysed with regards to savings potential, cost, implementation and other benefits or complexities. Also, consider the possible role of a BMS to assist these methods as well as the effect of green building certification on resource efficiency.

Objective 2: Use the information from the above objective to evaluate methods applied in the design, construction and operation of the Silo 5 building.

Objective 3: Test the functionality of the BMS against what was reported for the first objective.

Objective 4: Use actual data provided by the BMS from Silo 5 to investigate potential savings and present results.

1.6 Scope of work

This research aims to provide industry-specific views and knowledge of the research topic. The author has worked in the building services industry as an engineering consultant for the last three years and acted as the project engineer for the heating, ventilation and air conditioning (HVAC) services of the Silo 5 building, responsible for the bulk of the designs, coordinating with other service consultants and architects, supervising construction, attending project meetings and general daily project administration. The author was therefore uniquely positioned to obtain practical, real world data, information and opinions regarding a topic where the majority of existing research is theory based.

The scope of this research initially included the evaluation of both energy and water resources of the Silo 5 building. However, due to changes in the scope of the construction project, water usage will not be monitored or controlled by the BMS and as a result no actual consumption data is available. Water is however still included in the literature review of this research due to the urgent state of water as a resource in South Africa and the need for it to be included in any and all efforts to reduce consumption.

Furthermore the research focuses primarily on reducing energy consumption or improving system efficiencies of HVAC services due it being the only services that were, at the time of writing, being monitored and controlled by the Silo 5 BMS.

Apart from energy or water saving practices, the research includes in-depth discussions on green building rating systems, building management systems, the HVAC systems of Silo 5 and the quantifying of energy savings achieved by different features or methods.

1.7 Contribution

Through the work presented in this research to achieve the objectives in Section 1.5 within the scope set out in Section 1.6, valuable contributions have been made to this field of study.

Green buildings are reaffirmed to have immense potential for reducing resource consumption as well as providing financial benefits to owners at little to no extra capital costs compared to conventional buildings when managed correctly. The rating system for green office buildings in South Africa can however be improved upon in order to more accurately represent the urgent state of resources such as water.

Energy saving practices are identified that are not being utilised in most office buildings, but can provide substantial savings through minor adjustments or additions to building systems. These practices are in most cases transferable to buildings of any size or type. It is also shown that a comprehensive building management system is a crucial component in making the most of these methods.

Although it is difficult to assess the true effectiveness of these practices in a new office building, some of the energy saving features implemented in the Silo 5 building could be tested through data provided by its BMS. Results indicated that substantial energy savings are being achieved through the use of the seawater district cooling system. Testing of the building's central AC systems' economy cycle feature revealed valuable information regarding the savings achievable through this feature as well as the impact of the location of air conditioned areas and plantroom equipment on these savings. Other results helped to prove the usefulness and versatility of the building management system. Data trends are also used to interpret changes in the building's energy consumption in terms triggering events or in some cases, occupant behaviour.

The research also analyses and makes suggestions with regards to results that may justify further investigation.

1.8 Thesis structure

Chapter 2: The green building rating system of South Africa as well as building management systems are investigated in depth before a comprehensive review is given of existing literature on the use of alternative sources, systems optimisation and the monitoring of resource consumption in order to achieve savings. The use of these methods are evaluated in a case study before challenges of these methods are listed and conclusions are made.

Chapter 3: The essential HVAC systems serving the Silo 5 building are discussed in detail. Energy saving practices that apply to this building as well as methods to quantify the resulting savings are described.

Chapter 4: Methods, limitations and focus areas of data collection are considered before presenting and interpreting the data that was collected through the BMS.

Chapter 5: The study is concluded with a summary of the work that was done, conclusions that were made and potential future work that has been identified.

Appendix A: Selected HVAC design drawings are included to substantiate design discussions in Chapter 3.

Appendix B: Reports generated by the heat load calculation software, Carrier's Hourly Analysis Program (HAP), are included for one of the Silo 5 central air handling units to support discussions in Section 3.1.2.1.

Chapter 2

Literature Review

In this chapter an overview is given of current literature on green buildings and its effect on the building industry as well as building management systems, focussing on the system that was used for this research. These topics form an integral part of this research and inform the design selection.

This is followed by sections describing three areas that can provide meaningful opportunities for the management and decreasing of building energy and water consumption namely, the use of alternative sources, optimisation of systems and monitoring consumption.

These are then used to evaluate a case study of a building located in close vicinity of and with certain similarities to Silo 5. Some of the methods and tools described in this chapter are applied to this building and the effects thereof are assessed.

Finally, challenges relevant to this research that were identified through the work in this chapter, are summarised and conclusions are made.

2.1 Green buildings

This section describes and critically assesses the green building rating system of South Africa. The impact of the rating system on the building industry is investigated, focussing on the influence that it has to drive nationwide change.

2.1.1 Green Star SA

The Green Building Council of South Africa (GBCSA) is a non-profit organisation that was formed in 2007 to promote sustainability and the lessening of the environmental impact of the property industry in South Africa. It forms part of the World Green Building Council alongside similar bodies from Australia, the United Kingdom and the United States.

The GBCSA developed Green Star SA (GSSA), a comprehensive environmental rating system for South African buildings. The system is based on similar systems employed in other countries, particularly the Green Star system of the Green Building Council of Australia and adapted to suit the South African environment and marketplace. It also acknowledges and incorporates local standards and regulations.

By providing the property industry with an objective benchmark measurement for green buildings, GSSA aims to encourage building owners and developers to improve the environmental impact of development and operations. Furthermore GSSA focusses

on promoting integrated, whole-building design, identifying impacts on building life cycles, raising awareness of the benefits of green buildings and recognising environmental leadership [8].

By establishing GSSA as an industry standard, the GBCSA has created an incentive for companies to invest in green buildings. A GSSA rating ensures a higher building rental rate and is used to advertise a company's commitment to the environment, likely attracting more clients or business.

The Green Star SA rating system basic structure is shown in Figure 2.1. It focusses on nine environmental impact categories (including an innovation category). Each category is divided into credits that awards points for initiatives that can improve environmental performance. The number of points that are awarded within a category depend on the extent to which the credit criteria have been met. The number of points available in a credit also serves as a weighting, indicating the importance of each credit within a category. A category score is calculated using Equation 2.1.1.

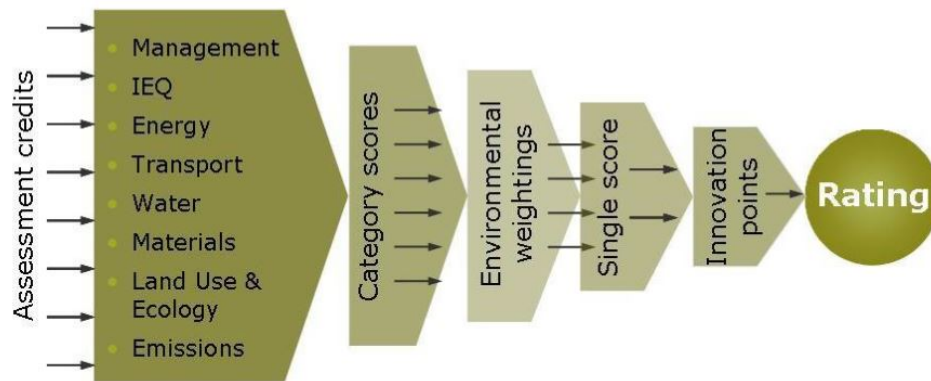


Figure 2.1: Green Star SA rating system structure [8]

$$Category\ Score = \frac{Number\ of\ points\ achieved}{Number\ of\ points\ available} \quad (2.1.1)$$

Environmental weighting factors are applied to each category as shown in Equation 2.1.2. These weighting factors differ for different building project types and reflect varying environmental concerns and imperatives in each type of project. The category weighting factors for office buildings are shown in Figure 2.2. The weightings are determined by the GBCSA according to information available to them at the time as well as their own opinion [8].

$$Weighted\ Category\ Score = Category\ Score\ (\%) \times Weighting\ Factor\ (\%) \times 100 \quad (2.1.2)$$

Once the weighted category scores have been calculated, they are added together with points for innovation, which is the ninth category. Innovation points are not weighted as it may apply to innovation in any of the other categories. Using the final score, a Green Star SA rating is awarded according to the rating scale shown in Table 2.1. To retain a degree of exclusivity and to award market leaders, the GBCSA only provides formal certifications to projects achieving a GSSA rating of four or higher.

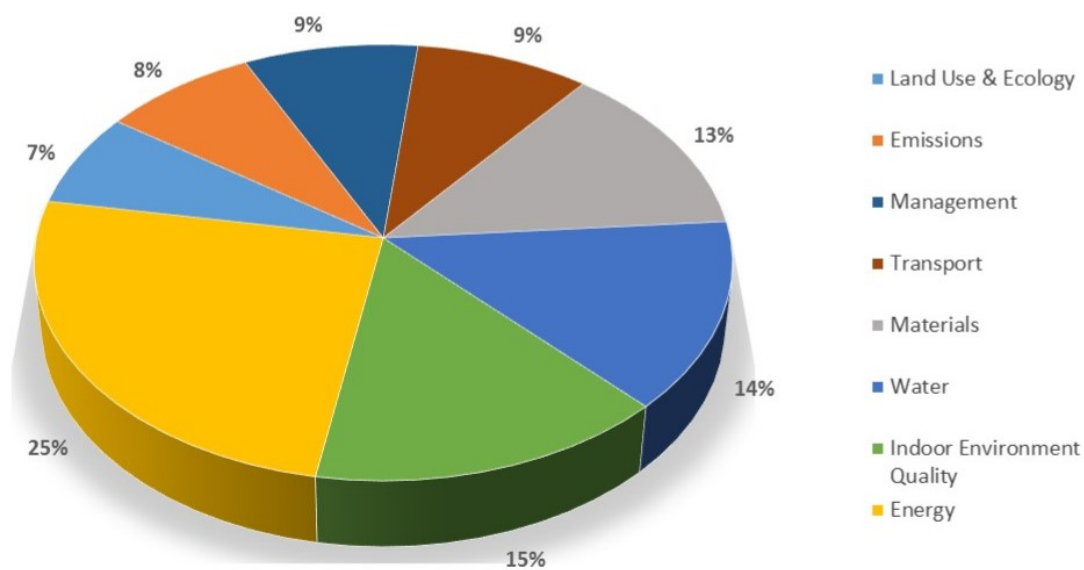


Figure 2.2: Green Star SA Office category environmental weightings [8]

Table 2.1: Green Star SA certification rating scale [8]

Green Star Rating	Required Score	Certification Description
One Star	10-19	Not eligible for certification
Two Star	20-29	Not eligible for certification
Three Star	30-44	Not eligible for certification
Four Star	45-59	Best Practice
Five Star	60-74	South African Excellence
Six Star	75+	World Leadership

The GBCSA developed different rating tools for different types of projects, including public and education buildings, multi-unit residential buildings, retail centres, offices, existing buildings and interior fit-outs. The structure of the rating system described above applies to all of these projects, but the category credits, credit weightings and environmental category weightings may differ.

Focussing on office buildings, GSSA Design and As Built certifications can be awarded based on the phase of the project. The same GSSA Office rating tool is used for both certifications, but the supporting documents required for the applications will differ. The Design certification can be applied for once the design stage of the building has been completed. The As Built certification can only be applied for after building construction is completed. The Design certification has been incorporated to allow a building to be marketed as a GSSA certified building to potential tenants before construction has been completed.

The GSSA Office rating tool was first released in 2008 and have since delivered a number of successful certifications. The No. 1 Silo building (see Figure 2.3) which forms part of the same Silo district as the No. 5 Silo building, was the first of only three office buildings nationwide to be awarded a six star As Built rating from the GBCSA. Other

notable office projects in the Western Cape region include the new Portside building (see Figure 2.4), occupied by First Rand, in the Cape Town CBD, and the new Chevron offices in Century City, both receiving five star As Built ratings [9]. A number of buildings such as the V&A Wharf Shopping Centre and the entire Black River Park campus of buildings, to name only a few, have received GSSA certifications through the Existing Building Performance tool showing a clear movement toward “going green” by existing and new building projects.



Figure 2.3: No. 1 Silo building [9]



Figure 2.4: Portside building [9]

2.1.2 Impact of going green

The potential environmental benefits that may flow from large scale implementation of the GSSA rating system are clear. The majority of the credits in all but one of the categories focus directly or indirectly on managing or decreasing the environmental impact of the construction and / or operation of buildings by decreasing consumption, wastage, pollution or at least by improving awareness of building consumption.

These requirements are usually set over and above what local standards and regulations require. Some examples include the green house gas emissions credit (ENE-1) in the energy category, the fuel-efficient transport credit (TRA-2) in the transport category, the occupant amenity water credit (WAT-1) in the water category and many more.

The indoor environment quality (IEQ) category is aimed at the well-being of building occupants. This category strives to bring balance to the other categories and will therefore in many cases work against the effects of those categories. Energy efficiency can, for example, easily be improved by reducing the capacity of air conditioning or ventilation systems, but this will have a negative effect on occupant comfort and well-being. The IEQ category asks for, among others, more natural light, increased fresh air supply, improved thermal comfort, reduced noise levels and reduced levels of indoor air pollutants. A high environmental weighting factor also makes this category impossible to ignore by GSSA applicants as it accounts for 15% of the total points on offer. Sick Building Syndrome has been attributed to poor indoor environmental quality and can therefore also be prevented by investment into IEQ [8]. The resulting additional benefits of performing well in this category are healthy and productive staff.

Apart from the apparent impacts on the natural and indoor environment, GSSA certified buildings also have financial impacts. Studies have shown that green buildings can command rental rates of three to six percent higher than otherwise similar buildings,

while the selling price for green buildings are up to 16% higher. Also, by investing only two percent more into the development of a green building than a conventional building, life cycle savings of up to ten times the additional investment can be achieved [4]. This figure includes savings from lower consumption figures, lower operation and maintenance costs as well as increased productivity.

Another study has found that on average, green buildings registered through the LEED rating system of the US Green Buildings Council, use 18 to 39% less energy per floor area than conventional buildings. Of the buildings included in that same study, 28 to 35% of the green buildings used more energy than non-green buildings. Also, the LEED certification level of these green buildings showed no real correlation with the energy performance [10]. This strengthens the consensus that, generally, green buildings save more energy, but also acknowledges that the amount that is saved, if any, relies on a number of other factors as well.

Green buildings also have an impact on the communities around them and are usually regarded as modern, innovative and altruistic through its consideration for the environment. This will have a positive effect on the public perception and brand name of building owners and especially its occupants, adding to the lure for potential tenants.

A popular perception is that the initial cost of a green building will be significantly more than that of a conventional building. This is one of the main impediments to the large scale adoption of green design principles. The reason for this is a lack of information and experience in a field that is still in its infancy in South Africa. Research has shown that by planning for a green building from the conception stage, involving professional consultants from the start and by setting clear goals, a four star GSSA certified building should cost no more than a conventional building. Higher star ratings can be achieved with minimal additional costs and as it is explained above, the long term return on this additional investment is well worth the price [4] [11].

As the GBCSA determines the terms and requirements for GSSA certification, it is worth critically considering the impact of the structure of the GSSA rating system. GBCSA members consist of parties from multiple sectors, the largest representation being in professional services (see Figure 2.5). Their decision making should therefore be objective and in line with the interests of all parties.

The GSSA system is revised regularly with technical clarifications and credit interpretation requests issued as and when needed. The GBCSA also encourages feedback from applicants. Fundamental changes to credit requirements are only applied to new versions of rating tools, such as the Office version 1.1 tool that was released in 2014, six years after the release of the first version.

Minor changes in credit requirements can have significant effects on the cost involved with achieving points for that credit. For example, see Table 2.2 for the changes that were applied to the ventilation credit (IEQ-1) from the Office version 1 rating tool to Office version 1.1. The changes were caused by a change in the national building regulations (SANS 10400-O [12]). The effect of the change is that with the new Office tool, more fresh air needs to be supplied to boardrooms and less points are awarded for the achievement. The effect on the point system might seem small, but the increased airflow requirement has a major effect on how air conditioning (AC) systems are designed. More fresh air requires more conditioning which consumes more energy. This also increases the size of equipment such as ducts, piping and the AC units themselves. If a central AC unit serves offices and boardrooms, enough fresh air must be fed into the AC unit to supply all of the rooms with the higher fresh air volume ($16.6L/s/person$) to ensure that the requirement is met in the boardrooms. This forces engineers to incorporate additional ventilation

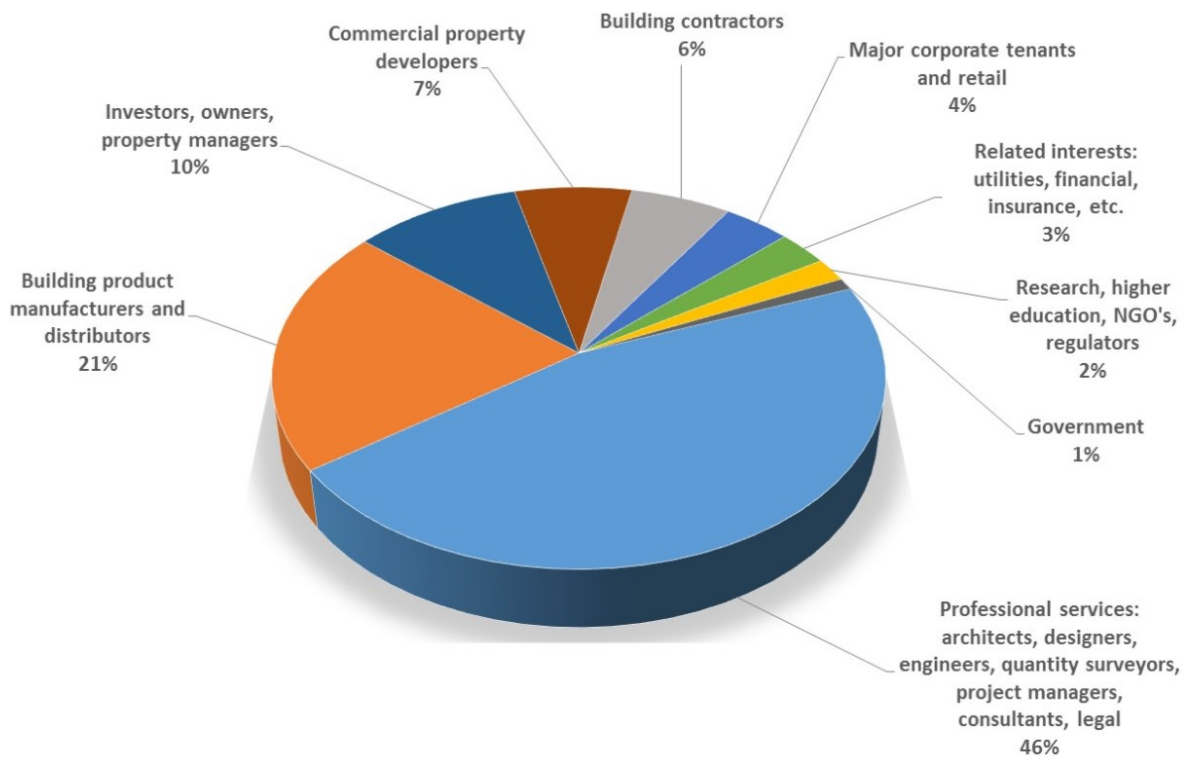


Figure 2.5: GBCSA membership breakdown [11]

systems for boardrooms or to drastically increase the capacity of the central AC units, both of which drive up the capital and operating costs, or to altogether abandon these points in their GSSA application.

Table 2.2: GSSA Office IEQ-1 credit changes [8] [12]

Type of room	GSSA Office version 1			GSSA Office version 1.1		
	Fresh air requirement ($L/s/person$)	Points awarded	Percentage of total IEQ points	Fresh air requirement ($L/s/person$)	Points awarded	Percentage of total IEQ points
Office	12.5	3	10.7%	12.5	2	8.3%
Boardroom	12.5			16.6		

The IEQ-1 credit aims to improve on national building regulation requirements, but with the changes to the regulations the requirements were already increased considerably. The change to this credit requirement does not seem well thought through, which indicates towards a communication or practical knowledge gap between GBCSA decision makers and industry professionals.

In the same way there seems to be lack of understanding in the GSSA rating system regarding the severity of the water crisis in South Africa. In Section 1.1.1 a brief description was given of some of the pressing issues of South Africa's water resources. Recent water restrictions that were put into place by multiple municipalities across the nation and entire towns going without running water for weeks should give further warnings of the urgency of this matter. Figure 1.1 also shows that 27% of the country's water demand comes from residential and commercial buildings. Water tariffs from 2015 to 2016 have increased by approximately 11%, however commercial buildings in the Cape Town area

are still paying only R17.10 for every 1000 litres of water that they consume. There is also no sliding scale in place in commercial tariffs that would benefit lower consumption and penalise higher consumption, as is the case for residential properties [13].

The government through the Department of Water and Sanitation have their part to play in this crisis, but there are clear opportunities to achieve considerable water savings by implementing small changes in this industry. Yet the environmental weighting of the water category in the GSSA rating system is only the third highest and a staggering 11% below the energy category weighting (see Figure 2.2). The water category description in the Office rating tool technical manual acknowledges the importance of water as a resource and refers to some of the challenges that the country faces [8]. The category credits also focus on important issues, ways to reduce consumption and incorporating sub-metering systems for additional points. However, no clear changes were made to the water category credits or their points allowance in the new Office version and there are only five water credits compared to the 17 IEQ credits.

2.2 Building management systems

The history of building automation can be traced as far back as the 1880's with the invention of the first electric thermostats, independently by Warren S. Johnson and Albert M. Butz [14]. Both of these men started a company with their invention and both of these companies survived and grew to become two of the biggest names in the building automation industry today, namely Johnson Controls and Honeywell International.

Building automation or management systems as they are known today only became a possibility after the development of a standard communication protocol. Interoperability was close to impossible before this as companies were developing HVAC equipment each with their own proprietary protocols. In 1995, after seven years of development, the Building Automation and Control network (BACnet) protocol was released by the Standard Project Committee of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and published as the ASHRAE Standard 135. In 2003 it was accepted by the International Organisation for Standardisation and published as the ISO 16484-5 standard. This development had an immediate effect on the industry and to date over 900 BACnet vendor ID's have been issued internationally [15]. Other standard protocols have also been developed and are widely in use, such as LonWorks and Modbus, however BACnet is unique in that it was developed specifically for communication between different devices in a building automation system and enjoys the majority of the market share in the industry.

2.2.1 What is a BMS?

A building management system can be described as a centralised electronic control system for the monitoring and control of a building's mechanical and/or electrical equipment. The system consists of hardware (controllers, integration devices, network infrastructure, etc.) and software (control, automation, user interface, etc.). As the software is hosted from a server and communication with this server is usually via an IP network, users can access the system remotely. By making use of a standard communication protocol such as BACnet over IP, a BMS can be extremely flexible in its design with near infinite possibilities for the integration of third party devices. The following types of systems or equipment can all be linked to a modern BMS:

- HVAC
- Fire detection & protection
- Lighting
- Security
- Access control
- Plumbing
- Lifts
- PA system
- Multimedia system

Although home automation systems are gaining popularity, complete building management systems are still predominantly employed in larger buildings. Originally the need for building automation developed from the HVAC industry as it accounts for a large amount of energy consumed in buildings. Due to the cost and complexity of such a system, equipment being monitored or controlled would have to account for at least 40% of building energy usage. The main functions of a BMS includes the improvement of the following:

- Occupant comfort
- Operating efficiencies & cost
- Water & energy consumption
- Equipment life cycles
- Amount of building staff and their productivity
- Fault finding & complaint reaction

2.2.2 Available solutions

It is clear, with very little in depth research, that any building without some sort of a control system will surely be wasting a considerable amount of resources such as water, electricity and even staff through inefficient operation. A number of companies have seen this as an opportunity to provide a cost-saving solution. Today there are numerous competing building automation products available in the market with little or nothing to decide between the performance and the quality of the most favoured products.

One product that will be focussed on in this research is Johnson Control's Metasys BMS package. Honeywell is another major competitor in the building automation industry, possibly the largest as this group has taken out a number of its competitors by either merging with or acquiring smaller companies. The Honeywell International group is the parent company to among others Honeywell Building Solutions, Alerton, Centraline and Tridium. Each of these companies have their own building automation product lines, internally competing against each other, but also sharing resources and information. This

enables them to be extremely competitive with their pricing and their provision of specialist solutions, preventing smaller companies with relatively high overhead costs to compete for the same projects. Companies such as Honeywell Building Solutions can provide a complete end-to-end solution with their Enterprise Buildings Integrator (EBI) product by pooling resources, labour and knowledge from other Honeywell companies, eliminating the need for a separate BMS contractor in a building project [16]. Other parties worth mentioning in this industry is Siemens and Schneider Electric.

Even though each company aims to provide a unique solution with their BMS product, there is a clear common thread throughout the industry. The general BMS configuration appears to be homogeneous for most of the favoured products. An IP network is commonly used for communication between devices where the BACnet protocol is used. Some companies offer adaptor devices for wireless connection to hard-to-reach equipment. A server hosts the proprietary software that integrates the different building systems and provides a user interface to monitor and control these systems. Most companies also offer controlling devices for different types of equipment to eliminate the need for intermediary devices from other suppliers. However the product will also include a means to connect all kinds of third party devices to the system where their own controllers are not sufficient or where clients might have preferred suppliers of certain hardware controllers or standalone systems. The standard configuration also includes on-site workstations for facility managers to access the system and some form of a web portal for remote access. Most companies also offer mobile applications for easy access from hand-held devices.

Besides the general configuration and physical products that are included in a BMS, companies also offer a host of features and capabilities through their software. These features combined with the software interface is usually what gives each product its own distinctive look and feeling. Dynamic graphical representations of plantroom equipment makes it less complicated to interpret equipment information for managers and facility operators alike. Navigation between different systems and all of the equipment connected to each system must be as simple as possible and may include different search capabilities, custom user views or multiple links included on a main graphics view.

Live equipment information is important for monitoring the immediate health of any system, but the real importance lies in historical data to keep track of consumption, simplify fault finding and to effectively optimise systems to name a few. Companies have different ways to provide the user with access to this data usually involving reporting and / or trending features. Reports can be as simple as a exported file with all the raw data to be processed by third party software packages such as SAP or Oracle software for billing purposes or even Microsoft Excel. It can also be highly complex, such as a weekly or monthly generated energy analysis including graphs and important indicators automatically calculated from the data that was measured. Most companies offer some form of energy management, analysis and / or billing features. Data can also usually be trended graphically or otherwise.

Other useful features include sending alarm notifications via SMS or email and the ability for trained facility managers to write, test and implement their own control algorithms for building systems and equipment. Most of these features are not part of standard packages, but rather offered as optional extras as clients have varying needs.

2.2.3 Limitations

Building management systems are not without their faults and limitations. For one, if any HVAC equipment are required to operate, by clients or regulations, during power

outages, the equipment and all of the BMS devices that are required for the controlling of the equipment need to be supplied with backup power. The BMS devices might not be located near the HVAC equipment and would therefore require additional electrical infrastructure.

As IP networks are normally used for communication between BMS devices, this presents a problem for facility operations in case of network failures or breakdowns. Due to the complexity of the loads on these types of networks for a campus of buildings, this may at times be a regular occurrence. A rooftop air handling unit that uses space temperatures to determine airflow and cooling or heating demand in a conditioned area will not be able to receive temperature measurements from sensors that use the IP network to relay this data. The only way to prevent this is by hard-wiring connections between essential equipment which vastly increases the amount of wiring required and defeats the purpose and benefits of using an IP network.

Another limitation to consider involves a building's fire detection, fire protection and life safety systems. The design of these types of services are required by law to follow extremely stringent regulations to ensure the proper functioning of systems during emergencies. As a result power supply cables, control cables and any control systems of these services need to have certain fire ratings and certifications, guaranteeing prolonged and unfaltering operation during emergencies. Most of the favoured BMS products do not offer these certifications even though most, if not all of them advertise the benefits of integrating life safety systems into their system. At most a BMS might be able to monitor life safety systems, but it is unlikely that it would be allowed to control any of these systems.

Even though the development of BMS products has come a long way, suppliers are still each developing their own software systems with limited knowledge sharing practices being implemented. Each company reinvents the wheel when it comes to user interface, each with their own strengths, but no single product can claim to work perfectly in all areas. This is however, still developing technology with massive potential. Care should still be taken when selecting the best solution to consider all aspects of a specific product, including its limitations.

2.2.4 Selecting the best solution

Some companies have been able to edge ahead of competitors by providing other additional, specialist features or add-ons. However, this rarely seems to be the deciding factor during project tendering procedures.

Generally, contractors, trained and experienced in the design and installation of one or more suppliers' products would tender to receive the contract for the design and supply of a BMS for a new or existing building. In smaller projects the contractor might be directly appointed by the building owner in which case they are responsible for all phases of the design and installation and answer directly to the owner. In larger or more complex projects a mechanical consultant is appointed by the owner or client to oversee and manage the project, but also to provide high level design requirements for contractors to meet. The consultant is also responsible for the evaluation of tenders and to provide a recommendation to the client regarding the appointment of a contractor.

Contractors typically align themselves with a specific supplier's product to provide a specialised service as different products might provide the same function, but differ substantially in their architecture. Suppliers, therefore, have agents that are tasked with the marketing of their products to local contractors and consultants.

As most of the major suppliers provide a similar service through their products, the choice of supplier and hence, contractor is first and foremost based on the cost of the product and installation. Secondly, clients require local support from a BMS supplier or contractor as extended downtime is mostly unacceptable and the cost of providing non-local support might overshadow any initial cost advantage over another product with local support. Alternatively, to minimise a building owner's dependence on supplier specific support services another critical requirement is usually that the product must use an open protocol, such as BACnet. This means that a contractor or someone other than a technician from the BMS supplier, trained in the use of the product, must be able to alter its programming to a certain extent to suit new monitoring or control requirements. For most types of buildings or clients, without this ability, a tender may immediately be excluded from consideration. Clients also value existing relationships where trust has been built up over time in a company or a product. Finally, a product's technical specification and performance will also be evaluated, but in most cases will only have an effect on the outcome if all other factors are equal between competing products.

This fact highlights an important flaw in this process with regards to the development of new and innovative technology and the progress towards a sustainable future. By excluding tenders, usually from smaller companies, based on their cost or their service capability without even considering the possible benefits that are available from a pioneer with an alternative product might prevent or considerably delay the next breakthrough in energy efficiency from being developed.

The problem does not stop with the tendering process. Mechanical engineering consultants, who, for most other services such as HVAC, are responsible for detail design, do not normally specialise in the design of building management systems as it requires knowledge of electronics, network infrastructure and programming. The equipment that is connected to the BMS is understood and how it can be controlled from a hardware perspective, but not the full potential of the software. Consultants are therefore unfamiliar with the full capabilities of different products and will not likely see the potential of new types of products. Many local contractors also lack an in depth knowledge of the product that they are selling. Initiative is seldom, if ever, taken to present a client with an alternative solution to a problem. Ever tightening budgets and unreachable deadlines seem to blind the industry from the true potential of a BMS.

In the case of the Silo precinct BMS project, two tenders were considered. After tender evaluation, Cape Automation Services was appointed to design and supply the Johnson Controls Metasys BMS for the district cooling system and all of the Silo buildings including Silo 5.

This choice was primarily driven by the fact that the V&A is using the same BMS in all of its existing buildings and already had a Metasys server in place that could also be used for this project. This also ensured that their tender price, which was already competitive, was well below the competitor's price which had to include the supply and installation of a new server. Through Cape Automation Services, Johnson Controls offers good local support service that can be attested to through their long standing relationship with the V&A [17].

2.2.5 Johnson Controls Metasys

Metasys is a web-based building automation system or BMS from Johnson Controls and is widely used in South Africa and more specifically in the Western Cape. It allows building operators access to a host of features through a user interface (UI) or front-end.

From the UI all connected building equipment may be monitored and controlled. The UI can be accessed from any computer with an internet connection and the Metasys Launcher application installed on it. User profiles with password protection are created by the system administrator, Cape Automation Systems for Silo 5, for anyone that needs to access the system. Depending on the person's role, limited access can be granted to prevent any accidental or unauthorised changes being made to system controls [18] [19].

2.2.5.1 Features

The system is scalable and can easily meet the requirements of a single building or a campus of buildings. The system is also flexible in its design. The UI can be set up with different user views where navigation can be based on areas and equipment serving those areas to easily identify and correct any problems. Some of the main features that are available to building operators include:

- Real-time data
- Historical data
- Data reporting, trending and exporting
- Alarm and event management and notifications
- Scheduling
- Dynamic graphics
- Customisable user views
- User controls
- Adjustable user access rights

Metasys also offers a number of optional extra features that can be extremely useful to facility operators as well as higher level management. One overlooked, but potential ground breaking feature is the Logic Connector Tool (LCT), that is being used to great effect at the Vodacom Techno Centre (see Section 2.6). It is the same feature that the contractor uses to do all of the initial programming of the BMS. It also enables trained facility managers to create their own control algorithms or application programs to be executed by equipment controllers. According to the Metasys System Configuration Guide [19] LCT is an easy to use drag-and-drop editor that allows users to connect data points with logic blocks that can carry out logical, mathematical and specialised control functions. Programs can be viewed, edited and simulated before actual implementation.

This tool should provide an almost limitless amount of possibilities for users that can now perform actions with software that are still largely being performed by hardware devices or calculate custom performance or consumption figures that would otherwise have had to be calculated by exporting raw data to third party software. System controls can be adjusted and tweaked without being limited by pre-set software options. The functionality of this type of feature supports the idea of employing fewer facility staff members with specialist training in building management systems, able to operate and manage large building systems at optimal efficiencies, significantly cutting costs and improving productivity from the current norm in South Africa.

Unfortunately the practical reality of this feature does not yet live up to its potential. Users are still limited with the range of calculations that can be performed and only certain data points are available to be included in calculations performed by certain controllers. This makes working with this tool frustrating for contractors and impractical for untrained facility operators. Even after the eighth release of this software, very few improvements have been made. A possible solution might be to open this software to outside developers to develop their own software extensions that improves the current functionality, for example, by adding spreadsheet like features to perform a wider range of calculations.

Another important added feature from Johnson Controls is the Metasys Energy Dashboard (MED), a software package that was developed to be integrated with the Metasys BMS. The software serves as an extension of the BMS, providing useful information from the raw data that is recorded by the BMS. MED takes the standard BMS reporting features a step further by providing in depth energy analysis and reporting as well as equipment performance monitoring. An intuitive and flexible user interface of its own provides sensible graph and reporting options.

A vital benefit of the MED software is its tenant billing capabilities. It can automatically generate tenant billing statements based on meter consumption data and user defined tariff data. Without it, consumption data would have to be exported to third party software packages such as Oracle or SAP in order to compile statements. This, in itself, is a significant improvement from having to manually obtain consumption data by taking readings at each meter, which is still the case in most parts of South Africa. MED also allows building occupants to request after hour schedule overrides through this application.

The software is also modular, meaning that clients with different needs only need to pay for the features that they use. Once again the potential of this software is immense. With real-time, in depth reporting of performance and consumption figures, facility operators can make informed adjustments to system controls and accurately diagnose system problems, financial departments can effortlessly and more regularly report on building running costs and management can use this information to justify upgrades or new investments. Tenants can also be kept up to date with their consumption figures, placing a degree of responsibility for their consumption back on them.

The V&A recently made the decision to add the MED package to the Silo district BMS and Johnson Controls was still in the process of configuring the software for the V&A's specific needs at the time of writing.

Other added features offered by Metasys includes object interlock, optimal start, demand limiting and load rolling, audit trails, system diagnostics and serviceability as well as a mobile application for access to the BMS from mobile devices [19]. With Metasys a company with multiple facilities in different locations can also integrate all of the individual building management systems into one central system from where corporate management can observe and guide the operation of each facility on a high level.

2.2.5.2 System configuration

A BMS normally makes use of the building IP network infrastructure for communication between different devices and the web-based BMS. Depending on the network infrastructure, setup and other factors, different options are available for the processing, transfer and storage of data. Landlord and tenant policies may differ for the use of this network. The different devices that are connected to the BMS might use different communication

protocols. Metasys also provides different options for the type of UI. All of these factors and more need to be considered when designing the BMS. Due to this high level of complexity there are number of possible variations for the system configuration.

The system configuration and different BMS devices for Silo 5 are discussed in-depth in Section 3.1.3.1.

2.3 Alternative sources

While alternative sources may provide substantial savings in the cost of resources used by a facility, it is not the main focus of this research. Discussions on the topic will be limited to general background and the savings from the district cooling plant that can be measured for Silo 5.

Ideally, the one sure way for a facility to have guaranteed access to a stable supply of energy and water would be to remove utility providers from the equation or at least by minimising its dependence on them. The extreme example of this idea becoming a reality can be seen in various Zero Energy Buildings being built around the world, which are designed to be so energy efficient that the significantly reduced amount of energy required for operation can be generated on-site by renewable energy sources. This might seem like an unrealistic goal for most buildings and an even further distant dream for buildings in South Africa, but a lot of value can be found in the energy saving measures and alternative sources being incorporated into these buildings.

The use of photovoltaic (PV) panels have come a long way in South Africa and equipment prices have gradually decreased with an increase in the variety of products available to a larger market. The work that some companies like SolarCity in the US are doing on the development of energy storage systems may also pave the way for solar energy to become the complete sustainable solution. Solar water heaters are widely used and even form an integral part of low cost housing projects in the country. Wind turbines have become a more commonplace sight in some rural areas, but the use of wind energy is limited to large scale applications, mostly assisting the utility provider, Eskom, with electricity supply to the national grid. On the water side, rainwater harvesting and recycling of water are implemented mostly by facilities and institutions where water shortages have become a serious concern.

Making use of any of these alternative sources is not always feasible due to a number of factors, including location, finances or the available technology. For example, using solar energy was investigated and at one point included in the scope for Silo 5, but the amount of energy that could be generated with the available roof space combined with the cost of a PV installation caused the notion to be abandoned, at least for the time being. However, as a result of the coastal location of the Silo district, the ocean could be used as an alternative source in an unconventional way.

2.3.1 Seawater district cooling

District cooling or heating is the practice of using a central plant with chillers, pumps and other equipment to provide a number of buildings with chilled and hot water through a piping network, mainly for air conditioning purposes.

The general consensus is that substantial savings can be achieved by investing in a centralised plant instead of each individual building having its own equipment, but usually only if it can be incorporated in concert with development of the buildings it will serve.

A simulation of the operation of a district cooling system in a business area in Japan has showed that energy savings of 29% are achieved over the use of decentralised systems [20].

District cooling plants are widely used across the globe to great effect. The largest of these plants, a 450MW district cooling plant in Qatar, provides chilled water for the cooling needs of a 400ha man-made island [21]. Due to the size of these plants it is financially reasonable and usually necessary to investigate alternative and more sustainable ways of cooling the large amounts of chilled water other than the conventional use of electricity and large amounts of potable water for cooling towers. The cooling sources that are currently in use include water from lakes, seawater, desalinated seawater, cold storages in the form of snow or frozen water and even treated sewage effluent.

The idea of using seawater as a method of “free” cooling in district cooling plants is by no means new technology in the global environment. The first feasibility studies that were completed regarding this topic date back as far as 1975 and the first successful seawater district cooling project was completed in 1986 in Halifax, Canada [22]. A simplified representation of a seawater district cooling system can be seen in Figure 2.6.

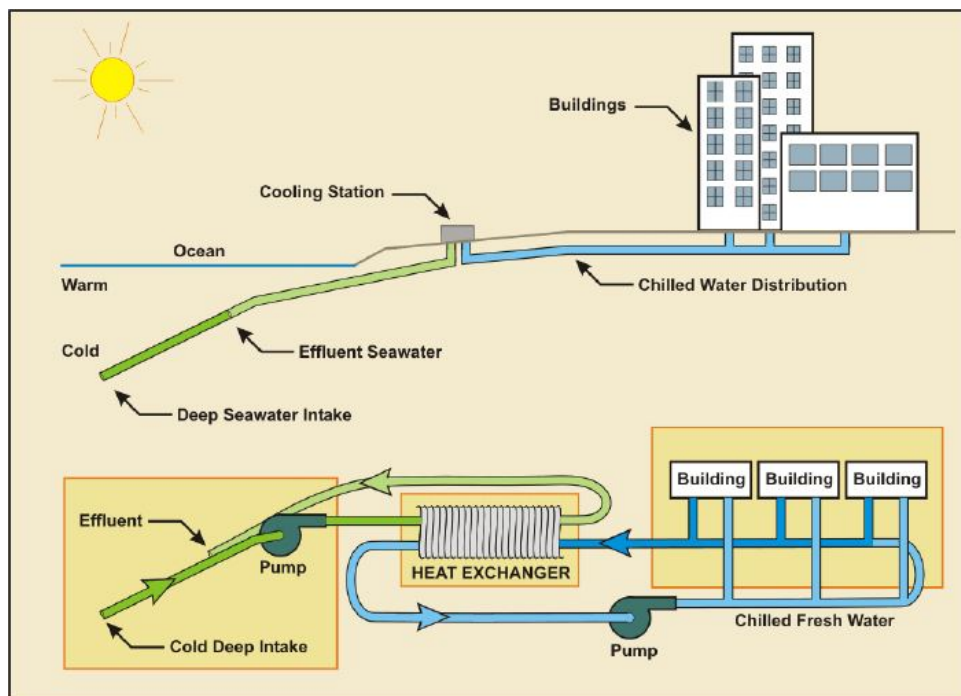


Figure 2.6: Schematic representation of the functioning of a seawater district cooling system [22]

2.3.1.1 Benefits

Benefits of this type of system include energy savings between 50 and 90%, reduced payback periods, an environmentally friendly solution with no potable water consumption and energy costs that are mostly independent of increasing electricity tariffs.

Decentralised systems would see each building supplied with its own chiller or other method of supplying the necessary cooling and heating. Pre-cooling water would not be a feasible option for all buildings as the cost of equipment increases considerably when working with salt water.

Systems would be designed for the peak load of that building whereas the district cooling system is designed according to the peak load as well as the time of day of the peak load of each building. As buildings served by such a system are usually wildly different in their use, peak load times will also differ. For example, the peak operating hours, and consequently the peak loads, for residential and commercial buildings will not coincide. Therefore the district cooling system peak load will be lower than the total of the peak loads of all the buildings. By using this type of system for different types of buildings with their peak loads at different times, the system peak load is automatically “clipped” which is one of the goals of Eskom’s ESCo model (see Section 2.4).

Also, even with the use of variable speed drives (VSD), all systems have a minimum running performance due to minimum running speeds of motors. Therefore the minimum load of a building might be less than its minimum running performance resulting in wasting of energy. With a number of different buildings it is less likely for this to occur with the district cooling system.

Even though the cost of this plant and piping system is extremely high, the system pays for itself through the “free” cooling that it provides and the alternative would still have been more costly in terms of space and cost if each building had to have its own plant with equipment.

2.3.1.2 Challenges

South Africa being a developing country, has not yet seen any real implementation of this type of technology. There are also, a number of limitations to these types of plants. Obviously the plant and area that it serves need to be in close vicinity of a coastal area as the capital cost, operational and maintenance costs of a system that needs to pump chilled water and / or seawater over large distances are prohibitively high. A comprehensive feasibility study is generally included in the conception stage of such a high value project, investigating various determining factors such as the environmental impact, all initial and running costs, achievable savings, payback period, equipment life cycles and scalability before it can be approved.

The system for such a network of diverse buildings and loads is inherently complex and difficult to balance. Commissioning is therefore a lengthy and labour-intensive process before the system can operate autonomously at optimum efficiency. With such a large and complex network each automated devices adds another degree of vulnerability to the system, a potential point of failure.

The nature of the design of such a system also does not lend itself to being utilised in existing building precincts. The cost of retrofitting such a system will outweigh its benefits. In this case building work was designed while considering pipe routes and plant-room space required for equipment. Shafts are built through concrete slabs for large pipes to run from the basement levels into each building. Electrical and data services also need to accommodate the power and data point requirements of the equipment and BMS components (electronic valves, pressure and temperature sensors, controllers, etc.).

Even though multiple backup procedures are in place there is still a possibility of a complete system breakdown when something goes wrong. Should a pipe burst or a leak occur in any of the buildings, the plant BMS will detect this and perform an emergency shut down in order to protect the equipment. Depending on where the leak is, the entire plant will be shut down until the problem is resolved or until the problem area can be isolated from the system. For a hotel that draws its hot water from the system, this will

be unacceptable. For this reason some of the Silo buildings have opted to only make use of the district cooling system for certain services.

2.4 Systems optimisation

Effectively utilising alternative sources is only the first step to cutting costs, looking after the environment and ensuring a sustainable future. Office buildings usually have fixed requirements in terms of services such as HVAC, lighting and water supply. It is therefore unlikely that consumption can be reduced by expecting occupants to reduce their usage of facilities. The next logical area to target in order to reduce consumption or operating costs is the systems that provide these services.

This section explores the savings potential of incorporating optimisation strategies or methods into all stages of each system's life cycle, from conception stage, to design stage, to construction stage and straight through the operational stage. Emphasis will later be placed on the design and operational possibilities of a building management system in this regard.

It is important to take note of the progress that has been made in the optimisation of building systems. National building regulations in South Africa (SANS 10400-XA and SANS 204) compel project teams to implement certain water and energy saving features into a building's design. Eskom, through its Integrated Demand Management division, have developed the Energy Services Company (ESCO) model that financially rewards companies that reduce their consumption, improve their energy efficiency, shift their energy load to off-peak hours and / or notably achieves peak demand clipping [23]. The 'green' movement is also being driven by the GBCSA through the widely used Green Star SA rating system that is explained in Section 2.1. This rating system provides numerous ways of improving system efficiencies that will not all be repeated in this section. Suppliers of all types of equipment are also constantly competing to provide the most energy efficient products to clients that are focussed on saving costs and improving their environmental footprint. Engineering consultants are also applying cost and energy saving principles to the designs of new buildings as standard practice.

2.4.1 Standard methods

This section describes a number of methods that are commonly being used to achieve considerable savings in water and energy consumption.

2.4.1.1 Water

Domestic water supply systems have limited areas that can be improved upon through the control of a BMS. Metering solutions are discussed in Section 2.5.1. Considerable savings can still be achieved in the selection of water fixtures.

Low-flow shower heads use 25% to 60% less water than conventional shower heads and help to save water as well as electricity through the heating of hot water. Laminar-flow and aerating shower heads are available at competitive prices. Aerators that effectively restrict water flow from taps are also available. Lavatory technology have also substantially improved over the years. Low-flow or low-flush toilets use less than half the water that full-flush toilets use without compromising on its effectiveness. Waterless urinals can save water and drainage costs. These products increasingly form part of the standard

specification for new office buildings. In the case of green buildings or where additional capital is available sensor activated taps, toilets and urinals are commonly used, eliminating wastage through human error.

During construction and commissioning stages of new building projects it is also standard practice to perform pressure tests on domestic water supply and sprinkler protection systems to ensure no leaks are present.

2.4.1.2 Energy

Incorporating energy efficiency principles should start from the conception of a building project. Building orientation, for example, has an immense effect on its internal heat load. A building's envelope must be carefully designed. Materials used for walls, windows and roofs must have a high thermal performance (low thermal conductivity). External shading of windows will also have a meaningful impact in warmer locations such as South Africa. If these types of factors are properly planned and budgeted for by clients, architects and other early role players it will have a substantial knock-on effect for energy savings and provide consultants with a valuable foundation to build their designs on.

In the energy field there are numerous design methods that are commonly used to achieve savings or to minimise usage during certain periods. As lighting typically accounts for more than 20% of an office building's energy consumption (see Table 2.3), building owners are willing to spend more initially to save even more over a building's life cycle.

Table 2.3: Office building energy consumption by end use in three vastly different countries [24]

Energy end use	USA(%)	UK(%)	Spain(%)
HVAC	48	55	52
Lighting	22	17	33
Equipment (appliances)	13	5	10
DHW	4	10	-
Food preparation	1	5	-
Refrigeration	3	5	-
Others	10	4	5

While fluorescent lamps have improved considerably over the years, they are no longer the only role players in the office lighting market. Compact fluorescent lamps (CFL) and light emitting diodes (LED) are offering attractive albeit relatively expensive alternatives. Providing adequate lighting to a building can be a science of its own, however loosely, for energy efficiency, lighting selections are made by balancing lumen per watt ratios, lifespans, costs and aesthetics, while also adhering to local regulatory requirements.

Lighting control systems have become more commonplace and an international standard, the Digital Addressable Lighting Interface or DALI, has even been developed for these systems. Such a control system can include scheduling, different usage profiles and activation by presence detection depending on the project budget. A DALI system can also be integrated into a BMS for centralised control.

Improving a building's lighting efficiency also benefits the HVAC side as less heat will be generated by more efficient lights. Similar to water fixtures, energy hungry appliances have significantly improved and energy efficient alternatives are available and preferred.

HVAC systems are responsible for the largest part of most buildings' energy consumption. It is commonly accepted in the industry and also backed up by research that, for office buildings, HVAC consumes roughly half of the total energy (see Table 2.3). Other than the normal energy conscious practices such as the selection of equipment to operate at the highest possible efficiency, there are other practices that can significantly reduce energy consumption from the design stage to the operating stage.

During the design process it is imperative to properly size equipment. For air conditioning a thorough understanding of the building load should be obtained by engineers with the aid of an in depth heat load analysis using certified software. Safety factors are included in final selections, but over sizing of equipment must also be avoided.

The type of AC systems that can be afforded can also have a savings effect. The AC systems for Silo 5 are centralised in the same way as the district cooling system. A handful of systems serve thermal zones over multiple floors. The alternative to this would be to use multiple smaller AC units on each floor, decentralising the air conditioning of the building. In order to achieve effective thermal control with this type of system, an increased number of AC units are usually required. This is the more conventional approach, but both of these systems have their benefits.

The centralised system is appealing from an energy efficiency perspective. By dedicating an AHU to a thermal zone instead of to a floor, the type of air conditioning demand should be consistent over all floors for each AHU. This means that at any point in the day all areas served by an AHU should be requiring either heating or cooling, but never both. In contrast, at certain times of the day, in certain seasons, the position of the sun in relation to the building may cause one side of the building to require cooling while another side might require heating. When this happens an AHU will either supply air at an average temperature between the two requirements or it will supply the required cooling and use electric terminal heaters at the diffusers where heating is required if this option is available. This is not ideal for building occupants and wastes energy. With the centralised system no energy is wasted in this way.

The centralised system also has a spatial advantage as it does not require plantroom space on each floor, only a shaft for ducting to run from the rooftop AHUs to each floor. The cost of this system is also considerably less than that of having multiple AC units on each floor.

The decentralised system is often preferred for its modularity. Building upgrades or changes in tenants can be accommodated by either retrofitting new AC systems or upgrading only the affected AC unit or system. Controlling and commissioning of a smaller AC system is a much less complex task due to less variance in area usage over a single floor compared to an AHU that serves multiple floors possibly with multiple tenants with different types of uses of their floor area.

The centralised system efficiency and performance will also be affected if the type of occupation varies per floor. This can typically happen when one floor is predominantly used for meeting rooms or even a cafeteria, which is the case on the 5th floor of Silo 5. This also presents a problem with different and higher ventilation requirements for these areas which was discussed in Section 2.1.2.

A variable air volume system is another option to consider and will be discussed in Section 3.1.3.2. Systems with this feature will achieve savings by automatically adjusting

the amount of airflow that is supplied to different areas based on feedback from these areas.

The sizing of ducts is important to keep air flow pressures and hence fan loads as low as possible. Ducts running through unconditioned spaces, refrigerant pipes as well as chilled or hot water pipes should all be insulated to prevent any undesirable heat losses or gains. Sensors are also used to detect when air filters need cleaning to prevent unnecessarily high pressure drops over dirty filters.

On the control side, South African building regulations dictate that where possible AC systems must be able to operate in economy cycle mode. When outdoor air conditions are acceptable this mode can be used to provide “free” cooling or heating by supplying outdoor air to a building without having to condition it. With favourable fresh air intake positions this feature can be used to great effect and produce substantial savings [17].

By using the full capabilities of a BMS such as the Metasys product, described in Section 2.2.5, optimisation is automated in many of its features. The holistic, whole-system view that it provides can shed light on and provide simple solutions to inefficiencies that would otherwise have been a labour intensive task to detect and / or resolve.

By optimising lighting and HVAC systems through these and other common practice interventions it is estimated that building energy savings of up to 30% can be achieved in office buildings [25]. Most of these methods have also been applied to Silo 5 or were at least investigated during the design stage.

2.4.2 Taking optimisation further

For this research emphasis is placed on decreasing building water and energy consumption by using a BMS and the data that it provides. It is important to consider that all system parts are interconnected. By improving equipment operating efficiencies through enhanced control and by improving equipment life cycles through a closely monitored maintenance schedule, considerable savings will also be made in energy consumption. By focusing on the optimisation of building systems instead of individual equipment, considerable benefits can be realised in all aspects of facility operations. This section describes practical methods to optimise systems, mainly through the use of a BMS, that are not usually considered or overlooked by many.

The main idea here is to convey the importance and value of shifting the focus of optimisation from control technology and hardware efficiencies to information technology. For buildings such as Silo 5 with numerous complex systems, a BMS generates more data than what humans can comfortably assimilate. The challenge then comes in finding ways to process this data into usable information and relaying it to concerned groups in an applicable format to assist them in making informed decisions.

All data that can be measured in a building can be of use in some way and should be recorded. It is therefore troubling to recognise that very few buildings possess anything near a complete record of operational data. Research suggests that most facilities only have one to two percent of its operational data easily accessible [26].

This reality supports the general notion that decisions made in facility operations are based primarily on engineering assumptions or even educated guesswork, a reality that would be unacceptable in any other business sector. In the past this could have been accepted due to the fact that there were no feasible ways of collecting all of this data for extended periods of time, but with technology and specifically building management systems where they are today, this should not still be an issue. The potential is there for

quantum leaps to be made in terms of efficiency and productivity, but a mind shift will have to be made in the facility industry to invest into data.

2.4.2.1 Cost-based optimisation

Operational costs of facilities are always under scrutiny and are the first to be investigated for potential savings. At the same time improving occupant comfort in an office building is usually a priority and even more important than saving on operational costs as it may serve to improve the productivity of staff members. Striving to achieve both of these objectives may seem counter-intuitive, but it is possible with data.

In order to obtain the best understanding of a facility's energy usage, power and energy consumption data need to be available, not only for each system, but for each piece of equipment, measured and recorded, not hourly, but at 15 minute intervals [26]. The utility rate structure, such as different electricity tariffs, time-of-day and / or seasonal pricing, can then be applied to this data in order to obtain a cost per hour rate for the running of the facility and even more specifically, for the running of each piece of equipment. Where space planning information is available this can also be used to determine the costs per hour per space. The utility rates can also automatically be applied by the BMS through an energy management package such as the Metasys Energy Dashboard (see Section 2.2.5).

With this information facility operators are now equipped to make instant control decisions that will deliver the lowest costs while still providing the necessary comfort to occupants. Knowing this level of costs every 15 minutes is incomparable to receiving a utility bill every month. One study has suggested that by using this information to shift energy usage from high price periods to lower price periods, energy costs can be reduced by as much as 11% [27]. This form of demand side management is also the goal of the ESCo model described at the start of Section 2.4, which means a company can receive funding from Eskom for these types of practices. The information also provides a way to quantify energy being wasted as well as to measure and report on operational savings.

Cost-based optimisation might not always benefit total consumption figures in the same way as its cost, but this solution also serves to alleviate pressure from utility providers such as Eskom at peak times, which will benefit the environment in the long run.

2.4.2.2 Interactive commissioning

The process of commissioning is used to confirm that building systems meet an client's project requirements and operate in the way that it was designed by architects and engineers. Commissioning in different stages, new construction, retrofit or recommissioning as well as continuous commissioning are all known to be labour intensive and therefore costly exercises. Thus far it has been difficult to prove the financial worth of these processes. There has also been no real way to validate prolonged or lasting effects of any improvements made. Once again these challenges can be overcome by effectively using data.

By using a comprehensive BMS with access to all the operational data of a facility, a commissioning process can be completed with greater effect by one person in a fraction of the time that it would take the team of people that would be required to complete the process manually.

Manual commissioning requires multiple measurements and tests to be done at each piece of equipment with no way of indisputably confirming that changes made based on

these readings had the desired effect without redoing most, if not all, of the readings. For example, for HVAC systems, the airflow rates at each diffuser need to be checked and systems adjusted until the airflows match the design values. As a result the sheer volume of this work in a large office building cause some commissioning agents, who need to validate the outcome of a commissioning process, to only sample around 10% of the results.

In contrast, interactive commissioning can provide assurance as all systems and individual equipment can be monitored after any changes. All commissioning data can also be processed and presented in a user friendly manner for painless and swift examination. This greatly simplifies the work of commissioning agents and helps to ensure the quality of their findings.

A case study has shown that for 115 AHU's, this interactive commissioning process was completed by one person in less than three days. The same procedure is estimated to require more than 400 man-hours to complete manually. The AHU optimisation that was implemented during this process resulted in annual savings of \$86,250 [26]. The Energy Systems Laboratory, a division of the Texas A&M Engineering Experiment Station and member of the Texas A&M University System, claims to be able to achieve substantial savings in some facilities through their own Continuous Commissioning service that they provide (see Figure 2.7). These types of services can be evaluated, the results can be verified and service providers can be held accountable by using a BMS.

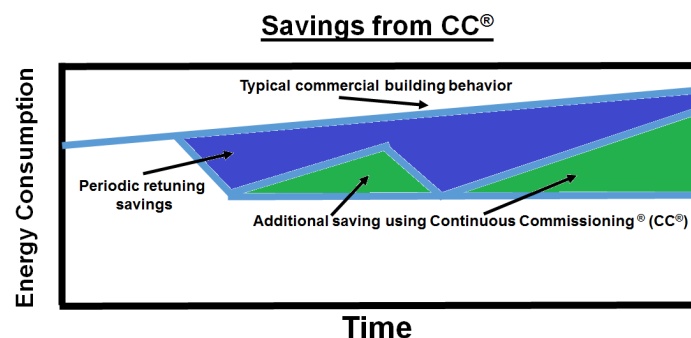


Figure 2.7: Achievable savings from Energy Systems Laboratory's Continuous Commissioning process [28]

By shifting from a labour based process to one that is information based substantial savings can be realised, not only in the cost of the commissioning process, but also in building operational cost. Results can be verified and long term effects continuously monitored. The data that is produced through this process can also help to prove the return on the investment made by owners.

2.4.2.3 Preventative maintenance

This term is self explanatory and should be a priority of any facility. By maintaining equipment before failures necessitates action can lengthen equipment life cycles, save a great deal of funds and prevent additional pressure on facility operational staff. However, it may not be impossible to know what equipment are strained or under-performing without the monitoring capabilities of a comprehensive BMS. Small discrepancies, an increase in power consumption, equipment trashing, hunting or cycling can easily be detected and help to diagnose an underlying problem that would otherwise only be realised

when it would already be too late. A BMS can also keep track of maintenance schedules and notify facility operators of actions needed to be taken before they become problems.

One source estimates that for every rand that is spent on preventative management, four times that is saved in reactive or postponed maintenance costs. At the same time this practice can add up to 20% to equipment life cycles. [26]. Being proactive instead of reactive in maintenance and making sure a facility operates optimally at all times also goes a long way to promote trust with building tenants.

2.5 Monitoring consumption

A final way to affect prudence with scarce resources is to create a timely awareness of the demand and consumption thereof as well as the related cost to the consumer. Existing metering solutions are often manually read by officials, and the information difficult to digest. Moreover, billing information, which serves as feedback, lags consumption by several weeks. By incorporating smart meters into a comprehensive BMS many of these challenges can be addressed by enabling electronic and real-time metering. Sub-metering of water and energy consumption also forms part of the Green Star SA requirements and can therefore contribute to the certification of a green building which is of great interest to investors.

This section investigates the use of metering technology to improve system performance and reduce consumption by creating constant awareness of consumption levels in various ways.

2.5.1 Metering Technology

Metering technology have greatly improved and evolved since the invention of water and electricity meters in the 19th century. The developed world has moved from using mostly rudimentary meters to a stage of gradual large-scale implementation of smart meters. These devices can be described as electronic metering systems that can not only continuously provide high accuracy consumption data, but can also transmit and receive data via some form of electronic communication. Smart meters can also provide other types of information about the system that it is monitoring as well as receive commands depending on its capabilities. Some meters have developed to the point where it can act as an independent control system of sorts, enabling users to gain remote access to its measured information and perform certain control functions through a user interface. This type of technology is increasingly being employed in the private sector, with only a few governments having adopted this approach.

Considerable research is being done into the successful implementation, optimal use and potential savings of smart metering systems [29] [30]. These systems can be extremely useful in large buildings with a number of complex systems. By incorporating smart meters into building management systems, monitoring and control functions can be decentralised for each system, providing specialised options for each application and reducing the processing requirements on a BMS as well as the risk of losing operational data. The market for this type of solution is saturated with a wide range of products, each with their own specialist qualities.

South Africa has lagged behind developed countries in the roll-out of smart meters. From a utility provider's perspective the only point of interest with metering is the main supply line into any building in order to bill building owners monthly for their water

and energy consumption. These meters are mostly still manually read each month by municipal staff in South Africa. This creates various problems with the consistency and quality of consumption data. Many rural areas in the country do not have any meters installed and many meters are installed on private properties or even buried underground.

For residential electricity this problem has been addressed by the use of prepaid meters, allowing users to control their own consumption by buying and pre-loading vouchers for a chosen amount of energy to be used after which the electricity supply is cut off until a new voucher has been loaded.

Another solution to the problem has come through the use of meters with AMR (Automatic Meter Reading) functionalities. This type of meter can, to a certain degree, be described as a smart meter. It eliminates the need for manual readings as consumption data is automatically logged and can be transmitted to a central point in various different ways depending on the available budget. This technology has successfully been implemented for municipal water metering in a select few areas in the country [31]. As these meters are managed and effectively owned by the government, they need to be government approved, which includes it being tamper proof and weather proof. It also needs to be relatively inexpensive in order to be considered for large scale implementation.

Within larger buildings where areas are leased out to different tenants, owners are usually interested in sub-metering of water and energy consumption per area in order to recover utility costs proportionately from each tenant. By having access to real-time consumption data, facility operators also have an improved understanding of operations. Wastage areas and breakdowns can easily be identified and system control decisions can be based on this information as described in the section above to effectively reduce consumption. As such, smart meters have had a much better implementation rate within the private sector than through the state.

Discussions in the sections below will mainly be centred around sub-metering products used in Silo 5. Precise requirements for metering products were set out in the project specification. For high cost equipment or large quantities of equipment, suppliers, through the subcontractors, had an opportunity to present their products to the client and engineers. Based on how well these products meet the project requirements as well as other factors such as cost, additional functionality and local support, products were eliminated and final products selected for use in the building.

2.5.1.1 Water

As discussed in Section 2.1.2 the integration of water metering infrastructure with the building management system was removed from the project scope of Silo 5 at a late stage. A type of AMR system was in the process of being developed for the building at the time of writing and will be implemented as part of a separate project. As a result in depth water consumption data was not available to be included in this study. Water meters used in the building are all of the volt-free pulsed output type, meaning that when these meters are combined with data loggers and a means by which to transfer data through a network it can be monitored on a BMS or export consumption data directly to third party software packages for tenant billing purposes.

Some suppliers offer a complete solution, including water meters, data logging or control devices, network devices as well software with a user interface to access meter data from. With a comprehensive sub-metering system of smart meters, building owners are not only able to determine accurate area specific consumption figures in real-time; system leaks and other problems can also easily be identified; alarm notifications can be

sent to facility operators and specific consumption data can also be shared with each tenant.

As sub-metering is a green building requirement, a total of 33 water meters are located throughout the Silo 5 building in order to accurately bill tenants for their usage. Until the AMR system is in operation, this requires the V&A to allocate staff to take manual readings at each meter on a monthly basis.

2.5.1.2 Energy

For the reporting of energy consumption in Silo 5, electrical and thermal energy are considered individually. The electrical energy relates to all electrical equipment supplied from the building. Tenant specific electricity supply is fed from dedicated distribution boards (DB's) each containing an electricity meter. Base building or landlord electrical energy is also metered and the cost is either divided between tenants or incorporated into an adjusted electricity tariff.

The meters used for this are predominantly the Schneider Electric Power Meter Series, offering basic to advanced capabilities. These meters can act as standalone devices with its own logging capabilities, displaying consumption data on its built-in LCD screen. It can also be set up to integrate with a BMS or other software via its RS-485 port, providing real-time reporting of a host of electrical variables that it measures. Different models offer varying ranges of measuring features, including among others instantaneous RMS values, energy values, power quality measurements and demand values for active, reactive and apparent power. It also features data recording of these values and other parameters such as electricity tariffs which it can apply to energy values to display the cost of the energy being used. Because of its accuracy these meters can be used to verify utility bills. The meter uses the Modbus protocol to communicate with other devices which is different from the BACnet protocol used by most BMS's, but BMS suppliers usually offer integration devices to facilitate this type of connection.

For Silo 5, only the meters located in HVAC equipment DB's are connected to the BMS. Therefore electrical energy consumption cannot be monitored in its entirety from the BMS. Other electricity meters are assumed to be manually read.

The major interest in this research lies with the monitoring of the thermal energy consumption of the HVAC equipment of the Silo 5 building. This thermal energy is provided through the pre-cooling water, chilled water and heating hot water supplied from the district cooling plant. As this plant has a decidedly high capital cost and uses large amounts of electrical and thermal energy of its own to serve the different buildings a way had to be found to accurately measure the thermal energy it is providing to each building and finally to each tenant.

Water from the district cooling plant is supplied to buildings through a closed loop system, meaning that water is circulated from the plant to the different buildings and back to the plant to be re-cooled or -heated. Therefore, if the volume flow and the difference in temperature between two points in the line are known, the power consumed or sensible heat flow between those two points can be determined through thermodynamic principles using Equation 2.5.1. The amount of energy consumed will simply follow from the integration of the measured power over time.

$$Q = \dot{m}c_p\Delta T \quad (2.5.1)$$

In order to measure the required values, a water flow meter is integrated with temperature sensors or probes. For the measuring of the building total load, in other words the difference between the inlet and outlet pipes of the Silo 5 building, the Siemens SITRANS MAG flow meter is coupled with temperature probes. The flow meter sends the measured flow and temperature values to the BMS which calculates power and energy values using the above equation.

For measurements at individual equipment such as rooftop air handling units, the Belimo Energy Valve is used. This device has its own processing unit and calculates power and energy values at the unit before relaying it to the BMS. The BMS uses the measurements and calculated values from these devices to determine the loads of the equipment and the building. The district cooling plant uses the loads to control the amount of pre-cooling, cooling or heating to supply to each building.

The Belimo Energy Valve, seen in Figure 2.8, is a unique product, developed specifically for application with air conditioning equipment. The product is not only a non-intrusive flow meter with temperature sensing, it also functions as an actuated, pressure independent, control valve. This means that the device reacts to changes in pressure and drives the valve open or closed to maintain a flow set point. The device also uses its Delta T Manager functionality to maintain a certain temperature difference between the inlet and outlet, thereby automatically adjusting the above mentioned set point. In addition to this the Energy Valve can communicate via BACnet with a BMS or users can connect to its own built-in web server with an impressive graphical user interface of its own (see Figure 2.9).



Figure 2.8: Belimo Energy Valves different size options [32]

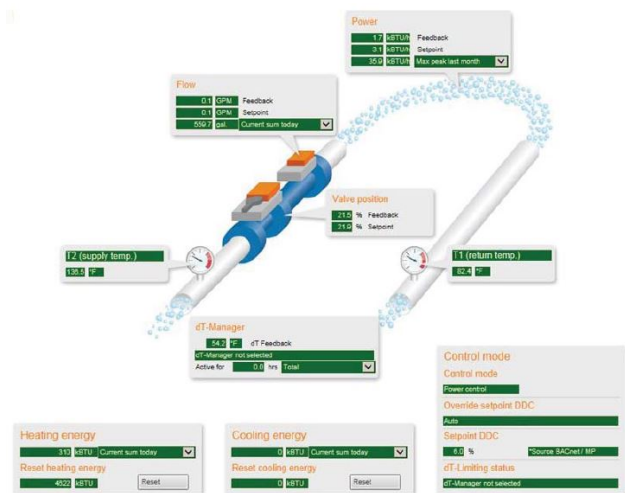


Figure 2.9: Belimo Energy Valve user interface [32]

The supplier of this product took all of the functions that are normally performed by individual devices and combined it into one very impressive product that is able to perform all of those functions better as it synchronises the different functionalities and does not need to rely on other devices. It is the definition of a smart meter, offering a whole range of added features that can all easily integrate with the BMS interface.

2.5.2 Influencing occupant behaviour

Aside from the value that access to real-time consumption data has for facility operators, financial staff and management, numerous studies have also investigated the value of using this information to influence occupant behaviour.

A nationwide change in behaviour is desperately required in all industries regarding the use of water. Despite the recent water shortages and the troubling state of water reserves in South Africa, water is still lavishly being used and vastly underpaid for. Bulk water prices for user associations and water authorities vary by extreme margins across the country and do not reflect the full cost of the infrastructure, maintenance, treatment and catchment care required to consistently supply water to all areas [3]. Reducing water consumption by making use of recycled water and rain water harvesting among other methods is seen as more of a moral obligation than a necessity. The same can also be said of the use of electricity primarily being generated through fossil fuels.

The only effective way to bring about change is by starting with the individual. Building owners can do their part to change occupant behaviour by introducing incentives for demand management of utilities and providing real-time consumption data to help facilitate this.

2.5.2.1 Continuous monitoring

In modern office buildings and specifically green buildings, most services are automated. In Silo 5, for example, HVAC systems are automated with no control left to the occupant, lighting systems operate on schedules and occupancy sensing and bathroom taps, toilets and urinals are sensory activated. The argument can thus be made that occupants have very little influence over their energy and water consumption. There are, however, higher level decisions that can be made that have substantial effects on consumption.

One study has investigated ways of analysing and quantifying the impact of occupant behaviour on a building's energy consumption. It found that, for HVAC purposes, where occupant behaviour strives toward thermal comfort it generally resulted in higher energy consumption [33]. While human thermal comfort may be a subjective matter, studies have also shown that humans are generally comfortable in an environment between 22 and 26°C, not considering the effect of humidity [25]. As people dress according to outdoor conditions, it should not be a problem to work in an office where temperature set points are closer to outdoor conditions, for example 26°C in summer and 22°C in winter. However, generally, this is not the case as human behaviour strive toward cooler indoor temperatures during summer and warmer temperatures in winter.

If human behaviour could be influenced to a point where the above type of thermal environment could be accepted, even a one degree shift in the air conditioning set point towards outdoor conditions would create substantial energy savings in a large building. By providing continuous feedback to occupants regarding their consumption, research have shown that this type of behaviour can be positively effected [34].

A good example of the value of consumption data in bringing about behavioural change can be found in some forms of residential water consumption. In residential complexes with multiple sectional title units or apartments, water sub-metering of each home is often not part of the initial installation. In these cases the monthly water bill for the entire complex is divided between all the apartments. Opulent water consumption behaviour by a handful of residents may drive this bill up considerably as a stepped tariff system applies to water prices of residential properties. This has forced body corporate trustees in

many complexes to opt for water sub-meters in answer to indignant resident complaints. In most, if not all, of these cases, the installation of sub-meters is immediately followed by a decline in the overall water bill as each resident is now held financially responsible for their own consumption. One source found a reduction in consumption of between 15 and 35% by implementing sub-metering [35]. The latest type of sub-meters used at these residences also allow users to monitor their consumption in real-time from within their properties similar to prepaid electricity meters which have the same effect.

Comprehensive consumption data provides a means to introduce a form of accountability with the consumption of resources. By setting a BMS up for timely reporting of consumption data to occupants, department heads or management and building owners, awareness can be created and maintained. This will hold each group accountable for their subordinates or tenants. Optimisation gains or savings can be promoted by recognising operational improvements by facilities staff or behavioural changes by occupants. Through this feedback system, occupants can also be educated on the consequences, financial and otherwise, of their actions and decisions. Even though many choices have been eliminated by automated systems, continuous monitoring and reporting can help to reassign partial responsibility for consumption back to occupants.

2.5.2.2 Consumer billing

By using similar methods to those used for cost based optimisation, explained in Section 2.4.2, a detailed cost allocation can be generated for the energy used per tenant, per floor, per department and even per work space. In depth consumption data and space planning information must be available for relevant and useful cost allocations to be made. In the ideal situation data can be used to associate actions with consumption. This data, provided by metering technology such as the Belimo Energy Valve and processed by BMS software such as the Metasys Energy Dashboard, can also be used for tenant billing purposes. Rather than waiting for the monthly utility bill, tenants can be provided with weekly or biweekly month to date bills to effectively keep track of consumption expenses.

By being able to assign costs to actual consumers instead of using averaged square meter rates, building owners can accurately bill high consumption tenants rather than having lower consumption tenants subsidise their costs [26]. Where tenants have multiple and / or wildly varying departments, costs can also be allocated to each department, further fostering an attitude of accountability within a company that would potentially lead to a positive change in behaviour regarding the responsible use of resources.

2.6 Case study: Vodacom Techno Centre

The Vodacom Techno Centre (see Figure 2.10) in Bellville, South Africa is located about 25km from Silo 5. The building provides an interesting case study for comparison with Silo 5, particularly for HVAC services.

The building consists of seven floors and two basement levels. The basement levels, the majority of the ground floor and a significant part of floors one and two are used for parking. A large part of the second floor and the majority of the third floor are used for data centres, housing servers for Vodacom, a mobile service provider company. The rest of the second and third floor as well as floors four through six are used as office space for Vodacom staff.



Figure 2.10: Vodacom Techno Centre [36]

The Techno Centre is an older building, completed in multiple phases around 1999. As such, it utilises more conventional HVAC systems, including four water-cooled chillers with cooling towers and five air cooled chillers. Offices are served by multiple constant air volume (CAV), chilled water air handling units (AHU's) on each floor compared to the centralised, variable air volume (VAV), chilled water AHU's used at Silo 5 [37].

Data centres have different HVAC requirements than offices. They require less ventilation, if any, but have extremely high cooling requirements in order to keep servers running at their optimum efficiency and to prevent them from overheating. As the failure of any of the servers may cause an interruption in service delivery or a loss of data, measures are put into place to prevent this at all costs. All servers and their AC equipment are connected to backup generators in case of power outages and for each AC unit that is required, an identical backup unit is also installed in case of equipment failure. Data centres, from an HVAC perspective, therefore contribute to increased capital and running costs for buildings.

The Techno Centre also makes use of the Johnson Controls Metasys BMS in a similar set-up to that of Silo 5. The Metasys software that is used is a slightly older version. The BMS graphical views for the building's first and third floors can be seen in Figures 2.11 and 2.12 respectively.

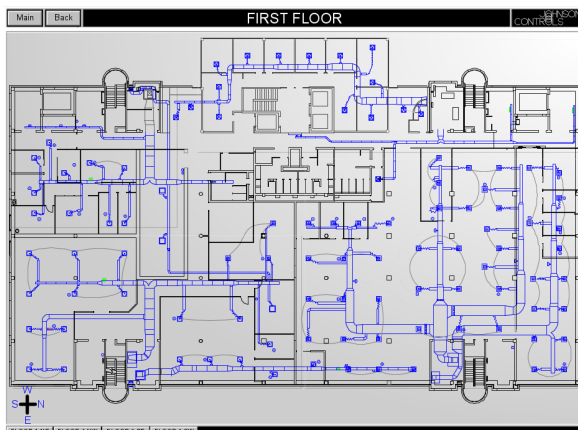


Figure 2.11: Vodacom Techno Centre: Level 1 BMS graphics view [37]

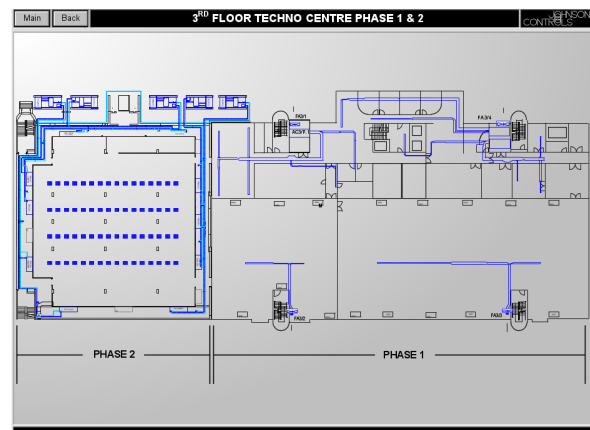


Figure 2.12: Vodacom Techno Centre: Level 3 BMS graphics view [37]

2.6.1 Building optimisation

The Vodacom Techno Centre is an excellent example for demonstrating the potential of using a BMS to its full extent. Vodacom looked into ways of reducing building running costs, specifically electricity costs, by identifying high consumption areas and investigating different strategies to reduce consumption in these areas.

The data centres stand out as a clear culprit as they consume a large amount of energy themselves, but the possible savings that can be achieved with the latest server technology is relatively low. The real opportunity lied in the HVAC services of the data centres, as it accounts for roughly 65% of the building's total HVAC costs.

Vodacom decided to focus on the Phase 2 data centre on level three, which can be seen in Figure 2.12. The data centre AC systems at that time was evaluated and compared to international best practices to identify alternative options [37]. The initial layout of the data centre and its AC units was simple with servers standing in a large open room and air conditioning provided to the entire room. Also, due to the importance of the information being stored here and the services being provided by these servers, the company initially had no problem with running eight of the AC units, in full load conditions all of the time, leaving only two units on standby.

To reduce energy being wasted by supplying air conditioning to the whole room, the company implemented cold aisle containment. With this method, air conditioned air is supplied into a sealed off cold aisle between two rows of server racks, with the front of the racks facing the aisle (see Figure 2.13). The air is forced through strategically placed openings in the server rack casings and cools the internal electrical equipment down. The now hot air enters the separated hot aisle at the back of the server racks from where it is ventilated back to the AC units to be cooled down again (see Figure 2.14). By separating the cold and hot air in this way and only supplying conditioned air to the required areas, the cooling load in the data centre is decreased significantly.

The other changes that were incorporated included the introduction of AC unit schedules and temperature management, both implemented through the BMS. The BMS, that controls the running of the AC units, uses weekly schedules to ensure all units run for equal amounts of time and ensures that only the necessary amount of AC units are running at any point in time. This reduces energy consumption, reduces the maintenance requirements and increases the life cycle of AC units. For temperature management, the BMS constantly monitors the temperature in the cold aisle and compares it to a user defined set point. If the temperature exceeds the room set point the BMS can choose to either turn on additional AC units or increase the cooling provided by the already running units by decreasing their own temperature set points. Once the cold aisle temperature has stabilised below the set point, units can be turned off again or their set points restored to default settings. By enabling the BMS to effectively manage temperatures, facility managers were also able to increase cold aisle temperatures to higher, but still acceptable levels to reduce the air conditioning load while still allowing servers to operate efficiently and prevent them from overheating.

The Phase 2 data centre upgrades or changes were implented in Febuary, 2014 and cost the company roughly one million rand. The BMS was used to closely monitor the effect of the changes on the energy consumption figures. The results can be seen in Figure 2.15. The data centre AC energy consumption cannot be monitored seperately as regular changes to servers has an effect on the AC load. Therefore the data centre equipment energy consumption is compared to the AC equipment energy consumption in Figure 2.15. A sharp decrease in AC energy consumption can be seen directly after the changes were



Figure 2.13: Data centre contained cold aisle [37]



Figure 2.14: Data centre hot aisle [37]

implemented. Before the changes $0.88kW$ of power was used for the air conditioning of every $1kW$ used by data centre equipment. This ratio was improved to $0.55kW$ for every $1kW$ directly after the changes. This improvement translated into monetary savings in energy costs of, on average, $R66,000$ per month. The payback period for the upgrade costs was only 14 months [37].

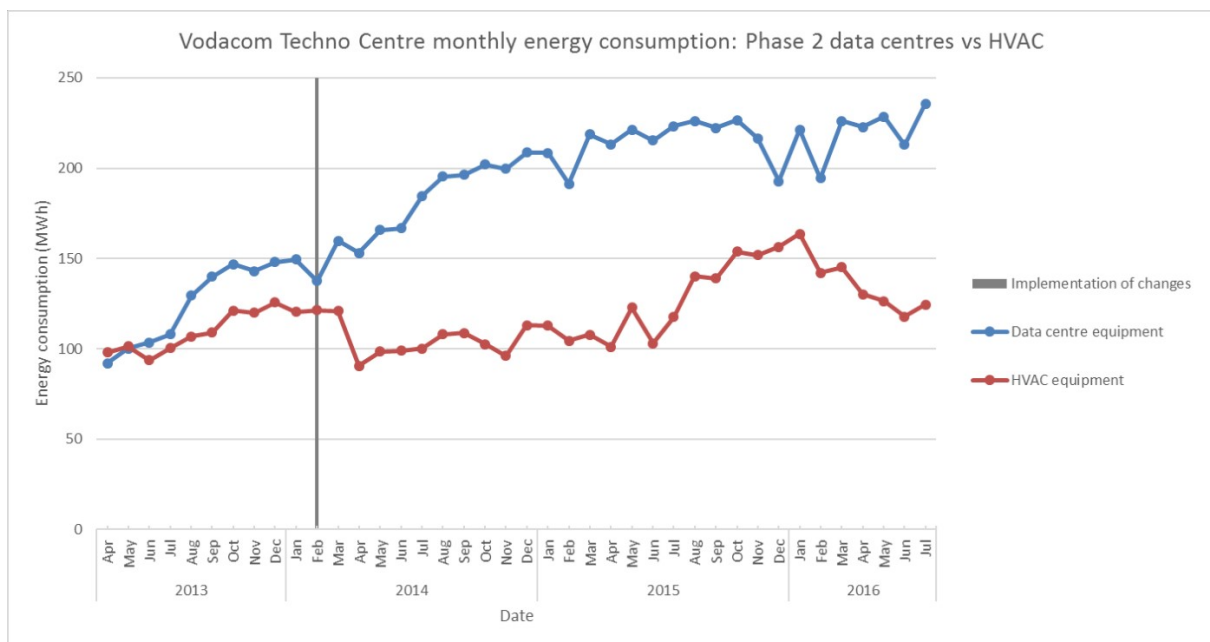


Figure 2.15: Monthly energy consumption of the Phase 2 data centres and their HVAC equipment

None of this would have been possible without a BMS to identify the problem areas in the first place and to effectively and instantaneously monitor the effects of any changes made to the system. The company also employs full-time facility managers, trained in the use of the Metasys software. These facility managers are capable of accurately interpreting information and making informed changes to systems, that they have an in depth knowledge of, through the BMS. The Techno Centre personnel make full use of the

Metasys software, using extra features such as the Logic Connector Tool, to create and implement their own control algorithms on building systems.

2.7 Challenges

The design of a resource efficient building is met with a number of challenges and limitations. It is vital to keep track of these limitations to manage client expectations and to be proactive in designing around these challenges.

Any building project aiming to achieve green building or GSSA certification will require significant deviations from conventional building projects. For the most part these deviations will contribute toward improved energy and water efficiency. However, excessive design goals need to be met in order to satisfy green building occupant comfort requirements in terms of HVAC services among others. While the issue of occupant comfort is an important one to promote employee health and productivity, the requirements aim to improve on already high national building regulation requirements.

On other issues such as water consumption, no real updates have been made to effectively combat excessive water consumption after serious water shortages have become more prevalent in South Africa. The lack of reform or failure to adapt to dwindling local resources in the GSSA rating system, specifically in the water category, suggests that the rating structure can be broadened with new ideas such as introducing water saving campaigns and interacting with the local community to raise awareness.

Points might be awarded for these types of initiatives under some of the existing credits, but the weighting of those points is still too low to motivate building owners and developers to make saving water a priority.

Silo 5 is a case-and-point example of this. There are electronic water meters installed in the building, capable of being connected to a control system to relay all readings to a central point, eliminating the need for someone to take monthly physical readings from each water meter for billing purposes. Readings would be available in real-time and can assist in leak or problem detection. The initial project scope also included the connection of such a system to monitors in the building reception to inform occupants of their daily, weekly or monthly usage. When the cost of this system was considered against the benefits, including the GSSA points on offer, it was decided to exclude this system from the project, to be reassessed at a later stage.

GSSA requirements also expects a certified green consultant to form part of the project team in order to manage the application process and to guide the rest of the consulting team to meet the green building goals in their designs. The green consultant expects reports from consultants for every GSSA credit that is targeted through their design, contractor procedures and supplier products need to be vetted for its environmental effects and additional GSSA clarification meetings need to be attended. All of these additional requirements demand extra time and therefore costs from consultants for a project where their tender prices still need to remain competitive. These additional tasks also need to be completed within a generally restrictive project schedule.

Building management systems greatly simplify and improve the monitoring and control of building services. The available technology is nevertheless still plagued by limitations in the development of software. System navigation is often uncomfortable and data manipulation options are limited. Suppliers specialising in controller hardware do not always have the capacity or the specialist skills required to develop and continually improve a functional and user friendly software package. Moreover with suppliers mostly refraining

from sharing their software with each other and the public, progress in this field is lagging behind.

The benefits of a comprehensive BMS are also not always well known building owners. When budget problems arise during a project and costs need to be cut, seemingly redundant BMS features are quick to be removed from the project scope. By doing this, as in Silo 5, a BMS ends up being limited only to HVAC services.

The use of alternative sources, specifically for energy, have become increasingly popular among companies that can afford the high capital costs of such an investment. The movement has seemingly been driven by public image and not by the urgency of resource shortages in the country. These resources are therefore not yet seen as sustainable solutions due to its high cost and general problems with scalability. Seawater district cooling as an alternative overcomes these obstacles, but is only feasible for new building projects in areas located near large water masses and requires complex controls.

In order to effectively adopt optimisation practices building owners require skilled facility managers that are invested in the optimal operation of their buildings. These type of staff members are unfortunately in short supply in the industry.

2.8 Conclusion

Developing and operating a truly energy efficient building involves incorporating a number of different facets. Most of these facets need to be carefully considered during the conception stage of a building project in order to construct such a building affordably.

Pursuing green building certification introduces numerous challenges, but also drives energy efficiency as one of its main objectives. The GBCSA is in a unique position to influence an entire industry and they are doing that in a significant manner already. However, they will have to reconsider their standing on the most important, life-giving resource that we have as soon as possible.

Modern building management systems provide an invaluable tool for the monitoring and control of all building systems from a central point. When utilised to its full potential, a BMS can produce substantial savings over and above standard optimisation practices.

Seawater district cooling, as an alternative energy source, provides an innovative and affordable solution that generates near free cooling to buildings, but is limited by when and where it can be implemented. Even though significant advances have been made in the optimisation of building systems, more opportunities exist to take control of a building's resource consumption through access to accurate and complete data. Real-time monitoring and reporting of consumption data also provides saving opportunities. Savings practices seem to be focussed primarily on the energy sector, overshadowing the dire need for reform within the water sector.

Finally, the Vodacom Techno Centre is a good example and proof that by correctly understanding a building's systems and monitoring it closely, savings can and are being achieved in the Cape Town area.

Chapter 3

Methodology

For this research the recently completed Silo 5 building, briefly introduced in the introductory chapter (see Section 1.3), was used as a case study. By closely observing and being part of the building project from its conception stage, through design and construction stages to the point of building occupation and all systems operating, provides valuable insight into the driving forces of this industry and where there are practical opportunities to reduce resource usage and promote methods of saving even more.

This chapter builds on the work presented in Chapter 2 and uses this work to critically evaluate Silo 5. The systems that serve this building are described to gain an understanding of where savings are or can be achieved and how these systems are monitored. Potential energy saving practices of this building are discussed and finally, methods for quantifying potential savings are also described.

As stated before the initial project scope included the monitoring and control of the building's domestic water system through the BMS, but had to be excluded due to financial constraints. The domestic water system is therefore not discussed any further in this chapter or the next.

3.1 System description

The three systems that are integral to this research, as described in Section 1.3, are the district cooling system, the central air conditioning system and the building management system. The operation and control of these systems are described over and above what has been discussed in Chapter 2.

3.1.1 District cooling system

The Silo district is served by a 6MW centralised or district cooling system which supplies heating hot water (HHW), chilled water (CHW) and pre-cooling water (PCW) mainly for the purpose of providing air conditioning (AC) as well as domestic hot water to the buildings in the Silo district.

The seawater district cooling plant is a result of one of the V&A's main goals of sustainability. Seawater is pumped from the harbour to the plant and is used to generate PCW directly through heat exchangers. The PCW is supplied to most of the buildings and provides a substantial amount of "free" cooling in terms of its required energy input. Seawater is also used as condenser water for chillers, providing heat rejection and heat recovery for the production of CHW and HHW respectively. This eliminates the need

for water hungry cooling towers that produce condenser water. It also means that PCW, CHW and HHW are generated at significantly higher than normal efficiencies. After the seawater has been circulated through the plant, it is delivered back into the ocean at a different location in the harbour.

The chillers, heat exchangers and primary pumps are located in one plantroom spread over two floors located in the basement parking area (see Figures 3.2, 3.3 and 3.4). Seawater pumps are located within the structure of a pier at the seawater intake point (see Figure 3.1). All of this equipment is automated and controlled by the district cooling building management system (BMS). By opting for this centralised system and controlling the system to always operate at the highest possible efficiency, the V&A can achieve considerable energy savings compared to using the decentralised alternative. The benefits and challenges of seawater district cooling systems are discussed in Section 2.3.1.



Figure 3.1: District cooling seawater pumps at the jetty



Figure 3.2: District cooling plant chillers and pumps

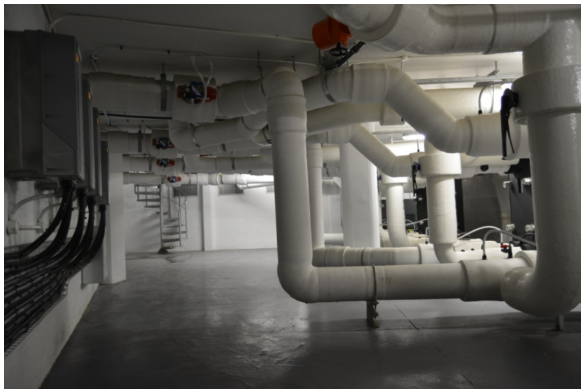


Figure 3.3: District cooling plantroom piping and VSD's



Figure 3.4: District cooling plant heat exchangers

3.1.1.1 System control

The district cooling BMS monitors and controls the water flow to each building. It assesses the real-time demand of the buildings through signals from the control valves at each building as well as differential pressure readings in various locations in the piping network. Pump speeds and chiller set points are adjusted accordingly. Not all chillers

operate all of the time, chillers are activated and deactivated as the demand in the system changes.

The control logic for a plant of this size is extremely complex. Multiple control valves, seawater pumps, chiller pumps and the chillers themselves all need to be controlled in the right order and to the right degree in order to effectively provide in the demand of the buildings connected to it. This also includes all the data points within the plant and at all the buildings that it needs to monitor in order to accurately determine the demand.

3.1.2 Silo 5 central air conditioning system

All five of the upper floors of the Silo 5 building are air conditioned by air handling units (AHUs) located in four plantrooms on the roof level (see Figure 3.5). The building is naturally divided into a northern and southern side by an atrium or street passing through the middle.



Figure 3.5: Silo 5 rooftop plantrooms

For air conditioning purposes the building is further subdivided into two internal (Internal North and Internal South) and five external or façade zones (North East 1, North East 2, South East, West 1 and West 2). All of these thermal zones are served by their own dedicated AHUs (see Figure 3.6). The Internal North, Internal South and South East zones each have two dedicated and identical AHUs due to their size.

Therefore, in total, there are 10 AHU's in the four rooftop plantrooms. These AHU's use the pre-cooling, chilled and heating hot water supplied by the district cooling system to condition the air that is supplied into the building according to its demand. Ground floor reception and retail areas are served by smaller fan coil units due to the load requirements and schedule varying from that of the upper floor office areas. These smaller units are also supplied by the district cooling system.

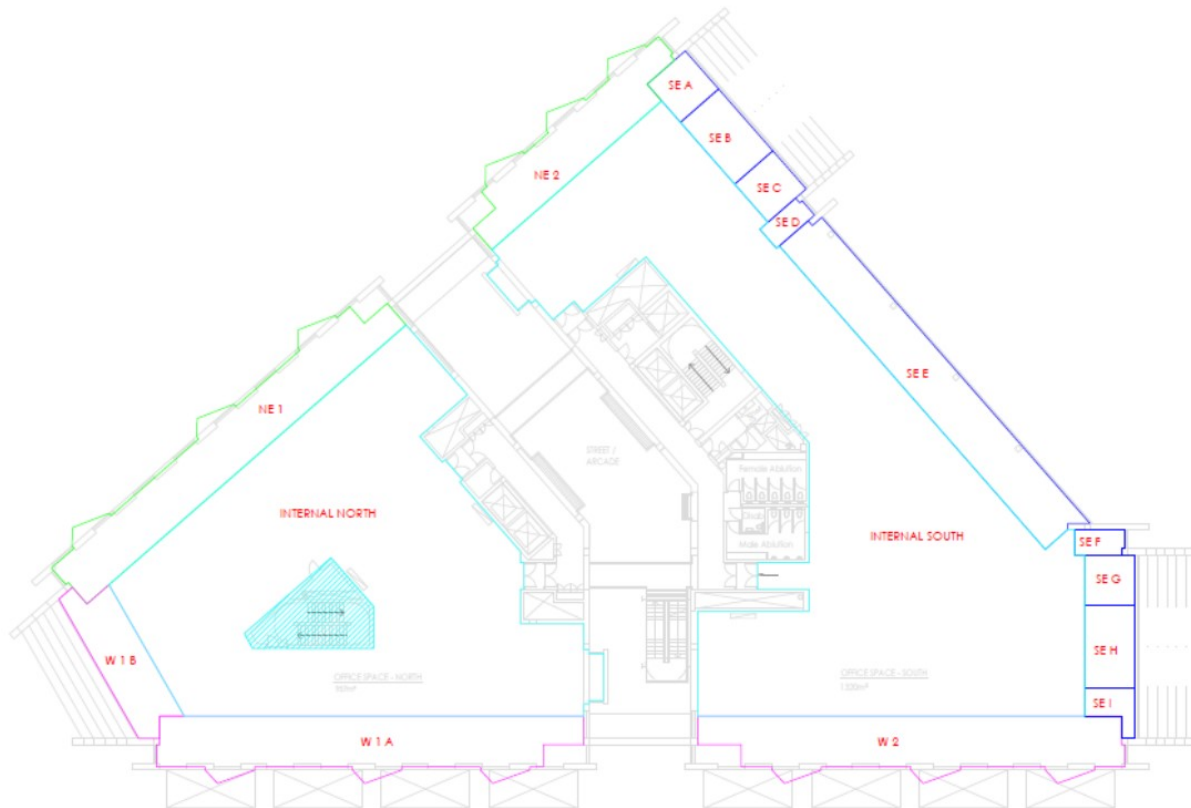


Figure 3.6: Silo 5 typical office floor thermal zone layout

3.1.2.1 System design

Each of the AC systems are unique in a variety of ways, but the design processes for all of them are the same. It starts by dividing each floor into thermal zones as seen in Figure 3.6 based on its location as stated in the above section. External or façade zones are the areas where the effects of the outdoor conditions have a reasonable influence on the air conditioning requirements of those areas due to the thermal conductivity of the building envelope. For internal zones these effects are assumed to be negligible.

The thermal zones are then further sub-divided into spaces based on tenant floor layouts. Each room is considered as a separate space in order to determine the AC load and airflow requirements of each individual room.

Different types of rooms may have different occupancy types according to the South African National Standards (SANS). SANS 10400 Part O contains the national building regulations for all lighting and ventilation systems [12]. This standard categorises different occupancy types for different types of buildings in order to set ventilation or fresh air requirements for each type of area. Two rate requirements are given, one based on the size of the room and the other according to the number of people that normally occupy the room. The larger amount is to be used.

The fresh air requirement for each room in Silo 5 is further raised by the GSSA ventilation credit (IEQ-1) that the building aims to achieve (see Section 2.1.2). This credit asks for a 150% improvement on the SANS requirements in order to achieve the maximum points for this credit.

Once all of the information of each space is available, the building heat load can be calculated. For this purpose, certified software such as Carrier's Hourly Analysis Program (HAP) is used.

Each space is created and attributed to a specific AC system. A comprehensive set of variables are considered for each space. User inputs include among others floor area, room height, minimum fresh air requirements, power requirements of (or heat generated by) lighting and other electrical equipment in the room, amount of people, type of work done in the room (level of activity) as well as the properties of outer walls, windows, floor and ceiling / roof of the room (area, facing direction, thermal properties, outer shading devices, etc.).

Once all of the spaces have been defined in this way the AC systems are configured. Once again a multitude of settings are adjustable for each AC system. The type of system is defined by selecting the different types of equipment to be used in the system. The design specifications for the system are then set, such as temperature set points, ranges for heating and cooling, entering and leaving water temperatures in coils, equipment schedules, weather conditions, safety factors and more.

The different systems can also be added to a plant in order to get an overview of the entire building's load. Once all this information has been entered into the software, detailed heat load reports can be generated for each system. A host of information can be included in these reports.

The Air System Sizing Summary gives an overview of the system, including, for chilled water AHUs, coil sizing data (total and sensible cooling / heating load, water flow, on- and off-coil air conditions at peak load, time of peak load, Watt per square meter, etc.), airflow requirements (supply, return and outdoor air) and other sizing calculation information.

The Zone Sizing Summary gives a breakdown of the loads and airflow requirements of each zone and the spaces within that zone that is served by the system. It includes, for each space, its peak load, time of the load (based on the average location weather conditions), airflow and more. This report is also used for the diffuser selections in each room and essentially determines the sizing of the duct network as well.

Another report, the Air System Design Load Summary, lists the different influencing factors of that system and attributes a sensible and / or latent cooling / heating load to each factor, clearly indicating what effect each factor has on the system. This can be very useful in preliminary design stages to determine what design changes can be made in order to achieve significant savings.

A number of other reports are also available, essentially providing an in depth model of the operation of a building's air conditioning systems. This model is therefore the foundation from where all the Silo 5 AC systems were sized and selected.

After the airflow requirements of all rooms are known and the diffusers have been selected, the ducting network from the rooftop AHUs to each room can be designed. When sizing duct work there are at least three variables to keep track of, that is airflow, air velocity and pressure. The total air pressure in a ducting system consists of a velocity and a static component (see Equation 3.1.1), which are, respectively, the results of kinetic and potential energy. Velocity pressure is therefore a function of the air velocity in a duct (see Equation 3.1.2).

$$P_T = P_V + P_S \quad (3.1.1)$$

$$P_V = \rho \frac{v^2}{2} \quad (3.1.2)$$

There are different methods for the sizing of duct work, including by velocity, equal friction or static regain. The static regain method is the most complex method, but tends to deliver the best results. It aims to achieve uniform static pressures at all outlets / diffusers by reducing duct velocities over the length of the duct network. This allows velocity pressure to be converted into static pressure which counteracts friction losses in subsequent ducting sections [38]. This method requires very little if any balancing of the system. The static regain method was effectively used to size all of the Silo 5 ducting systems.

3.1.2.2 Air distribution strategy

A typical schematic of the roof level AHUs and their ducting systems is shown in Figure 3.7. Fresh air or outside air is drawn into the AHU mixing box or plenum through an opening with a motorised damper (item 1 in the schematic) and then through the primary filters (item 4) after which it passes over the coils (items 5 and 6) to either be heated or cooled. The conditioned air passes through the supply fan (item 11) into the main shaft ducting and branches off onto each floor. There is a motorised fire damper (item 16) and pressure control damper (item 14) as the branch duct exits the main shaft on each floor. Air is distributed through the ducting to each diffuser (item 15) and into the different rooms.

All rooms are designed with a way for the excess air to escape and travel back to a return air grille (shown with “RA” designation) which is also connected to a return air ducting system, also with motorised fire dampers on each floor before it enters the main shaft. The air is drawn back to the roof level plantroom through the return air fan (item 13). After the fan the required amount of return air is directed back into the AHU plenum through an opening with its own motorised damper (item 2), to be mixed with the incoming fresh air. The remaining amount of relief air is extracted out of the system through another motorised damper (item 3) and vertical discharge unit (VDU).

3.1.2.3 Air conditioning strategy

For the rooftop AHUs the cooling or heating demand is determined by the average space temperature of the areas that it serves. If this average is less than the set point temperature of an AHU then heating is required, if it is higher than the set point then cooling is required.

The amount of cooling or heating that is to be transferred to the air is regulated by the amount of water that runs through the coils which is controlled by the control valves on each set of pipes (see Figure 3.8 as well as items 8 through 10 in Figure 3.7). The amount of cooling or heating is also affected by other variables, including the temperature of the incoming water, the size and geometry of the coil and the face velocity of the air onto the coil. However, for this process these variables are kept more or less constant.

The coil closest to the supply fan is a shared cooling and heating coil, meaning that when cooling is required a three-way valve (item 17) opens the cooling line for chilled water to flow through the coil. Once the demand changes to heating the three-way valve closes the cooling line and opens the heating line for heating hot water to flow through the coil.

The control valve mentioned above forms part of a multi-functional device that is used for this project, called the Belimo Energy Valve (see Section 2.5.1.2 and Figure 3.8). The device regulates the flow independent of the pressure in the pipe. It also measures the

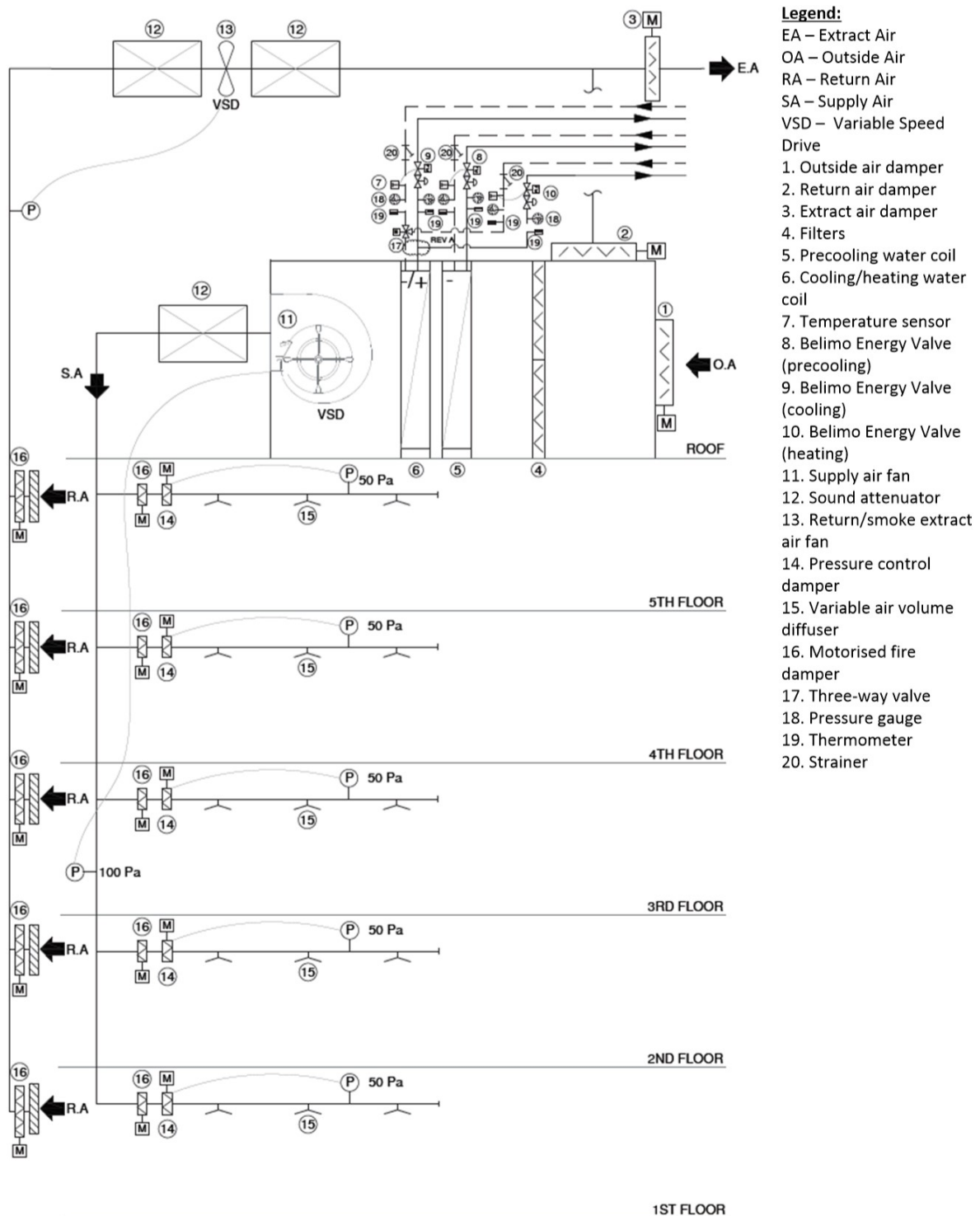


Figure 3.7: Air distribution schematic

water flow and temperature difference between the incoming and outgoing water pipes. It uses these measurements to calculate the heat flow or power being transferred from the coil to the air through Equation 2.5.1. By monitoring these measurements over time it also provides the cumulative energy that is consumed. Its built-in software also allows it to manage the temperature difference over the coil by controlling the water flow through it. These valves are all connected to the BMS via BACnet over IP communication.



Figure 3.8: Belimo Energy Valves installed on the return side of PCW, CHW and HHW pipes at one of the Silo 5 rooftop AHUs

3.1.3 Building management system

In Section 2.2 building management systems are discussed in depth. The high level functioning and features of the Johnson Controls Metasys BMS used at Silo 5 is also explained. For Silo 5 the BMS is only connected to the HVAC system and certain parts of the fire protection system that ties in with the HVAC equipment. Some of the other systems in the building have their own control systems or software, but none of them operate as a BMS.

3.1.3.1 System configuration

Figure 3.9 shows a simplified representation of the Silo 5 BMS configuration. For this project the BMS had to tie in with the V&A's existing BMS network and server and therefore also had to comply with its standards and regulations. As the company uses the Metasys system at all of their buildings a considerable part of the configuration was predetermined.

The BMS for this project uses the V&A's existing Metasys server (extended application and data server or ADX) as its site director to maintain all site information, provide a uniform point of entry for users, provide time synchronisation and manages all traffic (see item 1 in Figure 3.9). BACnet/IP is used as the main communications protocol, but BACnet MS/TP and Modbus protocols are also used by some devices.

A site workstation (laptop) is installed in the basement pumproom which connects directly onto the Silo 5 BMS via an Ethernet cable (see item 2 in Figure 3.9). From here facility staff can access the system via the Site Management Portal (SMP) UI even when the network to the server is down as the Silo 5 network infrastructure is on essential power. Power is therefore supplied from a generator in case of a power outage. All other users can access the BMS using their personal login details from any computer with internet connectivity and that has the Metasys UI software installed on their system (see item 3 in Figure 3.9).

Most of the HVAC equipment is controlled and automated by field equipment controllers (FEC's) or advanced application field equipment controllers (FAC's) which are

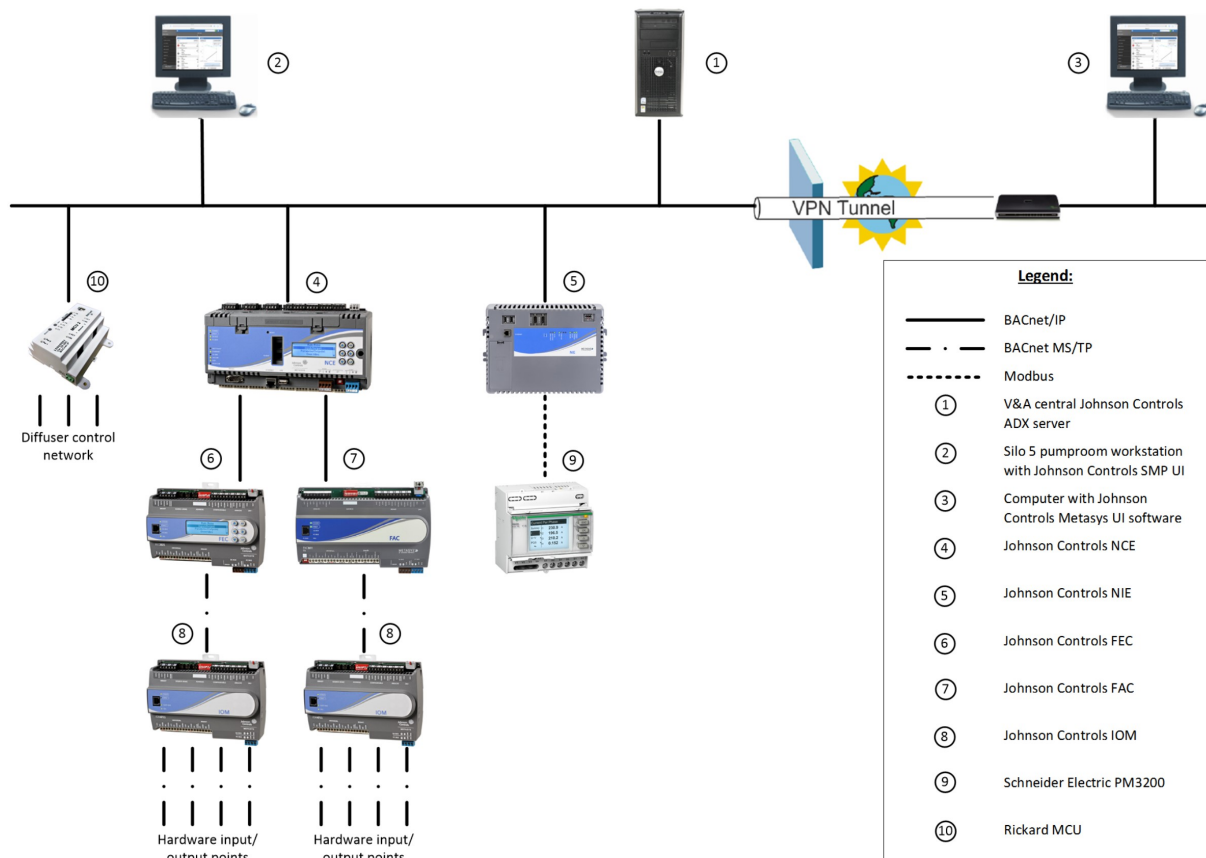


Figure 3.9: BMS configuration

located in BMS distribution boards (DB's) in the plantrooms at the equipment (see items 6 and 7 in Figure 3.9). These devices are programmed with the control logic for all of the equipment. This configuration and the location of these devices also ensure that HVAC equipment can continue to operate normally even in the event of the network crashing. Although the Belimo Energy Valves valves are commissioned to operate independently, they are monitored by the BMS through the FAC's. The amount of equipment that can be connected to these devices are increased by using input/output modules (IOM's, see item 8 in Figure 3.9).

The FEC's and FAC's are connected to and managed by network control engines (NCE's). The NCE provides connection to the IP network and manages all information between the server and the relevant FEC's and FAC's (see item 4 in Figure 3.9). Some devices like the Schneider power meters used in this project make use of other communications protocols such as Modbus (see item 9 in Figure 3.9). In these cases network integration engines (NIE's) are used to provide connectivity to the BACnet/IP network (see item 5 in Figure 3.9).

The Rickard air diffusion products on the other hand use BACnet/IP, but have their own control system (see Section 3.1.3.3) and can therefore connect directly to the IP network as third party devices (see item 10 in Figure 3.9).

All of the above combines into the system configuration seen in Figure 3.9 with multiple devices of each type connected to the system as each data or control point of all HVAC equipment needs its own wired connection. Alternatively, wireless adaptors can also be added for equipment in hard to reach locations, in which case controller connections to the BMS network would be wireless [18] [19].

3.1.3.2 Variable air volume

The AC systems for Silo 5 are variable air volume (VAV) systems, which means the amount of air supplied by AHUs is continuously adjusted based on building demand. The building's demand is determined by VAV diffusers in air conditioned areas that open or close to supply more or less air based on the temperature of the room. By comparison, constant air volume (CAV) systems are significantly less complex as diffusers and therefore also AHUs are set to supply a constant amount of air at all times.

The VAV aspect further assists the centralised system goal of increasing efficiency by only supplying the amount of air and cooling / heating that is required at any time. VAV is also a characteristic of an AC system, not the BMS, but is mentioned here as it determines how AC systems are controlled by the BMS.

3.1.3.3 Diffuser control

For this project Rickard Air Diffusion was the supplier of all diffusers and their accessories. This proved to be beneficial for the controlling of the AC system as Rickard supplies a comprehensive package including the hardware and software required for diffuser control. Their diffuser control system is also set up to interface with the BMS. Diffuser controls can therefore be monitored and controlled to a certain extent via the BMS.

A schematic of the Rickard Multi-loop Modular (MLM) VAV diffuser control system is shown in Figure 3.10. All diffusers are powered by and communicate through a power supply unit (PSU). Each PSU can be connected to up to 15 diffusers. Each PSU must be connected to a master communications unit (MCU) from where master and slave diffusers can be activated, monitored and controlled. Up to four PSU's can be connected to a single MCU. Each MCU is also connected to the BMS.

Each room or thermal zone is supplied by at least one master diffuser. Depending on the size of the area there could also be slave diffusers. Slave diffusers are set up to mimic its linked master diffuser. Master diffusers are equipped with remote temperature sensors and are configured with user defined temperature set points. Based on the difference between the measured temperature in a room and the set point temperature, the master diffuser and its slave diffusers are driven to either open or close to supply more or less air and thereby more or less cooling [39].

With the way that this system is set up in Silo 5, the master diffusers cannot determine when the system is in heating mode. Therefore, whenever actual temperatures are below set point temperatures and heating is required, the diffusers will close to its minimum point even when the system is in heating mode. It will continue to supply heated air to areas in this way until it has reached its set point temperature. This will cause heating to take longer than what is required which does not benefit the system's efficiency and is a current setback of this system.

Also, not being able to monitor diffuser plate positions from the BMS complicates the fault finding process when tenant complaints are received for specific areas. It forces facility operations staff to physically inspect problem areas which lengthens the process and is not preferred by tenants.

The diffuser can provide this data, but it must be incorporated on the BMS by the contractor which can be a labour-intensive programming task for an entire building. A more preferred alternative would be to have access to airflow measurements at master diffusers instead of plate positions, but this would require additional costly equipment for each diffuser.

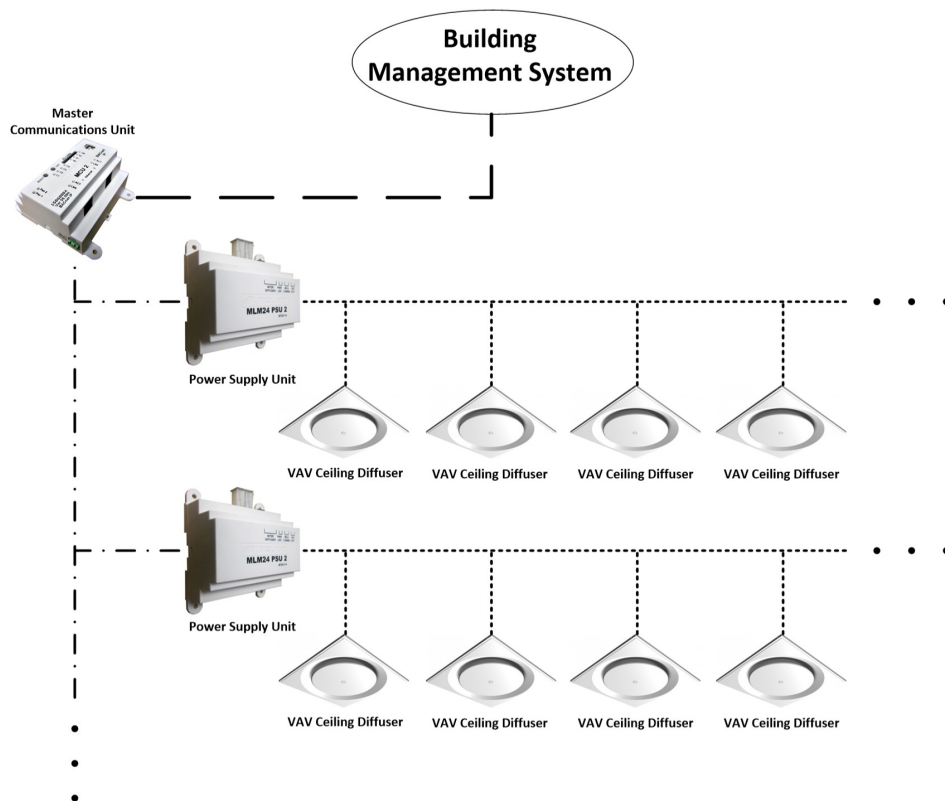


Figure 3.10: Rickard MLM VAV Diffuser controls

3.1.3.4 Supply air control

Due to the diffusers constantly reacting to the changing demand in each room and area, the airflow and pressure in the ducting system will change with it. However, for the diffusers to function properly, the air pressure needs to remain within a certain range. To manage these changes and to keep the system pressure balanced, the pressure control damper (PCD) on each floor (shown as item 14 in Figure 3.7) constantly measures the pressure at that point. When more diffusers start to close, the airflow is choked and pressure at the damper starts to build up. The damper will react by closing partly to choke the airflow from the supply fan, bringing the pressure back down on its downstream side. When diffusers open up, the pressure drops at the damper. The damper will open to allow more air from the supply fan and the pressure will rise down the line.

A supply fan driven at a constant speed would not be able to adjust to such varying airflow requirements. Therefore all supply fans are driven by variable speed drives (VSD). As shown in Figure 3.7 the supply fan and its VSD is connected to a pressure sensor down the line in the main shaft duct. The sensor relays the combined pressure effect of the current position of all the PCD's. The VSD regulates the fan speed and hence the airflow to keep this pressure reading constant. The supply fan with its VSD is commissioned to provide a minimum airflow of no less than the minimum fresh air requirement and a maximum airflow equal to its predetermined peak load airflow, both discussed in Section 3.1.2.1.

3.1.3.5 Fresh air and return air control

The return air fan is set up to mimic the supply air fan speed in order to provide return air to the system, but also to prevent pressure build-up by facilitating effective ventilation

within the otherwise sealed off conditioned areas. As such, both the fresh air and return air supplied to the system will also vary with the changing supply air fan speed, but the BMS can regulate the ratio of this air mixture. This is done by controlling the amount of return air that enters system through the motorised return air damper (item 2 in Figure 3.7). Air that is not used as return air is extracted through the exhaust air damper.

In order to satisfy building regulations and GSSA ventilation requirements (IEQ-1) the damper must be controlled to always allow enough fresh air in to meet the system's minimum fresh air requirements. The building also aims to achieve the GSSA CO_2 credit (IEQ-3). For this credit the amount of CO_2 in the ventilated areas must be continuously monitored. Should the CO_2 levels rise above $640ppm$ due to unusual occupancy levels, additional fresh air needs to be supplied by closing the return air damper further.

A higher fresh air ratio will usually cause an increased heating or cooling load as outdoor conditions are normally cooler or warmer than what is required indoors. However, when the outdoor conditions are favourable the system can be switched to economy cycle mode. In this setting the return air damper is completely closed as the outdoor air is better suited for satisfying the cooling or heating demand in the building than the air being returned from the building. The outdoor conditions therefore provide a component of "free" cooling or heating. The deficit between this component and the building demand is supplied through normal cooling or heating by the coils. Substantial energy savings can be achieved through this method.

In fire conditions the supply fan is off and all fire dampers are closed except for the supply and return air fire dampers on the floor where the fire is detected. The return air fan is driven at its maximum speed, the return air damper at the AHU is closed and the exhaust damper is fully open to extract smoke from the building. The supply air fire damper on the floor is left open to provide make-up air in order for smoke to be effectively extracted by the return air fan.

3.1.3.6 Cooling or heating control

As briefly discussed in Section 3.1.2.3, the cooling or heating demand of each AHU is determined by the average space temperature of the areas that it serves. The space temperature measurements of each master diffuser of a specific system is relayed via the BMS to the Belimo Energy Valves of the AHU in order to determine the cooling or heating load.

If the average temperature is below set point the heating valve is opened, if it is above set point the pre-cooling valve is first opened to make optimal use of the "free" cooling provided by the seawater. Valves will open further if the average temperature does not improve, up to its completely open or peak load point. If the pre-cooling valve has reached its peak load point and the cooling requirement is still not satisfied, the cooling valve will be opened. As discussed in Section 2.5.1.2 these valves can also use their Delta T Manager control capabilities to reduce or increase water flow to maintain a predetermined differential temperature between the incoming and outgoing pipe lines. This functionality is not used at Silo 5.

For Silo 5, the PCW, CHW and HHW is supplied from the district cooling plant into a basement plantroom of Silo 5 (see Figure 3.11). From here secondary pumps are responsible for pumping the water to all of the equipment. These pumps are also controlled by VSD's and operate in a similar way as the AHU supply air fans. For example, as more PCW valves open at the AHUs, the differential pressure between the supply and return

pipe lines will drop, the PCW pumps would interpret this as an increase in demand and the VSD's would increase the pump speed to maintain a pressure set point.



Figure 3.11: Silo 5 basement plantroom with secondary pumps and piping systems

The temperature difference between the incoming and outgoing pipes are also monitored. This measurement can be used for an alternative method of control. Once any AHU valves open and the pumps start up, a minimum flow pressure set point is used to drive pump speeds. After this set point has been reached pump speeds will be controlled to meet a differential temperature set point. Therefore, the differential pressure is allowed to increase above the minimum flow set point. Once again for PCW, if the differential temperature measurement increases above the temperature set point, pump speeds will be increased to provide more cooling to the AHUs and, as a result, drive down the measured differential temperature. When the differential temperature decreases below the set point, pump speeds will be decreased, but not below the minimum flow pressure set point. This method of control has been found to be more efficient in some cases.

The use of differential pressure control also applies to the district cooling plant which can identify changes in demand from the different buildings through changes in the differential pressure in the piping system, but also directly from the status of control valves at each building.

A drawback of these methods of control is that the entire system depends on the diffuser space temperature sensors providing accurate readings at all times. As the Rickard system communicates these readings via the IP network, a network failure at any point in time would cause significant problems for the system, not knowing what the building demand is.

A solution to this is using temperature measurements from the return air ducts on each floor during a network failure. These temperature sensors are not part of the Rickard system and there is only one sensor per floor per AHU, but they have a hard-wired connection to the BMS controllers instead of a network connection.

Another problem comes with the averaging of space temperature measurements. If any master diffuser is not registering a temperature this would be considered as zero

degrees within the averaging calculation which will pull down the average. This problem has not yet been resolved for the Rickard products without an extensive programming workaround by BMS contractors.

3.1.3.7 User interface

In order for all relevant stakeholders to understand and effectively interface with the BMS, its user interface (UI) must be carefully designed. For Silo 5 this was achieved through coordination between the client, the consultant, the contractor and the supplier.

Standard practice dictates that a workstation (laptop or desktop computer) with access to the system is incorporated on site. This station is set up in the Silo 5 basement pumphouse, with the Site Management Portal UI installed on the system that is connected to a network access point of the building. This UI for Johnson Controls' Metasys BMS is tailored specifically for facility operations staff with easy access to real-time and historical data views as well as extensive alarm management capabilities [19]. For direct access to the system during an inspection of a specific area, facility staff can connect a laptop to any network point in the building via an Ethernet cable. Johnson Controls also offer access to a BMS through a mobile application, but this functionality was not opted for by the V&A.

For all other personnel that requires remote access to the BMS, the Metasys UI application can be installed on their personal computers that have internet access. This UI is more broadly based and provides a user-friendly tool for users to find information based on its location. Information is displayed in a dashboard format providing a more holistic view of the Silo 5 systems (see Figure 3.12). Pop-up notifications call attention to any system alarms, which will continue to be displayed unless it is shelved, resolved or the notifications disabled. The Audit Trails feature keeps track of system activity and user actions.



Figure 3.12: BMS user interface: Silo 5 main graphics view

Building floor layouts are incorporated into some displays to arrange information according to its location (see Figure 3.13), which simplifies the visual processing of information compared to the text based displays that are also available (see Figure 3.14). In Figure 3.13, for example, the temperature measurements and set points can easily be seen for every room on that floor. The set points for each individual room can also be changed

from here. To display this data in a text only format would require each room to be uniquely and descriptively labelled and even then it would be problematic to keep track of the room locations.



Figure 3.13: BMS user interface: Level 3 floor layout graphics view showing temperature, pressure and CO_2 readings and set points

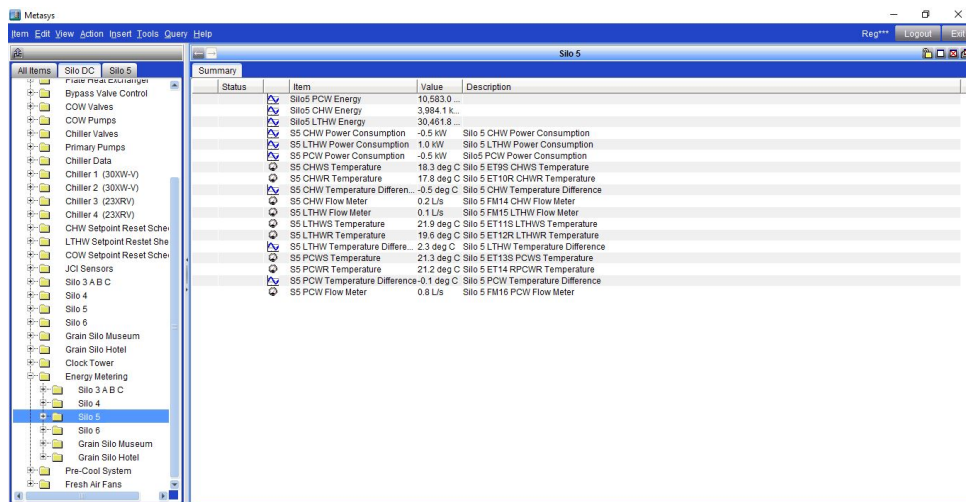


Figure 3.14: BMS user interface: Silo 5 energy metering data view

Dynamic graphics are included for plantroom equipment to further simplify and quicken the processing of information by users (see Figures 3.15 and 3.16). In Figure 3.15 it is also shown that the historical data of any data point can be trended directly from any view. Graphical views contain click-able links to easily navigate between related views.

All of the information relevant to Silo 5 is organised into a customised user view in the navigation panel as seen to the left of Figures 3.12 to 3.16. Also from this navigation panel all BMS information can be reached including information from BMS's of other V&A facilities (see the navigation panel in Figure 3.14). Ease of navigation and logical representation of information on the UI are critical to the value of the BMS for the client. If these aspects are not successfully achieved the BMS UI will likely be avoided by annoyed users.

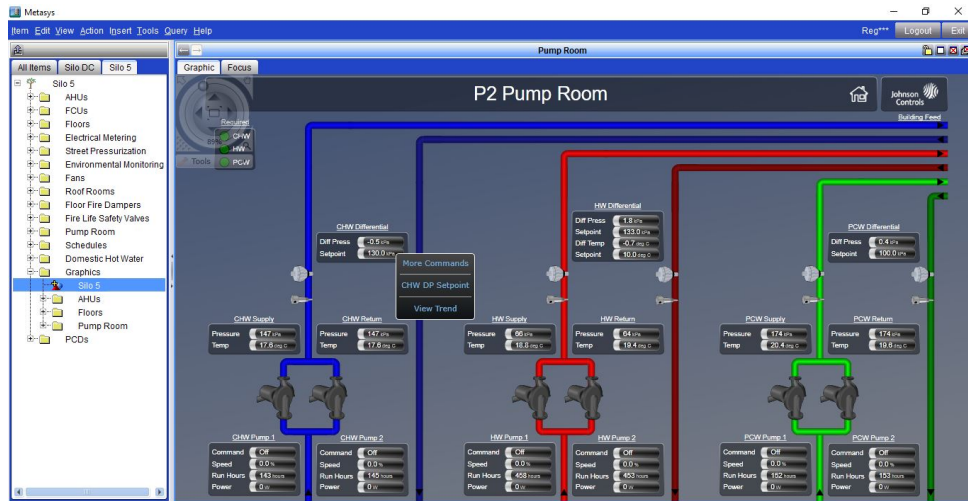


Figure 3.15: BMS user interface: Silo 5 pump plantroom graphics view showing the easily accessible trending option for each data point

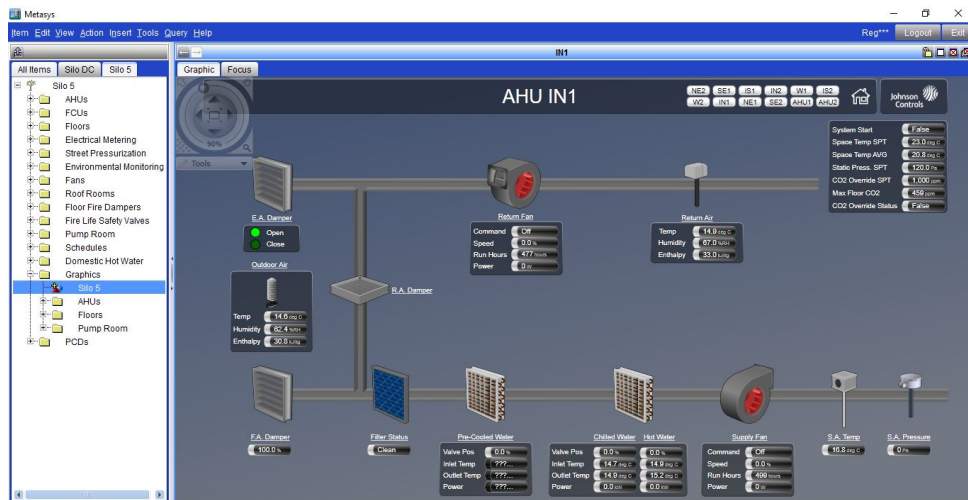


Figure 3.16: BMS user interface: AHU graphics view

This UI provides excellent functionality and ease-of-use. However, it also has some downsides. Only short-term (a few days) historical data can be viewed when directly trending a data point. In order to gain access to long-term historical data a trend study must be created which requires a much more cumbersome process. There are also limitations to the amount of variables that can be trended simultaneously. When working with large amounts of data the exporting of historical data is not always a straight forward process and a number of workarounds are required to use the data in the format that it is exported.

The Metasys UI that is accessible to the general user for Silo 5 allows for very limited reporting capabilities, which is disappointing when considering the amount of features that this product is advertised with (see Section 2.2.5). Without the Metasys Energy Dashboard software incorporated yet, no real cost analysis or cost reporting can be done directly from the UI. Energy data needs to be exported and processed through third party software.

3.2 Energy saving practices

With the focus on achieving a certified GSSA as-built rating and generally saving costs, a multitude of energy saving practices have been incorporated into the design of the Silo 5 building. Each discipline has its own GSSA credit requirements to meet as well as best practice principles that are applied to designs. Each of these practices, however small they may be, contribute to an overall more efficient building.

This section looks at the energy savings practices that have been applied to the HVAC services of Silo 5 in the three areas that were identified in Chapter 1. Most of these practices have been discussed in depth in Chapter 2 and will therefore only be listed.

3.2.1 Alternative sources

By making use of seawater instead of conventional cooling towers or even air-cooled chillers, the district cooling system can produce near free pre-cooling water and also produce chilled and heating hot water at much higher efficiencies. There is also no water being wasted as with cooling towers and there is no effect on the environment. By using seawater as an alternative source, substantial savings are achieved in operational costs of HVAC services of all of the buildings served by the district cooling plant. These savings are discussed in Section 2.3.1.

3.2.2 Systems optimisation

The Silo 5 building is benefiting from increased efficiencies due to numerous design decisions or methods used to optimise building systems. These systems can be further optimised by the V&A through operational methods discussed in Section 2.4 however, this section will focus on already implemented practices.

Apart from the savings generated by the use of seawater, as a centralised system, the district cooling system saves costs by having one plant instead individual plants for each building. A centralised plant also saves energy by, for example, using the heat rejected from PCW or CHW, used for air conditioning in one building, to generate HHW for domestic hot water required in another building.

For Silo 5 the process started in the conception stage of the project. By including a GSSA accredited consultant in preliminary design discussions, the building's orientation and envelope was taken into consideration in order to improve its heat load and thereby also achieving maximum green star points in that regard.

A comprehensive building heat load calculation, as described in Section 3.1.2.1, also allowed equipment to be sized correctly. For equipment selections, efficiency was one of the main determining factors.

For Silo 5 a central air conditioning system is used, which is also the most efficient type of system for this type of building. It provides savings through improved thermal control, less equipment and reduced spatial requirements. The AC systems are also VAV systems which provide further savings by only supplying the necessary amount of air and cooling / heating. The rooftop AHUs are designed to be able to run in economy cycle mode which saves energy by using favourable outdoor conditions to provide a portion of the required cooling or heating.

Ducting systems are sized according to the static regain method which requires the least amount of pressure and therefore decreases the supply fan load. All ducting and piping are also insulated to reduce heat loss.

Finally, Silo 5 makes use of a comprehensive building management system, which monitors and controls all HVAC systems and provides users access to all of its historical and real-time information from one central user interface. By having all the systems integrated and visible from one point, simplifies consumption reporting, maintenance, fault finding and identifying and eliminating wastage. This reduces consumption, increases equipment life cycles, improves staff productivity and increases occupant comfort and satisfaction.

3.2.3 Monitoring consumption

Resource consumption is also managed by monitoring and reporting on usage. For HVAC services Schneider Electric power meters are used at each DB to relay electrical energy consumption data to the BMS. These meters report on the energy consumed by each DB which is the total consumption of the equipment (mostly fans) that is supplied from each DB. The energy consumption of fans that are controlled by VSD's can however be monitored individually as VSD's provide a wide variety of its own operational data to the BMS. Electrical energy data is therefore not individually available for all equipment, but can be narrowed down to plantrooms and in some cases specific equipment. This type of sub-metering data can assist facility operational staff in ensuring that systems are operating at optimum efficiencies as well as testing new control strategies and instantly being able to see the effects of these changes.

For thermal energy measurement Siemens SITRANS MAG flow meters with added temperature probes are used on the main incoming pipes from the district cooling plant. These devices provide accurate water flow and differential temperature measurement data to the BMS that it uses to calculate the total thermal power and energy consumption of the Silo 5 HVAC systems.

For the monitoring of each system, Belimo Energy Valves are used at each AC unit instead of conventional control valves. They operate in the same way as the Siemens flow meters, but these intelligent devices perform their own power and energy calculations and provide a host of other functionalities for effective control of heating / cooling supplied by all systems.

Having access to total building energy data as well as the data for each AC unit, enable facility staff to allocate energy consumption figures to specific areas of the building instead of only looking at total consumption. Building owners or tenants can easily identify problem areas and where possible, address issues of excessive consumption.

Once incorporated, the Metasys Energy Dashboard will provide a comprehensive tenant billing feature as an add-on to the existing BMS. The software will use the above mentioned sub-metering data to generate tenant energy billing statements. This will eliminate the need for costly third party software to process exported energy data from the BMS in order to produce statements.

As the software is not dependent on statements from utility providers, biweekly or even weekly consumption reports or month-to-date statements can be provided to tenants in order to keep a closer eye on their consumption. The MED software will be specifically used to manage the down payment or payback of the initial capitol investment for the district cooling plant.

Plans are still in place for PWC to use a screen in their reception area to display certain information regarding the tenant's energy consumption and what savings are being made. This feature would be incorporated for marketing purposes to outside clients, but it also has the potential to influence their employees' consumption behaviour through awareness as described in Section 2.5.2, which could lead to further savings.

3.3 Calculating savings

The benefit of energy saving practices are clear, but decision makers need to be able to convert these benefits into a Rand-and-cent value to justify expenditure and prove a return on investment for all stakeholders. However, in new buildings, the value of most energy saving practices that are incorporated from the start cannot always be quantified in terms of actual, monetary savings contributed to specific features as there is no benchmark to compare it to.

The amount of “free” seawater cooling provided through PCW from the district cooling plant can physically be measured, but the savings effect of using the static regain method for duct sizing and insulating all ducting cannot be calculated without previous consumption data to compare it to which is only available in refurbishment projects. Alternatively equipment or plant running costs can be compared to conventional building running costs if that information is available.

This section discusses how quantifiable energy savings can be calculated and looks at what other benchmark information is available.

3.3.1 District cooling energy

The district cooling plant with its chillers, heat exchangers, pumps and accompanying equipment was an extremely costly investment which now needs to pay for itself through the savings that it provides and thereafter generate a profit for the V&A.

The savings are determined by the difference between running costs required to operate the plant and what the tenants of each building are being charged for the pre-cooling, cooling and heating energy that they consume through the PWC, CHW and HHW. The plant running costs are determined by the cost of the electrical energy consumed by the plant, paid to the utility provider which is the City of Cape Town municipality. The charge out rates to tenants are based on the rates that would be charged for a conventional plant while still remaining competitive with rates in order to attract tenants to the V&A’s buildings. The charge out rates also need to cover the plant’s annual maintenance costs. The higher these rates are, the shorter the payback period for the plant.

The disparity between a conventional district cooling plant and the seawater district cooling plant is accentuated by the difference in efficiencies between the plants. Where chillers are concerned, efficiency is expressed as a coefficient of performance (*COP*) which is a basic ratio of the cooling / heating provided over the work required to provide it (see Equation 3.3.1). A *COP* ratio is therefore calculated for each type of water, PWC, CHW and HHW. The true benefit of using seawater can thus be seen in the difference in *COP*’s between a conventional plant and a seawater plant in Table 3.1 with pre-cooling water providing 150% more cooling with same amount of work / energy input. It also provides 25*W* of cooling power for every 1*W* of electrical power that is consumed to generate it. It is therefore clear that it is in the interest of both the V&A and all tenants to use as much of the PCW for cooling purposes as possible as it is the least expensive to generate and provides the largest amount of savings, which will help to reduce the plant payback period and increase profits.

$$COP = \frac{Q}{W} \quad (3.3.1)$$

The conventional plant *COP* figures in Table 3.1 presents a complication. In order to effectively compare *COP* figures, the two types of plants have to be of a similar type

Table 3.1: Chiller COP: conventional vs seawater [17]

Water produced	Chiller <i>COP</i>		Percentage improvement
	Conventional	Seawater	
PCW	10.0	25.0	150.0%
CHW	4.0	5.6	40.3%
HHW	3.0	3.8	25.7%

and size. However, for the Silo district, a conventional district cooling system would not have been a feasible option due to its spatial requirements as well as from a cost perspective. The only practical solution would have been to have decentralised systems for each building, as described in Section 3.1.1, which would not have been able to achieve the tabulated *COP* figures. The *COP* calculation does not account for the water consumption costs of the cooling towers that would have been required for a conventional system. Also, the amount of pre-cooling water that the seawater system generates cannot be attained without an alternative source such as seawater.

Therefore the *COP* figures for CHW and HHW of the conventional plant are based on chiller efficiencies of a system that would not have been achievable and the PCW figure is an estimation based on a heat recovery process that could not be scaled to the required size. These estimations are therefore extremely generous and this fact further substantiates the added value of the seawater district cooling system.

3.3.2 Building energy

For Silo 5, the energy data provided to the BMS by the Siemens SITRANS MAG flow meters at the main pipes entering the building will eventually be used by the Metasys Energy Dashboard (MED) software, together with the above mentioned charge out rates, to generate billing statements for each tenant for the portion of the thermal energy supplied from the district cooling plant that they are responsible for.

Since it is a centralised AC system, the V&A has determined that each tenant's portion will be calculated on a gross leasable area (GLA) basis [17]. Therefore each tenant will pay for the HVAC energy based on the percentage of the total leased area that is being served by this system, that they are occupying. This cost is calculated through Equation 3.3.2, where ε_{tenant} is the tenant's portion of the central AC energy cost, ε_{total} is the total central AC energy cost, α_{tenant} is the area leased by the tenant and α_{GLA} is the GLA of the floors served by the central AC systems. This might not be the most accurate representation of each tenant's consumption, but without continuous airflow readings into each tenant's area, the GLA calculation is the most effective and fair way to allocate costs to tenants.

$$\varepsilon_{tenant} = \frac{\alpha_{tenant}}{\alpha_{GLA}} \varepsilon_{total} \quad (3.3.2)$$

The hope is also that for an office building, air conditioning requirements should not vary too much for different tenants. However, in this case the 5th floor consists primarily of meeting rooms on the north side and a canteen on the south side. It could be argued that when completely occupied, this floor will consume more AC energy than other floors or that for most of the day the floor would be largely unoccupied and therefore consume less energy. This variance is ignored to simplify the process and eliminate the possibility of any misunderstanding.

Energy consumed by AC systems, such as the roof rooms cassette units, that serve only one tenant will be billed directly to that tenant. For AC systems that serve public / landlord areas, such as the ground floor shared lift lobby and reception areas, the energy costs will be for the V&A's account. Tenants will benefit from lower AC energy costs than what can be expected in buildings served by conventional plants as described in the section above, especially with regards to pre-cooling water. The ability for tenants to calculate the exact amount of savings depend on the availability of comparative rates being charged by a conventional district cooling plant. The V&A might be able to provide tenants with a percentage saving figure for each type of water in order to report on these savings.

Another area that presents an opportunity to quantify savings to a certain degree is the economy cycle feature of the AHUs. By using the trending capabilities of the BMS it is possible to determine when each AHU is utilising its economy cycle feature. With this information and by making certain assumptions, the amount of energy saved by this feature can be calculated.

Firstly, to determine when an AHU is operating in economy mode from the BMS data, it must be determined whether the AHU is operating in heating or cooling mode. When the average of the measured space temperatures for an AHU is higher than the average space temperature set point, the unit will be operating in cooling mode and when it is lower than the set point it will be in heating mode.

The heating or cooling potential of air is determined by its enthalpy, measured in kilojoules of energy per kilogram of air. Therefore, if a unit is operating in cooling mode and the outdoor air enthalpy is measured to be less than that of the air returning to the unit from the conditioned space, there is potential for the outdoor air to provide at least a portion of the cooling required in the conditioned space.

Most of the time this would not be the case, as outdoor conditions are normally the primary cause for a cooling or heating demand in a building. However factors such as direct sunlight might cause certain areas of a building to be heated past its set point while the outdoor air is still relatively cool. Also, building façades that are covered by shade at certain times might cause those areas to be cooler than its set point while the outdoor air at the AHU fresh air intake is warmer and can provide heating.

Once the conditions required for economy mode are met for an AHU, its return air damper closes and therefore provides 100% fresh air to conditioned spaces, making optimal use of the favourable outdoor conditions. Thermal power consumption savings can then be calculated through Equations 3.3.3 and 3.3.4 for cooling and heating respectively. These calculations assume that the supply air fan speed percentage is directly proportionate to the airflow percentage and that the design ratio of fresh air to supply air is maintained at all times when AHUs are operating under normal conditions. These assumptions might not hold true at all times and results would be more accurate if actual airflow rates were available from the BMS. However, for the purpose of investigating whether notable savings are achievable, these inaccuracies are acceptable. Energy savings can be calculated by mathematically integrating these values over the time that it is measured.

$$Q_{cool} = (h_{FA} - h_{RA})(1 - r_{FA})\rho_{air}q_{peak}FSP_{SA} \quad (3.3.3)$$

$$Q_{heat} = (h_{RA} - h_{FA})r_{FA}\rho_{air}q_{peak}FSP_{SA} \quad (3.3.4)$$

These same equations can be used to determine the amount of energy that is wasted through the CO_2 override feature of the central AHUs. Whenever the CO_2 levels in the conditioned spaces rise above $640ppm$ the CO_2 override feature is enabled. This closes the return air damper, supplying 100% fresh air to the spaces to reduce the CO_2 levels and improve occupant comfort. When this feature is enabled while economy cycle conditions are not met, additional cooling or heating need to be supplied by PCW, CHW and HHW to condition the added outdoor air. At the time of writing, the accuracy of the CO_2 override feature was still in question and had to be refined. The calculation of the energy being wasted by it would need to be investigated at a later stage.

Besides the direct financial savings that are available, it can also prove beneficial to monitor all energy consumption data. By processing this data into visually understandable information and utilising methods such as cost-based optimisation and interactive commissioning, explained in Section 2.4.2, further savings may be achieved by identifying wastage or under-performing equipment.

The charge out rates mentioned in the section above can be applied to the thermal energy consumption data supplied by the Belimo Energy Valves of each AHU. Combined with electrical energy data from the fan VSD's and municipal electricity tariffs, this will provide the running cost of each AHU. At the very least this will be useful information for facility operators and building owners to keep track of on a long term basis. It might also provide insight into opportunities where savings can be achieved by adjusting the control strategies of systems in order to lower peak demand by shifting some of the demand to different times of the day.

There are various possibilities with building energy data and some of these methods will be tested in the next chapter.

Chapter 4

Tests & Results

In this chapter the data collection process from the BMS as well as its limitations are discussed. Various results from this process are graphically presented and analysed to identify trends and results triggered by events. The results also aim to quantify some of the savings achieved in the Silo 5 building by making use of the seawater district cooling system and the economy cycle feature of central AC system.

4.1 Data collection

While the real-time data that a BMS provides is invaluable for multiple reasons discussed up to this point, this chapter focuses mostly on the historical data that is also accessible from the BMS. Real-time data represents a single point in time and can only be used as it is measured. Historical data provides a more holistic and easily understandable view of systems and will be used in this chapter to provide quantitative results.

4.1.1 Method

The Johnson Controls Metasys BMS of Silo 5 records data from each and every variable or data point connected to each of the three network control engines (NCE) or the network integrator engine (NIE).

In order to achieve this, the trend extension must be activated and configured for each data point on the engines. This entails setting among others, a buffer size, sampling interval and transfer set point for each data point on the controller. The buffer size determines the amount of data samples to store on the controller before it either stops recording samples or starts to overwrite old samples. The sampling interval is the rate at which data must be recorded and the transfer set point is the amount of data samples that must be recorded by an engine before transferring it to the V&A's ADX server for permanent storage. For Silo 5 this was done by Cape Automation Systems as part of their design and setting up of equipment. The trend data temporarily stored on the network engines can then easily be accessed as shown in Figure 3.15.

To access all trend data for a specific data point, including data already stored on the server, a trend study must be set up. Multiple data points can be included in a trend study, allowing the user to group all the required information together into one report. This can be done by any user, selecting all required data points and setting a starting and ending point for the range of data. The start and end points can be absolute times or

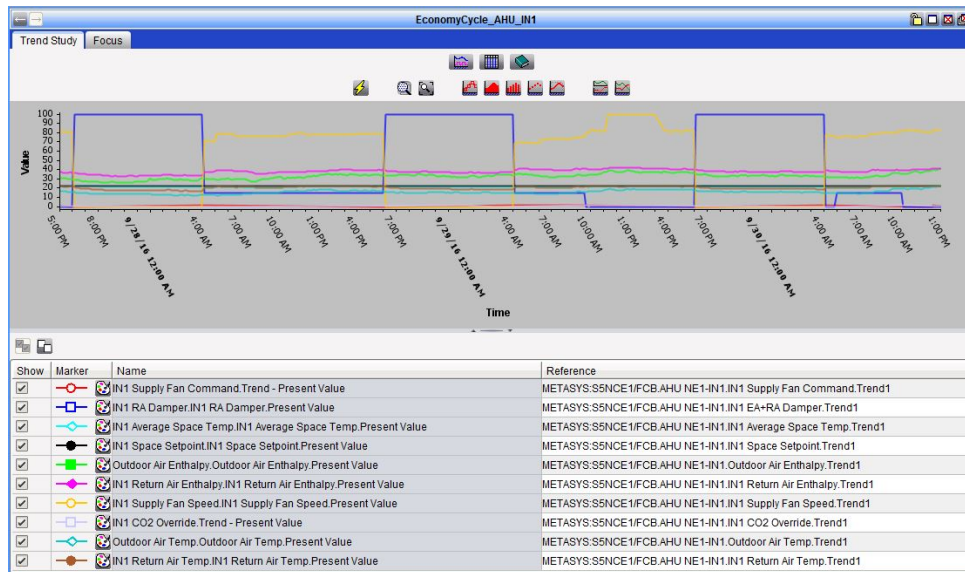


Figure 4.1: BMS user interface: trend study chart view

relative times, allowing a trend study to be updated with, for example, the latest month's data each time it is accessed.

Trend studies have a number of possibilities for the processing and displaying of trend data. Aggregate functions can be applied to data ranges, including average, maximum, minimum, standard deviation, range, sum or variance functions for which an aggregate interval also needs to be set.

The data can also be displayed in various ways. In the chart view, data can be displayed in different formats including a points chart, a line chart, a points line chart, area chart or bar chart. The chart y-axis can be formatted to accommodate a stacked or single axis and users can zoom in on any portion of a chart. Chart line and point colors and shapes can also be adjusted. Figure 4.1 shows an example of a trend study with a line chart displaying all data variables on a single y-axis.

Data can also be displayed in a table view. It is from this view that data can be exported by copying data to the computer clipboard to be pasted into third party software programs such as Microsoft Excel.

The definition view allows users to adjust range start and end points and add or remove variables from the trend study.

4.1.2 Limitations

Through use of the methods described above various limitations or impediments were found within the Metasys user interface that complicated the data collection process and rendered data processing capabilities inferior.

The activating and configuring of the trend extension must be done separately for each data point. If, for example, the sample interval needs to be changed from hourly to every 15 minutes for accurate billing purposes, this needs to be done individually for all relevant data points. Evidently users with administrator rights on the system have access to a feature that allows for multiple trends to be configured at a time, but normal users do not have access to this feature.

When creating trend studies, the software wizard that guides users through the process requires each data point to be selected from its root file location and not from a user

view where all relevant data points are grouped together. When including data points from different systems in a trend study these points are usually located in completely different controller sub-folders, occasionally with model numbers for names, which makes it extremely difficult to locate and identify data points and prolongs the entire process.

Although more than 10 variables can be added to a trend study, it only allows 10 variables to be displayed or even exported at any time. Also, for each data point only a set amount of data samples can be displayed at a time. Therefore, even though a trend study range might be set to display two months of data, the data of a data point trend with a high sample rate might only be displayed for a month.

On the data processing side the available options do not come close to the capabilities of spreadsheet software such as Microsoft Excel. Data point values cannot be filtered based on other data points, date and time formats cannot be manipulated, chart options and aggregate functions are limited etc. As the Metasys software cannot be used for all data processing, it makes more sense to perform all data processing with one software package that can perform all of the requirements and perform it well.

4.1.3 Focus areas

Any measured data point can be trended using the method described above. As a result an immense amount of data is available in various different formats and the challenge becomes the selection and processing of data that would be useful to different stakeholders. For a new building with unfamiliar systems, except for the obvious requirements, it is not always clear from the start what data would be useful. The process takes time to be tested and refined on a continuous basis with regular feedback to improve the results. Since the MED software had not yet been incorporated for Silo 5 at the time of writing, assumptions were made regarding which data to focus on.

For Silo 5, the amount of thermal energy consumed through the PCW, CHW and HHW that is circulated through the building equipment from the district cooling plant is important for tenant billing since the V&A pays for the electricity consumed by the plant to produce this water and also to determine the savings achieved through the seawater system.

Table 4.1 shows the electricity tariff structure that applies to the district cooling plant. This structure includes a demand charge that applies to a peak demand supplied for 30 consecutive minutes or more. For a 6MW plant at peak load during summer months this charge can greatly increase the total monthly electricity tariff. It is therefore also important to keep track of the building's peak thermal power demand should that need to form part of the tenant billing structure.

For billing purposes this data need only be reported on once a month, but through the research presented thus far a strong case has been made for the continuous monitoring of this data. From an operational perspective both the energy and the demand data can be used to identify problem areas and monitor the effects of any changes made to a system. For this and many other reasons described previously it is also extremely useful to monitor each system's consumption instead of only the total building figures. Using methods described in Section 3.2, the energy and therefore cost savings of the economy cycle feature of the central AHU's can be monitored.

Apart from the thermal energy, the Silo 5 building HVAC systems also consume significant amounts of electrical energy through fans and other equipment. For the same reasons as above the energy and power demand data for this usage is also important.

Table 4.1: City of Cape Town 2016/2017 Consumptive Electricity Tariffs - Commercial large power users, medium voltage ($> 1MVA$) [40]

Description	Unit	Tariff (incl. VAT)
Service Charge	<i>R/Day</i>	50.58
Energy	<i>c/kWh</i>	79.87
Demand	<i>R/kVA</i>	234.50

The above focus areas were used as guidelines for the testing of BMS data. Data was generated through trend studies and exported to Microsoft Excel. Built-in calculation functions and pivot tables were used to great effect to manipulate and process exported data into the charts and results presented in Section 4.2. A multitude of options are available for the reporting of consumption and it will be the prerogative of the facility manager to decide which methods work best for their needs.

4.2 Results

The results from the data collection processes described in the section above are presented graphically in this section and discussed in terms of energy savings through an alternative source, optimisation methods and monitoring of consumption.

4.2.1 Thermal energy

Figures 4.2 to 4.6 all focus on the Silo 5 building's thermal energy consumption in different ways. In some cases power consumption data is presented instead of energy consumption data as results are clearer in this form and to highlight the possibilities that are available with the BMS. Some assumptions are made before interpreting the results based on industry experience and through monitoring the system on a daily basis. There are two major contributing factors that cause large variations in this consumption in the early months after construction. The one is the ever-present influence of the weather or outdoor conditions and the other is the fact that HVAC systems are still settling. This means building system tuning is still continuously occurring, resolving newly found system errors or making adjustments for occupant comfort.

Building occupation started mid July 2016. Occupation figures are assumed to remain constant from Monday to Friday, with average working hours being between 08:00 and 17:00. The main tenant in the building is PwC that provides among others financial auditing services to their clients. Many of the audits need to be performed at the clients' premises, causing various staff members to be out of office during this time which could be multiple days or even weeks. The effect of this variance in building occupants around typical financial reporting seasons of the year may be investigated in future work.

For Figure 4.2, the hourly building thermal power consumption, measured by energy meters in the basement plantroom, was averaged from Monday to Friday for each month. From this graph it can be seen that during these winter months in Cape Town, HVAC systems are primarily used in heating mode, but some cooling is also required during warmer afternoon conditions. In June, the building was not yet occupied, but systems were operating and being tested, often forced to operate at peak conditions. This can be attested to by the high heating power consumption values. Pre-cooling and cooling power

consumption is also present and may be due to a combination of demand and tests being performed. Major testing had mostly been concluded by July and occupation was taken midway through the month.

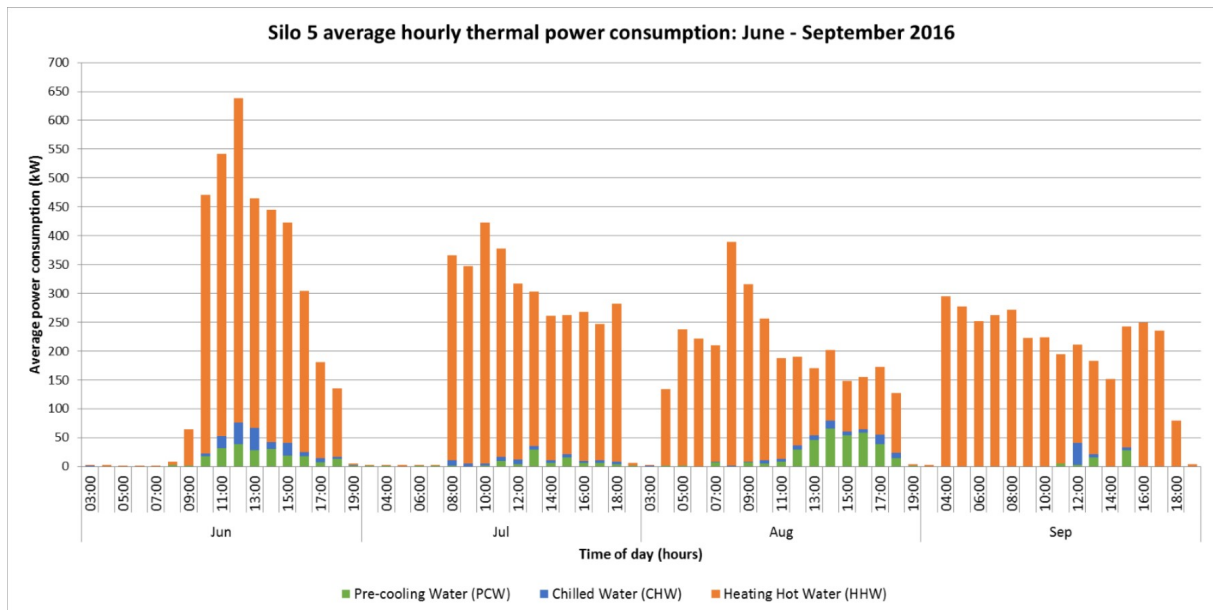


Figure 4.2: Average daily thermal power consumption from June to September

Being generally considered the coldest month during the South African winter, the high heating power demand during the morning is understandable as the building needs to heat back up to the 22°C space set point. Very little cooling was required. August was warmer than expected with a relatively high cooling demand for this time of the year between 12:00 and 17:00.

It can also be seen that most of the cooling was done by PCW which is beneficial for cost saving purposes since PCW is less expensive to produce for the V&A and tenants are charged less for its use as discussed in Section 3.3. This also shows that AHU's were never operating at very high cooling loads compared to its capacity as CHW is only used when an AHU cannot achieve its set point through PCW alone, which is a first indication of AHU's being sized correctly.

In August the decision was made to adjust the systems start-up time from 08:00 to 04:00 in order to systematically heat the building up before people start to enter the building. It lessens the effect of the sudden surge of people on the total building energy consumption and also serves to decrease the peak heating load of the building. This is an example of shifting energy use and peak loads to different times, described in Section 2.4, in order to achieve savings in energy (if time-of-use tariffs apply) and demand (lower peak demand on electrical grid) tariffs.

September again shows a higher heating demand. Although the month was generally colder than August, the higher demand can also partly be ascribed to system adjustments. Due to ground floor retail tenant fit-outs and shop fronts that have not been installed as of yet, the areas are open to outdoor conditions. As result a significant amount of heat from the first floor is lost by heat transfer through its concrete floor slab. This effect was not allowed for in the heat load calculations as the ground floor was assumed to be occupied and the spaces conditioned. Consequently a number of "cold-calls" or complaints were received from occupants on this floor which drove the decision to increase the temperature

set point for all first floor areas from 22°C to 23°C . Combined with increases in fan pressure set points to achieve higher airflow rates this significantly increased the heating power consumption.

This type of graph is useful for monitoring shifts in demand trends throughout the year as well as the long term effects of changes made to system controls. By plotting this graph for each AHU and monitoring it on a long term basis, it can assist with early problem detection and preventative maintenance. It also helps to keep track of average peak demands.

As the outdoor conditions heat up toward the summer months, this graph will change significantly with pre-cooling and cooling dominating the daily demand and very little, if any, heating required in the early hours of the morning. Peak demands will be during the afternoon and will also be significantly higher since it is accepted that the cooling demand is roughly double that of heating in South Africa [17].

The box-and-whisker plot in Figure 4.3 serves as an extension to the previous figure, giving an indication of the accuracy of using averages. For all four months the average value for daily heating energy consumption is more or less equal to the median and interestingly also remains relatively constant for the consecutive months except for July where the average daily heating energy consumption is about 500kWh higher than the that of August and September. This could be the effect of adjusting the systems start-up time in August resulting in decreased overall heating energy consumption, but since there also was very little cooling demand during this month, it could also be due to the colder conditions.

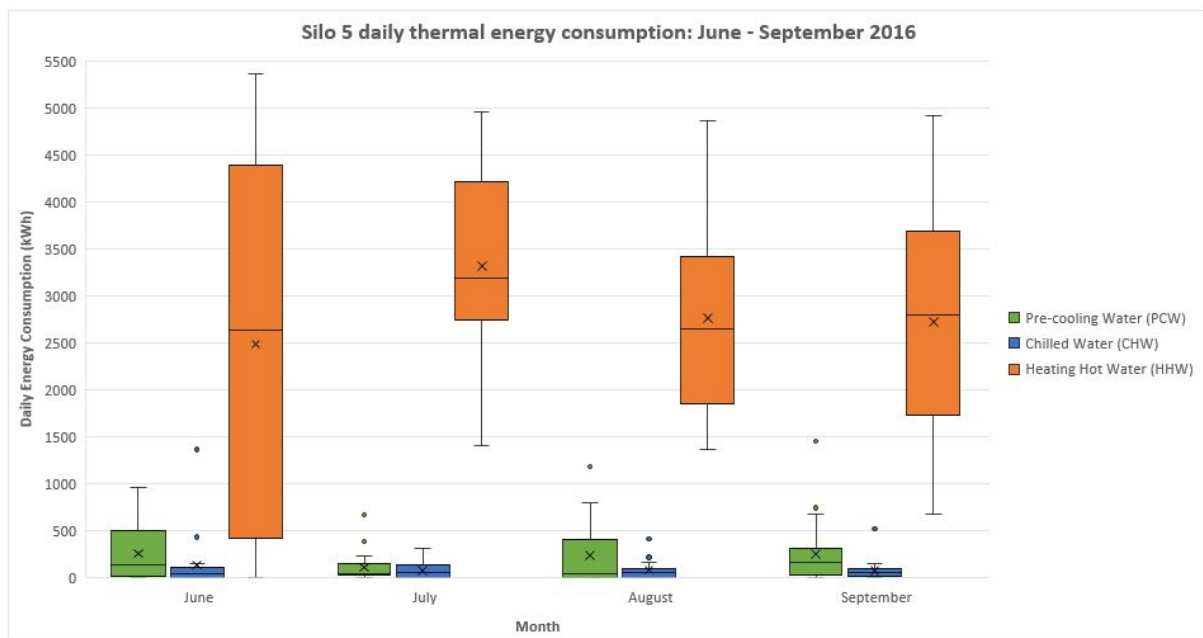


Figure 4.3: Distribution of daily thermal energy consumption for June to September

June stands out for its large inter quartile range which is no surprise with the testing and commissioning that occurred during this month. The variance in heating demand significantly decreases after this month and can, from July, be mainly attributed to the difference in daily outdoor conditions.

Similar to its average the variance for July is distributed over higher values, but is skewed towards the lower end and maximum and minimum values are in line with that of August.

For September the variance in heating energy consumed increased notably. This is likely an effect of the adjustments made to the first floor set points and fan pressures at different times of the month.

Very little can be determined from the comparatively low pre-cooling and even lower cooling energy consumption figures for these months. Unlike for the heating, outliers are present for both pre-cooling and cooling which indicates toward the rare warm days and tests in June. The low medians also attests to the fact that very few days had any pre-cooling or cooling energy consumption at all which might be slightly misrepresented when using only the average values.

This type of graph should be monitored for large variances in consumption which might indicated towards system problems or faulty equipment. Outlier events can also be investigated to determine the cause and prevent potential future problems.

Figure 4.4 provides a more close-up view of actual daily energy consumption instead of monthly averages or the distribution thereof. Maximum and minimum outdoor temperatures as well as the average room temperature set point is plotted on a secondary axis with the energy consumption.

This provides an interesting insight into the direct effect of outdoor temperatures on consumption figures. For the five weeks shown, wherever the maximum outdoor temperature experienced peaks above the average room temperature set point, a notable amount of pre-cooling and cooling energy was consumed. This maximum temperature would typically be experienced between 12:00 and 15:00, while the building would still require significant amounts of heating during the morning.

Also, where minimum temperature dips occur combined with relatively low maximum temperatures, heating energy consumption increases significantly. Systems would need to provide more heating in the morning to heat areas up to set point from the lower night temperatures and also sustain this heating throughout the colder day.

These results underline the importance of the selection of the room temperature set point by finding an acceptable balance between energy efficiency and occupant comfort. If occupants can work comfortably in an environment with the temperature adjusted slightly towards outdoor conditions, considerable energy savings can be achieved.

The effect of outdoor conditions on the indoor demand of a building designed to meet green building requirements also highlights the significance of the grade of thermal insulation of a building's envelope. Non-green buildings that do not need to adhere to the same heat transmission limitations would therefore experience significantly increased heating and cooling demands.

By applying the charge out rates, discussed in Section 3.3, to this graph for PCW, CHW and HHW, daily thermal energy costs can be monitored and used for cost based optimisation as well as for reporting purposes for management.

In order to have a thorough understanding of the results shown in Figure 4.6, Figure 4.5 was also included. It shows, for Silo 5, the sun's position in terms of an azimuth and altitude angle during all hours of the day for all seasons of the year. The outer circle represents the horizon and the points on this circle indicates the azimuth angle. The curve passing closest to the centre of the circle indicates the sun's path during the summer solstice on the 21st December of every year. The curve on the other end of the yellow band indicates the path during the winter solstice on the 21st of June. The points on these curves follow the hours of the from the right (east) to the left (west). The

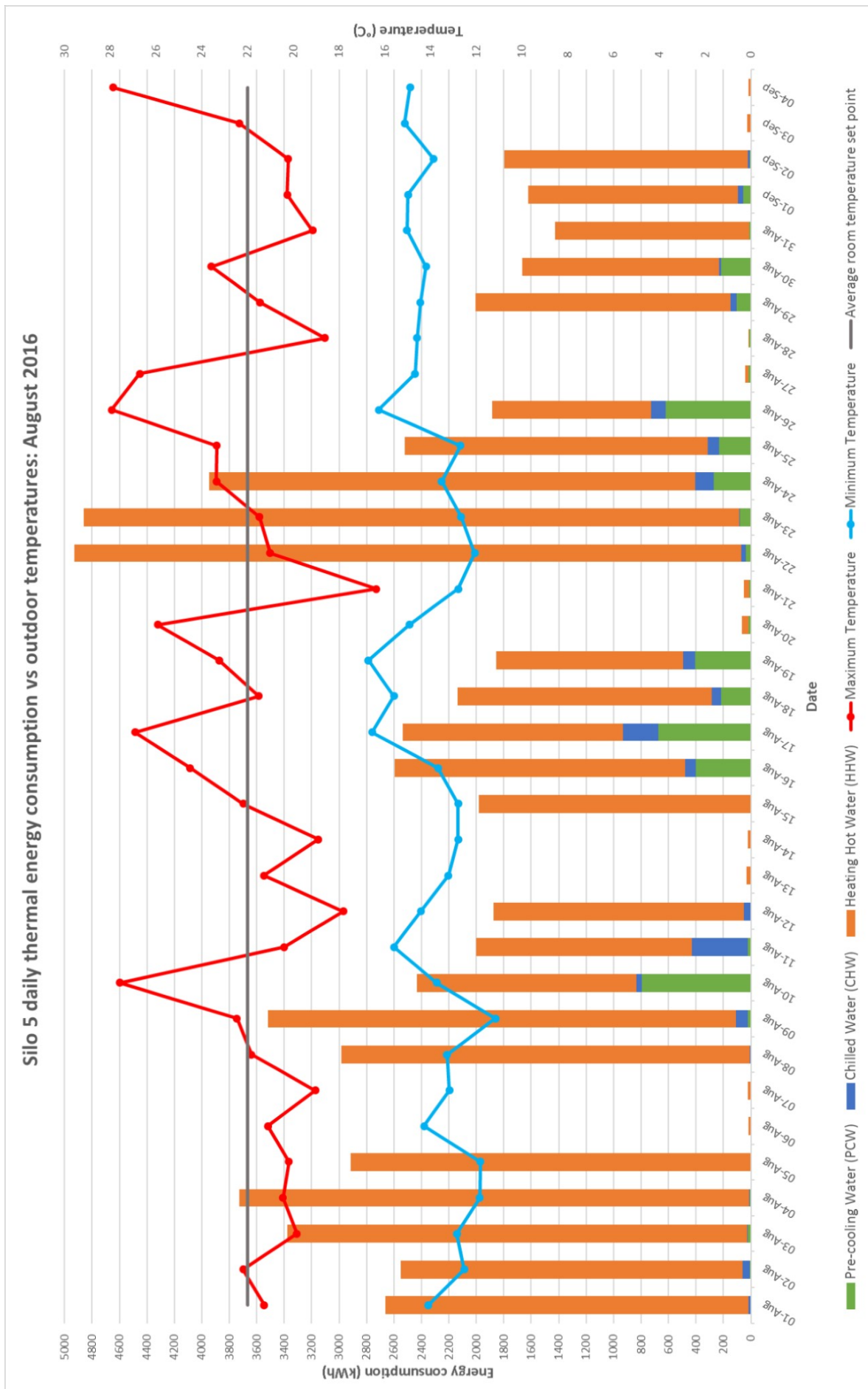


Figure 4.4: Daily thermal energy consumption vs outdoor temperatures for August

distance of each point from the centre of the circle indicates the altitude angle of the sun at that time.

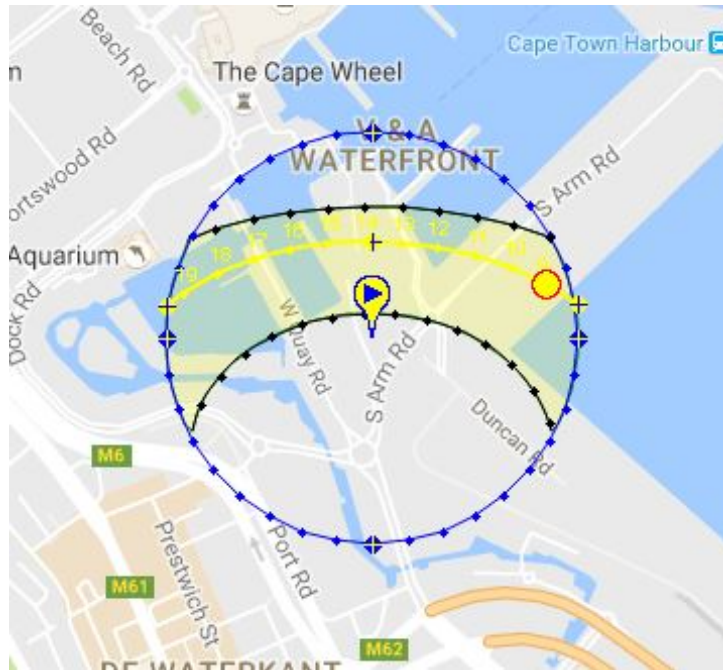


Figure 4.5: Sun position chart for Silo 5 [41]

The point circled in red within the yellow band shows the sun's position at 09:00 on the 1st of September. This chart provides insight into what times of the day direct sunlight on a building's façades will have a significant influence on its heat load.

The graphs presented in Figure 4.6 provided exceedingly interesting and valuable results. These graphs indicate the daily amount of cooling and / or heating provided through the economy cycle of four different rooftop AHU's over a two month period. The average outdoor temperature at each AHU is also plotted on a secondary axis. It therefore shows cooling or heating energy provided purely from the outdoor air, not from PCW, CHW or HHW and can be reported as direct savings from the economy cycle feature.

These types of figures are not normally available as all the required data points are rarely available without a comprehensive BMS and someone that is well informed on how to use this data. By using the method described in Section 3.3, the daily amount of heating and / or cooling energy was determined for each AHU. The AHU's were selected based on the areas that they serve. AHU IN1 serves an internal area (no bordering façades) and AHU NE1 serves an area that is bordered by a façade that faces in a north east direction. The same principle applies to AHU W1 (west facing) and AHU SE1 (south east facing).

The results are distinctive for each AHU. AHU IN1, not being influenced at all by direct sunlight or heat transmission through façades, did not benefit much from the economy cycle feature with very few occasions where low amounts of cooling energy was saved.

The areas served by AHU NE1 are however positioned to experience morning sunlight for most parts of autumn, winter and spring months. As a result these areas heat up more rapidly than others and requires cooling before the outdoor air has heated up to the same degree. With the outdoor air at a lower enthalpy than the return air from these areas, AHU NE1 can use 100% outdoor air to condition the areas and only provide pre-cooling or cooling for the remaining deficit.

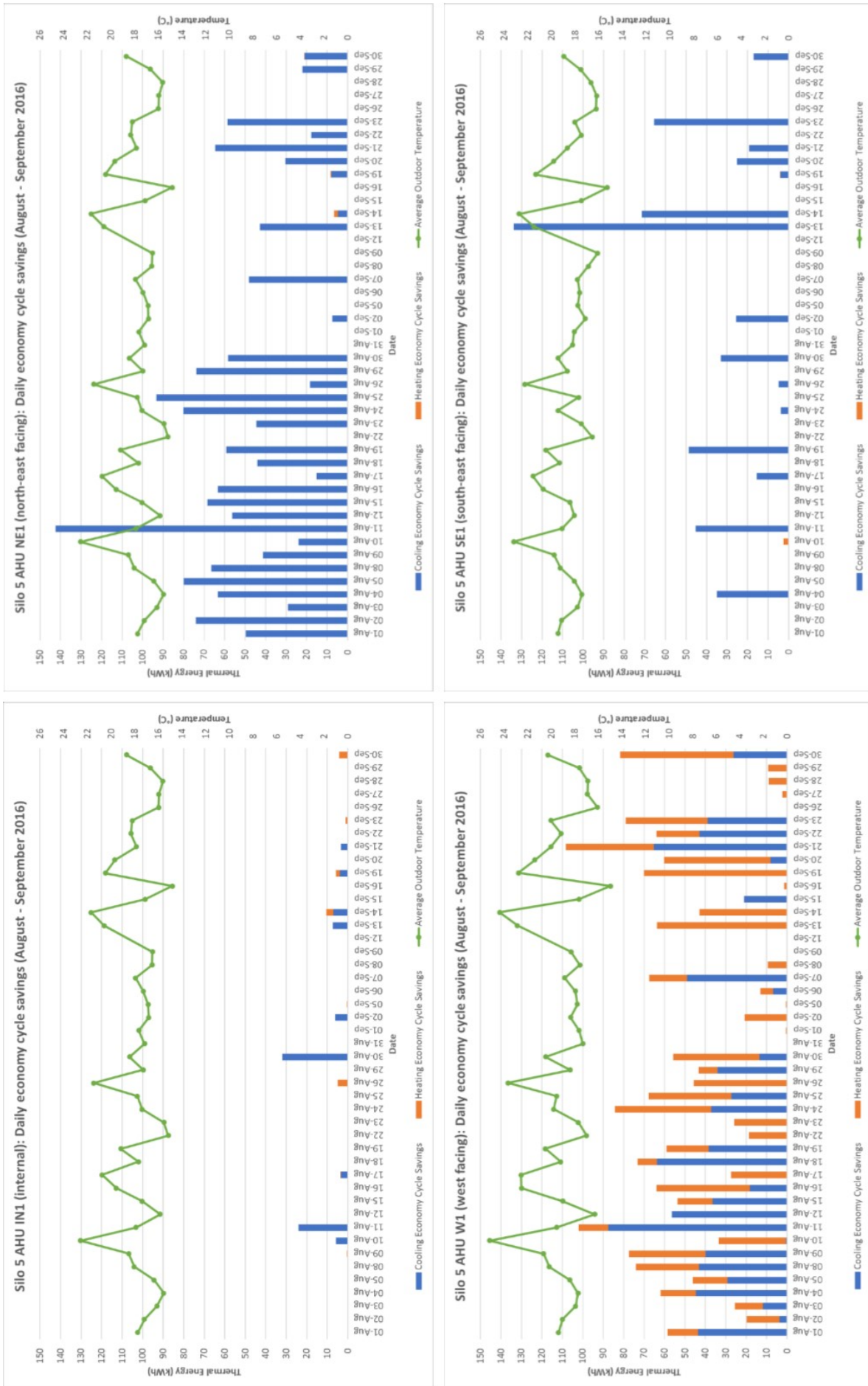


Figure 4.6: Thermal energy savings through economy cycle for AHU's IN1, NE1, W1 and SE1

The energy savings were especially inflated for the warmer August days, reaching an outlier peak of over $140kWh$ of cooling energy on the 11th of August. No heating energy is used here as areas are generally warmer in the afternoon than the cooler winter outdoor conditions, even though no direct sunlight is received by this façade after the sun has moved over.

AHU W1 experienced the interesting case where significant amounts of cooling and heating energy was used from its economy cycle. The western façade seems to be ideally positioned for harnessing the cooling and heating capabilities of the outdoor air. It may also betray the fact that these areas lose a lot of its heat through the façades.

Alternatively, the outdoor conditions at the AHU fresh air intake might be more favourable than that of AHU NE1. For example, when comparing the outdoor conditions for these two AHU's on 22 August, clear differences can be seen. On this colder day, where no cooling energy was used by either AHU, some heating energy was used by AHU W1. The average outdoor temperature on this day at AHU W1 was a full $2^{\circ}C$ higher at $17^{\circ}C$ compared to $15^{\circ}C$ at AHU NE1. The enthalpy was also $2kJ/kg$ ($5.6 \times 10^{-4}kWh/kg$) higher at AHU W1.

These results would need to be compared to the total consumption of each unit for this day, but it is clear that irrespective of contributing factors, this AHU is making use of the outdoor conditions for cooling and heating purposes that would otherwise have been performed by PCW, CHW or HHW. The total savings each day might not be as high as expected compared to AHU NE1, but the different AHU's operate at different loads making it impossible to compare the total consumption of any two AHU's.

AHU SE1 serves areas that are mostly devoid of direct sunlight during winter months, but on similar days to that of the cooling peaks for AHU NE1, it does experience some relatively high cooling energy being consumed through its economy cycle.

The possible repercussions of these results on HVAC designs will require further investigation, but it is clear that factors such as plantroom and / or conditioned area location play a considerable role in the effectiveness of the economy cycle feature. These results would also need to be monitored throughout the year for the effect of seasonal changes. The energy savings potential of this feature is also clearly visible when designed and positioned in the right way.

4.2.2 Electrical energy

Similar graphs were generated for the building's electrical energy consumption in Figures 4.7 and 4.8. The same assumptions apply here, although it has been observed that changes in outdoor conditions have a less extreme influence on the electrical power consumption.

The June testing and commissioning period has been excluded from Figure 4.7 as the recorded data for that period is unreliable and inconsistent. Due to a software issue with the electrical power meters up to the time of writing, only power consumption data was available on the BMS and no energy data.

Figure 4.7 shows the same data in three different formats. It looks at the electrical power consumption of the four main rooftop plantrooms measured by the Schneider Electric power meters in the DB's of each of these plantrooms.

Supply and return air fans of the central AHU's are responsible for most of the consumption in these plantrooms. However all of the plantrooms also power additional equipment from its DB's, like the printer room and tea kitchen extract fans powered from the W1 plantroom on the north side and from the NE2 plantroom on the south side. The ablution extract fan for levels one to five is powered from the W2 plantroom and each

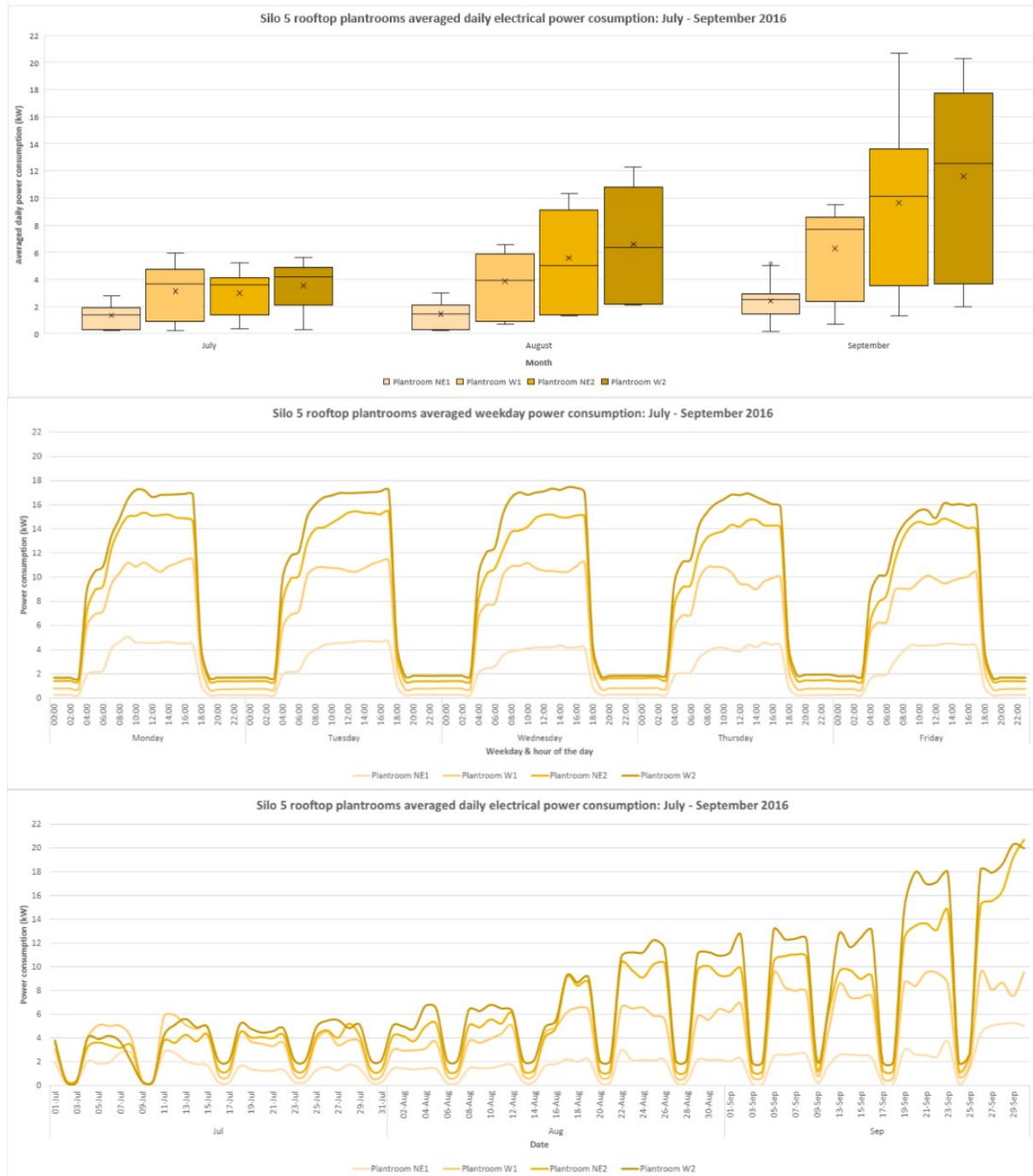


Figure 4.7: Multiple graphs of averaged daily electrical power consumption presented in different forms

of the plantrooms powers three of the twelve street pressurisation fans. The low voltage BMS panel of each plantroom is also powered from the DB's. NE1 and W1 plantrooms only house two central AHU's each, while the other two houses three each. As stated before, AHU's serve different areas and operate at different loads that cannot be compared to each other.

The box-and-whisker plot in Figure 4.7 show the plantrooms running at very similar loads during the first month of building occupation. In the following months the loads of the plantrooms increase by varying degrees, with the W2 plantroom experiencing the biggest increase in average daily electrical power consumption.

The varying increases for the different plantrooms confirms that changes were experienced by the central AHU's and not other equipment as it corresponds to the number of AHU's in the plantrooms. The generally high variance in the distribution can be explained by the fact that the data includes values for all hours of the day as well as weekends and therefore also accounts for non-working hours. The increases in electrical power demand do not correlate with the thermal power consumption data shown in Figure 4.2 or the energy consumption distribution shown in Figure 4.3. It is therefore assumed that these increases were caused by changes to system controls.

Specifically, in August, an overpressure problem in the building caused a decision to be made to increase the return air fan speeds for all AHU's to relieve this pressure. Also, as stated before the supply air fan pressure set points were increased considerably for all AHU's in September to achieve higher airflows in the building. As return air fan speeds are also interlocked with supply air fan speeds, the increase would have a cumulative effect on the power demand. The high maximum value for the NE2 plantroom in September might be a reason concern and should be investigated as this will increase the peak demand tariff that was discussed earlier.

The graph gives a good overview of the spread of a large amount of data and should be monitored for unusual changes. The interval of the box plots can be increased to weekly, to get a more accurate representation of sudden changes.

The second graph in this figure indicates the power demand profile of each plantroom from Monday to Friday, averaged over three months. It is not intended to give an accurate depiction of specific events, but rather provide a smoothed out view of daily demand patterns.

What is interesting from this is that by averaging the data over three months, the effects of varying outdoor conditions and other sudden changes should be neutralised and the curves should be more or less identical for all days of the week since equipment running schedules are the same for each day. The fact that this is not the case for all plantrooms may indicate towards the influence of occupant behaviour.

Plantroom NE1 has the most constant curve throughout the week except for a peak on Monday mornings and slight variance in demand during Thursday afternoons.

The Monday morning peaks are visible for all the plantrooms and might be caused by the building requiring extra conditioning after systems were turned off for the entire weekend. The effect of the changing of system start-up times midway through August is also clearly visible in the lower values between 04:00 and 06:00 on all days for all plantrooms.

Another interesting occurrence is that on all days of the week, the W1 plantroom experiences a decrease in demand around midday and at the same time the NE2 plantroom experiences an almost identical increase in demand. This can very well be caused by the fact that PwC's canteen area on the fifth floor is served primarily by the NE2 plantroom AHU's as well as two of the W2 plantroom AHU's. During lunch time people move from their office areas to the canteen area, decreasing the demand in the office areas and significantly increasing the demand in the canteen.

Most of the plantrooms experience an increase in demand right at the end of the working day. This is due to people becoming more active, packing up, moving out and opening doors which requires more conditioning, but also increased fan pressures to counteract the pressure drop caused by doors opening to unconditioned areas.

These demand profile curves can provide valuable insight into the effects of occupant behaviour on the energy consumption of a building that leaves occupants with very little tangible control over their consumption. More accurate insights should be visible by

plotting this graph for each AHU and averaging data for each season of the year. A logarithmic scale might also be useful to track notable changes.

The final graph in Figure 4.7 shows a more progressive view of the changes in demand, already discussed above, over time for the different plantrooms. Specific events can more easily be identified from the graph. Weekly trends are less clear, but it does seem as if there are weekly dips in demand on certain days for certain plantrooms. The effect of the control changes can also clearly be seen in the significantly increased demands which will have a negative effect on energy costs, but improve occupant comfort. The same graph for energy consumption might also be useful as soon as the data becomes available.

Figure 4.8 displays the aggregated hourly electrical power consumption of all the metered HVAC DB's, averaged over the month of August. This is of particular value to identify the contribution of each HVAC system to the total power demand at any point during the day. It highlights where to focus energy saving practices.

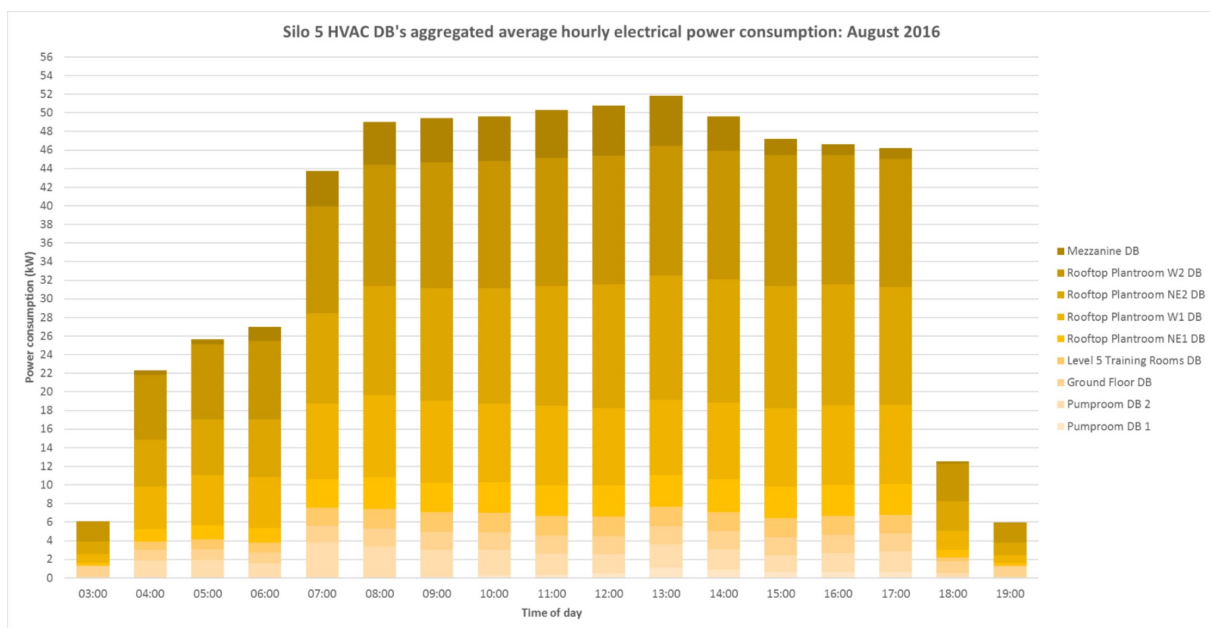


Figure 4.8: Aggregated average hourly electrical power consumption of all HVAC DB's

When this data is available for all building systems, an accurate view can be provided of a building's peak electrical power demand and the time at which it occurs. By looking into each system at that point, savings can be achieved through peak demand clipping.

For the BMS metered HVAC systems of Silo 5 the peak demand for August seems to around 13:00, which is when all extraction canopies in the PwC kitchen are operating (mezzanine DB) and the canteen area experiences an increased air conditioning demand. The option could be investigated, if certain areas are left unoccupied at that time, to switch those systems off or lower their operating speeds during that time.

There also exists a residual power demand after working hours to keep certain systems running. This demand needs to be minimised as far as possible to reduce unnecessary energy wastage during after-hours.

Chapter 5

Conclusion

This chapter concludes the research. A summary of the completed work is provided. Conclusions are made based on the research objectives and the results that were obtained. The potential application of these results are discussed and recommendations for future work are made.

5.1 Summary of work

This research focuses on the design and assessment of an energy efficient office building, with emphasis on the use of a building management system to improve efficiencies and reduce resource consumption.

In a country where water and energy supplies are volatile at best, it is essential for businesses to reduce their dependency on state supply of these resources, but also to do their part to decrease their environmental footprint. To that end, the design, construction and early operation of a new office building in the Cape Town area were critically assessed to establish the amount of savings or savings potential, if any, of such a building.

Chapter 1 introduces the Silo 5 building, provides a short summary of the current state of affairs regarding resources in South Africa and presents the research objectives.

This is followed, in Chapter 2, by a comprehensive literature review of different facets that influence a building's resource efficiency, focussing on areas that are applicable to Silo 5. In depth descriptions are given, challenges and limitations are discussed and previously achieved savings are continuously referenced. Discussion points include the green building rating structure, building management systems and different approaches toward reducing or controlling resource consumption. A case study of an existing building is also analysed to demonstrate the practical application of some of the approaches.

In Chapter 3, comprehensive descriptions are given of the design and operation of the Silo 5 HVAC systems as well as the district cooling system and Silo 5 BMS. This is followed by the energy saving practices from the previous chapter that were applied to the Silo 5 design and operations. The chapter is concluded with methods of quantifying savings that are achieved.

Processed data from the BMS is presented in Chapter 4, interpreting different results and discussing the usefulness of the different types of information. Visible savings are also identified from the results and discussed in depth.

In the next section these results are used to respond to the research objectives posed in the introductory chapter.

5.2 Conclusions

The research aimed to investigate and analyse different methods of reducing energy consumption or improving system efficiencies of a newly constructed office building. The impact of the green building certification process and, more specifically, the influence of a building management system on these methods were analysed. This information was used to evaluate energy saving practices incorporated into the design, construction and operation of the Silo 5 building in the Cape Town area. The Silo 5 BMS functionality was tested and actual data provided by the BMS was used to investigate potential savings achieved at the Silo 5 building.

Through this work all of the objectives set out in Section 1.5 were achieved, while also highlighting some unexpected, but valuable results.

The green building rating system in South Africa was shown to have an immense impact on improving the resource efficiency of office buildings due to its widespread implementation. Through this Green Star SA rating system, the GBCSA manages to create awareness about the responsible use of resources. With its different categories and credits it drives the improvement of resource efficiencies as well as the reducing of, or at least the closely and real-time monitoring of resource consumption. It was however, also found to be flawed in some areas, where its points structure could better reflect the urgency of the state of a critical resource such as water in South Africa.

Numerous energy and water saving practices were found that, while not currently being widely employed by office buildings, are reported to achieve substantial savings while still being affordable. Some high cost, high savings methods were also found to be feasible through shortened payback periods. The consolidation of this broad-ranging material provides a uncommon and valuable source of information.

The BMS has been proven, through vigorous testing, to be an invaluable tool when utilised to its full potential. The range of operational data that it can provide was shown to be extremely useful for the monitoring of building systems' health, identifying wastage, keeping track of equipment maintenance as well as assisting with the optimisation of all systems. When effectively processed, its data also provides insights into resource consumption trends and can, with further research, be used to model and predict consumption profiles.

It is scalable and transferable to almost any size or type of facility. Its primary benefit lies in the provision of comprehensive building systems data from a central point. Additional features such as the Johnson Controls MED software further increases its functionality by providing energy analysis and billing capabilities. The system can be developed to be the central control point of all electronic building services.

The Silo 5 tests also provided valuable insights into the driving force behind varying energy consumption of HVAC systems and how this can be controlled to a certain degree. It also showed that savings are being achieved at Silo 5 through the use of the seawater district cooling system, validating design expectations presented in Section 3.3.

Pre-cooling water provides near free cooling in terms of the required energy input and is exclusively used for the building's cooling purposes as long as it can satisfy the demand. Chilled and heating hot water are produced through chillers operating at above average efficiencies also due to the use of seawater. The savings generated from the CHW and HHW efficiencies cannot be confirmed without baseline or conventional system data, but plant efficiencies can be calculated and compared to traditional system efficiencies (see Section 3.3).

In addition to the district cooling savings, favourable results were also observed through the use of the economy cycle feature of Silo 5 central AHU's. Units serving spaces bordering façades that face a north easterly or western direction were shown to achieve substantial savings through this feature, while internal or south easterly facing areas experienced negligible savings during the winter months for which data was captured. Western facing areas were also benefiting from both heating and cooling savings, while north easterly facing areas only experienced cooling savings.

These type of results has not previously been reported on or is not commonly known in the industry. The application thereof can have far reaching effects for the design and placement of HVAC equipment as well as tenant layouts or even building orientation. The results are however only based on the two months of data that was available at the time and will need to be monitored further.

5.3 Future work

While the research succeeded in achieving its objectives, it also uncovered numerous areas or factors that warrant further investigation. Due to its practical nature, the research was also restricted by the scope and time frame of the building project it investigated. Recommendations for future work are thus made below, including potential applications of the above mentioned results.

Due to building construction only being completed in June of 2016, extensive usage data could not be captured in the available time frame. As with all new buildings, system operations and control need to be refined in the months after construction which may cause irregularities in measured data. The tests performed in Chapter 4 should therefore be re-evaluated after building data has been captured for more than a year. HVAC systems will be operating under higher demand during the sometimes extremely warm summer months and savings from the district cooling system and economy cycle feature would need to be monitored throughout this time to provide a true indication of available yearly energy savings. Operating efficiencies of all systems should be calculated and monitored throughout the year as well to compare against published conventional system efficiencies.

Monitoring and controlling of domestic water services by a BMS is still a possibility that the V&A is considering at Silo 5. The potential savings that can be achieved with such a system as described in Chapter 2 should be investigated as it could provide a way forward for businesses and the country to use water more responsibly.

The behavioural effect of providing timely consumption data to building occupants has been shown through literature in Section 2.5.2 to be worth investigating for possible savings. Even in modern office buildings where the control of resource consumption is mostly automated, results in Section 4.2.2 have shown that occupant behaviour might still have a meaningful influence on consumption. PwC, the main tenant at Silo 5, is interested in providing resource consumption data to clients and staff members through a screen located in their ground floor reception area. This should provide an opportunity to perform preliminary tests for this cause.

There is also a general notion from literature and industry experience that building owners utilising building management systems rarely have access to all of a facility's operational data, current and historical, preventing them from using the BMS to its full potential. The optimisation methods described in Section 2.4.2 and utilising monitored consumption data as in Section 2.5 cannot be achieved without access to all of building's operational data. In the case of Silo 5 the data might be accessible, but it is not being

used to this extent. One limitation in terms of HVAC services is the lack of airflow or disk position data at each diffuser, which causes great uncertainty when troubleshooting a system. The Vodacom Techno Centre employs some of these methods (see Section 2.6), but it would be beneficial to investigate the savings that can be achieved by a green office building through these methods.

Finally, the Johnson Controls MED software that is in development for Silo 5, will provide energy analysis and billing capabilities that can also contribute towards meaningful savings.

Results achieved through this research have proved the savings potential of certain energy efficient practices. It has also displayed the value of investing into a comprehensive building management system. Green buildings have in some circles been misleadingly represented as a public relations ploy used by corporate establishments to win over public opinion and increase profits. However, Green Star SA certified buildings have been shown to be just as affordable as conventional buildings in many cases, providing meaningful savings in resources and costs. Besides the financial benefits, the dire state of energy and water resources in South Africa calls individuals and businesses to action. Saving energy and water can no longer be only a moral obligation. It needs to become a way of life and resource efficient buildings is big step towards that solution.

Appendices

Appendix A

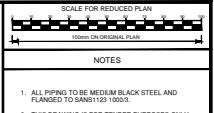
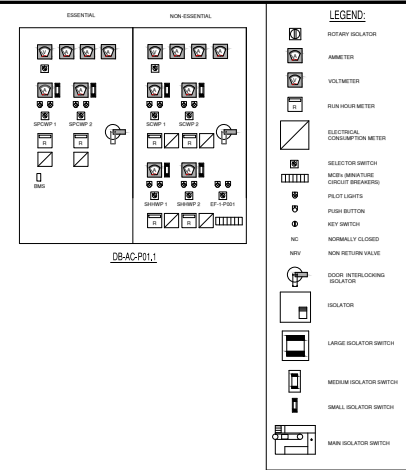
Silo 5 HVAC design drawings (NTS)

SCHEDULE OF FANS							
NUMBER	DESCRIPTION	MAKE	MODEL	SIZE	DUTY	ACCESSORIES	CONTROLS
EF-1-F001	WALL MOUNTED FAN	AMS	HM 003	400mm x 400mm	200 Pa @ 30 Pa static		ON OFF WITH THERMOSTAT
NOTE: EQUIPMENT NAME ON DRAWINGS WILL BE ABBREVIATED. THE 4 DIGIT INDICATING THE DRAWING NUMBER WILL BE OMITTED.							

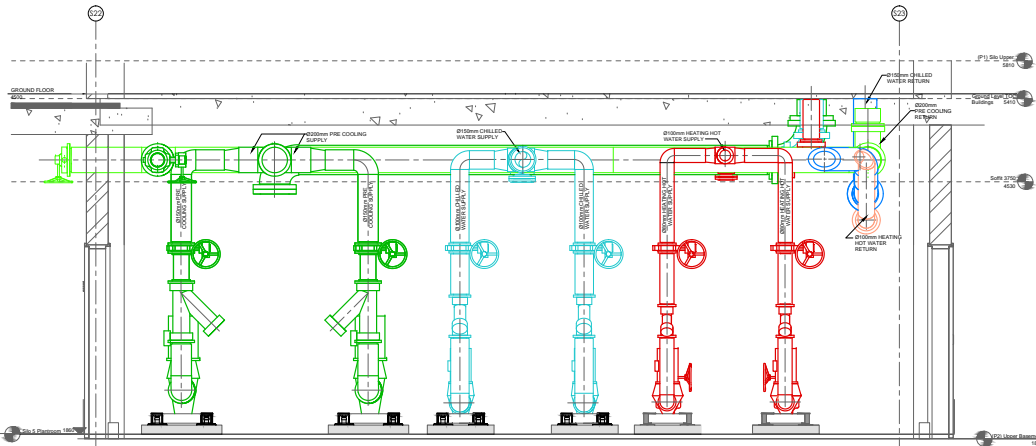
SCHEDULE OF EQUIPMENT							
NUMBER	DESCRIPTION	MAKE	SIZE (NECK)	TYPE	FRAME	ACCESSORIES	QTY
MC-1	MECHANICAL CONTROL	ELCOPAK	400mm x 400mm	S&P	SP 001	QED, EPC	2
EP-1	ELECTRICAL POWER SUPPLY	ELECTROTEC	400mm x 400mm	EPD	-	-	2

SCHEDULE OF PUMPS							
PUMP NUMBER	MAKE	MODEL	DUTY	IMPELLER DIAMETER	MOTOR RPM	VSD	CONCRETE PLINTH SIZE (mm)
SPCWP1	BRUNNEN	TPE	125000	183.075	1465	YES	TBC
SPCWP2	BRUNNEN	TPE	125000	183.075	1465	YES	TBC
SCWP1	BRUNNEN	TPE	125000	183.075	1465	YES	TBC
SCWP2	BRUNNEN	TPE	125000	183.075	1465	YES	TBC
SHWP1	BRUNNEN	TPE	125000	183.075	1465	YES	TBC
SHWP2	BRUNNEN	TPE	125000	183.075	1465	YES	TBC

FAULT LEVEL RATING - 10KA					
DB-AC-P01.1 ELECTRICAL POWER REQUIREMENTS kVA (400/3/50)					
PUMP	NON ESSENTIAL POWER		ESSENTIAL POWER		TOTAL
	SUMMER	WINTER	SUMMER	WINTER	
SPCWP1	0.00	0.00	0.00	0.00	
SPCWP2	0.00	0.00	0.00	0.00	
SCWP1	4.5	0.00	0.00	0.00	
SCWP2	4.5	0.00	0.00	0.00	
SHWP1	4.5	0.00	0.00	0.00	
SHWP2	4.5	0.00	0.00	0.00	
Control	0.00	0.00	1.2	1.2	
	18.00	0.00	28.20	00.00	



- NOTES**
- ALL PIPING TO BE MEDIUM BLACK STEEL AND FLANGED TO SANS120 12003.
 - THIS DRAWING IS FOR TENDER PURPOSES ONLY. WORKING DRAWINGS SHALL BE SUBMITTED FOR APPROVAL PRIOR TO CONSTRUCTION.
 - REDUCING SHALL BE MANUFACTURED WITH A MAXIMUM 8° DEFLECTION ANGLE.
 - FIRE - FLANGED BOTH ENDS
F&E - FLANGED ALL ENDS
TBC - TO BE CONFIRMED ON SITE
 - PIPE INSULATION TO BE 30kg/m³ O-GOP FRODOFORM-K1.
 - PIPE INSULATION THICKNESS AS FOLLOWS:
CHILLED WATER
15 - 40mm - 20mm
45 - 100mm - 25mm
105 - 200mm - 30mm
HOT WATER
15 - 20mm - 20mm
45 - 100mm - 25mm
105 - 200mm - 30mm
PRE-COOLING WATER
15 - 40mm - 25mm
45 - 100mm - 30mm
 - VAPOUR BARRIER TO BE GRP COLOUR CODED FOR CW, HW, & PCW.

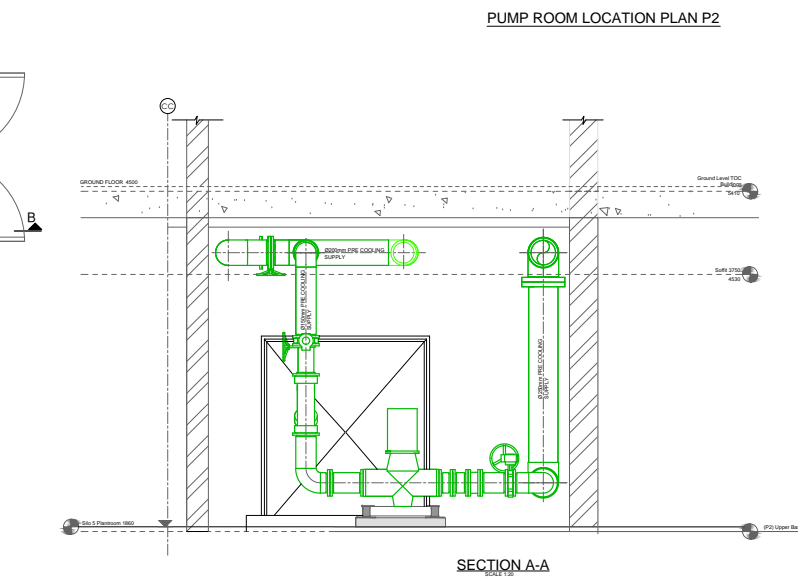
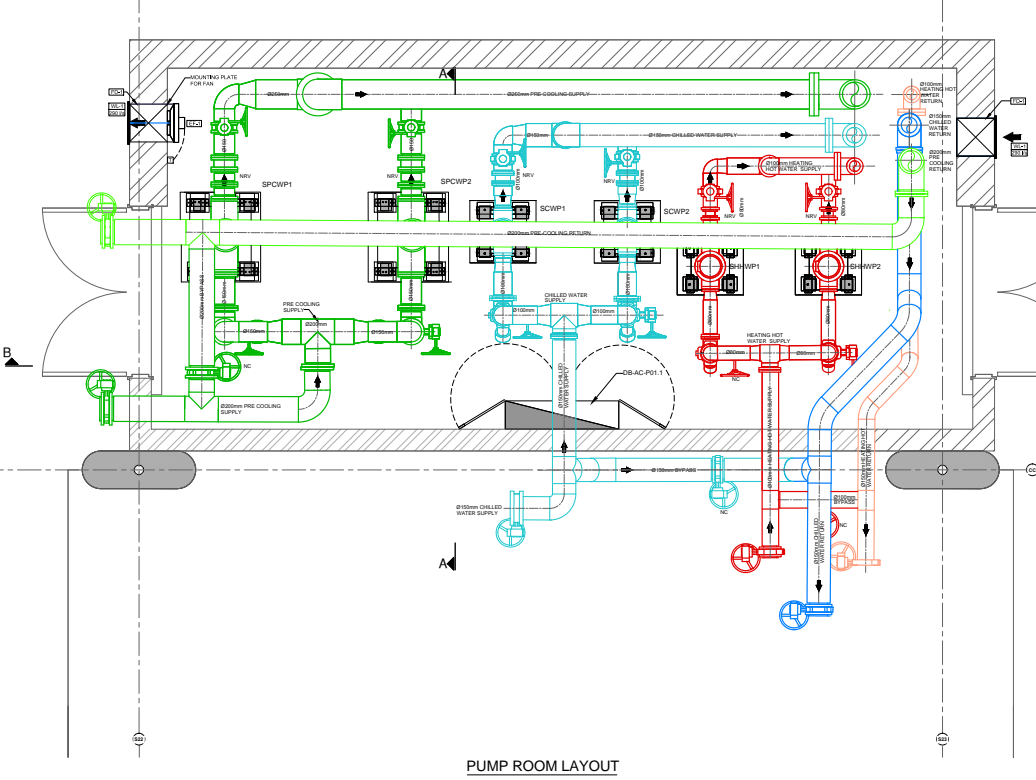
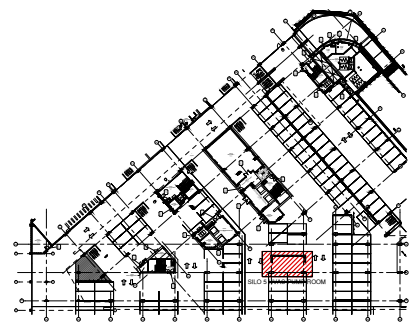


- PROTECTION**
- PUMP SHALL BE PROTECTED VIA THE FOLLOWING ITEMS:
WHEN PUMP IS PUMPING AT AGAINST SHUT CONTROL, VALVES 1/4 MINIMUM FLOW, AN ADJUSTABLE DELAY TIMER SHALL STOP PUMPS WHEN NO-COOLING, HEATING OR PRE-COOLING IS REQUIRED.
 - OVERLOAD PROTECTION: MCC OR VSD SHALL INCLUDE PUMP OVERLOAD PROTECTION (AMPS) TO SAT.
 - PRESSURE SWITCH WHEN IN RUNNING MODE, PRESSURE DROPS SIGNIFICANTLY BELOW MINIMUM PRESSURE, INDICATING A PIPE BURST, PUMP SHALL BE STOPPED AT SET PRESSURE, TO PREVENT OVERLOADING.

- OPERATION**
- IN AUTOMATIC MODE, MCC WILL RECEIVE START SIGNAL FROM BMS CONTROLLER VIA A CONTROL CABLE (BOTH SUPPLIED BY OTHERS).
 - IN MANUAL MODE, MCC WILL START PUMP AND WILL STOP AS SOON AS THE STOP BUTTON IS DEPRESSED, OR THE PUMP CUTS OUT AS A RESULT OF ANY OF THE PROTECTION FEATURES.
 - IN OFF MODE, CONTROL SIGNALS SHALL NOT BE ABLE TO START PUMPS.

- MECHANICAL SPECIFICATION**
- ALL VALVES, FITTINGS AND EQUIPMENT SHALL BE RATED AT A MINIMUM OF 10 BAR.
 - NUTS, BOLTS, READY BAR (THREADED ROD) AND WASHERS (TWO PER BOLT SET) SHALL BE GALVANISED MILD STEEL.
 - PLANT WORKING DRAWINGS SHALL BE SUBMITTED BY THE SUCCESSFUL CONTRACTOR FOR APPROVAL PRIOR TO CONSTRUCTION.

- ELECTRICAL SPECIFICATION**
- MCC SHALL BE HOUSED IN A LOCKABLE CABINET (COLOUR TO BE CONFIRMED), ON A GALVANISED STAND.
 - MCC SHALL INCLUDE MAIN CIRCUIT BREAKER, AND AMMETERS TO SAT, AS WELL AS ALL OTHER NECESSARY FEATURES AS PER SPECIFICATION AND DB DRAWING.
 - MCC SHALL HAVE SELECTOR SWITCH GIVING A CHOICE BETWEEN AUTOMATIC / OFF / WITH STOP / START BUTTONS FOR MANUAL MODE.
 - MCC SHALL HAVE RUNNING INDICATOR LIGHT, AS WELL AS INDICATOR LIGHTS FOR ALL POSSIBLE FAULTS (AS PER PROTECTION SPECIFICATION), AND LAMP TEST.



AMENDMENT		
NO.	DATE	DESCRIPTION
1	15/08/2015	ELCOPAK

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resources & energy

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TEL: (021) 912 3200
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www.worleyparsons.com

DESIGNED	DRAWN	CHECKED
ELRM	CWS	EL

DATE: 2015-08-26
CONSULTING ENGINEER

CLIENT: _____ DATE: _____

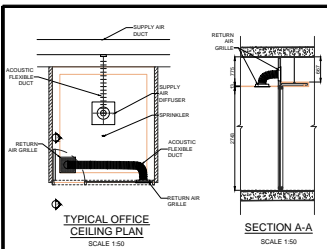
CLIENT: Reg. No. 880634007
P.O. Box 50001
Waterfront
8002
Cape Town
South Africa
Tel. +27 421 418 2350

PROJECT: **V&A WATERFRONT SILO 5**

DRAWING DESCRIPTION: **HVAC PUMP ROOM UPPER BASEMENT (P2) LAYOUT**

SCALE	DATE
AS SHOWN	NOVEMBER 2014

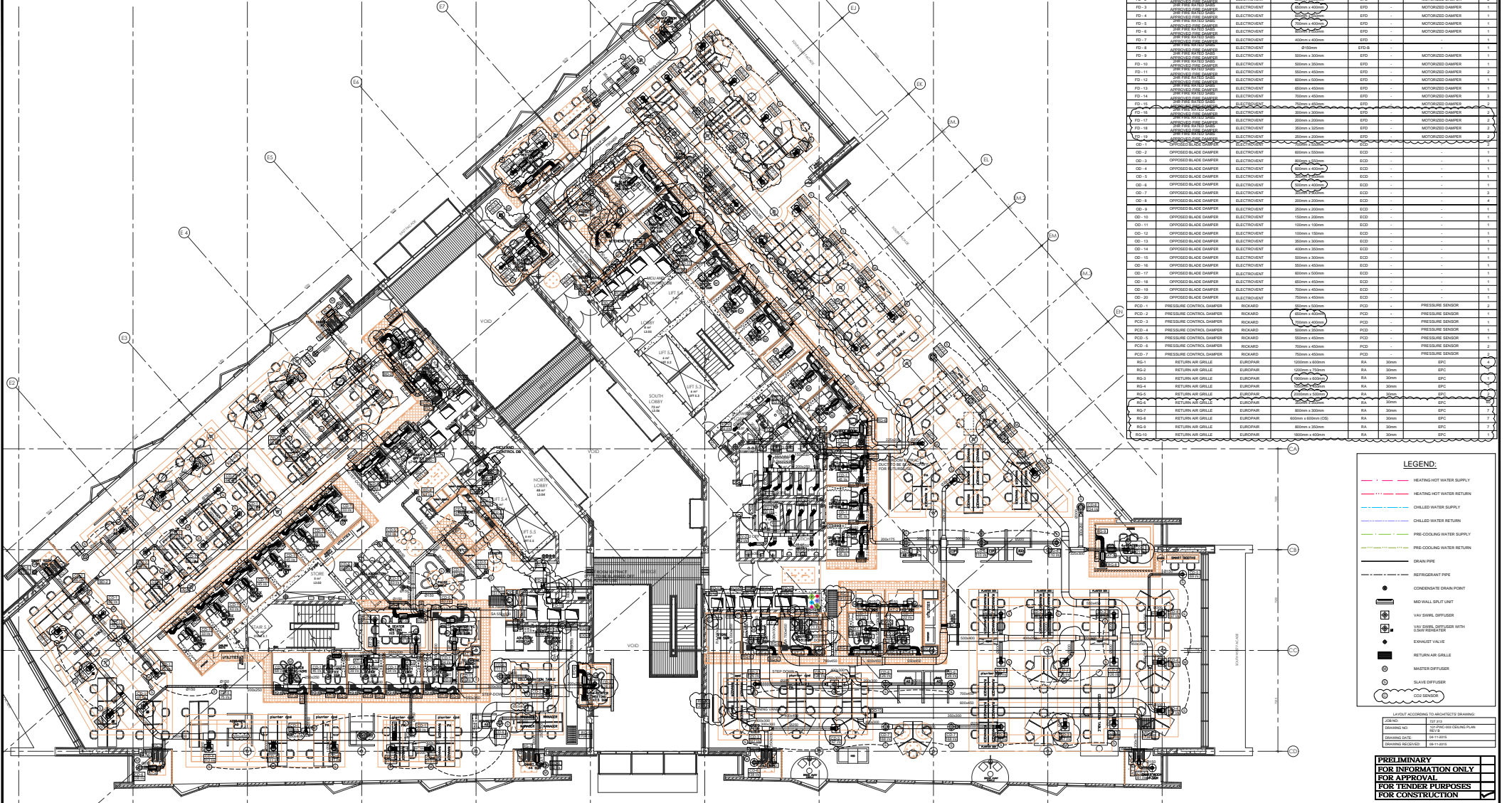
DRAWING NUMBER: 28155-S5-HV-DAL-0009
REV NO: A



- NOTES:
1. SUPPLY AIR AND RETURN AIR TO BE INSULATED IN CEILING VOIDS.
2. RETURN AIR DUCTING TO BE 1.6mm BLACK STEEL FOR SMOKE EXTRACT PURPOSES.
3. SPRINKLER PIPES TO RUN HARD-UP AGAINST SOFFIT.
4. DUCTING TO BE INSTALLED HARD-UP AGAINST SPRINKLER PIPES.
5. REFER TO INTERIOR ARCHITECT'S DRAWING FOR FINAL DIFFUSER/GRILLE POSITION AND COLOUR.
6. WHERE DUCTS PENETRATE PARTITIONS, REFER TO ACOUSTIC CONSULTANT'S DUCT PENETRATION DETAIL.

SCHEDULE OF EQUIPMENT table with columns: NUMBER, DESCRIPTION, MAKE, SIZE (NECK), TYPE, FRAME, ACCESSORIES, QTY. Lists circular and rectangular sound attenuators.

SCHEDULE OF EQUIPMENT table with columns: NUMBER, DESCRIPTION, MAKE, SIZE (NECK), TYPE, FRAME, ACCESSORIES, QTY. Lists butterfly and ceiling diffusers.



LEGEND: HEATING HOT WATER SUPPLY, HEATING HOT WATER RETURN, CHILLED WATER SUPPLY, CHILLED WATER RETURN, PRE-COOLING WATER SUPPLY, PRE-COOLING WATER RETURN, DRAIN PIPE, REFRIGERANT PIPE, CONDENSATE DRAIN POINT, MID-WALL SPLIT UNIT, VAV SPLIT DIFFUSER, VAV SPLIT DIFFUSER WITH LEAK REDUCTOR, EXHAUST VALVE, RETURN AIR GRILLE, MASTER DIFFUSER, SLAVE DIFFUSER.

Preliminary information block including drawing title 'V&A WATERFRONT SILO 5 LEVEL 3 HVAC LAYOUT', scale '1:100', date 'DECEMBER 2014', and 'FOR TENDER PURPOSES' disclaimer.

Revision table with columns: NO, DATE, CHECKED BY, DONE BY, DESCRIPTION. Lists amendments to the drawing.

WorleyParsons resources & energy logo and contact information.

Project and client information table including 'DESIGNED', 'DRAWN', 'CHECKED', 'DATE', 'CLIENT', 'PROJECT', 'DRAWING DESCRIPTION'.

Client and project details table including 'CLIENT: V&A WATERFRONT SILO 5', 'PROJECT: V&A WATERFRONT SILO 5', and 'DRAWING DESCRIPTION: LEVEL 3 HVAC LAYOUT'.

SCHEDULE OF EQUIPMENT

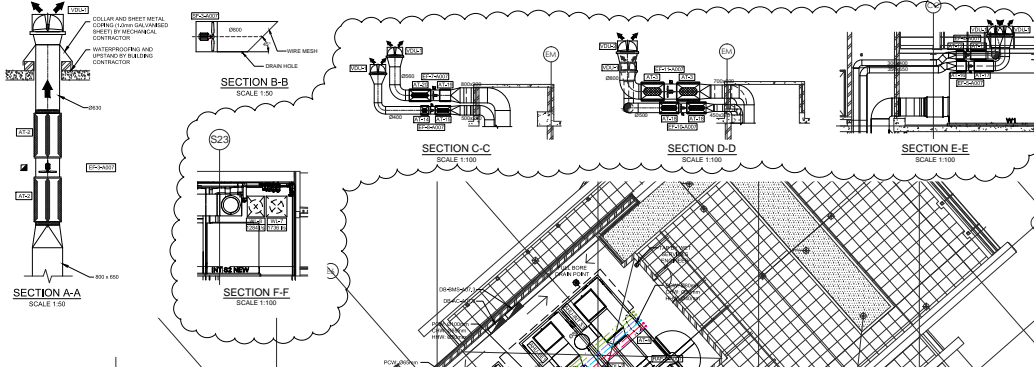
Table with columns: NUMBER, DESCRIPTION, MAKE, SIZE (NECK), TYPE, FRAME, ACCESSORIES, QTY. Lists various equipment like cylindrical sound attenuators, ductwork, and filters.

SCHEDULE OF CHILLED / HOT WATER AIR HANDLING UNITS (4 - PIPE)

Table with columns: NUMBER, MAKE, TYPE, COOLING (TOTAL kW, ENTERING/LEAVING DBWB, PCW FLOW), HEATING (TOTAL kW, ENTERING/LEAVING DBWB, HW FLOW), SUPPLY AIR (L/S), CONTROLS, FIRE INTERLOCK.

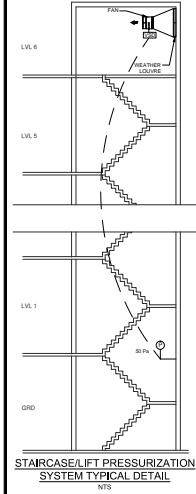
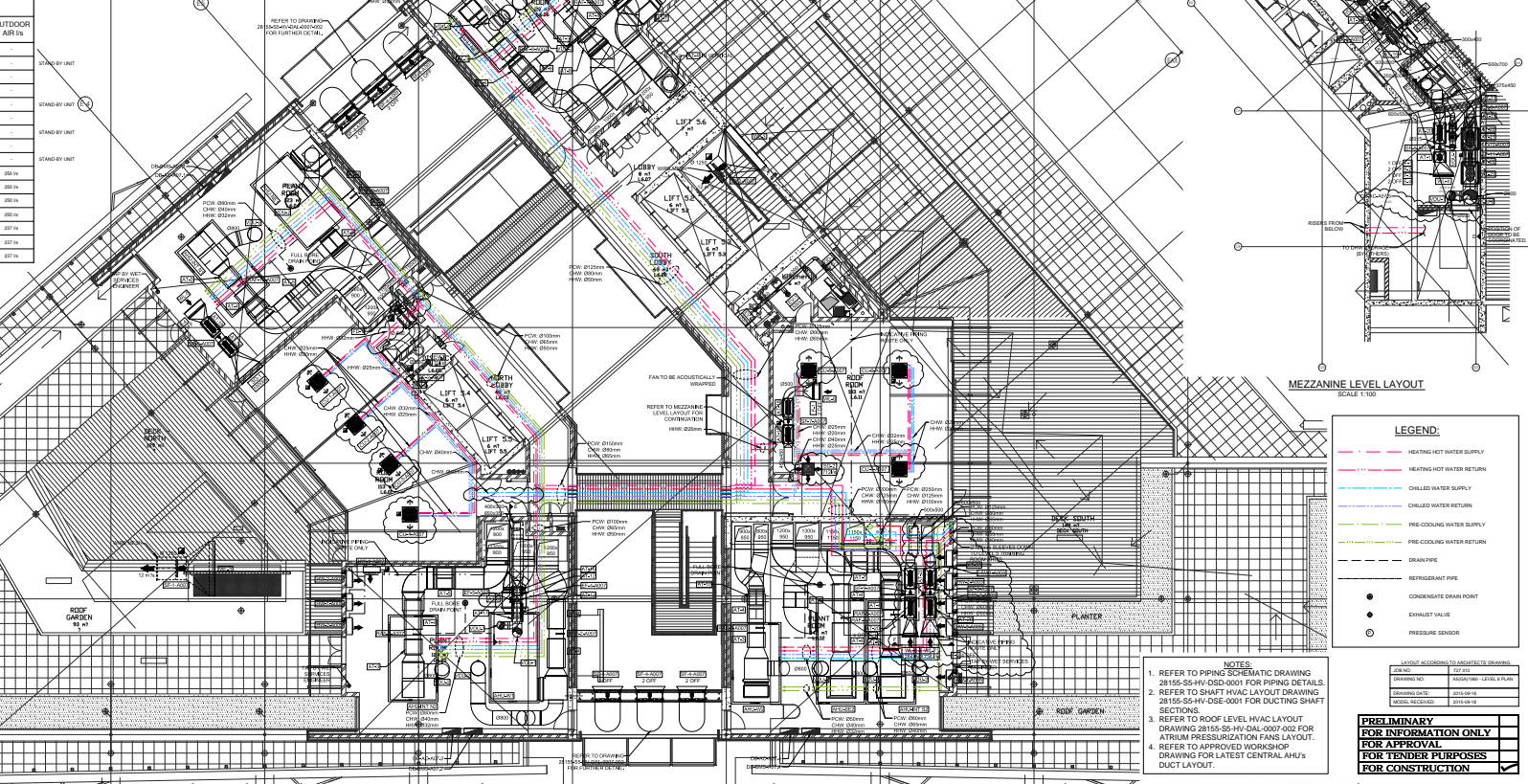
SCHEDULE OF FANS

Table with columns: NUMBER, DESCRIPTION, MAKE, MODEL, SIZE, DUTY, FAN SPEED, CONTROLS, FIRE INTERLOCK.

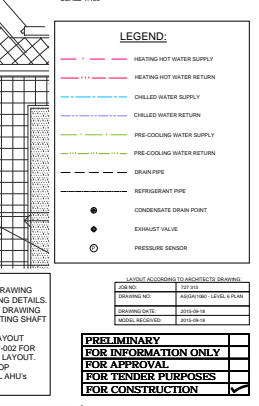


SCHEDULE OF AIR CONDITIONING UNITS

Table with columns: UNIT NO, MAKE, MODEL, OUTDOOR UNIT, TOTAL COOLING, SENSIBLE COOLING, HEATING, ON COIL TEMPERATURE, OFF COIL TEMPERATURE, UNIT SUPPLY AIR @ ESP, OUTDOOR AIR IS.



MEZZANINE LEVEL LAYOUT



LEGEND and NOTES. Legend includes Heating Hot Water Supply, Chilled Water Supply, Pre-cooling Water Supply, etc. Notes refer to piping and ducting drawings.

Table with columns: NO, DATE, CHECKED, DRAWN, DESCRIPTION. Lists drawing amendments.

SCALE FOR REDUCED PLAN and SYSTEM OPERATION details. Includes a scale bar and operating conditions for the AHU.

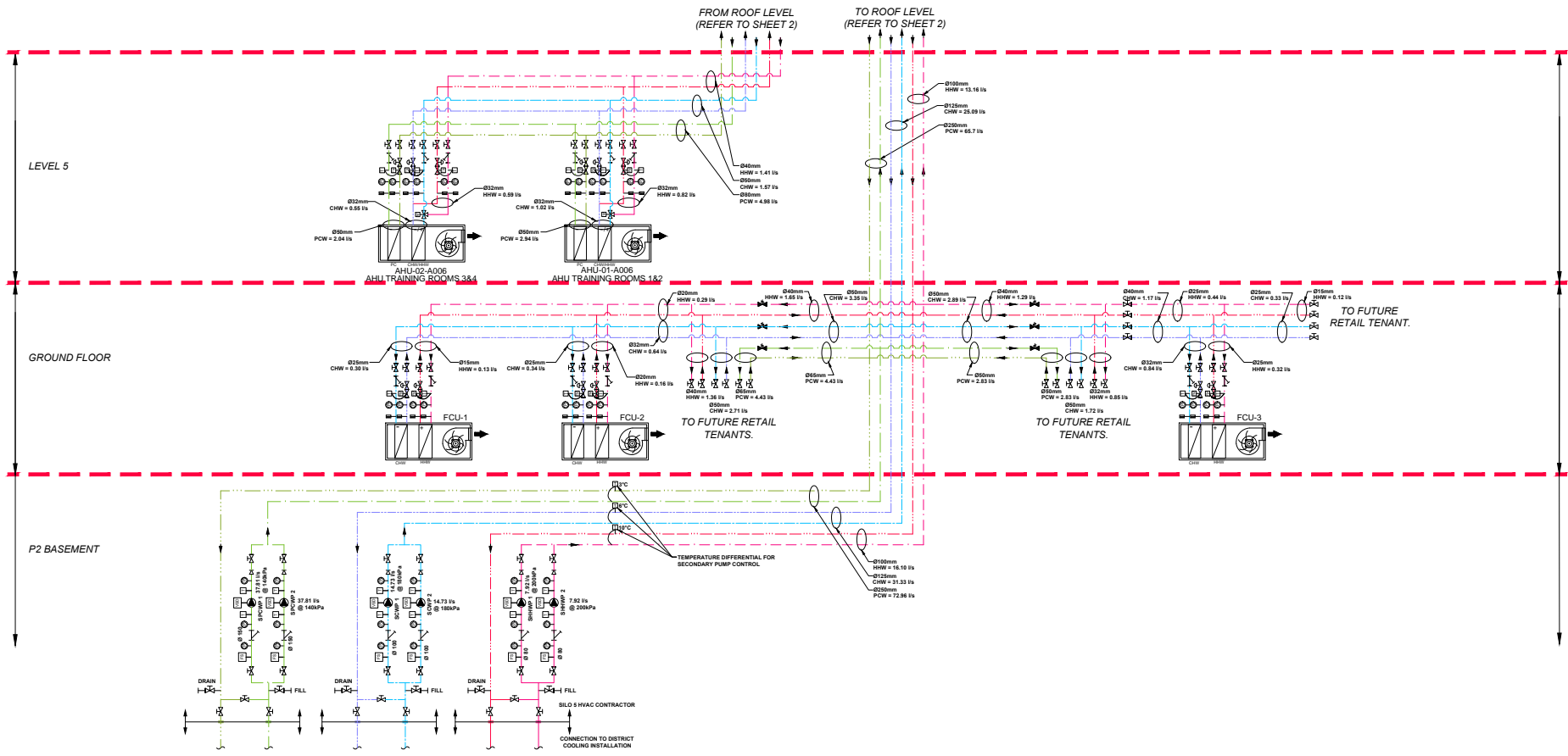
WorleyParsons logo and contact information.

CLIENT and PROJECT information. Includes drawing title 'ROOF LEVEL HVAC LAYOUT' and drawing number '28155-SS-HV-DAL-007-001'.

CONSULTING ENGINEER and ARCHITECT information. Includes names and contact details for the engineering firm and the architect.

DATE, DRAWING DESCRIPTION, SCALE, and REVNO information. Includes the date '2016-02-09' and drawing scale '1:100'.

- NOTES:**
1. ALL PIPING SHALL BE INSULATED.
 2. ALL INSULATION MATERIAL TO BE GIBCSA APPROVED.
 3. NO PVC ALLOWED.
 4. ALL CLOSED LOOP PIPING SHALL BE STEEL PIPING TO SABS 402.
 5. INTERNAL EXPOSED PIPING SHALL BE INSULATED WITH GIBCSA APPROVED INSULATION AND GRP VAPOUR BARRIER.
 6. REFER TO ROOF LEVEL HVAC LAYOUT DRAWING AND RISE MODEL FOR PIPE HEIGHTS.
 7. PIPING INSTALLATION IS SUBJECT TO THE PROJECT SPECIFICATION.
 8. PRESSURE RELIEF VALVES TO BE INSTALLED AT ALL HIGHEST POINTS.



- LEGEND:**
- Thermometer symbol
 - Temperature sensor symbol
 - Flexible bellow symbol
 - Strainer symbol
 - Pump symbol
 - Behind energy valve symbol
 - Included flow meter, energy meter, control valve, temperature sensing symbol
 - Pressure gauge symbol
 - Non return valve symbol
 - Motorized three-way valve symbol
 - Motorized shut-off valve symbol
 - Isolating valve symbol
 - Isolating valve symbol
 - Two way flow control valve symbol
 - Automatic air relief valve symbol
 - Variable symbol
 - Constant symbol
 - Variable speed drive symbol
 - Pressure sensor symbol
 - Flow switch symbol
 - Flow meter symbol
 - Water detection switch symbol
 - SPCHP symbol
 - Secondary pre-cooling water supply pump symbol
 - SCHWP symbol
 - Secondary chilled supply water pump symbol
 - SHHP symbol
 - Secondary hot water supply pump symbol
- Color-coded lines for water supply and return:
- Heating hot water supply (red dashed)
 - Heating hot water return (red solid)
 - Chilled water supply (blue dashed)
 - Chilled water return (blue solid)
 - Pre-cooling water supply (green dashed)
 - Pre-cooling water return (green solid)
 - Domestic hot water (yellow dashed)
 - Domestic cold water (yellow solid)

PRELIMINARY
FOR INFORMATION ONLY
FOR APPROVAL
FOR TENDER PURPOSES
FOR CONSTRUCTION

NO.	DATE	CHECKED	BY	DESCRIPTION
01	04/12/14	EL	CVL	Add notes
02	05/02/15	EL	PSM	Add training rooms & DRY Heat exchanger. Update flows.
03	13/03/15	EL	PSM	Add ground floor FCUs.
04	21/03/15	EL	PSM	Decrease one 3 way valve on AHU's. Add 022 S. Refer to Rev 02/15.
05	02/03/15	TS	PSM	Corrected piping schematic to match layout.



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DESIGNED	RM	CONSULTING ENGINEER
DRAWN	EA	DATE: 2016-03-10
CHECKED	EL	CLIENT
		DATE

CLIENT

Reg. No. 88/06340/07
 P.O. Box 50001
 Waterfront
 8002
 Cape Town
 South Africa
 Tel. +27 21 418 2350

PROJECT

V&A WATERFRONT
 SILO 5

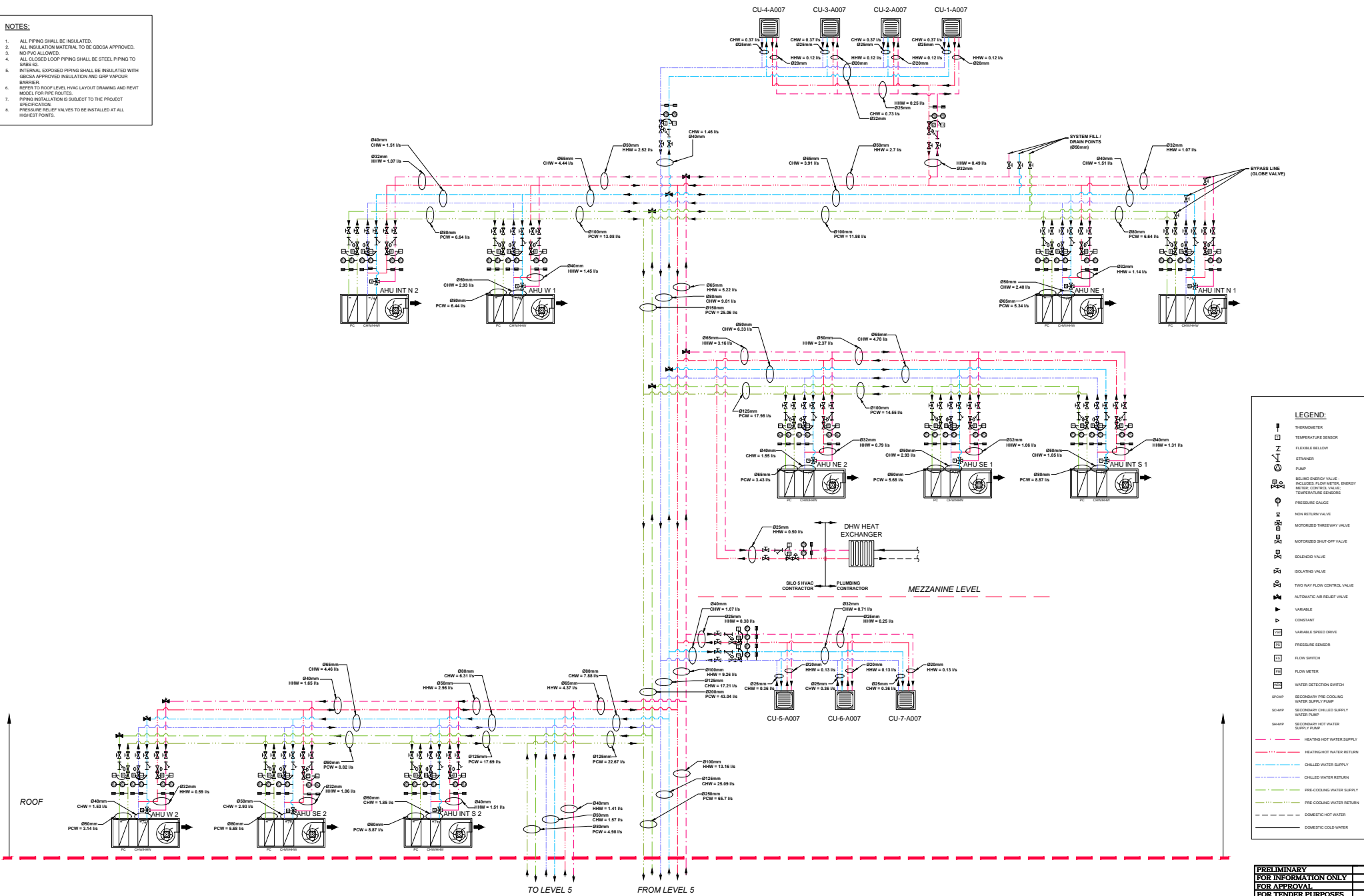
DRAWING DESCRIPTION

PIPING SCHEMATIC

SCALE	NTS
ORIGINAL DWG SIZE A3	
DATE	NOVEMBER 2014
DRAWING NUMBER	28155-S5-HV-DSD-0001-001
REV NO	B

NOTES:

1. ALL PIPING SHALL BE INSULATED.
2. ALL INSULATION MATERIAL TO BE GIBCSA APPROVED.
3. NO PVC ALLOWED.
4. ALL CLOSED LOOP PIPING SHALL BE STEEL PIPING TO SABS 42.
5. INTERNAL EXPOSED PIPING SHALL BE INSULATED WITH GIBCSA APPROVED INSULATION AND GRP VAPOUR BARRIER. REFER TO ROOF LEVEL HVAC LAYOUT DRAWING AND REVIT MODEL FOR PIPE ROUTES.
6. PIPING INSTALLATION IS SUBJECT TO THE PROJECT SPECIFICATION.
7. PRESSURE RELIEF VALVES TO BE INSTALLED AT ALL HIGHEST POINTS.



LEGEND:

- ⊡ THERMISTOR
- TEMPERATURE SENSOR
- ⌋ FLEXIBLE BELLOW
- ⊘ STRAINER
- ⊕ PUMP
- ⊕ RELIEF ENERGY VALVE
- ⊕ INCLUSIVE FLOW METER, ENERGY METER, CONTROL VALVE, TORQUE/TYPE SENSING
- ⊕ PRESSURE GAUGE
- ⊕ NON RETURN VALVE
- ⊕ MOTORIZED THRESHOLD VALVE
- ⊕ MOTORIZED SHUT OFF VALVE
- ⊕ ISOLATING VALVE
- ⊕ SCALING VALVE
- ⊕ TWO WAY FLOW CONTROL VALVE
- ⊕ AUTOMATIC AIR BLEED VALVE
- ⊕ VARIABLE
- ▶ CONSTANT
- ⊕ VARIABLE SPEED DRIVE
- ⊕ PRESSURE SENSOR
- ⊕ FLOW SWITCH
- ⊕ FLOW METER
- ⊕ WATER DETECTION SWITCH
- ⊕ SCWP SECONDARY PRE-COOLING WATER SUPPLY PUMP
- ⊕ SCWP SECONDARY CHILLED WATER SUPPLY PUMP
- ⊕ SHWP SECONDARY HOT WATER SUPPLY PUMP

--- HEATING HOT WATER SUPPLY
 --- HEATING HOT WATER RETURN
 --- CHILLED WATER SUPPLY
 --- CHILLED WATER RETURN
 --- PRE-COOLING WATER SUPPLY
 --- PRE-COOLING WATER RETURN
 --- DOMESTIC HOT WATER
 --- DOMESTIC COLD WATER

PRELIMINARY	<input type="checkbox"/>
FOR INFORMATION ONLY	<input type="checkbox"/>
FOR APPROVAL	<input type="checkbox"/>
FOR TENDER PURPOSES	<input type="checkbox"/>
FOR CONSTRUCTION	<input checked="" type="checkbox"/>

NO.	DATE	CHECKED BY	DESCRIPTION
01	04/12/14	EL	Issue for tender
02	05/03/15	EL	Add training rooms & DRY Heat exchanger. Update flows.
03	13/03/15	EL	Add ground floor FCUs.
04	21/03/15	EL	Dimensions and key valves on AHUs. Add S23. Refer to Rev 02/15.
05	02/03/15	EL	Corrected piping schematic to match layout.

SCALE FOR REDUCED PLAN

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resources & energy

DESIGNED: RM
 DRAWN: EA
 CHECKED: EL

DATE: 2016-03-10

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CLIENT	V&A WATERFRONT SILO 5	PROJECT	V&A WATERFRONT SILO 5	DRAWING DESCRIPTION	PIPING SCHEMATIC
SCALE	NTS	DATE	NOVEMBER 2014	DRAWING NUMBER	28155-S5-HV-DSD-0001-002
REVISION		REV NO			B

Appendix B

Silo 5 HAP reports: AHU IN1 & IN2

Air System Sizing Summary for Internal North AHUProject Name: Silo 5 Heat Load_PWC Layout (20150401)
Prepared by: Worley Parsons12/03/2015
11:52AM**Air System Information**

Air System Name	Internal North AHU	Number of zones	5
Equipment Class	CW AHU	Floor Area	3083.0 m ²
Air System Type	VAV	Location	Capetown, South Africa

Sizing Calculation Information

Calculation Months	Jan to Dec	Zone L/s Sizing	Peak zone sensible load
Sizing Data	Calculated	Space L/s Sizing	Individual peak space loads

Central Cooling Coil Sizing Data

Total coil load	73.0 kW	Load occurs at	Dec 1600
Sensible coil load	49.7 kW	OA DB / WB	34.1 / 21.9 °C
Coil L/s at Dec 1600	13884 L/s	Entering DB / WB	18.5 / 16.9 °C
Max block L/s at Jan 1600	14673 L/s	Leaving DB / WB	15.5 / 15.4 °C
Sum of peak zone L/s	14673 L/s	Coil ADP	15.2 °C
Sensible heat ratio	0.681	Bypass Factor	0.100
m ² /kW	42.3	Resulting RH	65 %
W/m ²	23.7	Design supply temp.	16.0 °C
Water flow @ 6.0 °K rise	2.91 L/s	Zone T-stat Check	5 of 5 OK
		Max zone temperature deviation	0.0 °K

Precool Coil Sizing Data

Total coil load	161.0 kW	Load occurs at	Feb 1500
Sensible coil load	161.0 kW	OA DB / WB	35.0 / 22.0 °C
Coil L/s at Feb 1500	14024 L/s	Entering DB / WB	28.0 / 20.0 °C
Max coil L/s	14673 L/s	Leaving DB / WB	18.5 / 16.9 °C
Sensible heat ratio	1.000	Bypass Factor	0.100
Water flow @ 6.0 °K rise	6.42 L/s		

Supply Fan Sizing Data

Actual max L/s at Jan 1600	14673 L/s	Fan motor BHP	15.85 BHP
Standard L/s	14673 L/s	Fan motor kW	12.58 kW
Actual max L/(s-m ²)	4.76 L/(s-m ²)	Fan static	600 Pa

Return Fan Sizing Data

Actual max L/s at Jan 1600	14673 L/s	Fan motor BHP	5.28 BHP
Standard L/s	14673 L/s	Fan motor kW	4.19 kW
Actual max L/(s-m ²)	4.76 L/(s-m ²)	Fan static	200 Pa

Outdoor Ventilation Air Data

Design airflow L/s	6025 L/s	L/s/person	16.19 L/s/person
L/(s-m ²)	1.95 L/(s-m ²)		

Zone Sizing Summary for Internal North AHUProject Name: Silo 5 Heat Load_PWC Layout (20150401)
Prepared by: Worley Parsons12/03/2015
11:52AM**Air System Information**Air System Name **Internal North AHU**
Equipment Class **CW AHU**
Air System Type **VAV**Number of zones **5**
Floor Area **3083.0** m²
Location **Capetown, South Africa****Sizing Calculation Information**Calculation Months **Jan to Dec**
Sizing Data **Calculated**Zone L/s Sizing **Peak zone sensible load**
Space L/s Sizing **Individual peak space loads****Zone Sizing Data**

Zone Name	Maximum Cooling Sensible (kW)	Design Airflow (L/s)	Minimum Airflow (L/s)	Time of Peak Load	Maximum Heating Load (kW)	Zone Floor Area (m ²)	Zone L/(s-m ²)
Zone 1	19.6	2708	966	Jan 1600	3.2	639.7	4.23
Zone 2	20.3	2800	947	Jan 1600	3.6	627.2	4.46
Zone 3	23.0	3181	1357	Jan 1600	3.7	642.9	4.95
Zone 4	22.1	3046	1231	Jan 1600	3.6	635.0	4.80
Zone 5	21.3	2938	1524	Jan 1600	5.4	538.2	5.46

Zone Terminal Sizing Data

No Zone Terminal Sizing Data required for this system.

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (kW)	Time of Load	Air Flow (L/s)	Heating Load (kW)	Floor Area (m ²)	Space L/(s-m ²)
Zone 1							
1 Int N A (open office)	1	4.1	Jan 1600	569	0.6	144.4	3.94
1 Int N B (open office)	1	5.3	Jan 1600	731	1.4	157.0	4.65
1 Int N C (open office)	1	1.2	Jan 1600	168	0.8	31.1	5.41
1 Int N D (staff pause)	1	0.8	Jan 1600	109	0.3	19.9	5.48
1 Int N F (mail room)	1	0.9	Jan 1600	127	0.0	30.2	4.20
1 Int N G (IT office)	1	0.5	Jan 1600	65	0.2	13.9	4.66
1 Int N H (kitchen)	1	0.4	Jan 1600	62	0.0	15.6	3.95
1 Int N O 01 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 02 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 03 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 04 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 05 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 06 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 07 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 08 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 09 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 10 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 11 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 12 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 13 (office)	1	0.3	Jan 1600	38	0.0	9.6	3.98
1 Int N O 14 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 15 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 16 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 17 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 18 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 19 (office)	1	0.3	Jan 1600	44	0.0	11.5	3.85
1 Int N O 20 (office)	1	0.3	Jan 1600	43	0.0	11.0	3.88
Zone 2							
2 Int N	1	20.3	Jan 1600	2800	3.6	627.2	4.46
Zone 3							
3 INT N A (open office)	1	6.7	Jan 1600	930	0.1	212.3	4.38
3 INT N B (open office)	1	1.6	Jan 1600	226	0.0	51.8	4.37
3 INT N C (open office)	1	1.5	Jan 1600	204	0.2	58.9	3.46
3 INT N D (open office)	1	1.6	Jan 1600	222	0.4	43.1	5.15
3 INT N E (pause area)	1	3.7	Jan 1600	506	0.7	112.5	4.50

Zone Sizing Summary for Internal North AHUProject Name: Silo 5 Heat Load_PWC Layout (20150401)
Prepared by: Worley Parsons12/03/2015
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Zone Name / Space Name	Mult.	Cooling Sensible (kW)	Time of Load	Air Flow (L/s)	Heating Load (kW)	Floor Area (m ²)	Space L/(s-m ²)
3 INT N M1 (meeting)	1	0.9	Jan 1600	117	0.3	11.4	10.30
3 INT N M2 (meeting)	1	0.6	Jan 1600	80	0.2	8.9	9.00
3 INT N M3 (meeting)	1	0.5	Jan 1600	68	0.1	8.2	8.29
3 INT N M4 (meeting)	1	0.9	Jan 1600	122	0.2	15.1	8.11
3 INT N M5 (meeting)	1	0.6	Jan 1600	88	0.0	11.6	7.57
3 INT N M6 (meeting)	1	0.9	Jan 1600	126	0.7	7.2	17.46
3 INT N O 01 (office)	1	0.3	Jan 1600	44	0.1	8.0	5.49
3 INT N O 02 (office)	1	0.2	Jan 1600	33	0.0	8.1	4.13
3 INT N O 03 (office)	1	0.2	Jan 1600	33	0.0	8.1	4.13
3 INT N O 04 (office)	1	0.3	Jan 1600	38	0.1	8.1	4.71
3 INT N O 05 (office)	1	0.3	Jan 1600	45	0.1	8.1	5.51
3 INT N O 06 (office)	1	0.3	Jan 1600	45	0.1	8.1	5.51
3 INT N O 07 (office)	1	0.3	Jan 1600	43	0.1	8.1	5.33
3 INT N O 08 (office)	1	0.2	Jan 1600	33	0.0	8.1	4.13
3 INT N O 09 (office)	1	0.3	Jan 1600	45	0.1	8.2	5.48
3 INT N O 10 (office)	1	0.3	Jan 1600	39	0.1	8.2	4.74
3 INT N O 11 (office)	1	0.2	Jan 1600	34	0.0	8.2	4.12
3 INT N O 12 (office)	1	0.2	Jan 1600	34	0.0	8.2	4.12
3 INT N S1 (smart room)	1	0.2	Jan 1600	29	0.0	4.4	6.63
Zone 4							
4 INT N A (open office)	1	8.1	Jan 1600	1125	1.0	230.5	4.88
4 INT N B (open office)	1	1.6	Jan 1600	216	0.0	55.9	3.87
4 INT N C (open office)	1	2.4	Jan 1600	337	0.5	82.4	4.09
4 INT N F (open office)	1	1.4	Jan 1600	194	0.2	51.0	3.81
4 INT N G (pause area)	1	3.3	Jan 1600	454	0.8	96.9	4.68
4 INT N M3 (meeting)	1	0.7	Jan 1600	90	0.1	10.6	8.49
4 INT N O 8 (office)	1	0.3	Jan 1600	41	0.1	8.0	5.11
4 INT N M5 (meeting)	1	0.5	Jan 1600	66	0.1	8.1	8.17
4 INT N M6 (meeting)	1	0.7	Jan 1600	102	0.2	13.5	7.57
4 INT N M8 (meeting)	1	0.5	Jan 1600	71	0.1	9.3	7.62
4 INT N O 1 (office)	1	0.2	Jan 1600	33	0.0	8.1	4.13
4 INT N O 2 (office)	1	0.2	Jan 1600	33	0.0	8.1	4.13
4 INT N O 3 (office)	1	0.3	Jan 1600	45	0.1	8.1	5.52
4 INT N O 4 (office)	1	0.3	Jan 1600	45	0.1	8.1	5.52
4 INT N O 5 (office)	1	0.2	Jan 1600	33	0.0	8.1	4.13
4 INT N O 6 (office)	1	0.2	Jan 1600	33	0.0	8.1	4.13
4 INT N O 7 (office)	1	0.3	Jan 1600	45	0.1	8.2	5.49
4 INT N S1 (smart room)	1	0.2	Jan 1600	25	0.0	3.0	8.29
4 INT N S2 (smart room)	1	0.2	Jan 1600	25	0.0	3.0	8.29
4 INT N H (patch room)	1	0.2	Jan 1600	31	0.1	6.0	5.21
Zone 5							
5 INT N A (open office)	1	4.6	Dec 1600	640	0.9	152.5	4.20
5 INT N D (open office)	1	2.2	Dec 1600	301	0.5	57.1	5.27
5 INT N E (open office)	1	0.5	Dec 1600	70	0.1	13.4	5.19
5 INT N F (open office)	1	2.2	Jan 1600	302	1.1	41.5	7.28
5 INT N G (open office)	1	1.1	Jan 1600	157	0.4	34.3	4.59
5 INT N H (print room)	1	1.6	Dec 1600	217	0.4	45.8	4.75
5 INT N I (stationary)	1	1.1	Jan 1600	154	0.5	26.7	5.76
5 INT N J (open office)	1	0.5	Jan 1600	69	0.3	11.9	5.82
5 INT N M1 (meeting)	1	1.0	Dec 1600	165	0.1	21.8	7.57
5 INT N M2 (meeting)	1	2.3	Dec 1600	331	0.4	43.7	7.57
5 INT N M3 (meeting)	1	1.4	Jan 1600	187	0.3	24.1	7.77
5 INT N M4 (meeting)	1	1.4	Dec 1600	210	0.1	27.7	7.57
5 INT N O 1 (office)	1	0.3	Jan 1600	43	0.2	6.0	7.22
5 INT N O 3 (office)	1	0.3	Dec 1600	47	0.0	9.8	4.83
5 INT N P (sick bay)	1	0.3	Dec 1600	36	0.0	6.9	5.15
5 INT N Q (mothers room)	1	0.3	Dec 1600	36	0.0	6.9	5.15
5 INT N O 2 (office)	1	0.3	Dec 1600	40	0.0	8.1	4.99

Air System Design Load Summary for Internal North AHUProject Name: Silo 5 Heat Load_PWC Layout (20150401)
Prepared by: Worley Parsons12/03/2015
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	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Dec 1600			HEATING DATA AT DES HTG		
	COOLING OA DB / WB 34.1 °C / 21.9 °C			HEATING OA DB / WB 6.0 °C / 5.5 °C		
ZONE LOADS	Details	Sensible (W)	Latent (W)	Details	Sensible (W)	Latent (W)
Window & Skylight Solar Loads	0 m ²	0	-	0 m ²	-	-
Wall Transmission	0 m ²	0	-	0 m ²	0	-
Roof Transmission	538 m ²	3352	-	538 m ²	2180	-
Window Transmission	0 m ²	0	-	0 m ²	0	-
Skylight Transmission	0 m ²	0	-	0 m ²	0	-
Door Loads	0 m ²	0	-	0 m ²	0	-
Floor Transmission	0 m ²	0	-	0 m ²	0	-
Partitions	842 m ²	10653	-	842 m ²	17186	-
Ceiling	0 m ²	0	-	0 m ²	0	-
Overhead Lighting	24664 W	20156	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	55495 W	50968	-	0	0	-
People	372	20625	22362	0	0	0
Infiltration	-	0	0	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	105755	22362	-	19367	0
Zone Conditioning	-	112434	22362	-	-20185	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	13884 L/s	3674	-	6025 L/s	-656	-
Ventilation Load	5701 L/s	75682	884	2474 L/s	22838	0
Supply Fan Load	13884 L/s	11023	-	6025 L/s	-1967	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	202814	23246	-	30	0
Central Cooling Coil	-	49721	23250	-	0	0
Precool Coil	-	153093	0	-	0	0
>> Total Conditioning	-	202814	23250	-	0	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

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