

Exergenics + AG Coombs Application – 2025 Innovation Awards IDEA.

1. Project/Program Title: Sydney Airport International Terminal T1 Chilled Water Plant Optimization

2. Name and Location of District Energy System or Project: Sydney Airport International Terminal 1, Sydney Airport, Mascot NSW 2020

3. Name of System Owner : Sydney Airport

4. Name, relationship to the project/program, address, phone number & email of the person submitting the application

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5. Executive Summary – In 700 words or less, summarize the project /program, demonstrating the key aspects of what was done and the overall benefits.

The Sydney Airport Chilled Water Plant Optimization project by A.G. Coombs Advisory and Exergenics exemplifies excellence in HVAC innovation, leveraging machine learning, model

predictive control, evolutionary optimization algorithms, and a purpose-built measurement and verification methodology specific to the chilled water plant. This project's success is attributed to its innovative approach, requiring no equipment upgrades or additional hardware, ensuring minimal disruption while delivering rapid implementation and measurable results.

Traditional chilled water system tuning relies on manufacturer data as a proxy for optimal performance. This project significantly advances that approach by utilizing machine learning tools to determine real-time operational efficiency profiles of chillers, pumps, and cooling towers, which change over time due to wear and tear. As a result, the final control logic implemented on-site was optimized for actual field performance, rather than relying on static design parameters.

Project Objectives & Implementation

The primary objective of the project was to enhance energy efficiency and reduce greenhouse gas emissions, ensuring optimal temperature conditions for millions of passengers annually. The project aimed to achieve these goals without major capital expenditure or disrupting airport operations. Aligning with Sydney Airport's Net Zero 2030 targets, the initiative leveraged existing BMS data and advanced machine learning algorithms to drive substantial energy savings and emissions reductions.

Energy savings were achieved through the following optimized control strategies:

- Secondary pump staging and flow reset
- Updated chiller sequencing strategy
- Revised chiller stage-up & stage-down demand setpoints
- Stage-based dynamic condenser water temperature reset algorithm

Project Outcomes & Measured Success

The project delivered significant efficiency improvements and cost savings, verified through rigorous Measurement & Verification (M&V) processes.

- Annual energy savings: ~1.74M kWh, compared with 2019 consumption
- Carbon emissions reduction: 1,377 tCO₂ per year
- Annual cost savings: \$243,880 AUD
- Simple payback period: 12 months (originally projected at 2 years)
- Chilled plant system efficiency improvement: 33.4%
- Secondary chilled water pump consumption reduced by: 75%
- Optimal secondary chilled water flow hours improved from: 32.3% to 93.9%
- Optimal secondary supply water temperature hours improved from: 19.1% to 91.0%

By eliminating the need for additional hardware, the project lowered upfront costs, accelerated deployment, and delivered energy savings significantly faster than traditional optimization methods.

This initiative underscores A.G. Coombs Advisory and Exergenics' commitment to scalable, cost-effective sustainability solutions, providing substantial environmental and financial benefits to the HVAC and infrastructure industries.

6. In 300 words or less, explain how the project/program is innovative and unique.

The implementation of the project was novel for Central Plant Optimization (CPO) technologies, which normally rely on installing third-party hardware to assume control of the plant equipment and optimize the system in real-time. Because of the innovative optimization loop, which seeds the chilled plant model with all potential conditions that the plant could face leveraging cloud computing, the methodology that was developed was able to produce algorithms that are bespoke for the equipment and cooling/weather dynamics of Sydney Airport.

By generating a Functional Description rather than installing an additional controller, the investment in the existing BMS meant that the existing system could be optimized with no additional capital expenditure. This method of implementation reduced upfront costs and subsequently reduced the payback period of the project, but also significantly accelerated the timelines for project delivery, allowing the end client to benefit from efficiency improvements and energy savings much sooner than they otherwise would have installing and commissioning new hardware.

7. With supporting data, demonstrate the improved energy efficiency benefit offered by the project/program, in 250 words or less.

The project achieved a 33.4% increase in efficiency, reducing energy consumption by 890,094 kWh and cutting GHG emissions by 704 tCO₂ and energy cost savings of \$124,600 over nine months. The overall annual project reduction in energy consumption was 1,742,000 kWh, 1,377 tCO₂ and \$243,880. These benefits were measured through rigorous data analysis and verified by both preliminary and final Measurement and Verification (M&V) processes. All M&V was conducted following the International Performance Measurement and Verification Protocol Option B (Retrofit Isolation).

The substantial improvements in efficiency and cost savings underline the effectiveness and potential of such initiatives to drive significant environmental and financial benefits across the sector. The project also provides a model for other facilities looking to achieve similar goals, demonstrating the scalability and adaptability of the methodology. The accuracy that can be accomplished when utilizing real-world data to train simulation models and the benefits of evolutionary optimization algorithms when dealing with complex optimization problems that are highly dimensional, non-linear and discontinuous, as is the case with chilled water plants, was demonstrated with the quantum of savings that were achieved on an already highly efficient plant with an operating COP of 6.25 prior to the optimisation program. Regular updates were provided to the Sydney Airport stakeholders to be utilized in wider decarbonization reporting and for the

assessment of the financial performance of the project, which was estimated to have a 2-year payback period but achieved a 12-month payback period.

8. With supporting data and graphics, explain the financial advantages of this project / program in 250 words or less.

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9. In 250 words or less, please provide any additional information about the project/program (What challenges did you face? What plans do you have for the future? How did your customer base or community react?, etc.)

Key challenges included integrating the optimization with the existing BMS and ensuring minimal disruption to airport operations. These were addressed by adopting a software-based approach that required no additional hardware. The project team collaborated closely with Sydney Airport's facilities management team to ensure smooth implementation and continuous performance monitoring. The use of a cloud-based model facilitated seamless data integration, while regular stakeholder engagement ensured that the project met all operational and sustainability objectives. Importantly once operational stability was achieved, the Measurement & Verification (M&V) of energy savings was continuously monitored throughout the 12-month project duration.

The project advances machine learning-based optimization in building services demonstrating its ability to enhance efficiency, reduce emissions and lower costs without major capital investment. By leveraging historical data and simulations, it optimizes HVAC performance and unlocks applications in system design, equipment upgrades, and load shifting.

With a 12-month payback period, the project serves as a scalable model for other facilities. It encourages broader adoption of data-driven, non-invasive solutions, fostering a more sustainable industry. The project's results will be shared through a case study and implementation guide, providing insights for facility owners, contractors, and technology vendors aiming to improve energy performance.

Following the optimization works, Sydney Airport has utilized the technology for equipment analysis simulation of a chilled water plant that is undergoing a retrofit of the chillers on site. The site team was evaluating 3 different brand chillers, the Exergenics model was able to provide precise paybacks/ROIs for choosing OEM A vs B vs C.

10. Please provide 3 to 5 attachments as images, diagrams or photographs in jpeg format with identifying captions.

Kindly refer to the attached documents on the next page.

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Supporting Documentation:

Sydney Airport International Terminal T1 Chilled Water System Description

The Sydney International Terminal Central Services Building plant includes:

- Eight (8) Chillers – total capacity 26,230 kW_r
- Seven (7) Cooling Towers, Five single cell and two x six cell towers
- Four (4) Secondary Chilled water pumps, total capacity 1,200 L/s

Chilled water is delivered to the international terminal through a secondary chilled water tunnel, approximately ½ km long. Pipe sizes within the tunnel are 1 x 600mm and 1 x 350mm flow pipes.

Twelve (12) branch connections feed out of the secondary pipework to separate terminal locations.

The length of water distribution (rather than height) made this project more unique and therefore the challenges less common.

Last major upgrade (new chillers and reconfiguration of pipework in the plantroom) was in 2014. The BMCS program was extremely complex and was not running according to the functional description (design).

Allegorically, the plant furthest from the central plant was ‘always hot’ during design day temperatures or above. (This problem was solved during the optimization period). In some ways, this was a welcome “unplanned outcome” but is feedback that the operation of the BMCS and associated mechanical plant has been made good, potentially for the first time in many years.

As with most large plants, maintenance and maintenance repairs are a constant consideration. The co-ordination and interaction between A.G. Coombs Service and A.G. Coombs Advisory ensured smooth project co-ordination for the airport.

Chilled Water Plant Optimization Project

The prime objective of this project was to improve energy efficiency, reduce energy consumption and the associated carbon emissions. A welcome and unplanned outcome was improved temperature conditions within the terminal.

Sydney Airport reached out to A.G. Coombs Advisory to seek an opinion on how best to optimise the International Terminal’s Chilled Water Central Services Building.

A preliminary analysis was conducted by A.G. Coombs Advisory using BMCS trend data.

A.G. Coombs Advisory presented a statistical analysis of the plant deficiencies and recommended energy improvement initiatives including:

- 1) Recommission / retest the operation of the BMCS programme found to be incorrect.
- 2) Correct operation of the decoupler flow.
- 3) Correct secondary chilled water supply temperature
- 4) Correct secondary chilled water pump staging
- 5) Correct thermal capacitance model
- 6) Implement Artificial Intelligence (Exergenics) to statistically predict energy improvements and recommend programme changes to improve energy consumption.

Sydney Airport commented favourably that the A.G. Coombs methodology was not based on rules of thumb, as others had proposed, but on the actual data.

Exergenics' chilled water plant optimisation solution is a powerful optimisation engine that leverages operational data to recommend optimal control strategies that yield significant energy savings.

The prime levers for optimisation are:

- Staging set points
- Reduction of short cycling
- Revised condenser water approach algorithm

Project Period

- Project works - October 2022 – December 2022.
- Monitoring & Verification Period - 1 December 2022 – 30 November 2023

Project Process

Stage 1 – Plant Flow

Objective

- Control plant flow to prevent elevated temperatures

Optimisation strategy

- Re-commission chiller staging strategy
- Implement primary variable speed control

Results

- Significant improvement of optimal plant flow
- Greater understanding of flow characteristics – best outcomes outside optimal flow.

Note:

- Outside optimal =
 - < -20L/s, > 50L/s and temperature >8 °C
 - Curfew hours excluded
 - Stage 0 "thermal capacitance" mode excluded

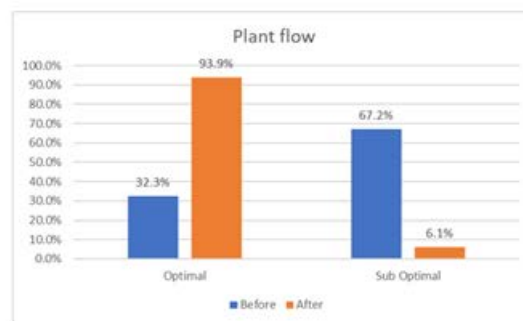


Figure 1. Plant Flow demonstrating the operational performance percentage

Stage 1 – Secondary Supply Water temperature

Objective

- Fix low differential temperature operation
- Lower supply water temperature towards design of 6°C
- Optimal temperature is < 8°C

Optimisation strategy

- Implement primary variable speed control
- Recommission Secondary chilled water pump control

Results/Notes

- Significant improvement of elevated supply water temperature
- Thermal capacitance mode (Stage 0) excluded.

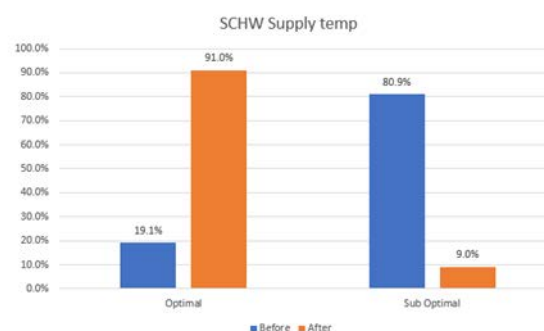


Figure 2. Optimal SCHW supply temperature time

Stage 1 – SCHW Pump staging

Objective

- Re-commission secondary pump staging strategy and ensure stage up and stage down parameters are tuned correctly

Optimisation strategy

- Enable smaller secondary chilled water pumps to operate
- Calculate and re-programme BMCS to operate under optimal staging parameters

Results

- Overall savings 24/7 minimum of 100kW

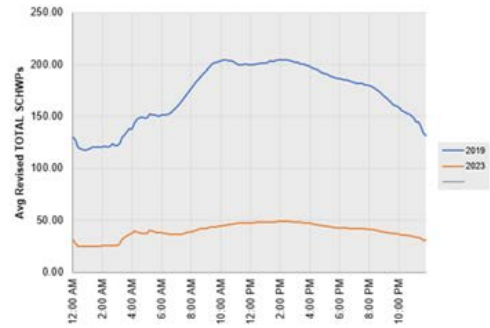


Figure 3. Average daily SCHW Pump energy consumption vs benchmark

Stage 3 – Chiller staging and efficiency

Objective

- Utilise Artificial Intelligence analysis to improve plant efficiency.
- Reprogramme BMCS to fit AI analysis.

Optimisation strategy

- Optimise chiller efficiency at most common load requirements, that is, less than 7MW for 90% of operations
- Calculate optimal staging parameters and implement
- Recommission "thermal capacitance mode" (where primary chillers are turned OFF)

Results

- Greater than expected savings
 - Estimated savings 2.5%
 - Actual savings 32%
- Primary Chilled water system was operating 24/7 now up to 5 hour off per (winter) night
- Improvements in COP
 - COP modelled baseline (2022) = 6.25
 - Initial projection = 6.55
 - Optimised efficiency = 7.07

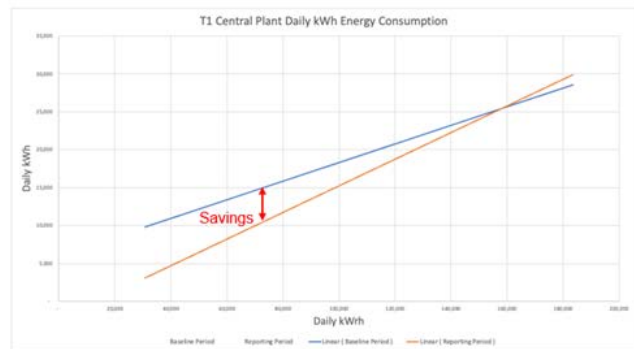


Figure 4. Scatter chart – Power consumption vs Delivered Refrigeration energy

Blue = Benchmark data
Orange = Optimised data

2019 vs 2023

- Benchmark Data from 2019
- Passenger data YTD to November
 - 2019 – 15.29m
 - 2022 – 7.07m
 - 2023 13.04m, up 84.3% from 2022, down 14.7% from 2019
- Annual savings from December 22 to November 23 was **1,742,000 kWh**

Note:

- Based on instantaneous BMCS data
- Staging modifications were not complete until April 2023. Improvements during summer expected.
- Adjustments made for SCHW pump during January 2019 – March 2019 due to Pump 11 data missing
- Adjustments made with Chiller 4 kWh error (consumption benchmarked against plant COP excluding chiller 4)
- Chiller faults for Chillers 6 and 1B have affected staging, reducing potential savings from September 2023

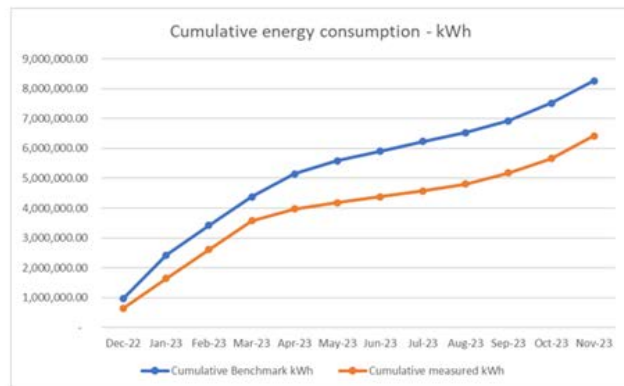


Figure 5. Cumulative energy consumption (adjusted) vs 2019 Benchmark

Savings Calculation	Targeted Energy Saving in 22/23 (kWh)	Targeted Energy Saving in Y1 to Y5	Y1 Cost Savings	Y5 Cost Savings
Business Case – Estimated savings	575,000	2,609,500	\$69,000	\$313,140
Savings vs Benchmark consumption	1,742,000	8,710,000	\$243,880	\$1,219,400

Notes

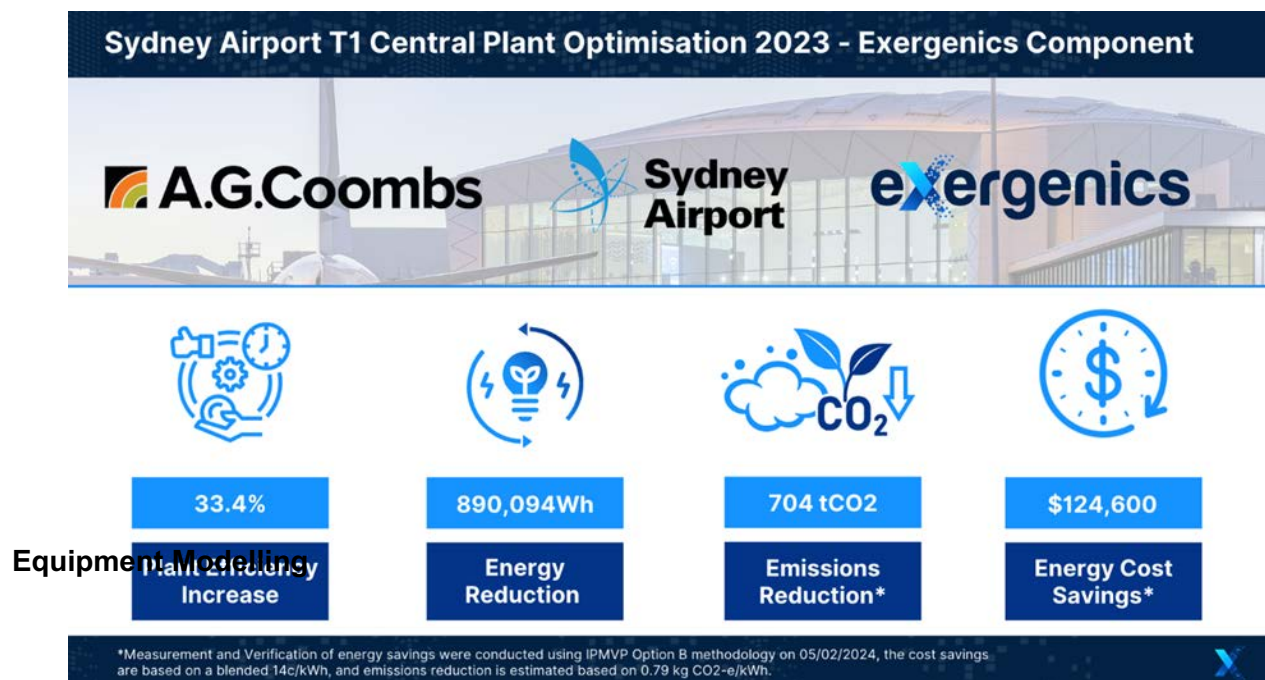
- Based on blended rate of \$0.14
- Initial savings were based on 2022 data.
- Passenger movements for 2023 up 76.6% from 2022, down 13.9% from 2019
- ROI approximately 0.95 years. Target ROI was 1.97 years
- Payback including additional programme modifications \$124 / MWh pa saved

Project Outcomes

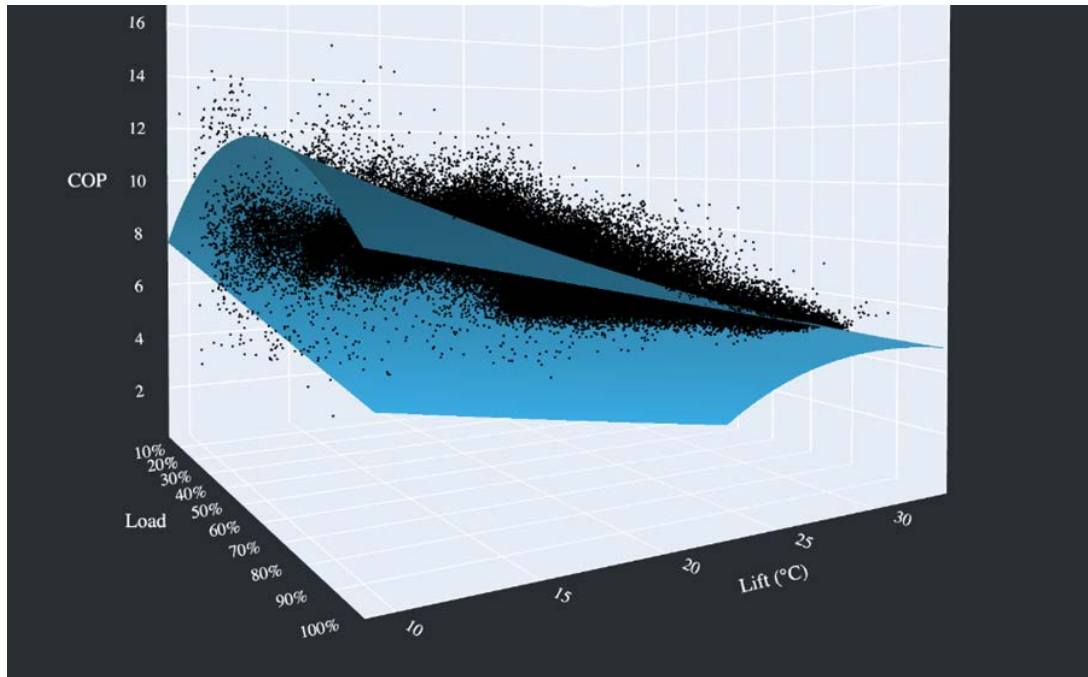
Outcomes can be summarized as follows:

- Energy savings ~ 1.74M kWh pa, compared with 2019 consumption
- Optimal secondary chilled water flow, supply water temperature and consumption.
- The factors which affect these conditions include:
 - o Excessive secondary chilled water flow resulting in higher pump energy and possibly increased system pressure.
 - o Insufficient secondary chilled water flow possibly leading to low flow particularly in the index leg(s).
 - o Incorrect pump staging.
- Optimal secondary chilled water flow improved from 32.3% to 93.9% of operational hours.
- Optimal secondary supply water temperature improved from 19.1% to 91.0% of operational hours.
- Secondary chilled water pump consumption reduced by 75%

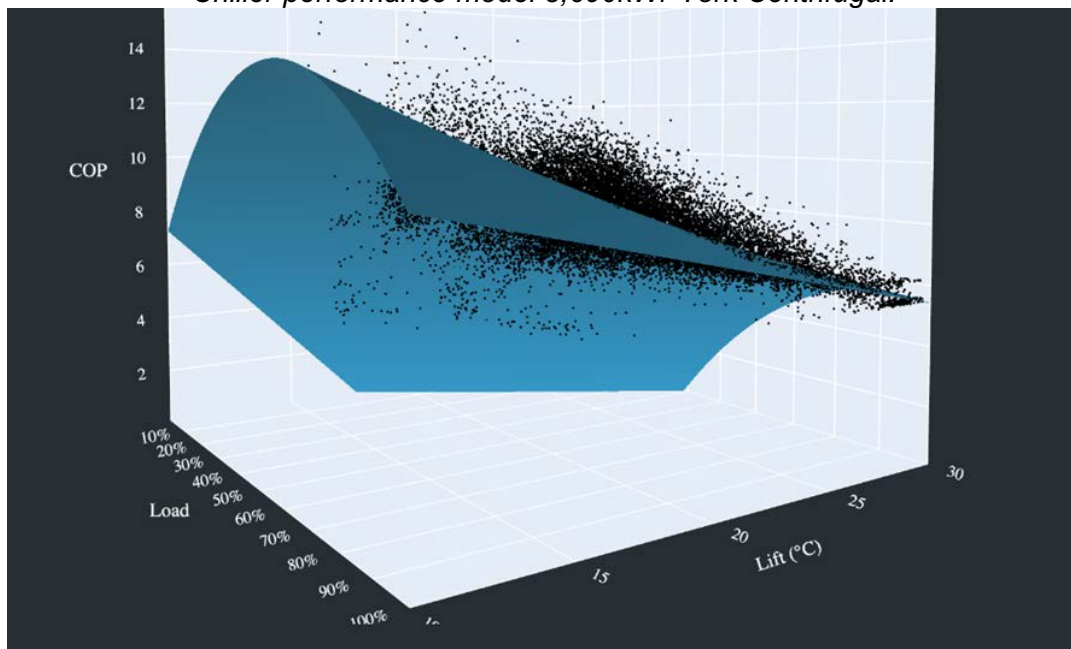
For the previous ten-year period, Pier C was always struggling to achieve design conditions during design heat days with the space being over temperature. During the optimization period, COLD complaints were received. A testament to the improvement in pump staging and flow condition.



Equipment modelling was undertaken leveraging historical BMS data. Below are examples of bi-polynomial regression chiller performance models, which are used to predict chiller COP based on the lift and part loading of the machine in the wider plant simulations.



Chiller performance model 3,690kW York Centrifugal.



Chiller performance model 2,000kW York Centrifugal.

Controls Recommendations

Below are some of the controls recommendations which were modelled as part of the project, including updates to chiller sequencing, chiller staging setpoints and a dynamic condenser water reset algorithm.

Staging Setpoint Recommendations

Staging Setpoints

Staging Strategy

Strategy Chart

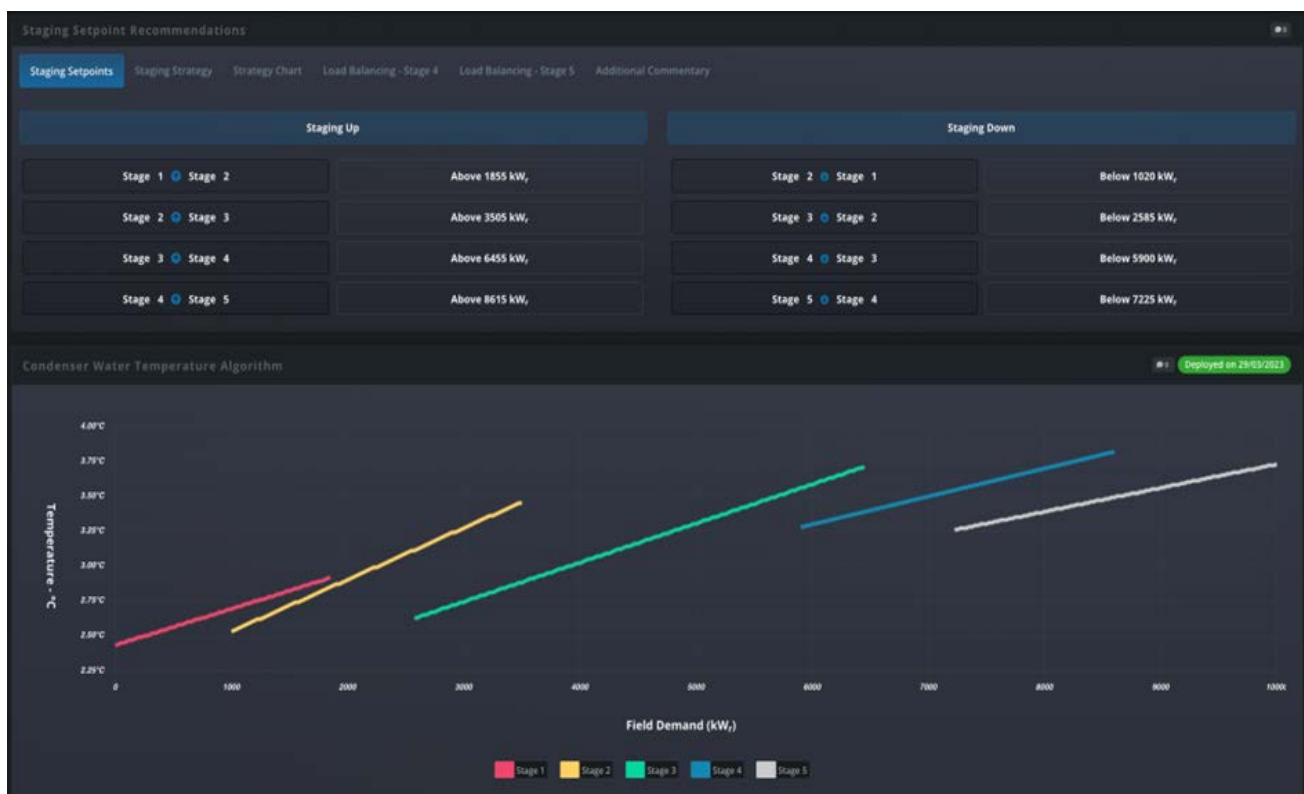
Load Balancing - Stage 4

Load Balancing - Stage 5

Additional Commentary

	Chiller 1A or 1B (Lead or Lag)	Chiller 1A or 1B (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)
Stage 1	Enabled			
Stage 2			Enabled	
Stage 3			Enabled	Enabled
Stage 4	Enabled		Enabled	Enabled
Stage 5	Enabled	Enabled	Enabled	Enabled

Optimised chiller sequencing based on historical load profiles and equipment performance.



Chiller staging setpoints and graphic CDW reset by stage.

Dynamic Condenser Water Temperature Algorithm - Header #1

For Stage 1

$C_t = W_t + 2.43 + (0.00026 \times kW_c)$

For Stage 2

$C_t = W_t + 2.15 + (0.00037 \times kW_c)$

For Stage 3

$C_t = W_t + 1.90 + (0.00028 \times kW_c)$

For Stage 4

$C_t = W_t + 2.10 + (0.00020 \times kW_c)$

For Stage 5

$C_t = W_t + 2.03 + (0.00017 \times kW_c)$

C_t

Condensing Water Setpoint (°C)

kW_c

Cooling Load (kW)

W_t

Ambient Wet Bulb (°C)

The condenser water temperature algorithm is a 'dynamic approach' algorithm, considering both the wet bulb temperature and cooling load.

To ensure that chillers are operating within their manufacturer specific safe operating ranges, upper and lower limits should be placed on the algorithm above to ensure that condenser water inlet temperatures do not fall outside this range. Where the plant is configured with a common condenser water header, the upper and lower bounds should be restricted to the largest possible range incorporating each chiller than is enabled in the current stage.

Dynamic staged-based CDW reset, modulating approach temperature by Load (kW_r).

Functional Description – Chilled Water Update

Below is the unique functional description that was generated for the project using the plant simulation. The recommendations in section C4 are detailed here with technical advice on the implementation of advanced energy efficiency strategies that can be deployed in any existing modern controller.

Functional Description

Chilled Water Plant Update
Sydney Airport



For
Sydney Airport
Airport
17th July 2024

Prepared By
Exergenics Pty. Ltd.
4/333 Exhibition St
Melbourne VIC 3000

**Functional Description for the optimisation of the Chilled Water (CHW) Plant
using the Exergenics optimisation strategy.**

Table of Contents

General	3
Definitions	3
Overview	3
Equipment List	3
Chillers	3
Cooling Towers	4
Pumps	4
Copyright Notice	4
Scope of Works	5
Overview	5
Equipment for Reuse	6
Measurement & Verification (M&V) Requirements	6
Functional Description - Optimised Chilled Water Plant Control Strategy	7
General	7
Field Demand Based Controls	7
Stabilisation Delay	7
Chiller Staging	8
Staging Sequence	8
Stage Up	9
Stage Down	9
Chiller Demand Limits (Load Balancing)	10
Stage 4 Chiller Demand Limits	10
Stage 5 Chiller Demand Limits	12
Dynamic Condenser Water Temperature	13
Condenser Water Dynamic Approach Algorithm - Header #1	14
Appendix A - Strategy Lookup Tables	16
Chiller Load Balancing - Stage 4	16
Chiller Load Balancing - Stage 5	17

General

Definitions

Symbol	Meaning
C _i	Condenser water temperature setpoint (in °C)
kW _i	Field Demand (in kW)
W _i	Ambient wet bulb temperature (in °C)

Overview

This document outlines the optimised chilled water plant control strategy produced by Exergenics for AG Coombs at Sydney Airport, located at Mascot NSW 2020, Australia. The optimisation has determined the setpoints and control parameters to achieve the highest possible efficiency from the chilled water system.

This functional description describes the control strategy changes that need to be implemented by the BMS/BAS technician to achieve optimal control of the chilled water plant. Generally, the BMS/BAS technician shall update the BMS/BAS chilled water system control strategies by inputting the optimised setpoints into the existing building management system.

The setpoints are not automatically adjusted by the Exergenics system. The Exergenics software creates a model of the chilled water system from historical trended data to determine the most efficient control setpoints at various conditions for the entire chilled water plant.

Equipment List

Chillers

Our Chiller Reference	Make/Model	Capacity (kW)	BMS/BAS Identifier
Chiller 1A or 1B (Lead or Lag)	York (Centrifugal)	2000	CH-01A
Chiller 1A or 1B (Lead or Lag)	York (Centrifugal)	2000	CH-01B
Chiller 6 or 7 (Lead or Lag)	York (Centrifugal)	3690	CH-06
Chiller 6 or 7 (Lead or Lag)	York (Centrifugal)	3690	CH-07

Cooling Towers

Our Reference	Make/Model	Rated Power (kW)	BMS/BAS Identifier
Cooling Tower 1		33	
Cooling Tower 2		33	
Cooling Tower 3		33	
Cooling Tower 4		33	
Cooling Tower 5		33	
Cooling Tower 6		39	
Cooling Tower 7		39	

Pumps

Our Reference	Make/Model	Rated Power (kW)	Associated Chiller
Chilled Water Pump 1A		7.7	Chiller 1A or 1B (Lead or Lag)
Chilled Water Pump 1B		7.7	Chiller 1A or 1B (Lead or Lag)
Chilled Water Pump 6		12.5	Chiller 6 or 7 (Lead or Lag)
Chilled Water Pump 7		12.5	Chiller 6 or 7 (Lead or Lag)
Condenser Water Pump 1A		23.8	Chiller 1A or 1B (Lead or Lag)
Condenser Water Pump 1B		23.8	Chiller 1A or 1B (Lead or Lag)
Condenser Water Pump 6		50.6	Chiller 6 or 7 (Lead or Lag)
Condenser Water Pump 7		50.6	Chiller 6 or 7 (Lead or Lag)

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Scope of Works

The functional description provides the intent for scope and quality. The technician shall allow for and provide a complete, fully functioning control strategy, irrespective that the design is not fully detailed as it is to be integrated into the existing control system.

The provided Exergenics Functional Description provides an example of the preferred format, e.g., setpoints and parameters confirmed in tables and required headings for the system overview and equipment lists etc. This is to assist in understanding the existing control strategy, design parameters, equipment references, lead/lag configuration, etc.

The final installed strategy shall take into consideration the existing system control strategies, the on-site operation and maintenance manuals, existing graphics, alarms and trends, and the site conditions. When the final updated Functional description is submitted for review by Exergenics, the technician confirms a fully coordinated design. The updated functional description shall not be a theoretical design created from this one. I.e The control strategy intent in this functional description shall be further expanded to consider the existing mechanical system, the existing management system design, and existing conditions

If it is believed that a conflict exists between statutory requirements and the documents, notify the contract administrator immediately and provide a recommendation to resolve the conflict.

Overview

- This scope of work applies to the chilled water system only. No modifications are required to the remaining control systems, e.g., AHUs, boilers etc.
- Prior to commencing any reprogramming, the technician is to confirm the existing BMS/BAS functional description accurately reflects the existing control strategies. Should any differences be discovered the technician is to alert the instructing body.
- Update the existing BMS/BAS database, graphics, alarms, trends etc., as required, to support the modifications made to the chilled water control strategies.
- Document any existing issues or faults (e.g., faulty sensors or actuators).
- Document any missing instrumentation or existing conditions that may prevent the Exergenics control strategies from being implemented.
- All works shall be provided by the incumbent controls technician or an approved agent.
- The new chilled water control strategy shall be tested offsite, downloaded, and commissioned outside normal hours.
- Recommission the new chilled water control strategies and the remaining control strategies to confirm the correct operation of the complete system.
- Update the BMS/BAS Operation and Maintenance manual to record all modifications, for example, but not limited to:
 - BMS/BAS Functional description.
 - BMS/BAS Points list (if changes were made).
 - BMS/BAS Network architecture drawing (if changes were made).
- Set-up of relevant trends (if not already trended) for the purposes of Measurement & Verification. Points shall be logged with a maximum sample rate of 15-minutes and readily available for a minimum of 3 years.
- No modifications are required to the BMS/BAS network.
- Use only appropriately qualified persons and conform to all statutory requirements.

Equipment for Reuse

All hardware & software shall be retained and not modified, replaced, or upgraded; including, but not limited to:

- BMS/BAS Servers, network controllers and field controllers.
- Network switches, gateways, routers, protocol converters etc.
- The BMS/BAS application.
- Ethernet and RS485 sub-networks.
- Control panels.
- 240VAC and 24VAC power supplies.
- Valves, actuators and sensors.
- Instrumentation cabling.

Measurement & Verification (M&V) Requirements

BACnet trend objects shall be created if not already available. All trends from the local controllers and HLI's shall be uploaded to the BMS/BAS server for long-term history storage. Trend data stored on the BMS/BAS server shall be readily available for a minimum 3-years. To aid in measurement and verification, the following points shall be trended with a maximum sample rate of 15-minutes:

- All physical inputs and outputs.
- All HLI points that are associated with chiller optimisation. E.g., data from the following devices:
 - Chiller HLI's.
 - VSD HLI's (chilled water pumps, condenser water pumps and cooling tower fans).
 - Electric and thermal meter HLI's.
 - Chiller HLI's.
 - Site weather station HLI.

Functional Description - Optimised Chilled Water Plant Control Strategy

General

This document is designed to provide specific updates for the items listed within only - it is not a complete strategy and must be incorporated into the existing Functional Description for the site. This document provides specific control setpoints designed to optimise the energy consumption and operation of the chilled water plant. All existing and relevant controls strategies and safety mechanisms must be retained unless otherwise stated.

Field Demand Based Controls

The strategies outlined in this document rely on responding to field load demand (kW) on the chilled water plant. As many existing systems do not control from field demand, changes to the logic and programming are often needed. This section describes the calculation for field demand, based on what information is available on the BMS/BAS in order of reliability.

1. Where common supply and return chilled water temperatures flow is known for the field:

1. Where common supply and return chilled water temperatures flow is known for the field:

$$\text{Field Demand kW,} = \text{Field Flow rate (l/s)} \times (\text{Field Return Temp} - \text{Field Supply Temp}) \times 4.187$$

2. Where supply and return chilled water temperatures and flows are known for each chiller:

$$\text{Chiller kW} = \text{Chiller Flow rate (l/s)} \times (\text{Chiller Return Temp} - \text{Chiller Supply Temp}) \times 4.187$$

$$\text{Field Demand} = \sum (\text{Chiller}(n) \text{ kW})$$

3. Where chiller load % and capacity is known for each chiller:

$$\text{Chiller kW,} = \text{Chiller Load \%} \times \text{Chiller Capacity kW}$$

$$\text{Field Demand} = \sum (\text{Chiller}(n) \text{ kW})$$

Stabilisation Delay

Stage up stabilisation delay: 15 minutes (adj.)

Stage down stabilisation delay: 20 minutes (adj.)

Condenser Water Temperature Setpoint Reset Rate: Max 0.2°C per minute. (adj.)

CHW & Condenser Water Flow Setpoint Reset Rate: Max 1 l/sec per minute. (adj.)

Chiller Staging

The staging strategy described below only pertains to the stage up and stage down demand set points, described in terms of the total field demand (kW_e) experienced by the chillers. All other controls should be maintained or adjusted as appropriate to align with the new staging strategy, including but not limited to:

- Minimum decoupler flow, or
- Bypass valve position
- Staging runtime
- Cooling call
- Emergency Stage Up
- Optimum start / stop
- Hot day stage-up
- Lead / Lag & Duty/Standby rotation
- Chiller/Pump failure changeovers
- Pump status confirmation and run time delays
- Stage up/down & runtime delay timers
- VSD ramp up/down timers
- Chilled Water Temperature Setpoints, Resets and Rate Limiters
- Any other chiller operational safety measures

Staging Sequence

The staging strategy referred to in this document is to be implemented for when the existing strategy enables the first chiller. The site may have additional stages that are utilised prior to calling a chiller online that make use of free, passive, stored or other cooling, such as, CHW circulation or thermal storage. These 'pre' stages remain relevant to the site and are compatible with the active cooling stages prepared by Exergenics. These stages are referred to collectively as 'stage 0' in this document. The stage numbering in this document may need to be adjusted to align with the existing plant stages (if any) prior to chillers being enabled.

Stage	Chiller 1A or 1B (Lead or Lag)	Chiller 1A or 1B (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)
0	*	*	*	*
1	enabled	-	-	-
2	-	-	enabled	-
3	-	-	enabled	enabled
4	enabled	-	enabled	enabled
5	enabled	enabled	enabled	enabled

*Existing Site Strategy

Stage Up

The stage-up sequence is initiated when the following conditions are satisfied:

- The system load is equal to or greater than the capacities tabled below.
- The stabilisation delay has expired.

Stage	Stage Up Cooling Load Setpoint (kW,)
0 → 1	*
1 → 2	1855
2 → 3	3505
3 → 4	6455
4 → 5	8615

**Existing Site Strategy*

Stage Down

The stage-down sequence is initiated when the following conditions are satisfied:

- The system load is equal to or greater than the capacities tabled below.
- The stabilisation delay has expired.

Stage	Stage Down Cooling Load Setpoint (kW,)
1 → 0	*
2 → 1	1020
3 → 2	2585
4 → 3	5900
5 → 4	7225

**Existing Site Strategy*

Chiller Demand Limits (Load Balancing)

Each chiller's maximum demand is limited depending on the combination of running chillers and at which point each chiller is most efficient. Chiller load balancing refers to the restriction of loading to one or more chillers to favour the highest part load efficiency possible whilst still meeting the chilled water field demand. E.g.,

- Identical chillers running concurrently shall distribute the load between them equally.
- Smaller capacity chillers shall also be favoured when applying a demand limit – allowing the larger chiller(s) to service the load dynamically.

If a combination of unique, identical and/or unequally sized chillers are running concurrently, a demand limit will be placed on the least number of chillers possible. Where some chillers have HLIs and are capable of demand limiting and others are not, the chillers with existing HLIs should be demand limited where possible to ensure that implementation costs are minimised.

To ensure the chilled water system can continually meet the field demand, the following logic is recommended to be programmed in to the BMS/BAS:

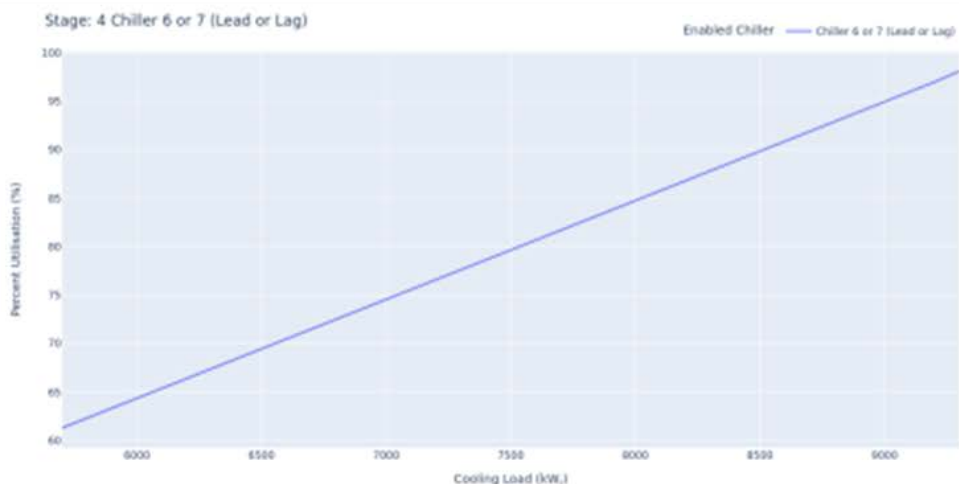
- When the system is called to stage up, all chillers shall be allowed to run at 100% for the first 30 minutes. Once 30 minutes has elapsed, the demand limiting shall be enforced.
- This strategy allows the aggregated limited capacities of the chillers to be 10% higher than the system cooling demand.
 - As an additional safety precaution, if the demand limiting strategy is enabled, and the common leaving chilled water temperature is above setpoint + 3C or the decoupler flow gets below -3l/s [if available] for 10 minutes, the demand limiting shall be disabled for 90 minutes, allowing all the chillers to run up to 100% of their capacity.

Stage 4 Chiller Demand Limits



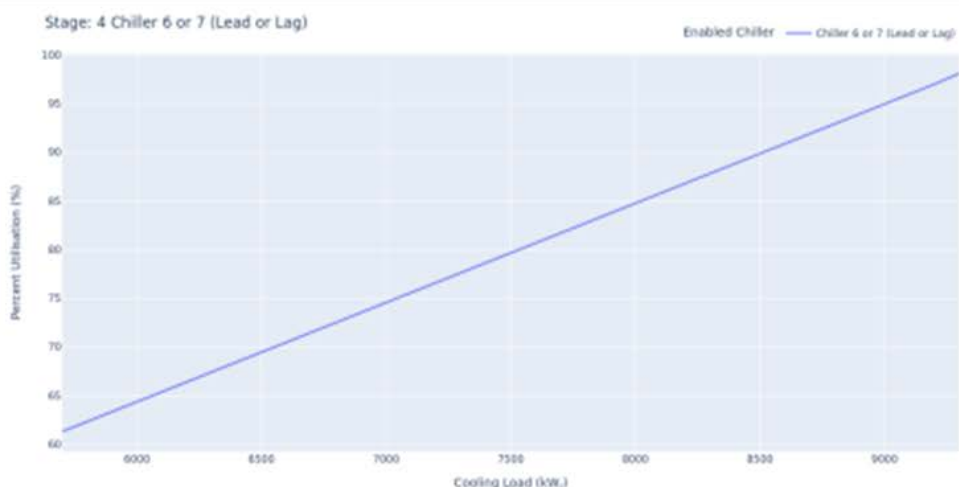
Chiller 6 or 7 (Lead or Lag) Coordinates (Field Demand kW, Chiller Demand Limit)

(5700, 61%), (9300, 98%)



Chiller 6 or 7 (Lead or Lag) Coordinates (Field Demand kW, Chiller Demand Limit)

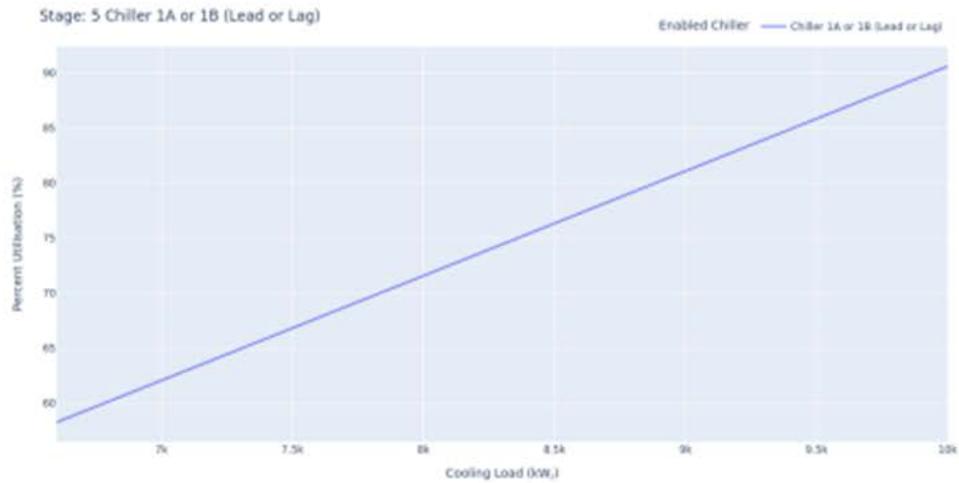
(5700, 61%), (9300, 98%)



Stage 5 Chiller Demand Limits

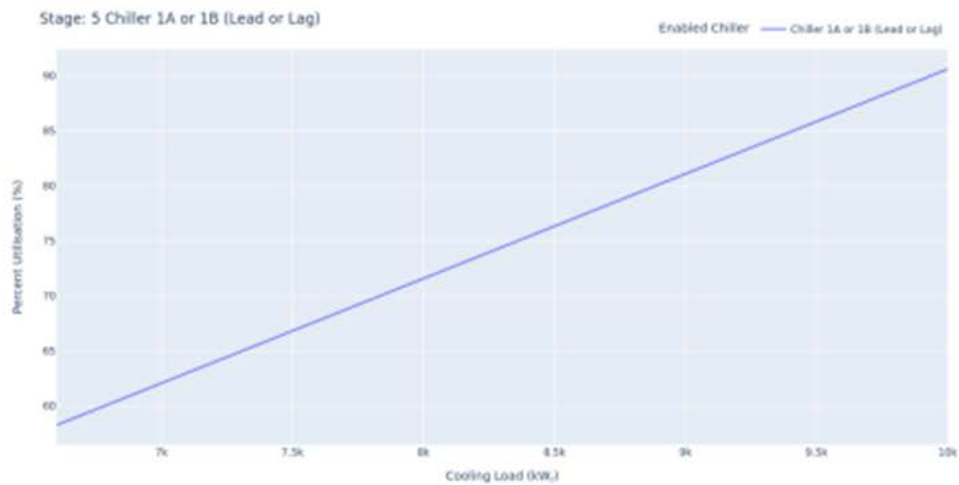
Chiller 1A or 1B (Lead or Lag) Coordinates (Field Demand kW,, Chiller Demand Limit)

(6600, 58%), (10000, 91%)



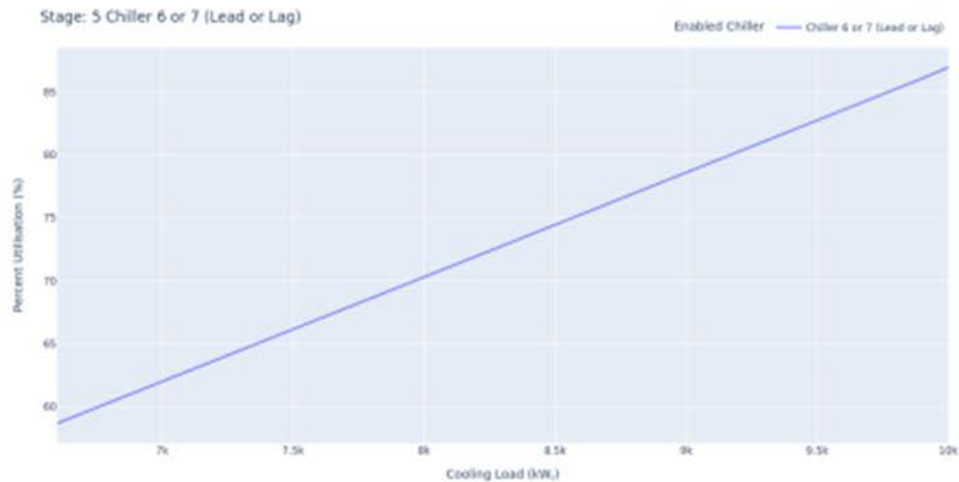
Chiller 1A or 1B (Lead or Lag) Coordinates (Field Demand kW,, Chiller Demand Limit)

(6600, 58%), (10000, 91%)



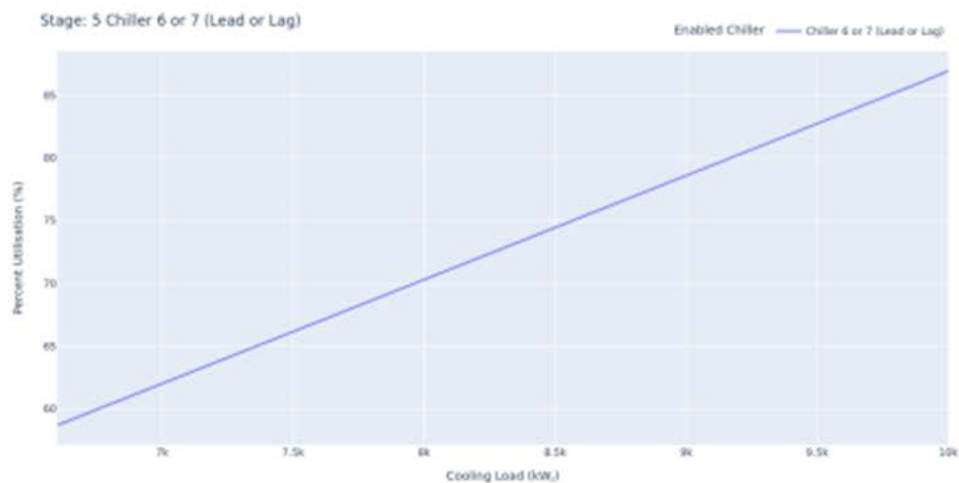
Chiller 6 or 7 (Lead or Lag) Coordinates (Field Demand kW, Chiller Demand Limit)

(6600, 59%), (10000, 87%)



Chiller 6 or 7 (Lead or Lag) Coordinates (Field Demand kW, Chiller Demand Limit)

(6600, 59%), (10000, 87%)



Dynamic Condenser Water Temperature

The condenser water temperature algorithm has been provided for all potential combinations of chiller sequencing, which are outlined in the Staging Legend. Not all Stages presented may be possible or utilised on site, and the stage names may not be reflective of what the existing naming convention on site.

The intent of this section is not to reprogram any staging on site, but to match the algorithms provided to the existing and relevant site stages.

The condenser water temperature algorithm utilises a 'dynamic approach', which considers both ambient wet bulb temperature and system cooling load. The dynamic approach is presented in simplified formulas to calculate the setpoint at various cooling load setpoints are listed below. All other controls should be maintained or adjusted as appropriate to align with the new dynamic condenser water strategy, including but not limited to:

- Absolute Min. & Max. Condenser Water Temperature Setpoints
- Cooling Tower Bypass
- Temperature setpoint rate limiters
- Minimum decoupler flow, or
- Bypass valve position
- Pump failure changeovers
- Pump status confirmation and run time delays
- Staging timers
- Stage up/down & runtime delay timers
- VSD ramp up/down timers
- Any other chiller & Cooling Tower operational safety measures

Condenser Water Dynamic Approach Algorithm - Header #1

Coordinates (Field Demand kW, W_i + °C)
(0, 2.43), (1855, 2.92), (1020, 2.53), (3505, 3.45), (2585, 2.63), (6455, 3.71), (5900, 3.28), (8615, 3.82), (7225, 3.26), (10000, 3.73)

For Stage 1

$$C_i = W_i + 2.43 + (0.00026 \times kW_i)$$

For Stage 2

$$C_i = W_i + 2.15 + (0.00037 \times kW_i)$$

For Stage 3

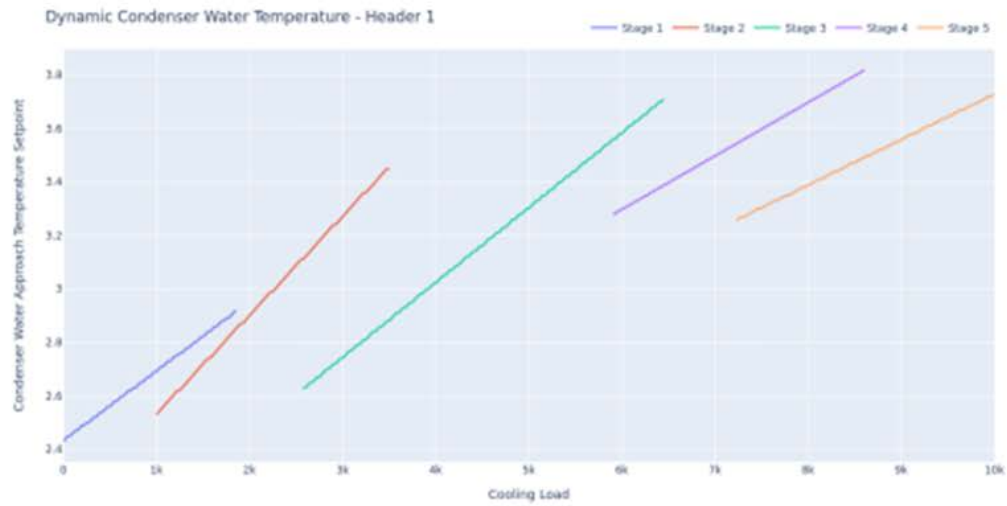
$$C_i = W_i + 1.90 + (0.00028 \times kW_i)$$

For Stage 4

$$C_i = W_i + 2.10 + (0.00020 \times kW_i)$$

For Stage 5

$$C_i = W_i + 2.03 + (0.00017 \times kW_i)$$



To ensure that chillers are operating within their manufacturer specific safe operating ranges, upper and lower limits should be placed on the algorithms above such that condenser water temperatures do not fall outside this range. Where the plant is configured with a common condenser water header, the upper and lower temperature limits should be restricted to the highest minimum temperature and lowest maximum temperature of all chillers enabled. If the manufacturers limits are not known, the existing site upper and lower temperature limits shall remain in place.

Required Cooling (kW _e)	Chiller 1A or 1B (Lead or Lag)	Chiller 1A or 1B (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)
8000	87%	-	85%	85%
8100	88%	-	86%	86%
8200	89%	-	87%	87%
8300	91%	-	88%	88%
8400	92%	-	89%	89%
8500	93%	-	90%	90%
8600	94%	-	91%	91%
8700	95%	-	92%	92%
8800	96%	-	93%	93%
8900	97%	-	94%	94%
9000	99%	-	95%	95%
9100	100%	-	96%	96%
9200	100%	-	97%	97%
9300	100%	-	98%	98%

Chiller Load Balancing - Stage 5

Required Cooling (kW _e)	Chiller 1A or 1B (Lead or Lag)	Chiller 1A or 1B (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)
6600	58%	58%	59%	59%
6700	59%	59%	60%	60%
6800	60%	60%	60%	60%
6900	61%	61%	61%	61%
7000	62%	62%	62%	62%
7100	63%	63%	63%	63%
7200	64%	64%	64%	64%
7300	64%	64%	65%	65%
7400	65%	65%	65%	65%

Appendix A - Strategy Lookup Tables

Chiller Load Balancing - Stage 4

Required Cooling (kW _e)	Chiller 1A or 1B (Lead or Lag)	Chiller 1A or 1B (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)
5700	61%	-	61%	61%
5800	62%	-	62%	62%
5900	63%	-	63%	63%
6000	64%	-	64%	64%
6100	66%	-	65%	65%
6200	67%	-	66%	66%
6300	68%	-	67%	67%
6400	69%	-	68%	68%
6500	70%	-	69%	69%
6600	71%	-	71%	71%
6700	72%	-	72%	72%
6800	74%	-	73%	73%
6900	75%	-	74%	74%
7000	76%	-	75%	75%
7100	77%	-	76%	76%
7200	78%	-	77%	77%
7300	79%	-	78%	78%
7400	80%	-	79%	79%
7500	81%	-	80%	80%
7600	83%	-	81%	81%
7700	84%	-	82%	82%
7800	85%	-	83%	83%
7900	86%	-	84%	84%

Required Cooling (kW _e)	Chiller 1A or 1B (Lead or Lag)	Chiller 1A or 1B (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)	Chiller 6 or 7 (Lead or Lag)
7500	66%	66%	66%	66%
7600	67%	67%	67%	67%
7700	68%	68%	68%	68%
7800	69%	69%	69%	69%
7900	70%	70%	70%	70%
8000	70%	70%	70%	70%
8100	71%	71%	71%	71%
8200	72%	72%	72%	72%
8300	73%	73%	73%	73%
8400	67%	67%	74%	74%
8500	68%	68%	74%	74%
8600	70%	70%	75%	75%
8700	71%	71%	76%	76%
8800	73%	73%	77%	77%
8900	74%	74%	78%	78%
9000	76%	76%	79%	79%
9100	77%	77%	79%	79%
9200	79%	79%	80%	80%
9300	80%	80%	81%	81%
9400	82%	82%	82%	82%
9500	83%	83%	83%	83%
9600	85%	85%	84%	84%
9700	86%	86%	84%	84%
9800	88%	88%	85%	85%
9900	89%	89%	86%	86%
10000	91%	91%	87%	87%

Measurement & Verification Report – Chilled Water Optimisation at Sydney Airport T1

Below is the Measurement and Verification Report for the project, which aligns to the International Performance Measurement and Verification Protocol (IPMVP) Option B Retrofit Isolation Guidelines. The plant energy baselining methodology takes into account both building load and ambient weather conditions to create a boundary condition around the chilled water plant and consistently generate models of >90% R2. Note this report only covers part of the reporting period so the annualised kWh savings figures are higher than published.



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Measurement & Verification Report

Exergenics Chilled Water Plant Optimisation at Sydney Airport T1



05/02/24
Version 1
Author: Sam McMaster
Reviewer: Iain Stewart

Table of Contents

Executive Summary	3
Project Context	4
Project Boundary	4
The International Performance Measurement and Verification Protocol (IPMVP)	5
Baseline and Reporting Period details	5
Modelling Variables Summary	6
Independent Variable	6
Dependent Variable	6
Baseline Period Data	6
Static Factors	6
Changes to static factors	6
Baseline Adjustments	6
Baseline Energy Model	7
Results	10
Summary of Results	10
Reporting Period Data	11
Appendix A - Baseline Period Data	12
Appendix B - Reporting Period Data	25

Executive Summary

Exergenics Optimised Chilled Water Plant strategy has been implemented by JCI at Sydney International Airport, T1. Chilled water plant data was collected to baseline the existing system from January 2022 to August 2022. Modelling was carried out by Exergenics in November 2022 and the updated control strategy was commissioned in March 2023. The M&V has been conducted to quantify the energy (kWh) savings resulting from the updated controls, using data from March 2023 to October 2023.

The following recommendations were implemented on the chilled water plant:

- Chiller Staging Strategy
- Dynamic Condenser Water Temperature Algorithm

The International Performance Measurement and Verification Protocol (IPMVP) has been used in this report, which outlines the current international best practice techniques available for verifying results of energy efficiency, water efficiency, and renewable energy projects.

The findings below illustrate the modelled versus actual energy consumption during the reporting period, where the modelled data represents the energy consumption of the plant had it been operating in its pre-optimised state during the reporting period.

Key findings from the M&V are listed below:

Variable	Modelled (Adjusted Baseline)	Actual	Difference	
CHW Plant Energy Consumption [kWh]	1,778,455	2,668,549	890,094	33.4%
Greenhouse Gas Emissions [kgCO ₂ -e]	1,298,272	1,948,041	649,769	

Actual Energy and Adjusted Baseline

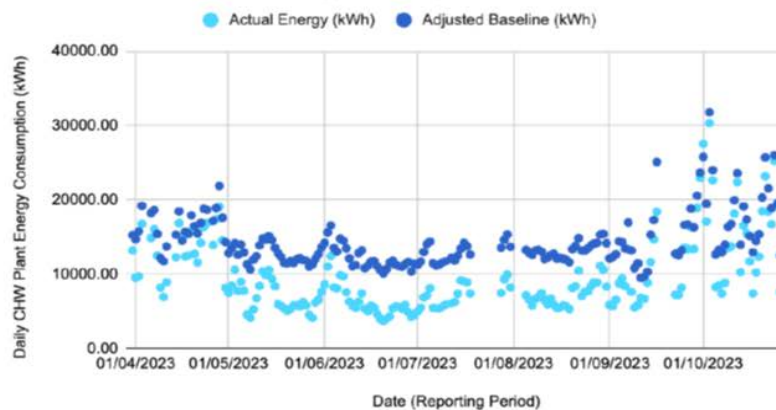


Figure 1: Actual Daily Energy Use compared to the Modelled Energy Use during the Reporting Period

Project Context

Exergenics has been engaged by A.G Coombs to provide chilled water plant optimisation recommendations at Sydney Airport, T1. The optimised chilled water plant control strategies recommended by Exergenics were applied to the plant via the BMS in March 2023.

The following recommendations were implemented on the chilled water plant:

- Chiller Staging Strategy
- Dynamic Condenser Water Temperature Algorithm

Project Boundary

This M&V report is for the electrical energy consumed by the chilled water plant at Sydney Airport, T1. The energy from the following equipment has been measured and compared:

Chillers

Reference	Type	Capacity [kW _r]	BMS Identifier
Chiller 1A	York YKEEETQ75EMG	2000	CH-1A
Chiller 1B	York YKEEETQ75EMG	2000	CH-1B
Chiller 2	Trane CVHG 1067	4500	CH-02
Chiller 3	Trane CVHG 565	2250	CH-03
Chiller 4	Trane CVHG 1067	3600	CH-04
Chiller 5	Trane CVHG 1067	4500	CH-05
Chiller 6	York YKKCKSH95CVG	3690	CH-06
Chiller 7	York YKKCKSH95CVG	3690	CH-07

Cooling Towers

Reference	Rated Power [kW]
CT1	33
CT2	33
CT3	33
CT4	33

CT5	33
CT6	39
CT7	39

Pumps

Reference	Make/Model	Rated Power [kW]	Associated Chiller
CHWP-1A	KSB Etanorm/Etabloc 125-250	11	Chiller 1A
CHWP-1B	KSB Etanorm/Etabloc 125-250	11	Chiller 1B
CHWP-2	KSB Etanorm/Etabloc 150-250	22	Chiller 2
CHWP-3	KSB Etanorm/Etabloc 125-250	15	Chiller 3
CHWP-4	KSB Etanorm/Etabloc 150-250	22	Chiller 4
CHWP-5	KSB Etanorm/Etabloc 150-250	22	Chiller 5
CHWP-6	KSB Etanorm/Etabloc 150-250	18.5	Chiller 6
CHWP-7	KSB Etanorm/Etabloc 150-250	18.5	Chiller 7
CWP-1A	KSB Etanorm/Etabloc 150-250	30	Chiller 1A
CWP-1B	KSB Etanorm/Etabloc 150-250	30	Chiller 1B
CWP-2	KSB ELITE E250-32	90	Chiller 2

CWP-3	KSB ELITE E150-315	37	Chiller 3
CWP-4	KSB ELITE E250-32	55	Chiller 4
CWP-5	KSB ELITE E250-32	90	Chiller 5
CWP-6	KSB ELITE E250-32	55	Chiller 6
CWP-7	KSB ELITE E250-32	55	Chiller 7
SCHWP-11	KSB OMEGA 350-510 C	450	-
SCHWP-12	KSB OMEGA 350-510 C	450	-
SCHWP-13	KSB ETANORM-R 250-500	220	-
SCHWP-14	KSB ETANORM-R 250-500	220	-

The International Performance Measurement and Verification Protocol (IPMVP)

The International Performance Measurement and Verification Protocol (IPMVP) has been utilised for the M&V reporting. The IPMV outlines the current best practice techniques available for verifying results of energy efficiency, water efficiency, and renewable energy projects.

The equipment energy gathered from the baselining period is baselined against Total Daily Cooling Delivered (kW_h), allowing a model to be created that can accurately predict the energy use of the plant operation prior to optimisation based on the amount of cooling delivered. This model is then used to compare against the reporting period (post optimisation) data so that the energy savings can be quantified.

Baseline and Reporting Period details

	Start Date	End Date	Days Total
Baseline Period	1/1/2022	31/8/2022	241
Reporting Period	31/3/2023	26/10/2023	186

Modelling Variables Summary

Independent Variable

Type	Source	Aggregation
Building Cooling Load (kWrh)	Manual	Daily
Weighted Average Wet Bulb (°C)	Manual	Daily

Dependent Variable

Type	Source	Aggregation
Energy Consumption (kWh)	Manual	Daily

Baseline Period Data

The baseline period data has been gathered from January 2022 to August 2022 and is presented in **Appendix A**. Error days (sensor issues) and days with no cooling delivered have been omitted.

Static Factors

The static factors are as follows:

- Chilled water plant equipment:
 - Chillers
 - Cooling Towers
 - Condenser Water Pumps
 - Primary Chilled Water Pumps
 - Secondary Chilled Water Pumps
- Building NLA

Changes to static factors

Changes to static factors are required when any of the factors listed above are altered from the baselining period, e.g a chiller was replaced with a different model or the building and plant has been expanded.

None were identified.

Baseline Adjustments

Baseline adjustments are required when there are data errors which cause the daily energy consumption or cooling delivered to not be representative of reality. This can be caused by communication errors in the building management system or calibration errors with sensors within the chilled water plant.

No baseline adjustments were necessary.

Baseline Energy Model

The two independent variables used in the chilled water plant energy baseline model as predictors of Daily kWh on the plant energy consumption are:

- Daily Sum of Cooling (**DSoC**, kWh)
- Weighted Average Wet Bulb Temperature ($^{\circ}\text{C}$)

DSoC is the sum of the total cooling delivered to the field in a given day 24 hour period of operation, calculated by integrating the area under the curve of the daily cooling load profile.

Weighted Average Wet Bulb Temperature is the instantaneous wet bulb temperature weighted by the instantaneous cooling (kW) delivered, and summed to a daily average value.

The Goodness of Fit (R^2) value achieved was 0.9 ($R^2 = 0.9$) therefore both variables are used in a multivariate regression model as predictors of mechanical plant energy consumption (kWh). An R^2 value greater than or equal to 0.8 is considered a good fit and is fit for purpose for M&V. The multivariate least-squares regression function has been produced using the following methodology:

Baseline model:

$$f(x,y) = a + b*x + c*y + d*x*y + e*y^2$$

where:

$f(x,y)$ = Predicted Daily Mechanical Equipment Energy Consumption (kWh)

x = Weighted Average Wet Bulb Temperature (Daily sum [Temp x kWh] / Daily sum [kWh])

y = Daily Sum of Cooling (kWh)

Coefficients:

$a = 9510$

$b = 532.5$

$c = -0.14$

$d = 4.856e-3$

$e = 6.926e-7$

Goodness of fit:

Adjusted R-square: 0.9

The figure below shows the relationship between actual energy consumption and the predicted model versus Weighted Average Wet Bulb Temperature during the baselining period.

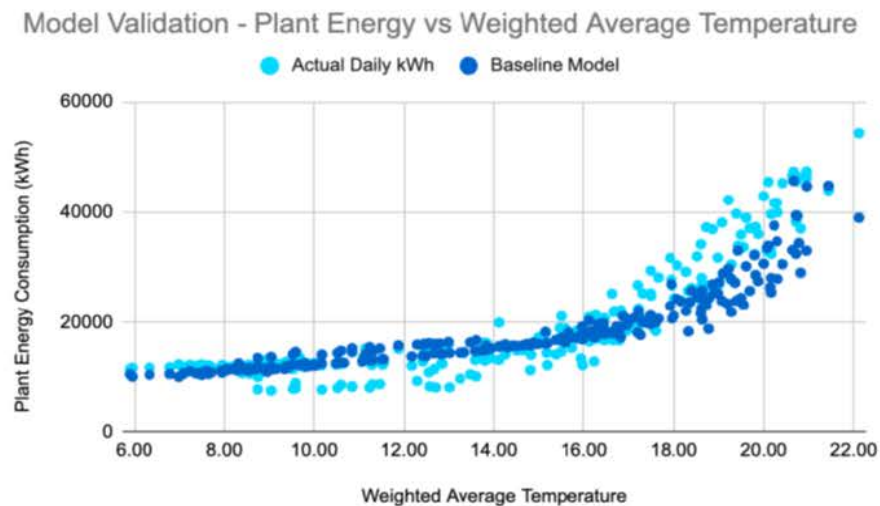


Figure 2: Relationship between actual energy consumption and the predicted model versus weighted average temperature during the baselining period.

The figure below shows the relationship between actual energy consumption and the predicted model versus Daily Sum of Cooling (kWh) during the baselining period.

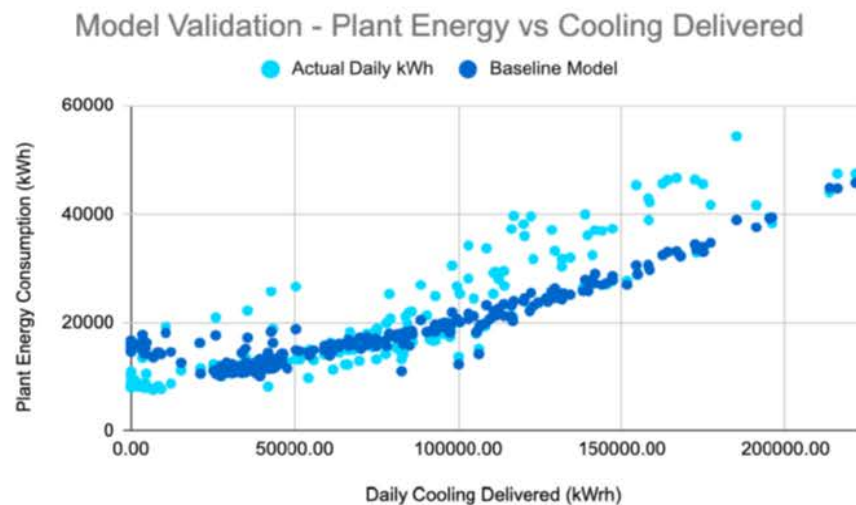


Figure 3: Relationship between actual energy consumption and the predicted model versus Daily Sum of Cooling (kWh) during the baselining period

The figure below shows the relationship between actual energy consumption and the regression model built from Weighted Average Wet Bulb Temperature and Daily Sum of Cooling during the baselining period, demonstrating the accuracy of the model.

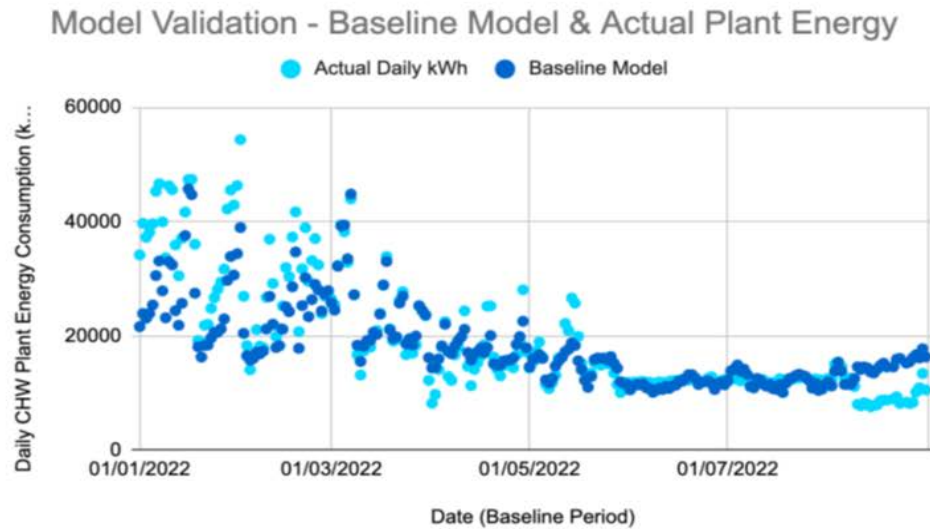


Figure 4: Relationship between actual energy consumption and the regression model built from weighted average temperature and Daily Sum of Cooling during the baselining period

Results

Using the regression model developed in the previous section it is possible to predict the energy consumption of the chilled water plant in its pre-optimised state in the post implementation period. The model has been used to calculate the difference in energy consumption in accordance with IPMVP principles.

The figures below illustrate the modelled versus actual energy consumption during the reporting period, where the modelled data represents the energy consumption of the plant had it been operating in its pre-optimised state during the reporting period. There is a consistent reduction in actual energy consumption during the reporting period, clearly demonstrating the success of the chilled water plant optimisation.

Summary of Results

Key findings from the M&V are listed below:

Variable	Modelled (Adjusted Baseline)	Actual	Difference	
CHW Plant Energy Consumption [kWh]	1,778,455	2,668,549	890,094	33.4%
Greenhouse Gas Emissions [kgCO ₂ -e]	1,298,272	1,948,041	649,769	

Actual Energy and Adjusted Baseline

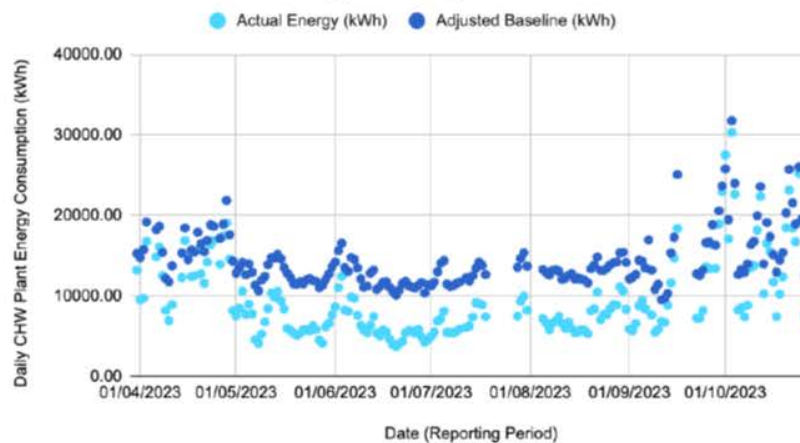


Figure 4: Actual Energy Use compared to the Modelled Energy Use during the Reporting Period

Reporting Period Data

The reporting period dataset can be found in **Appendix B**. Days with no cooling delivered have been omitted.

Appendix A - Baseline Period Data

Date	Weighted Average Temperature (°C)	Cooling Demand (kWh)	Energy Consumption (kWh)
01/01/2022	18.61	103106.48	34199.18
02/01/2022	19.39	116940.84	39726.59
03/01/2022	18.73	116215.56	37275.33
04/01/2022	19.07	119892.86	38153.67
05/01/2022	20.16	122241.65	39649.15
06/01/2022	20.42	154345.25	45325.59
07/01/2022	20.65	166760.56	46653.36
08/01/2022	20.31	138727.47	39989.27
09/01/2022	19.55	108680.88	33694.78
10/01/2022	20.96	164042.96	46296.54
11/01/2022	20.73	162558.99	45615.66
12/01/2022	19.50	120201.78	35946.56
13/01/2022	19.28	98087.87	30548.75
14/01/2022	19.69	128608.06	37110.51
15/01/2022	20.24	191044.33	41682.04
16/01/2022	20.67	221536.82	47401.40
17/01/2022	20.96	215993.39	47418.05
18/01/2022	19.87	139528.90	36063.93
19/01/2022	17.20	10620.71	19250.15
20/01/2022	15.59	43291.95	18887.34
21/01/2022	16.68	84833.11	21887.90
22/01/2022	16.68	85821.35	22046.65
23/01/2022	17.49	93020.10	24859.65
24/01/2022	17.96	99550.65	26729.33
25/01/2022	17.66	103094.86	28172.48
26/01/2022	17.49	111365.77	29422.91
27/01/2022	17.92	122950.13	31731.51
28/01/2022	19.22	158529.77	42227.00

Appendix B - Reporting Period Data

Date	Weighted Average Temperature (°C)	Cooling Demand (kWh)	Energy Consumption (kWh)	Adjusted Baseline Energy Consumption (kWh)	Energy Savings (Loss) (kWh)
31/03/2023	13.02	92485	13205	15270	2065
01/04/2023	13.51	61011	9511	14745	5234
02/04/2023	14.74	61208	9709	15763	6054
03/04/2023	16.32	101897	16784	19199	2415
06/04/2023	15.63	98545	14873	18244	3371
07/04/2023	15.90	100402	16082	18659	2577
08/04/2023	13.49	86248	12532	15419	2887
09/04/2023	10.38	57871	8210	12175	3965
10/04/2023	9.71	51374	6951	11739	4788
11/04/2023	12.28	64695	8920	13746	4826
14/04/2023	13.74	77906	12285	15318	3033
15/04/2023	15.26	106288	16880	18455	1575
16/04/2023	11.84	100291	15110	14510	-600
17/04/2023	13.94	83280	12397	15719	3322
18/04/2023	13.69	82477	12506	15451	2945
19/04/2023	15.04	102513	15734	17930	2196
20/04/2023	14.84	81612	12752	16480	3728
21/04/2023	13.94	77659	11570	15498	3928
22/04/2023	15.10	85426	14220	16909	2689
23/04/2023	15.81	103812	16355	18833	2478
24/04/2023	15.35	107783	16902	18671	1769
26/04/2023	14.89	93732	13946	17183	3237
27/04/2023	15.40	110030	17434	18921	1487
28/04/2023	16.52	126845	19069	21872	2803
29/04/2023	15.50	90953	14571	17608	3037
30/04/2023	13.03	58140	8178	14329	6151
01/05/2023	11.18	54788	7491	12845	5354
02/05/2023	12.03	63711	8468	13527	5059

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