The Innovation Hub

for Affordable Heating and Cooling

Report #LLHC4-004

Healthcare Living Laboratories: Queensland Children’s Hospital - Technology Evaluation Report for Exergenics’ Optimised Chiller Staging

QUT

About i-Hub

The Innovation Hub for Affordable Heating and Cooling (i-Hub) is an initiative led by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in conjunction with CSIRO, Queensland University of Technology (QUT), the University of Melbourne and the University of Wollongong and supported by Australian Renewable Energy Agency (ARENA) to facilitate the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry's transition to a low emissions future, stimulate jobs growth, and showcase HVAC&R innovation in buildings.

The objective of i-Hub is to support the broader HVAC&R industry with knowledge dissemination, skills-development and capacity-building. By facilitating a collaborative approach to innovation, i-Hub brings together leading universities, researchers, consultants, building owners and equipment manufacturers to create a connected research and development community in Australia.

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.
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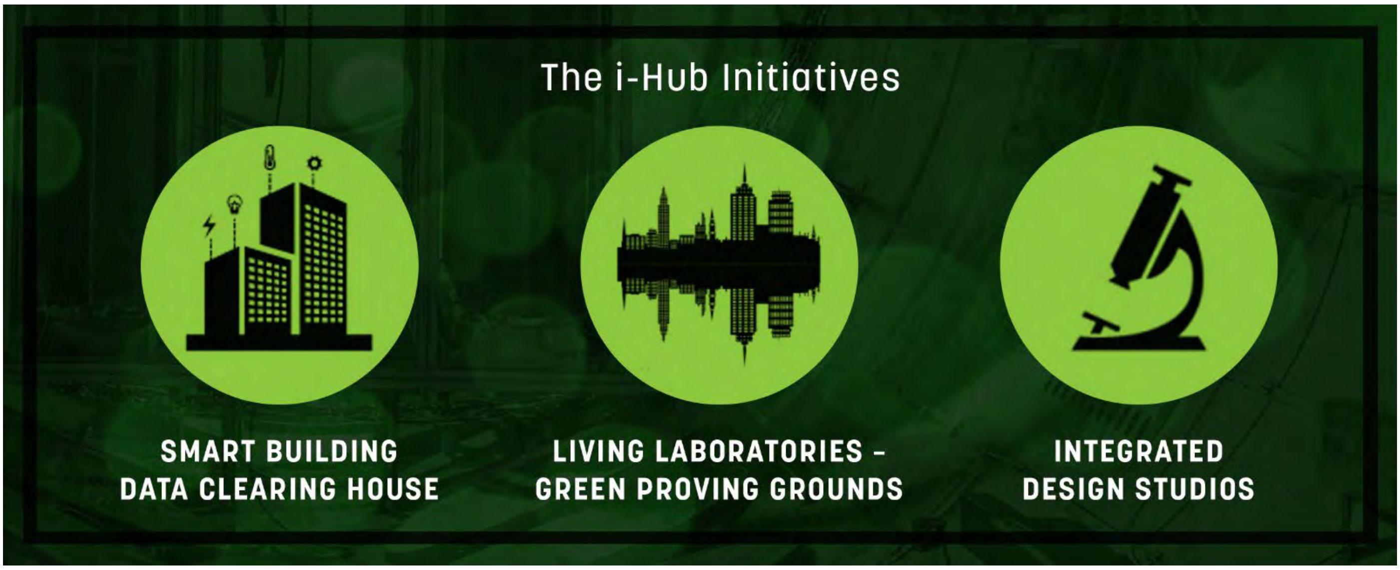

Healthcare Living Laboratories: Queensland Children’s Hospital – Chiller System Optimisation

The Living Laboratory in Queensland Children’s Hospital (QCH) will support the hospital sector to transition to a net-zero energy/demand future. In particular it will validate the impact of emerging technologies in demand reduction, demand management, renewable energy and enabling technologies, in terms of core health services (patient and worker health and comfort), building maintenance and operations, environmental impact and financial management (including participation in energy markets).

Heating, ventilation and air conditioning system (HVAC) is often the largest energy user and peak demand contributor for commercial buildings and electricity networks. The HVAC system at QCH has six chillers. Through the operation optimisation of the chiller system, energy use and peak demand can potentially be reduced as well as reducing operational cost and limiting impact to the electricity network.

Lead organisation

Queensland University of Technology (QUT)

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Project Participants

Living lab host: Children’s Health Queensland (Queensland Children’s Hospital’s parent body)

Technology provider: Exergenics

Implementation of the technology: DeltaFM (QCH site principal facility management contractor)

VERSION HISTORY

ID & Version #	Prepared By	Revision Date	Approved By	Approval Date	Reason
1.0	Aaron Liu	01/05/2022			For reviewing
2.0	Aaron Liu	26/05/2022			For reporting

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1 EXECUTIVE SUMMARY

Hospitals are often energy intensive to ensure the quality and reliability of healthcare provision. Also, public hospitals and health services are regularly a top energy user, a leading CO_2 emitter and a major budget component for governments. As Australia is transitioning to a low carbon society, our health sector is piloting low risk innovative technologies to realise health care decarbonisation [1].

For healthcare facilities, heating ventilation and air conditioning system (HVAC) is often a main energy consumer. Chiller systems are an essential component of a HVAC system for hospitals. This project is a second stage of Exergenics digital twin and chiller optimisation at Queensland Children's Hospital Living Lab. At this stage, QCH's chiller system staging sequence is optimised to save energy, reduce emissions, improve resilience to climate change, and help futureproof our healthcare provision.

Table 1 provides a summary of the project outcomes. The optimised chiller system staging created an energy saving of 24,000 kWh and emission reduction of 19 tonnes of CO_2 in the project test period. The projected annual energy reduction is 187 MWh with a reduction of 150 tonnes CO_2 emissions and an annual bill savings of $28,000. The simple payback period of the technology implementation is 1.5 years.

Table 1 Outcome summary

		Outcomes
In the test period	**Energy savings**	**24,000 kWh**
	Energy saving percentages	**3.3%**
	Emission reduction	**19 tonnes**
Projected impact	**Annual energy savings**	**187,000 kWh**
	Annual emission reduction (QLD grid emissions intensity of 0.80 kg CO_2-e/kWh)	**150 tonnes**
	Annual bill savings (assuming $0.15/kWh)	**$28,000**
Simple payback period		**1.5 years**

Overall, Exergenics' technology is a data driven, low risk option which has been implemented without exposure to clinicians or patients, nor changes to occupant's comfort level. The simple payback period indicates possible financial viability for the technology to be implemented more broadly.

2 INTRODUCTION

2.1 Problem Statement

Heating, ventilation, air conditioning and refrigeration (HVAC&R) is essential in most settings to ensure a pleasant, comfortable, and safe work environment. In commercial buildings around the world, 70% of energy usage and 63% of greenhouse gas emissions are estimated to be contributable to heating, cooling and ventilation. HVAC typically accounts for 40% to 50% of the total energy bill for businesses and commercial buildings. Inefficient HVAC&R system may lead to higher than expected electricity bills and more emissions.

HVAC systems accounted for 52% of healthcare building energy use, based on a US study in 2012 (Figure 1, [2]). In Queensland, the main energy use of a HVAC system is often for cooling supplied by the chilled water system [3][4]. With optimised chillers' operation, multi-faceted benefits can be realised, e.g. cost control, energy use, peak demand and carbon footprint.

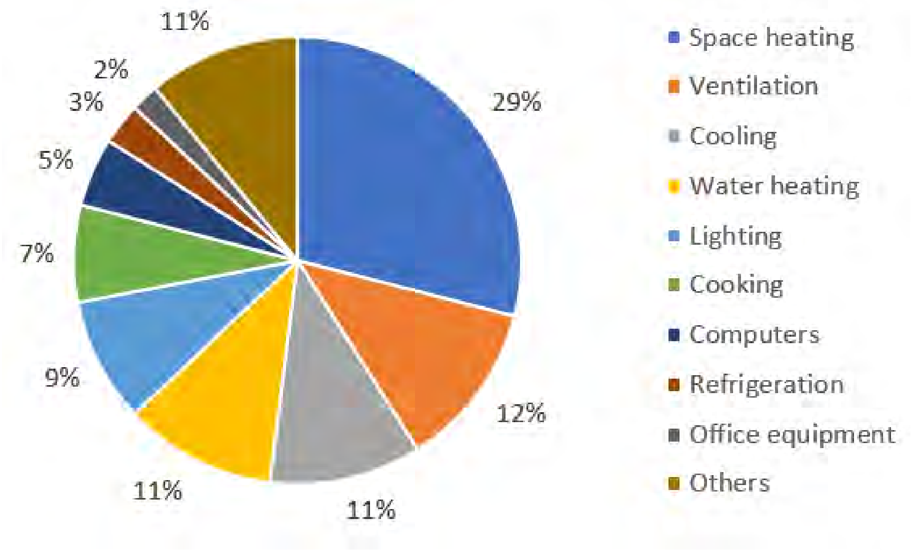

Figure 1 US healthcare building energy breakdown by end-use

2.2 Site Descriptions

The Queensland Children's Hospital precinct is comprised of three buildings:

- the Main Hospital (MH) Building;
- the Centre for Children's Health Research (CCHR); and
- the Central Energy Plant (QCH EP) Building.

The central energy plant supplies the hospital and research facility with their chilled water needs for air conditioning. The chiller system comprises one 1,100kWr low-load swing variable-speed drive (VSD) low-voltage electric centrifugal chiller, and five VSD low-voltage electric centrifugal chillers of 3,315kWr each, with a full-load minimum coefficient of performance (COP) of 6.7. These are configured in an N+1 redundancy arrangement. Combined, the total chilled water capacity of the central energy plant is up to 20MWr.

The QCH water cooled chillers are shown partially in Figure 2. Information about these six chillers is provided in Table 2. More details about the site's energy infrastructure and baseline information are in [5] and [6].

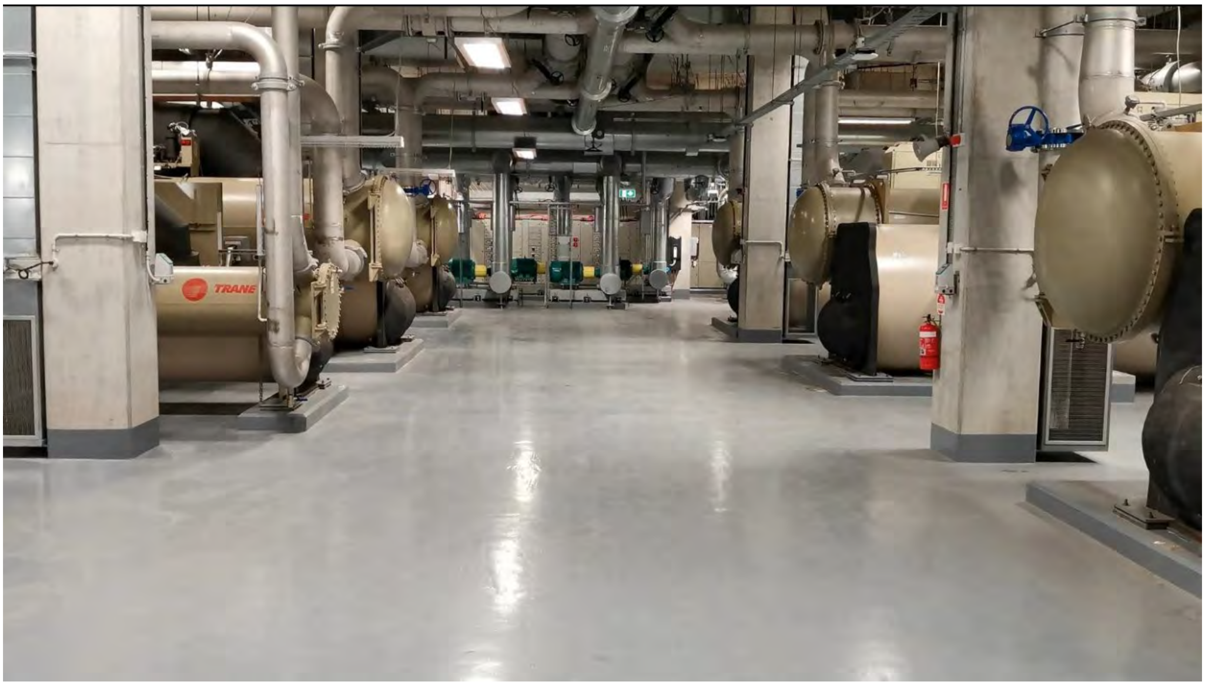

Figure 2 QCH chillers plant room

Table 2 QCH centrifugal chillers

Chiller Reference	Description	Rating
CH-B1-3	VSD low voltage electric centrifugal chiller	Trane 1100kWr
CH-B1-4	VSD low voltage electric centrifugal chiller	Trane 3315kWr
CH-B1-5	VSD low voltage electric centrifugal chiller	Trane 3315kWr
CH-B1-6	VSD low voltage electric centrifugal chiller	Trane 3315kWr
CH-B1-7	VSD low voltage electric centrifugal chiller	Trane 3315kWr
CH-B1-8	VSD low voltage electric centrifugal chiller	Trane 3315kWr

3 TEST DESCRIPTION

3.1 Technology Overview

Exergenics' chiller system optimisation technology has been implemented at QCH in a previous stage of the project [7]. As Table 3 shows, there were three major steps in the optimisation process. The first step was to acquire data for chillers, pumps and cooling towers. The datasets included primary pump VSD speed, flow rates, condenser water temperatures and chilled water temperatures and ambient weather data. In the next step, the data were fed into advanced machine learning algorithms to build a working mathematical model for the physical plant. Then algorithms looped through numerous possible scenarios and identified the best way to control the chiller system. In the last step, a set of recommendations was provided to improve the plant's efficiency. Also, potential energy and cost savings were estimated with each recommendation.

Table 3 Exergenics optimisation process

Step	Name	Purpose
1	Data collection	Collect primary pump VSD speed, flow rates, condenser water temperatures, chilled water temperatures and ambient weather data.
2	Building a digital twin for the primary side of the chiller system	Advanced machine learning algorithms are used to train data to build a working mathematical model of a physical plant
3	Chiller primary system optimisation	A set of implementable items is recommended for improving plant's operation

In the previous stage, three sets of recommendations were provided to optimise the site's HVAC operation. Updating chiller staging logic was one of the recommendations. This recommendation is evaluated and considered to be a low risk option and approved to be implemented by the site facility management.

3.2 Objectives

There are two main objectives in this part of the project:

- Implementation and evaluation: the site's chiller system sequencing logic is updated and impact is evaluated
- National impact study: extrapolating QCH chillers' sequencing optimisation to Australian major hospitals

3.3 Staffing / Resource Needs

Resource needs of this test are summarised in Table 4.

For this testing, QCH has an Energy Management System (EMS) with historical data for the chiller system's electricity use. QCH has engaged the site principal contractor and implemented the optimised chiller sequencing logic. A new automatic weather station has been installed on QCH's CCHR building to observe and transfer weather data to a cloud storage.

Table 4 Resource needs

	Sources
Ambient temperature and humidity	A weather station on QCH
Energy data for QCH chiller system	History data provided by QCH
Report writing and national impact study	QUT

The roles and responsibilities of staff are provided in Table 5.

Table 5 Roles and Responsibilities

Role	Responsibility
Bruce Bonney, Jason Sanders (QCH)	- Living lab host - Provide the historic data - Coordinate the research requirement with QUT Report any problems that might hinder/stop the testing.
Iain Stewart Nathan Johnstone Smity Ganoo (Exergenics)	- Build a digital twin model - Test the digital twin's accuracy - Virtually quantify savings potential in monthly energy, monthly peak demand and monthly emission reduction. - Provide training to QUT and QCH on installation/site configuration, operation and maintenance (if applicable) Provide all required documents in Section 3.1, 4.1 of the test plan.
Aaron Liu (QUT)	Project manager of the test and research living lab; organise and coordinate the testing; write the test report; distribute the test report according to contractual arrangements
Wendy Miller (QUT)	Project Leader; oversee the test regime and report writing / distribution

3.4 Instrumentation Plan

No specific additional instrument is required. This stage of testing is based on data and chiller control logic updates from QCH. In the previous stage, Exergenics provided the computing power and relevant software to build the digital twin.

4 METHODOLOGY

4.1 Test Approach and Description

This research uses quantitative methods, utilizing historical data and in-situ site data.

To present the energy improvement of the optimised chiller staging logic, the key performance indicators include:

- energy savings after the optimised staging logics are implemented
- peak demand reduction after the optimised staging logics are implemented
- expected CO_2 emission reduction after the optimised staging logics are implemented

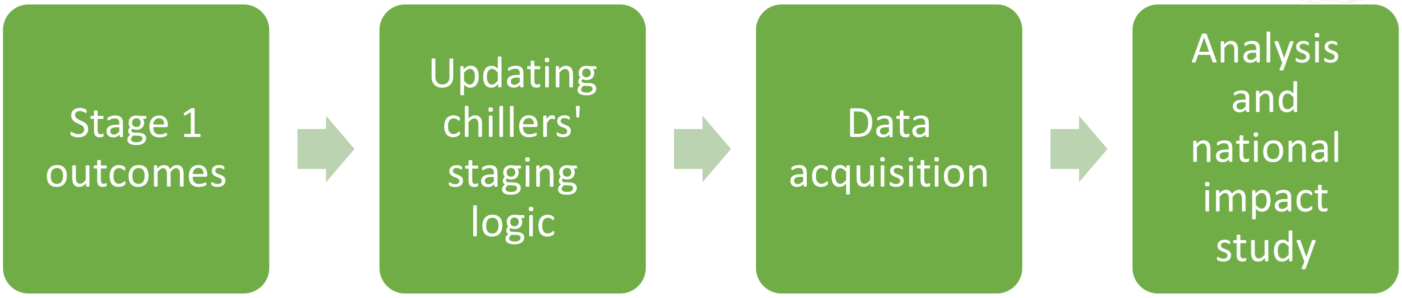

Figure 3 Test stages

The test consists of 4 steps as shown in Figure 3.

Step 1

In the previous Stage 1, a set of historical data were used to train machine learning algorithms that built a working mathematical model of the physical chiller primary system. Another optimisation engine looped through numerous possible scenarios (such as temperature events, load increase) that could be experienced by the chiller primary system, learning how to best control the system (Item 3 in Table 2). An outcome of the previous Stage 1 is to recommend updating the site's chiller staging logic.

Step 2: updating chillers' staging logic

The optimised chiller staging logic is shown in Table 6. Please note the crossed out ~~ON~~ logic was for the existing chiller staging. The Off and ON are new logic added to the staging program.

The updated staging logic was implemented on controller A and B, tested on the simulation mode, reflected in graphics and then commissioned on 16th March 2022. The new logic became fully operational on 28th March 2022.

Table 6 Optimised chiller staging logic

Chiller Reference	Stages								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
CH-B1-3	ON		ON						ON
CH-B1-4		ON	ON	ON	ON	ON	ON	ON	ON
CH-B1-5			~~ON~~ Off	ON	ON	ON	ON	ON	ON
CH-B1-6				~~ON~~ Off	ON	ON	ON	ON	ON
CH-B1-7					~~ON~~ Off	ON	ON	ON	ON
CH-B1-8						~~ON~~ Off	ON	ON	ON

Step 3: data acquisition

The weather station on QCH CCHR building provides continuous weather data which were available for download from the weather station manufacturer's website.

The site's chiller system's electricity use data were provided by QCH facility management, including electricity use data for chillers, chilled water pumps, condenser pumps and cooling towers.

Step 4: analysis and national impact study

The QCH results are extrapolated to hospitals in Australian capital cities to reveal its national impact, considering different climate differences and to the extent possible based on available data.

The above steps are summarised in Table 6. Test types and data needed are included in Table 7.

Table 7 Test stages

Step	Description	Duration
1	Stage 1	6 months (completed in 2021)
2	Updating chillers' staging logic	1 month
3	Data acquisition	2 months
4	Analysis and national impact study	0.5 month

Table 8 Test data description

Category	Description / Purpose	Estimated Period	Responsibility
QCH site weather data	Weather observations, including • Drybulb temperature • Relative humidity • Solar radiation	Jan 2021 – May 2022	Aaron Liu
QCH historical data for the chiller system	Electricity use measurements: • electricity use data for chillers, • chilled water pumps • condenser pumps • and cooling towers	Jan 2021 – May 2022	Bruce Bonney, Jason Sanders, Aaron Liu
Climate data for Australian capital cities (for National impact study for hospitals in Australian capital cities)	Impact of optimised chiller staging under different weather conditions	May 2022	Aaron Liu

4.2 Excluded Items

Items specifically excluded from testing are summarised in Table 9.

Table 9 Excluded items

Item Not to be Tested	Comment
HVAC system energy efficiency	Not in the scope

5 RISK AND MITIGATION

A Risk Management Plan for the QCH Living Lab has been developed by QUT in consultation with QCH (LLHC4_RMP_V3). Risks associated with this specific test plan are listed below.

The testing is all data based so there is no risk to patients, clinicians, plant or operations. QCH and QUT commit to ensuring that, the technology testing has no impact on the hospital and provides benefits to energy, environment and financial sustainability.

As a part of the risk management process, the following requirements have been satisfied:

1. Technology providers must be Australian companies, and provide details of ABN and TFN
2. Technology providers must provide details of
    a. relevant insurances (PL, PI)
    b. product warranties
    c. relevant certified test reports if compliance with Australian Standards or other standards is necessary
3. No site visit or site work is expected for this technology testing.

COVID-19 and other health related events may result in limited or no access to the test site, at short notice. This risk may be irrelevant to the technology testing.

6 TEST RESULTS

6.1 Energy Performance Results

This section of the report outlines the Measurement and Verification (M&V) of the Energy Conservation Measures (ECMs) that were recommended by Exergenics and commissioned by the BMS contractor. Modelling was carried out by Exergenics in 2021 and the updated control strategy was commissioned by the BMS contractor on March 28th, 2022. M&V was conducted to quantify the energy (kWh) savings resulting from the updated controls, using data from May 2021 to March 2022 as the baseline period and data from March 2022 to May 2022 as the reporting period (post commissioning).

The M&V methodology chosen was Option B (Retrofit Isolation) of the International Performance Measurement and Verification Protocol (IPMVP). Key findings from the M&V are listed below:

- Energy savings: 24,000 kWh for the test period
- Carbon abatement: 150 tonnes CO_2e (assumes QLD grid emissions intensity of 0.80 kg CO_2e/kWh)
- Measured cost savings: $3,600 (assumes blended electricity tariff of $0.15/kWh)
- Projected energy savings: 188,000 kWh for a year
- Projected cost savings: $28,000 for a year

A baseline of the chilled water plant was constructed by performing a regression on Cooling Degree Days (with a 12°C reference temperature) and daily cooling demand in kilowatt refrigeration hours (kWrh) with a strong correlation across the baseline period (Goodness of fit, $R^2 = 0.8784$ and $R^2=0.9819$ respectively).

Figure 4 illustrates the relationship between chilled water plant energy consumption (kWeh) and chilled water produced (kWrh). Using the two independent variables of CDD & kWrh as a predictor of kWeh on the MSSB there was a slight increase in $R^2 = 0.9821$. Therefore, both variables were included in the multivariate regression model as predictors of mechanical plant energy consumption, kWeh.

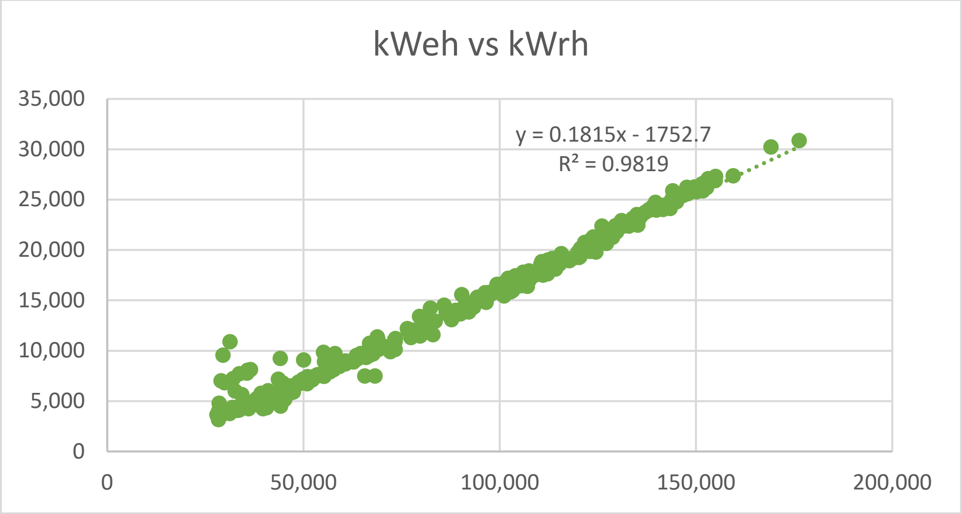

Figure 4 Chilled water plant energy consumption (kWeh) vs chilled water produced (kWrh)

Figure 5 shows the relationship between chilled water plant energy consumption (kWeh) and cooling degree days with a reference temperature of 12 ºC. An approximate linear relationship is visible with the goodness of fit value (R^2) at 0.8784.

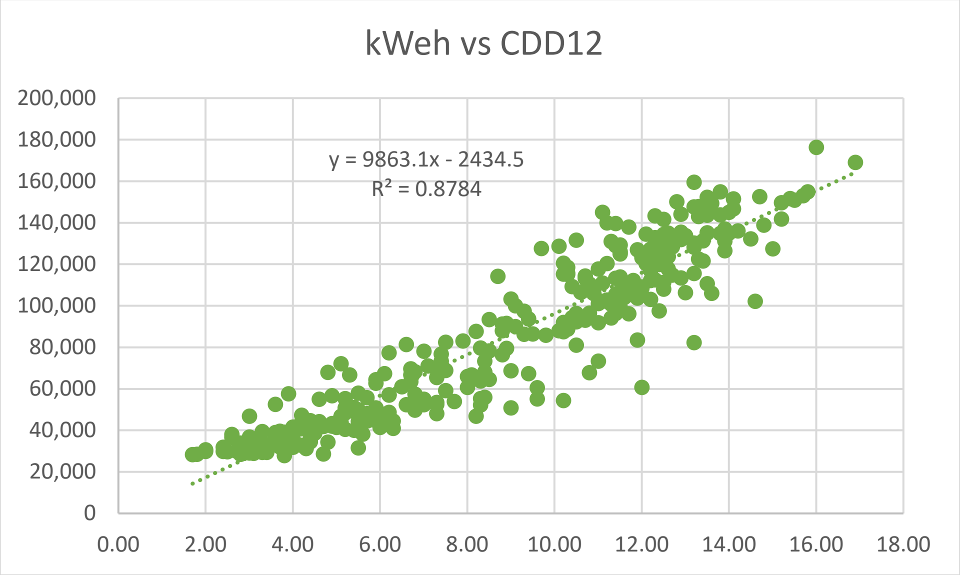

Figure 5 Chilled water plant energy consumption (kWeh) vs CDD12

Figure 6 illustrates the actual energy consumption of the plant versus the predicted energy consumption from the baseline model. The dotted line is for the predicted energy consumption and the solid line is for the actual energy consumption.

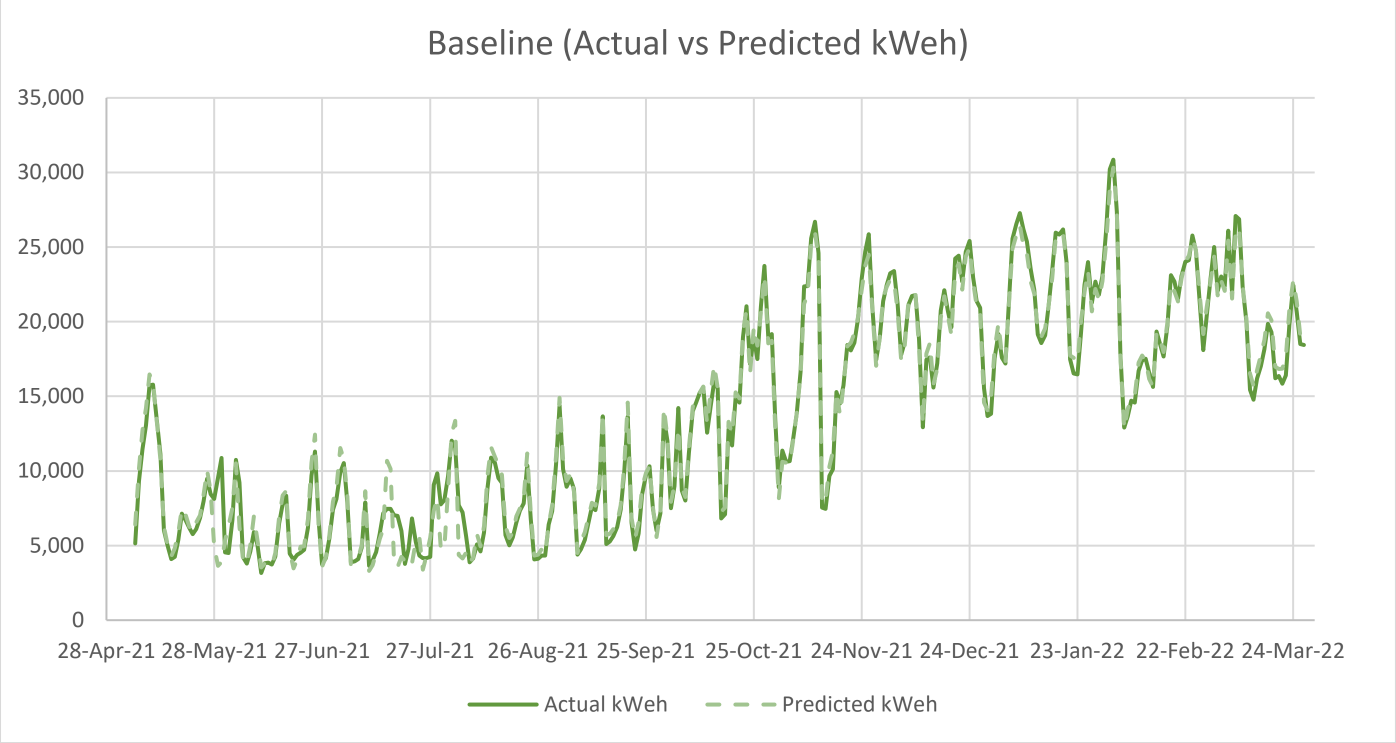

Figure 6 Actual energy consumption vs the predicted energy consumption

The baseline model can be expressed as a multivariate linear model:

$f(x,y) = p00 + p10*x + p01*y$

where,

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

x = Daily Cooling Degree Days with a 12°C reference temperature (CDD)

y = Daily Building Cooling Load (kWrh)

Coefficients:

$p00 = -1659.42$

$p10 = -72.33$

$p01 = 0.18798$

Goodness of fit:

R-square: 0.9821

Figure 7 illustrates the actual energy consumption of the chilled water plant in the reporting period versus the modelled (predicted) energy consumption for the same period.

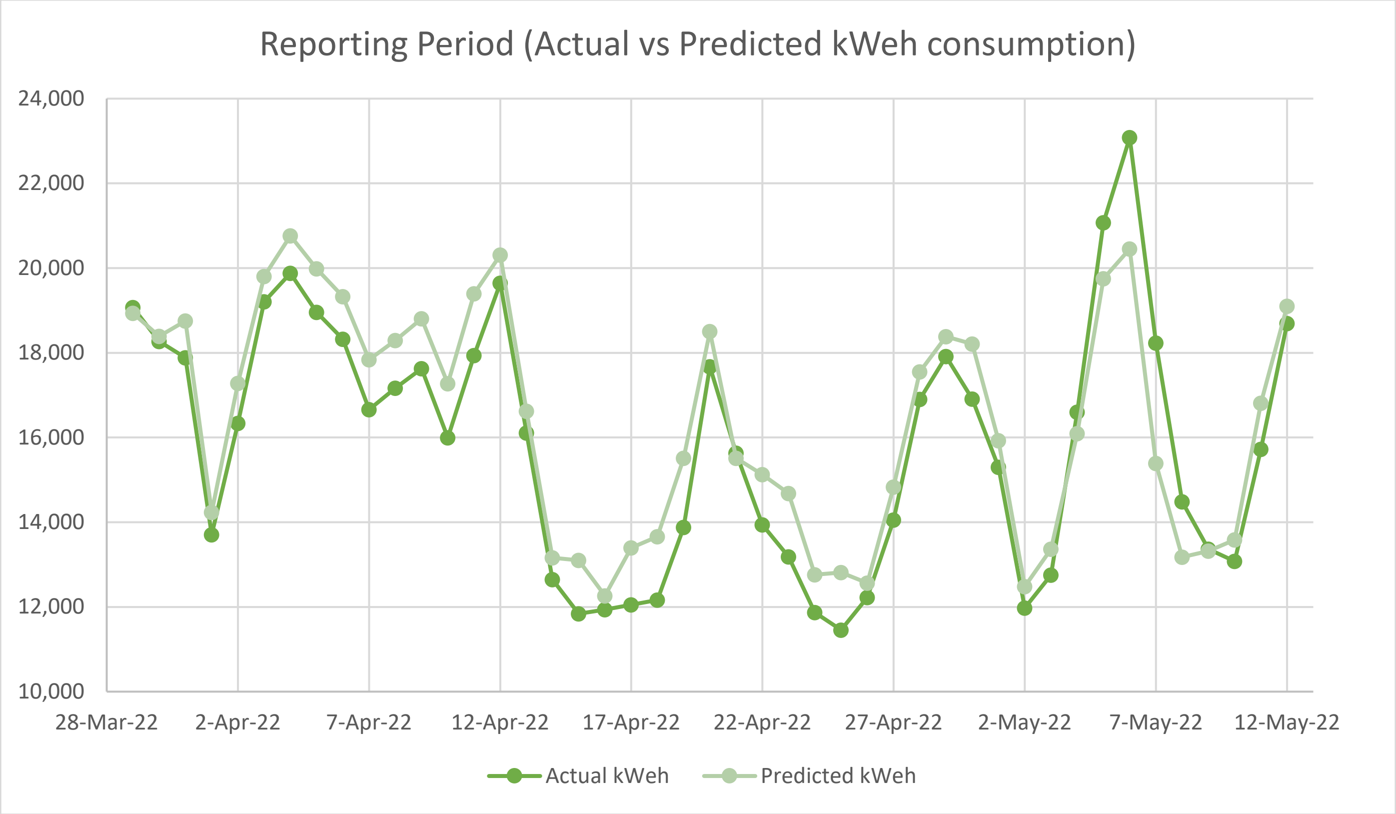

Figure 7 Actual energy consumption versus the modelled energy consumption

Table 10 shows the summary of variables captured during the reporting period including the predicted consumption and avoided energy consumption.

Table 10 Summary of variables

Date	CDD12	kWrh	Actual kWeh	Predicted kWeh	Avoided Energy Consumption (kWeh)
29-Mar-22	9.30	113,127	19,070	18,934	-135
30-Mar-22	11.40	111,034	18,273	18,389	116
31-Mar-22	12.60	113,431	17,884	18,753	869
1-Apr-22	10.70	88,645	13,708	14,231	523
2-Apr-22	10.60	104,827	16,335	17,280	945
3-Apr-22	11.90	118,740	19,208	19,801	593
4-Apr-22	11.40	123,656	19,879	20,762	883
5-Apr-22	11.50	119,543	18,959	19,981	1,022
6-Apr-22	11.60	116,103	18,321	19,327	1,006
7-Apr-22	10.70	107,846	16,656	17,840	1,184
8-Apr-22	11.10	110,382	17,164	18,288	1,124
9-Apr-22	9.50	112,528	17,629	18,807	1,178
10-Apr-22	10.60	104,800	15,992	17,275	1,282
11-Apr-22	11.10	116,273	17,937	19,395	1,458
12-Apr-22	11.60	121,318	19,645	20,308	663
13-Apr-22	9.50	100,899	16,106	16,621	515
14-Apr-22	8.70	82,194	12,647	13,163	516
15-Apr-22	8.80	81,888	11,841	13,098	1,257
16-Apr-22	8.60	77,380	11,938	12,265	327
17-Apr-22	8.60	83,405	12,054	13,398	1,344
18-Apr-22	8.90	84,913	12,163	13,659	1,496
19-Apr-22	9.30	94,898	13,877	15,508	1,630
20-Apr-22	11.50	111,663	17,672	18,500	827
21-Apr-22	9.80	95,122	15,630	15,513	-117
22-Apr-22	9.70	93,020	13,938	15,125	1,187
23-Apr-22	7.40	89,772	13,187	14,681	1,495
24-Apr-22	7.20	79,497	11,866	12,764	899
25-Apr-22	6.50	79,470	11,457	12,810	1,353
26-Apr-22	7.40	78,494	12,224	12,561	337
27-Apr-22	8.40	90,942	14,056	14,829	773
28-Apr-22	9.10	105,694	16,901	17,551	650
29-Apr-22	9.60	110,301	17,913	18,381	468
30-Apr-22	10.00	109,550	16,909	18,211	1,302
1-May-22	7.90	96,596	15,301	15,928	627
2-May-22	8.50	78,486	11,971	12,480	509
3-May-22	7.50	82,814	12,753	13,366	613
4-May-22	8.30	97,610	16,600	16,090	-510
5-May-22	10.50	117,915	21,072	19,748	-1,325
6-May-22	10.60	121,703	23,079	20,452	-2,626
7-May-22	8.50	93,980	18,230	15,393	-2,838

8-May-22	7.10	81,646	14,487	13,175	-1,311
9-May-22	5.60	81,852	13,367	13,323	-44
10-May-22	7.90	84,109	13,081	13,580	499
11-May-22	8.00	101,314	15,723	16,808	1,084
12-May-22	9.50	114,076	18,694	19,098	405

6.2 Cost Effectiveness

Using the baseline model to predict the energy consumption during the reporting period a total of 24,052 kWh of energy consumption was avoided. This represents **a 3.3% energy saving** over the 43-day reporting period.

An extrapolation was performed using the average total CDD from 2020 and 2021 (Table 11), and the using the sum of the CDD during the days in the reporting period.

Table 11 Aggregated monthly CDD in 2020 and 2021

Aggregate CDD	2020	2021
January	448.6	401.5
February	392.4	365.9
March	364	366.7
April	309.8	257.4
May	189.9	191.2
June	142.5	120.3
July	125.2	124.6
August	153.8	167
September	228	207.3
October	298.9	315.9
November	343.9	325.5
December	411.8	382.5
Total	**3408.8**	**3225.8**

Average CDD from 2020 and 2021 = 3317.3

Aggregate CDD during the reporting period = 424.5

Projected Savings = [Average Yearly CDD] / [Aggregate CDD during reporting period] * [Savings observed during the reporting period]

Project Savings = [3317.3] / [424.5] * [24,052]

= 187,959 kWeh

Using a standard electricity tariff of 15c/kWeh this represents $28,194 per annum.

The simple payback is:

([Cost of Exergenics product] + [cost of implementation]) / [savings]

= ($36,000 + $5,280) / $28,194

= 1.46 years

6.3 Environmental Benefits

The projected annual energy avoided (187,959 kWh) represents **an approximate reduction of 150 tonnes** of CO_2-e using the QLD Emissions Intensity of 0.8 kgCO_2-e/kWh.

7 SUMMARY FINDINGS AND CONCLUSIONS

7.1 Overall Technology Assessment

Exergenics chilled water optimisation is a frictionless software that can be implemented into a very wide range of buildings and facilities including large hospitals. ‘Big data’ from a site’s chilled water system can be transformed into useful recommendations that reduce the energy consumption of the plant.

A total of 24,000 kWh of avoided energy consumption has been measured through the analysis described in this report, representing a 3.3% saving over the 43-day reporting period. Assuming a generic electricity tariff of 15c/kWh, this represents an immediate cost saving of $3,600. Using Queensland’s grid emissions intensity of 0.80 kg CO_2e/kWh, this ECM also delivered a carbon abatement of roughly 40.9t CO_2e

These savings were projected over a year using CDD data, providing the expected benefits below:

- 187,000 kWeh energy consumption savings
- Savings of $28,000
- Simple payback of 1.5 years.

It is worth mentioning that the initial energy simulation from the Exergenics software predicted a saving of 170,366 kWh per annum, demonstration a simulation accuracy of 91%.

7.2 Barriers and Enablers to Adoption

The primary enabler (and barrier) for this technology is data. A year or more of time series data can be used to generate recommendations to improve chilled water plant and serve as the baseline for future measurement and verification. Sites with an existing, long term data capture are ideal candidates for this technology. In situations where a site does not yet have suitable data capture in place the technology can be attempted to be implemented and advice provided on the type of data needing to be captured and stored.

7.3 National Impact Study

This section considers cooling degree days (CDD) as a key indicator to extrapolate the site’s findings to a national impact study [8][9]. As temperature rises, there is a need of having space cooling which is often provided by chiller systems. Figure 8 illustrates the chillers’ energy use in relation to CDD12 values, based on the linear fitting results in Figure 5.

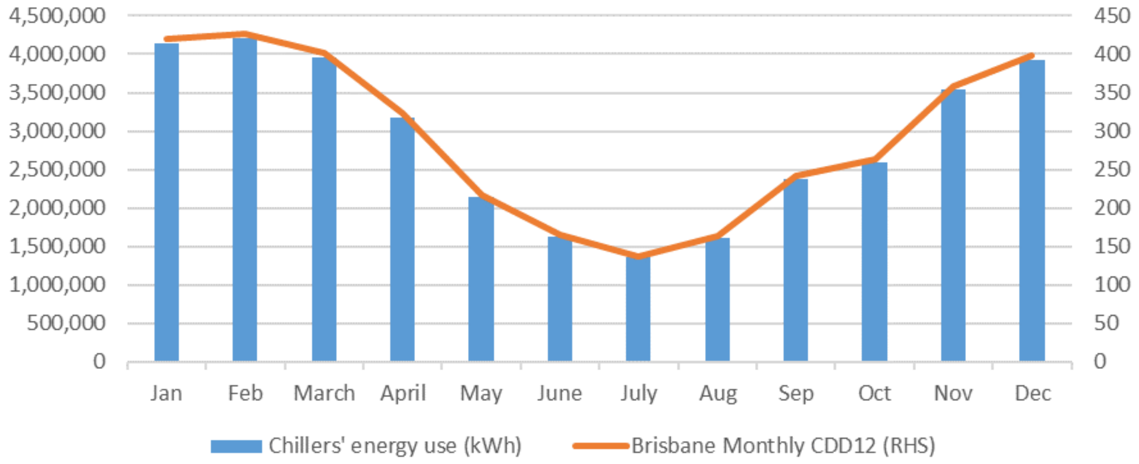

Figure 8 QCH Chillers' energy use and monthly CDD12

The following facts and assumptions are used to estimate the potential impact of chiller staging optimisation on energy and environment when the technology is applied to all Australian capital cities' hospitals:

- Electricity is the main energy source for air conditioning cooling across Australia
- Cooling degree days are associated with electricity use for cooling at hospitals
- 12^{O}C is used as the reference temperature to calculate cooling degree days in relation with the chiller system's operation
- Hospitals in Australian capital cities have similar cooling technologies
- When Exergenics digital twin and optimisation technology is applied to all hospitals at Australian capital cities, a similar level of energy saving per floor space per cooling degree day can be achieved.
- CSIRO 2030 projected weather file business as usual scenario (RCP8.5) is used in the CDD calculation. The 2030 scenario represents the typical climate year for 2020 to 2040 [[10]].

Table 12 shows the highest energy saving would occur in Sydney, Brisbane and Perth due to climate conditions and large hospital spaces. The highest CO2 emission reduction would occur in Sydney, Brisbane and Melbourne (Melbourne takes over Perth, due to high emission factor).

Nationally, this technology has an annual potential of over 58GWh of electricity saving and over 43,000 tonnes of CO_2 emission reduction.

Table 12 Extrapolate to all capital cities

	Cooling degree days (CDD12 in 2030 scenario)	Hospital gross floor areas ('000m^2)	Potential electricity savings (MWh)	Emission factor kg CO2-e/kWh ([11])	CO_2-e reduction (tons)
Brisbane	3,516.65	1,520	12,895	0.80	10,316
Sydney	2,785.30	3,075	20,662	0.79	16,323
Canberra	1,478.00	229	801	0.79	633
Melbourne	1,440.90	2,144	7,454	0.96	7,156
Hobart	986.65	160	381	0.16	61
Adelaide	2,213.45	897	4,790	0.35	1,677
Perth	2,814.60	1,400	9,507	0.68	6,464
Darwin	5,971.45	121	1,743	0.54	941
Total		9,546	**58,232**		**43,571**

REFERENCES

[1] J. Karliner, S. Roschnik, R. Boyd, B. Ashby, K. Steele, R. Guinto, Global Road Map for Health Care Decarbonization: A navigational tool for achieving zero emissions with climate resilience and health equity - Green Paper Number Two, 2021. https://www.arup.com/-/media/arup/files/publications/h/hcwh-road-map-for-health-care-decarbonization.pdf.

[2] K. Bawaneh, F. Ghazi Nezami, Md. Rasheduzzaman, B. Deken, Energy Consumption Analysis and Characterization of Healthcare Facilities in the United States, Energies (Basel). 12 (2019) 3775. https://www.mdpi.com/1996-1073/12/19/3775.

[3] A. Liu, W. Miller, J. Chiou, S. Zedan, T. Yigitcanlar, Y. Ding, Aged care energy use and peak demand change in the COVID-19 year: empirical evidence from Australia, Buildings. (2021). https://doi.org/10.3390/ buildings11120570.

[4] A. Liu, W. Miller, J. Chiou, S. Zedan, X. Chen, C. Susilawati, How is occupancy related to energy use in healthcare buildings ?, in: T.K. Saha (Ed.), 10th IEEE PES Innovative Smart Grid Technologies Conference - Asia, IEEE, Brisbane, Queensland, Australia, 2021.

[5] A. Liu, W.F. Miller, Healthcare Living Laboratories: Queensland Children’s Hospital - Energy Baseline Data, Australian Institute of Refrigeration, Air-conditioning and Heating (AIRAH), Brisbane, QLD, Australia, 2020. https://www.ihub.org.au/llhc4-queensland-childrens-hospital/.

[6] A. Liu, W.F. Miller, Healthcare Living Laboratories: Queensland Children’s Hospital - Operation Manual and Baseline Data, Brisbane, Queensland, Australia, 2020. https://www.ihub.org.au/llhc4-queensland-childrens-hospital/.

[7] A. Liu, W. Miller, Healthcare Living Laboratories : Queensland Children’s Hospital – Exergenics QCH Chiller System Digital Twin and Optimisation, Australian Institute of Refrigeration, Air-conditioning and Heating (AIRAH), Brisbane, Queensland, Australia, 2021. https://www.ihub.org.au/llhc4-queensland-childrens-hospital/.

[8] A. Liu, W. Miller, G. Crompton, S. Zedan, Has COVID-19 lockdown impacted on aged care energy use and demand ?, Energy and Buildings. 235 (2021). https://doi.org/10.1016/j.enbuild.2021.110759.

[9] Y. Ma, S.C. Saha, W. Miller, L. Guan, Comparison of Different Solar-Assisted Air Conditioning Systems for Australian Office Buildings, Energies (Basel). 10 (2017). https://doi.org/10.3390/en10101463.

[10] Z. Ren, Z. Tang, M. James, Projected weather files for building energy modelling - User Guide, 2022. https://agdatashop.csiro.au/future-climate-predictive-weather.

[11] Australian Dept of Industry Science Energy and Resources, National Greenhouse Accounts Factors, 2021.