LOW CARBON LIVING CRC

RP1026: Evaluation of Next-Generation Automated Fault Detection & Diagnostics (FDD) Tools for Commercial Building Energy Efficiency

Part I: FDD Case Studies in Australia

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Title	RP1026: Evaluation of Next-Generation Automated Fault Detection & Diagnostics (FDD) Tools for Commercial Building Energy Efficiency - Part I: FDD Case Studies in Australia
ISBN	-
Date	Feb 2018
Keywords	Fault Detection & Diagnostics (FDD), Smart Building Analytics, Building Energy Efficiency
Publisher	Prepared by CSIRO Energy for Low Carbon Living CRC
Preferred citation	Wall J. and Guo Y (2018). Evaluation of Next-Generation Automated Fault Detection & Diagnostics (FDD) Tools for Commercial Building Energy Efficiency – Final Report Part I: FDD Case Studies in Australia, RP1026, Low Carbon Living CRC, Feb 2018, pp 68.

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Programme

Acknowledgements

The Project Team would like to sincerely thank the Facility Management team at each of the FDD Case Study sites for their contribution and invaluable feedback, the steering committee for their invaluable feedback, as well as each of the FDD Solution Providers for taking part in a challenging yet highly worthwhile multi-stakeholder engagement and assessment that will ultimately benefit the building industry in increasing the energy efficiency of Australia's building stock.

This research is funded by the CRC for Low Carbon Living Ltd supported by the Cooperative Research Centres program, an Australian Government initiative.

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- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

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Acronyms

AFDD	Automated Fault Detection & Diagnostics
AI	Artificial Intelligence
BI	Business Intelligence
BIM	Building Information Model
BMCS	Building Management & Control System
CRCLCL	Cooperative Research Centre – Low Carbon Living
DLP	Defects Liability Period
FDD	Fault Detection & Diagnostics
FM	Facility Manager
HVAC	Heating, Ventilation & Air Conditioning
HVAC&R	HVAC & Refrigeration
IT	Information Technology
IoT	Internet of Things
M&V	Measurement & Verification
Mt CO_2-eq	Mega-tonnes CO_2 equivalent
NABERS	National Australian Built Environment Rating System
O&M	Operation & Maintenance
OT	Operational Technology

Introduction

Beyond expensive building and equipment upgrades and retrofits, re-commissioning (analogous to performing a comprehensive tune-up on your car) and automated fault detection and diagnostics (FDD) for building systems offer significant energy efficiency opportunities in commercial buildings.

With Heating, Ventilation & Air Conditioning (HVAC) systems attributed to 40-50% of commercial building energy consumption (46 Mt CO_2-eq. p.a.) in Australia (Pitt & Sherry, 2012), FDD tools and services are driving energy savings and emissions reductions, in addition to improved maintenance practices and outcomes from commercial building HVAC systems and more recently other building energy systems.

Literature on related building case studies suggest that virtually all buildings have some sort of HVAC operational problems, and the vast majority of buildings are not carefully tuned or commissioned (Claridge et al., 1994; Piette et al., 1996, Clarke et al., 2015). It is estimated that performance degradation, improperly tuned controls and malfunction of HVAC systems and equipment wastes up to 16% whole building energy (Mills, 2009). An independent evaluation of FDD and ongoing commissioning tools and techniques in the United States demonstrated average energy savings of 10%, with as much as 25% in some cases, and found the median normalised cost to deliver commissioning for existing buildings was ($3.20/$m^2$) with a payback time of 1.1 years (Mills & Mathew, 2009).

Project Scope

With numerous commercial offerings and delivery models for FDD solutions available in the Australian market, it is often difficult for potential customers and end users to determine which solutions offer the most value considering factors such as implementation cost, ease of use, energy savings, improved maintenance practises and outcomes, and ultimately improved comfort and productivity of the building occupants.

The scope of this project was to undertake a rigorous and systematic independent evaluation of the potential benefits of automated FDD solutions delivered as a managed service in Australia. The intent of the evaluation is to encourage greater uptake of FDD tools and services in Australia by assisting building owners, operators and HVAC&R maintenance contractors to evaluate and select their preferred FDD solution for future roll-out across their respective building or portfolio, therefore significantly increasing the energy efficiency of commercial building stock in Australia.

The main objective of this Final Report (Part I), is to highlight key benefits and outcomes made possible through the implementation and ongoing use of automated FDD solutions in Australian commercial building stock. A subsequent confidential report (Part II) will provide an objective performance evaluation of some of the leading FDD solutions in Australia.

WHAT IS FDD?

FDD is an area of investigation concerned with automating the processes of detecting faults within building systems and diagnosing their causes.

While there are several software tools and applications that have proven beneficial for building operations and energy management, one software application showing promising results and cost effectiveness is fault detection and diagnostics or FDD.

FDD are a subset of the larger category of analytic software related to buildings. Analytics are critical because buildings are becoming more complex, new systems are being introduced into buildings that bring with them vast amounts of data, and energy consumption metrics and key performance indicators are now of great interest to operators and corporate management. In general, analytic software tools and services primarily support technicians and engineers in the field who are dealing with both the everyday issues of building operations as well broader issues of complicated systems, bid data, advanced technology and higher expectations for building performance. The analytic tools and services provide insights into building systems resulting in reduced energy consumption, improved building performance and lower operation and maintenance costs (Sinopoli, 2012).

FDD is an area of investigation concerned with automating the processes of detecting faults with physical systems and diagnosing their causes.

FDD itself is frequently described as consisting of three key processes: fault detection, fault isolation, and fault identification. The first, fault detection, is the process of determining that some fault has occurred in the system. The second involves isolating the specific fault that occurred, including determining the kind of fault, the location of the fault, and the time of detection. The third process, fault identification, includes determining the size and time-variant behaviour of a fault. Together, fault isolation and fault identification are commonly termed fault diagnostics. In most cases, detection of faults is relatively easier than diagnosing the cause of the fault or evaluating the impacts arising from the fault (Katipamula & Brambley 2005).

Fault detection and diagnostics for HVAC systems are not new. For many years, FDD has been an active area of research and development in the aerospace, process controls, automotive, manufacturing, nuclear, and national defence fields and continues to be today. Over the last decade or so, efforts have been undertaken to bring automated FDD out of the research domain with limited real-world examples and laboratory trials, and into the HVAC&R industry through a range of commercially available FDD tools and services.

More recently, the technology has matured to a point where more powerful FDD solutions have been developed and refined, and are now commercially available to the HVAC&R industry. Like all new technology, FDD solutions that are implemented properly and backed by the support of building operation and maintenance (O&M) domain experts where required (either in-house or external service providers), are demonstrating enormous value in improving the operational performance of commercial buildings and high energy consuming HVAC systems.

Figure 1. shows a classification of the different types of FDD methods that underpin many if not all of the solutions available commercially. The coloured boxes highlight the most common methods we see in use today, including Rule-Based methods and Process History-Based (data driven) methods. Exact definitions of these methods can be found in the seminal article by (Katipamula & Brambley 2005).

Rule-Based methods include simple limit checks (which server as the basis for alarms), logical rules or expressions based on physical first principles of HVAC and other building energy systems, and expert systems that invoke a database or library of targeted rules and thresholds or other expert knowledge that may be better suited to a particular climate zone, building type, building system or piece of equipment.

Process History-Based (data driven) methods including Black-Box and Grey-Box methods are emerging as viable automated FDD techniques in their own right (Sands & Macelroy, 2006; Wall et al., 2011; Li & Wen, 2014; Guo et al., 2017), and have also been shown to complement Rule-Based methods, particularly for HVAC and other building energy systems where rules may be non-existent or difficult to define, or for more complex multi-variable systems where large amounts of historical data from different input sources is available.

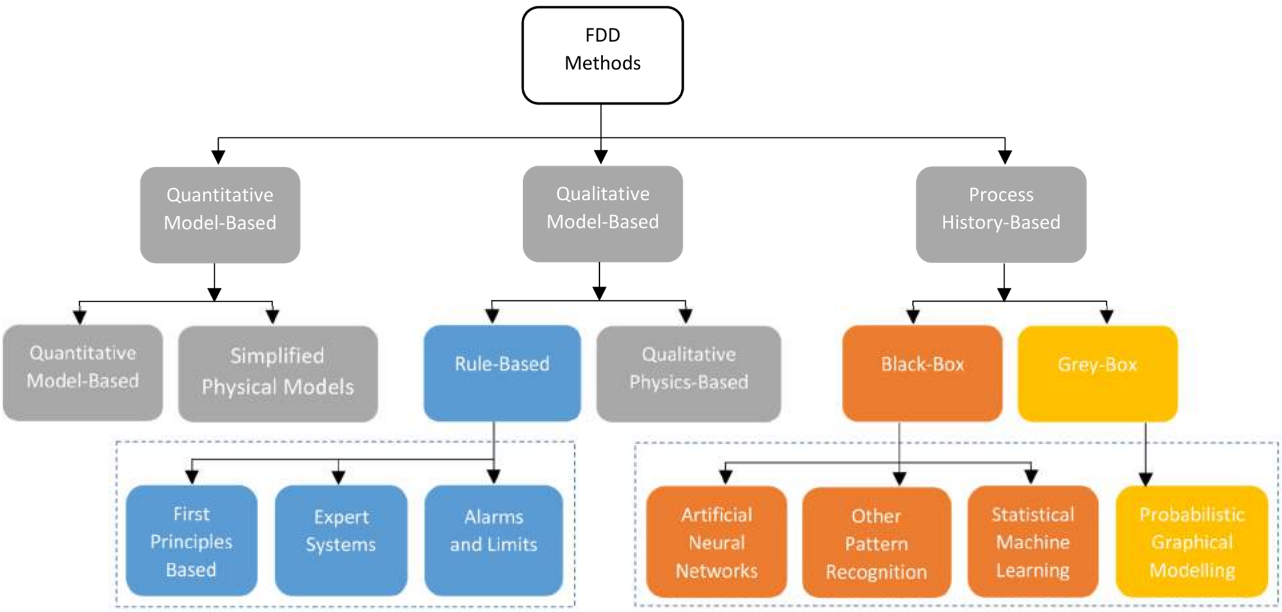


Figure 1. Types of Automated FDD Techniques (adapted from Katipamula & Brambley, 2005)

What FDD Features to look for…

With a plethora of building energy-related services and solutions now claiming to offer some form of advanced analytics or fault detection functionality, it is important to understand the key features to look out for and how to differentiate those solutions that can really add value to improving building operational performance and ultimately the triple bottom line.

A key challenge that currently exists is ensuring analytics solutions are not too sensitive so as to create an overwhelming number of results or false alarms, but sensitive enough not to miss critical issues. Another challenge is ensuring that identified faults and operational issues are prioritised and presented in a way that facilitate actual remedial actions for best practise O&M, without causing information overload.

When considering potential FDD solutions, be sure to inquire about the underlying automated techniques or algorithms employed, as opposed to straight manual investigation by engineers and domain experts (which may incur unnecessary labour costs), and how the FDD results can be shared and used to benefit all stakeholders involved towards achieving best practise in the O&M of buildings.

For rule-based methods, FDD solutions that use hierarchical rule sets with inherent knowledge of inter-system dependencies (e.g. AHUs depend on primary plant supply) can help in more accurately detecting system and equipment faults and with less false alarms. Likewise, many solutions are beginning to utilise process history-based (data driven) methods either as stand-alone techniques or to compliment more traditional rule-based methods. Be sure to inquire about the amount of historical data required to achieve meaningful results, and what other input data sources can be integrated to improve the FDD results and insights.

Collating and extending the advice by leading experts in the HVAC&R Industry (Clarke et al., 2015), some of the questions professionals should be asking themselves when investigating automated FDD solutions include:

- Does it provide a real-time multi-user interface as well as periodic reporting for delivery of actionable insights?
- Can it integrate and utilise BMCS data, energy/power sub-meter data, and other building and external systems data?
- Can it pinpoint the source of failure at the sub-system or equipment level?
- What are the upfront and ongoing costs, and are there any extra or hidden costs?
- What data and information is required to fully implement the solution and what is the setup time?
- Can it integrate with maintenance processes and work-order systems to remove manual handling and data entry to fast-track rectification works?
- Does it provide the flexibility to adopt new emerging technology such as, data-driven FDD methods, predictive maintenance and intuitive visualisation tools?

Future Trends in FDD

An emerging trend that is being driven by advances in artificial intelligent (AI) and machine learning is that of automated prognostics or data-driven predictive maintenance. Prognostics address the use of automated methods to detect and diagnose degradation of physical system performance, anticipate future failures, and project the remaining life of physical systems in acceptable operating state before faults or unacceptable degradations of performance occur. Together with automated FDD, these methods provide a cornerstone for condition-based predictive maintenance of HVAC&R and other engineered building systems.

Emerging AI and machine learning tools will enable large amounts of data from disparate data sources, such as BMCS, sub-metering, localised high resolution weather data, building occupancy, thermal comfort, building information models (BIM) and commissioning data, to be analysed in a way that provides meaningful insights into the longer term performance and degradation of HVAC systems and equipment. It can estimate remaining time to failure (or time before reaching an unacceptable level of performance), the rate of degradation, and the nature of the failure if it were to occur.

Finally, the Internet of things (IoT) and convergence of information technology (IT) and operational technology (OT) is at peak hype, and is promising to transform the facility management sector. By assembling an unprecedented amount of data from one or multiple buildings, IoT and business intelligence (BI) solutions will open up data-rich environments creating opportunities for new smart building applications and actionable insights only just starting to be realised. These include increased energy savings from more efficient devices that provide intelligence at the edge of subsystems; cloud-based processing that enables enhanced data analysis of device or system functionality; enhanced operational efficiency through two-way connectivity and greater insights from more granular operational performance data; and preventive maintenance capabilities from devices that can sense anomalies before they become costly problems (Jung & Talon, 2017).

Here's what existing FDD users are saying…

"Using CIM Enviro, we have achieved a seven half-star jump for $48,000 Opex, but most impressively, for no Capex expenditure "

- Associate Director | Asset Management, NSW

"The introduction of Synengco FDD for at our hospital site will enable us to use predictive techniques to proactively manage our energy usage."

- Facilities Maintenance Manager, QLD

"Building Analytics by Schneider Electric has helped us improve our proactive maintenance program of critical assets enabling us provide a high level of service to our customers"

- Mechanical Asset Manager, VIC

"Automated FDD deployment has enabled our organisation to save a lot of energy and cost, and in becoming proactive about building management. The C&E Analytics tool has detected not only faulty equipment, which would have been picked up only later through maintenance processes, but also behaviour that would have not been known without the tool"

- Sustainability Manager, ACT

"Coppertree Analytics has been an integral part in driving our maintenance activities and lowering our energy consumption.
It's implementation has helped streamline our maintenance, which means more time can be spent fixing problems instead of identifying them."

- Senior Building Manager, ACT

"CIM Enviro has allowed Museum Victoria to find faults from the BMCS system that cannot be diagnosed by normal fault finding alone."

- Project Manager, VIC

"The ACE Platform has contributed to a sharp reduction in energy usage at Melbourne Museum."

- Project Manager, VIC

"The Joule AnalytiX platform integrates with our existing BMCS and helps us get the most from our contractors."

- Operations Manager, NSW

ACE Platform
by CIM Enviro

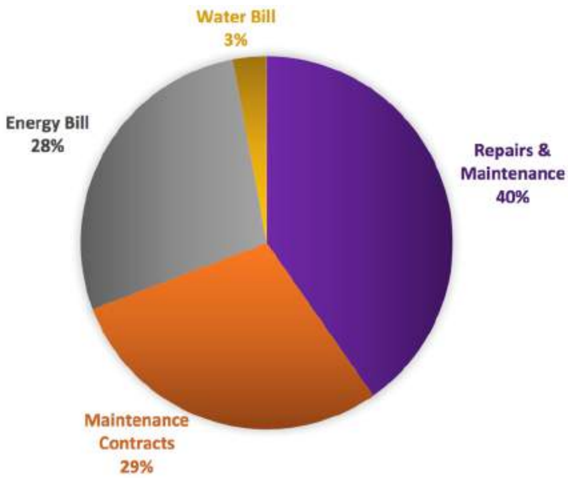
A Balance Sheet Optimisation Technology

CIM Enviro's technology, the ACE Platform, is a real-time Balance Sheet Optimisation portal that seeks to streamline the three biggest expense items in property management budgets:

- Energy (~28%)
- Repairs & Maintenance (~40%)
- Maintenance Contracts (~29%)

Pricing is based on delivering a target payback of 6-12months and a target cost saving of between 14% and 32%.

Figure 2. ACE Platform (Melbourne Museum) – A Typical Expense Breakdown *



* Based on financial data sourced from Annual Financial Reports for three Australian companies, spanning 2014-2017.

Features

The ACE Platform's Application

Users of the ACE Platform typically have one driver in common, namely: getting *more* out of their existing systems and assets for *less* cost. This market-led mantra has seen the ACE Platform being used to resolve the following twelve common pain-points in property management:

1. Energy Optimisation (at pump, fan & valve level)
2. Preventative Maintenance Planning
3. Defects Liability Protection & Reporting (DLP)
4. Monthly Contractor Performance Reporting
5. NABERS Uplift & Protection
6. Hot & Cold Tenant Complaint Optimisation
7. Asset-level OPEX & CAPEX Forecasting (1-3yrs)
8. Streamlining Maintenance Contracts
9. New Asset Commissioning Validation
10. 24/7 BMS Performance Reporting
11. Asset Lifecycle & Criticality Reporting
12. Energy & Asset Sustainability Reporting

To date, the ACE Platform has been used on: commercial office-towers, universities, museums, galleries, aircraft hangars, casinos, hotels, shopping centres, state and federal government assets, printing presses, prisons, research facilities, large sports clubs, schools and large banks.

A Quick End-to-End Overview

The ACE Platform continuously sifts through massive stores of data, measuring temperatures, pressures, flows, set points, and control commands, amongst other things. The platform gathers a few thousand data points every five minutes, which is a finer level of granularity than meter-level analytics software. Once the ACE Platform registers an asset-level performance deterioration, the machine learning logic then: (1) diagnoses the precise root cause, (2) designs the required solution, and (3) quantifies the $ impact on the energy bill.

Company Ethos No. 1: Preventative, not Reactive

By streaming real-time building performance data across energy and maintenance practises, anytime an asset moves even slightly away from its optimal performance-level, the ACE Platform registers the performance deterioration.

Users of the ACE Platform are therefore empowered to drive a preventative maintenance agenda across their buildings, instead of the customary and reactive fix-on-fail programmes, which typically cost three-times more. Furthermore, tenant hot & cold complaints, *which account for approx. 60% of all complaints,* typically reduce to <5%.

Company Ethos No. 2: More for Less

For many years now, industry has been supplied with solutions offering paybacks around two-to-three-years. As technology improves, so too should payback periods.

Today, the average payback of an ACE Platform user is 5.7 months, with savings ranging from 14% (lowest) to 32% (highest). This step-change in payback and return-on-investment is enabled by removing the need to install multiple new hardware devices on-site to obtain data, e.g. sub-meters.

CIM Enviro has consolidated its data acquisition capability down into one mobile phone-sized device, which takes less than 5seconds to install, and uses a building's existing network of sensors and controllers to obtain the required data.

Contact

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Case Study Project: Melbourne Museum

Location:	Melbourne, VIC
Asset Type:	Cultural Institution
Sector:	Public
Objectives:	• New BMS Commissioning Validation • Energy Savings
Key Outcomes:	• $203,000 reduction on energy bill • $35,000 saving from resetting demand threshold • 20% Electricity Reduction (kWh) • 13% Demand Reduction (kVA) • 28% Gas Reduction (GJ) • 117 BMS and Mechanical-Asset Faults Identified

Case Study Overview

Covering 70,000m^2, Melbourne Museum is the largest museum in the southern hemisphere. Year-on-year, the museum consistently ranks as one of the top tourist destinations in Australia, with an annual footfall of almost one million visitors. In 2016, the museum invested heavily in a new BMS to help meet the ever-evolving demands of managing a complex public asset that houses sensitive cultural installations.

All too often, the assets and systems building owners inherit are not to the standard they paid for. With this in mind, and combined with a commitment to ensuring maximum value-for-taxpayer-money, the museum employed independent technology provider CIM Enviro, to continuously monitor and validate the real-time commissioning of their new BMS. Using an independent set of real-time 'digital eyes-and-ears' throughout Defects Liability Period (DLP), the museum has been provided with real-time data-driven assurance that the asset they will inherit from their BMS contractor in a few months will be fully optimised and free of defects.

Over the last nine months, CIM Enviro's technology, the ACE Platform, has identified 117 BMS and mechanical-asset faults across the estate, which would have otherwise gone unnoticed and been loaded onto the museum, post DLP, as additional risk. Resolving these 117 issues has the museum on course to reduce their annual energy bill by $203,000 this year, *a 20% reduction on electricity and 28% on gas,* in addition to a $35,000 saving from resetting their demand threshold, *a 13% reduction*.

All this was achieved for a 4-and-a-half-month payback, which represents a 300%-to-400% step-change from many existing industry practises. In a time when asset owners and operators are required to deliver *more for less*, CIM Enviro has provided the answer, in the form of advanced machine learning and continuous data analytics to optimise total building performance.

ACE Platform (Melbourne Museum) – Top 5 Issues Identified

Summary of Top 5 Issues Identified

Table 2. ACE Platform (Melbourne Museum) - Summary of Top 5 Issues Identified

ID / Rule Name	Equipment	Rule Description	Solution	Benefit	Energy Savings (kWh)	Cost Savings ($)
AHU00013 Supply Air Temperature Poor Control-(Monitoring Chilled And Hot Water Valves)	AHU-4-10	The alarm is generated since AHU's supply air temperature is not within +/-1°C of the supply air temperature set-point when AHU is operating.	1. Check and calibrate the supply air temperature sensor. 2. Check for valves' leakages. 3. Check the CHWV and HWV control strategy. 4. Check the chilled water leaving temperature and it's set-point.	Energy & Thermal Comfort	82,579	$1,274
VAV0008-1 Low Air Flow w/Damper not open fully	VAV-622	This alarm is generated when the VAV airflow is below the desired airflow by 20l/s or more and the damper is not fully open	1. Check and calibrate air flow sensors. 2. Check the operation of the dampers. 3. Check the control strategy.	Thermal Comfort	N/A	N/A
VAV0008-2 High Air Flow w/Damper not fully shut	FAVAV-219	This alarm is generated when the VAV airflow is above the desired airflow by 20l/s or more and the damper is not fully closed	1. Check and calibrate air flow sensors. 2. Check the operation of the dampers. 3. Check the control strategy.	Energy	6,320	$1,264
AHU00011-3 Economy Cycle To Be Enabled-3	FCU-2-01	Economy Cycle should be enabled when all of the following conditions are met: 1. The supply fan is enabled and status is being received. 2. RA enthalpy - OA Enthalpy > 2 kJ/kg 3. Cooling is required and chilled water valve is open.	1. Check and calibrate the return and outside air temperature and relative humidity sensors. 2. Check the economy cycle control strategy 3. Check how the enthalpies are calculated	Energy	22,293	$4,458
AHU00016-1 Chilled Water Valve Leakage	AHU-1-03	Air handling unit supply air temperature is lower than return air temperature by more than 2°C, however all the outside air dampers and chilled water valve are closed and air handling unit supply fan is operating.	1. Check and calibrate the supply and return air temperature sensors 2. Check for chilled water valve leakage. 3. Check for outside air damper leakage.	Energy	12,752	$2,550

ACE Platform (Melbourne Museum) – Technical Deep-Dive into Top 5 Issues Identified

Issue: AHU00013 - Supply Air Temperature Poor Control

Figure 3. ACE Platform (Melbourne Museum) – Issue ID: AHU000013

FDD Rules Engine APP 9:36 AM
Alert evaluated at 2017-06-20 9:36:47 AM
AHU00013
The alarm is generated since AHU's supply air temperature is not within +/-1°C of the supply air temperature set-point when AHU is operating.

Solutions:
1. Check and calibrate the supply air temperature sensor.
2. Check the operation of the chilled and hot water valves.
3. Check the CHWV and HWV control strategy.
4. Check the chilled water leaving temperature and it's set-point.

Melbourne Museum

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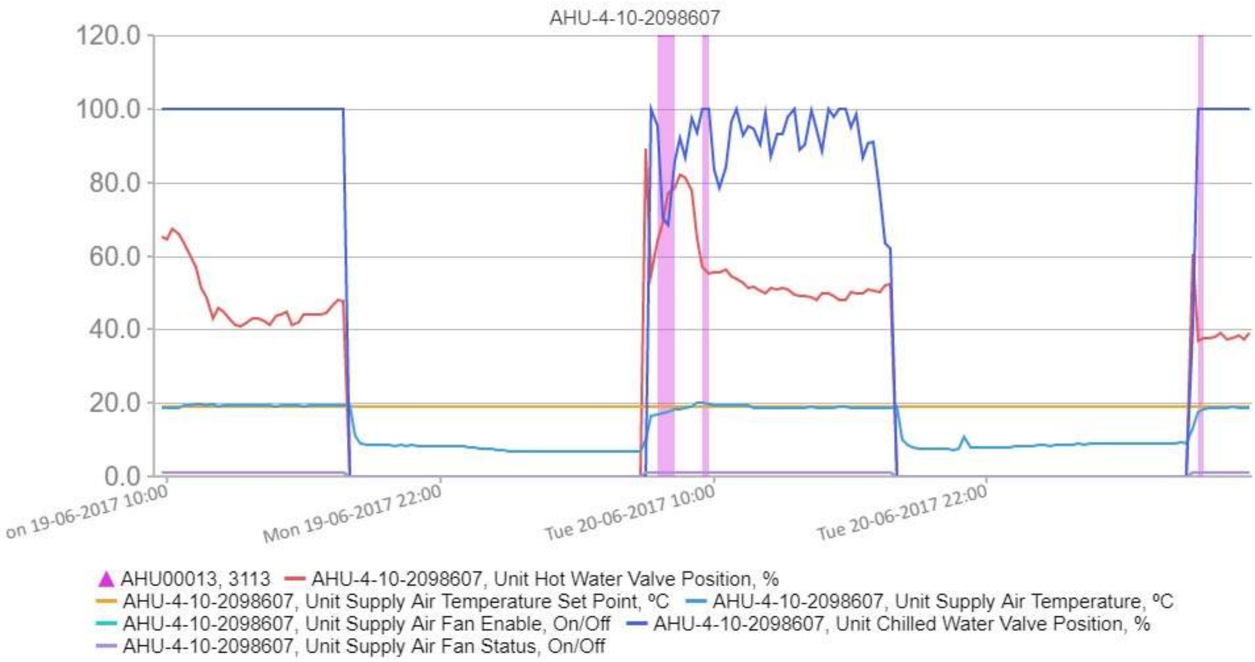
AHU-4-10-2098607
Equipment id: 165356240918, Site: Melbourne Museum
Unit Chilled Water Valve Position = 100 %
fav_id: 165356241173 2017-06-20 09:31:21 (Australia/Melbourne)
Unit Hot Water Valve Position = 56.90 %
fav_id: 165356241174 2017-06-20 09:31:21 (Australia/Melbourne)
Unit Supply Air Fan Enable = 1 On/Off
fav_id: 165356241175 2017-06-20 09:31:21 (Australia/Melbourne)
Unit Supply Air Fan Status = 1 On/Off
fav_id: 165356241176 2017-06-20 09:31:21 (Australia/Melbourne)
Unit Supply Air Temperature = 20.13 °C
fav_id: 165356241178 2017-06-20 09:31:21 (Australia/Melbourne)
Unit Supply Air Temperature Set Point = 19 °C
fav_id: 165356241179 2017-06-20 09:31:21 (Australia/Melbourne)

Monitor Task #3113 AHU00013 Rules Wiki



Issue: VAV0008-1 - Low Air Flow w/Damper not open fully

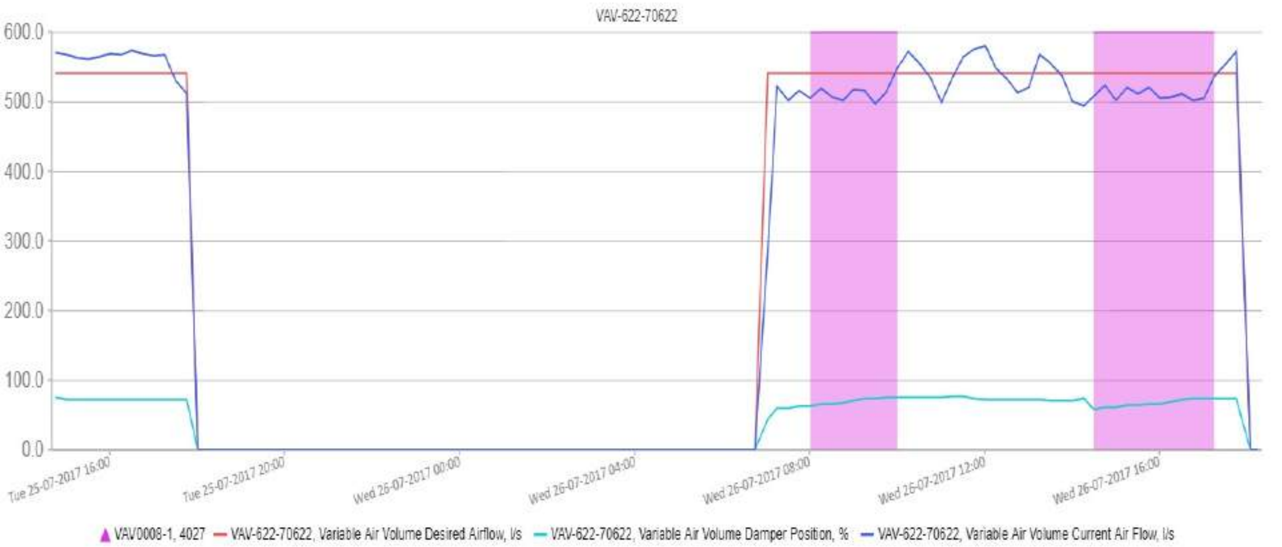
Figure 4. ACE Platform (Melbourne Museum) – Issue ID: VAV0008-1

FDD Rules Engine APP 2:42 PM
Alert evaluated at 2017-07-26 2:42:39 PM
VAV0008-1
This alarm is generated when the VAV airflow is below the desired airflow by 20l/s or more and the damper is not fully open

Solutions:
1. Check and calibrate the airflow sensors.
2. Check the operation of the dampers.
3. Check the control strategy.

Melbourne Museum
Missing - Evaluated Description
VAV-622-70622
Equipment id: 165356241108, Site: Melbourne Museum
Variable Air Volume Current Air Flow = 507.68 l/s
fav_id: 165356243458 2017-07-26 14:30:44 (Australia/Melbourne)
Variable Air Volume Desired Airflow = 540 l/s
fav_id: 165356243459 2017-07-26 14:30:44 (Australia/Melbourne)
Variable Air Volume Damper Position = 57.23 %
fav_id: 165356243462 2017-07-26 14:30:44 (Australia/Melbourne)
Monitor Task #4027 VAV0008-1 Rules Wiki

Data Point History Graph
-24hrs/+24hrs (81kB)



Issue: VAV0008-2 - High Air Flow w/Damper not fully shut

Figure 5. ACE Platform (Melbourne Museum) – Issue ID: VAV0008-2

FDD Rules Engine APP 11:11 AM

Alert evaluated at 2017-06-14 11:11:33 AM

VAV0008-2

This alarm is generated when the VAV airflow is above the desired airflow by 20l/s or more and the damper is not closing.

Solutions:

1. Check and calibrate airflow sensors.
2. Check the operation of the dampers.
3. Check the control strategy.

Melbourne Museum

Current Damper Value: 13.80, Previous Damper Position Value: 13.8

FAVAV-219-71219

Equipment id: 165356241038, Site: Melbourne Museum

Variable Air Volume Current Air Flow = **145.08** l/s

fav_id: 165356242817 2017-06-14 11:01:07 (Australia/Melbourne)

Variable Air Volume Desired Airflow = **125** l/s

fav_id: 165356242818 2017-06-14 11:01:07 (Australia/Melbourne)

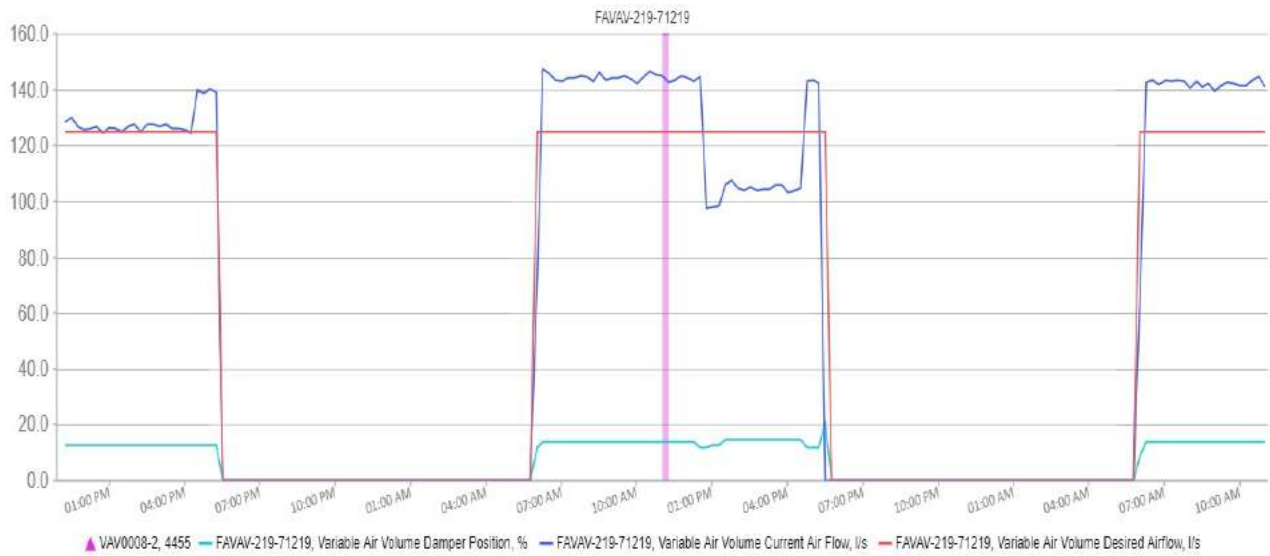
Variable Air Volume Damper Position = **13.80** %

fav_id: 165356242821 2017-06-14 11:01:07 (Australia/Melbourne)

Monitor Task #4455 VAV0008-2 Rules Wiki

Data Point History Graph

-24hrs/+24hrs (66kB)



Issue: AHU00011-3 - Economy Cycle To Be Enabled-3

Figure 6. ACE Platform (Melbourne Museum) – Issue ID: AHU00011-3

Alert evaluated at 2017-07-27 1:48:41 PM

AHU00011-3

Economy Cycle should be enabled when all of the following conditions are met,

1. The supply fan is enabled and status is being received.
2. RA enthalpy - OA Enthalpy > 2 kJ/kg
3. Cooling is required and chilled water valve is open.

Solution:

1. Check and calibrate the return and outside air temperature and relative humidity sensors.
2. Check the economy cycle control strategy
3. Check how the enthalpies are calculated

Melbourne Museum

.

FCU-2-01-2098308

Equipment id: 165356241014, Site: Melbourne Museum

Unit Chilled Water Valve Position = 5.46 %

fav_id: 165356242584 2017-07-27 13:46:13 (Australia/Melbourne)

Unit Outside Air Damper Position = 1 %

fav_id: 165356242592 2017-07-27 13:46:14 (Australia/Melbourne)

Unit Return Air Enthalpy = 37.88 kJ/kg

fav_id: 165356242591 2017-07-27 13:46:14 (Australia/Melbourne)

Unit Supply Air Fan Enable = 1 On/Off

fav_id: 165356242586 2017-07-27 13:46:13 (Australia/Melbourne)

Unit Supply Air Fan Status = 1 On/Off

fav_id: 165356242587 2017-07-27 13:46:13 (Australia/Melbourne)

AHU-COMMON-SIGNALS

Equipment id: 165356240934, Site: Melbourne Museum

Unit Outside Air Enthalpy = 28.25 kJ/kg

fav_id: 165356241492 2017-07-27 13:46:19 (Australia/Melbourne)

Monitor Task #4351 AHU00011-3 Rules Wiki

Issue: AHU00016-1 - Chilled Water Valve Leakage

Figure 7. ACE Platform (Melbourne Museum) – Issue ID: AHU00016-1

FDD Rules Engine APP 3:36 PM
Alert evaluated at 2017-07-26 3:36:49 PM
AHU00016-1
Air handling unit supply air temperature is lower than return air temperature by more than 2°C, however all the outside air dampers and chilled water valve are closed and air handling unit supply fan is operating.

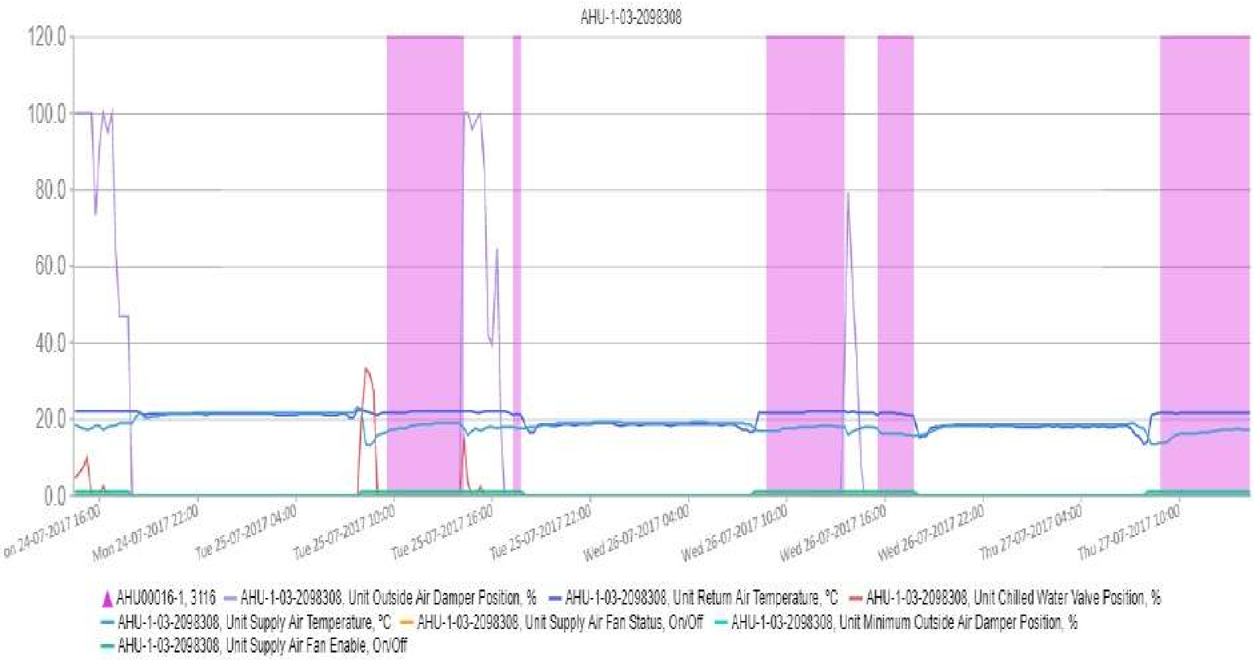
Solution:
1. Check and calibrate the supply and return air temperature sensors
2. Check for chilled water valve leakage.
3. Check for outside air damper leakage.

Melbourne Museum

.

AHU-1-03-2098308
Equipment id: 165356240904, Site: Melbourne Museum
Unit Chilled Water Valve Position = **0** %
fav_id: 165356240913 2017-07-26 15:31:15 (Australia/Melbourne)
Unit Outside Air Damper Position = **0** %
fav_id: 165356240915 2017-07-26 15:31:15 (Australia/Melbourne)
Unit Return Air Temperature = **20.98** °C
fav_id: 165356240909 2017-07-26 15:31:15 (Australia/Melbourne)
Unit Supply Air Fan Enable = **1** On/Off
fav_id: 165356241024 2017-07-26 15:31:16 (Australia/Melbourne)
Unit Supply Air Fan Status = **1** On/Off
fav_id: 165356240929 2017-07-26 15:31:15 (Australia/Melbourne)
Unit Supply Air Temperature = **17.51** °C
fav_id: 165356240918 2017-07-26 15:31:15 (Australia/Melbourne)
Unit Minimum Outside Air Damper Position = **0** %
fav_id: 165356240914 2017-07-26 15:31:15 (Australia/Melbourne)

Monitor Task #3116 AHU00016-1 Rules Wiki



ACE Platform (Melbourne Museum) – Demonstration of Outcomes

Annual Energy Summary

Table 3. ACE Platform (Melbourne Museum) – Annual Energy Summary

Time Period	Electricity Saving (kWh)	Electricity Saving (%)	Demand Saving (kVA)	Demand Saving (%)	Gas Saving (GJ)	Gas Saving (%)	Cost Savings ($)
July 2016 to July 2017	1,190,080	19.9%	4,128	13%	19,561	27.66%	$203,471

Note: All savings numbers presented in this case study have been verified by the client (i.e. building owner and/or facility manger).

END OF CASE STUDY

Case study Project: 99 Elizabeth Street

Location:	Sydney, NSW
Asset Type:	A-Grade Commercial Office Tower
Sector:	Private
Objectives:	• NABERS Improvements • Tenant Complaint Reductions
Key Outcomes:	• 1.5stars to 5stars in 24 months for $48,000 OPEX, no CAPEX. • Reduced tenant temperature complaints to less than 5%.

Case Study Overview

Approximately 24 months ago, Kyko Group (landlord) set CBRE (operator) a target of achieving a 4.0 NABERS star rating on one of their A-grade commercial offices. Typically, a six half-star jump requires significant Capex investment. With continual and rapid step-changes in data analytics, CBRE went to market in search of a smarter way of getting 'more for less' for their client, Kyko Group.

After 24 months and, in partnership with CIM Enviro, CBRE have not only exceeded their 4.0-star target, by achieving 5.0 NABERS stars, they're actually on track to reach 5.5 stars next year. Using CIM Enviro, CBRE have achieved a seven half-star jump and a 13% gas reduction for $48,000 OPEX, but most impressively, for no CAPEX expenditure.

Furthermore, tenant comfort complaints have reduced to less than 5%, as CIM Enviro's solution (the ACE Platform) preventatively targets potential hot and cold complaints, which typically account for 60% of all tenant complaints in a commercial office. In total, 69 building performance faults were identified and resolved, 52 BMS faults and 17 relating to large equipment lifecycle issues.

Together, Kyko Group, CBRE and CIM Enviro have demonstrated the benefit of collaborating with new machine learning technology, in pursuit of getting 'more for less' for FMs and their landlords.

ACE Platform (99 Elizabeth Street) – Top 5 Issues Identified

Summary of Top 5 Issues Identified

Table 4. ACE Platform (99 Elizabeth Street) - Summary of Top 5 Issues Identified

ID / Rule Name	Equipment	Rule Description	Solution	Benefit	Energy Savings (kWh)
AHU0001 Mismatch Alarm	AHU-N-8	The alarm is generated when the status feedback does not correspond with the output command status for longer than a defined time delay period.	1. Check the status switch. 2. Check and ensure that AHU's fan is not manually overridden.	Energy	71.5
AHU0007-1 High CO_2 parts per million (ppm)-MOAD	AHU-N-3	Return CO_2 level is higher than CO_2 set-point (e.g. 800 ppm) and main outside air damper is not fully open.	1. Check and calibrate the CO_2 sensor. 2. Check the operation of the main outside air damper. 3. Check the control strategy and tune the PI loop.	Air Quality	N/A
AHU0008-1 Low Supply Air Static Pressure	AHU-N-13	Air handling unit supply air static pressure is not tracking the supply air static pressure set-point and it is continuously lower than the set-point by at least 20 Pa when the air handling supply air fan is operating.	1. Check and ensure that fan is operating at it's maximum speed and is not manually overridden. 2. Check and calibrate the static air pressure sensor. 3. Check and ensure that the fan belt is not loose or is not dislocated. 4. Check and ensure that the current static air pressure set-point matches the design or commission value obtained based on the spaces' air flow requirements. 5. Check and ensure that the fan is not undersized for the current required static air pressure set-point.	Thermal Comfort	N/A
AHU0008-2 High Supply Air Static Pressure	AHU-C-1	Air handling unit supply air static pressure is not tracking the supply air static pressure set-point and it is continuously higher than the set-point by at least 20 Pa when the air handling supply air fan is operating.	1. Check and ensure the fan is not operating at it's maximum speed and is not manually overridden. 2. Check and calibrate the static air pressure sensor. 3. Check and ensure that the current static air pressure set-point matches the design/commissioning value obtained based on the spaces' air flow requirements. 4. Check and ensure that the fan is not oversized for the current required static air pressure set-point.	Energy	77.9
AHU00013-WLT Supply Air Temperature Poor Control (with reference to CHWLT & HWLT)	AHU-N-13	The alarm is generated since AHU's supply air temperature is not within +/-1°C of the supply air temperature set-point when AHU is operating.	1. Check and calibrate the supply air temperature sensor. 2. Check the operation of the chilled and hot water valves. 3. Check the CHWV and HWV control strategy. 4. Check the chilled water or hot water leaving temperature and their set-points.	Energy & Thermal Comfort	23,120

ACE Platform (99 Elizabeth Street) – Technical Deep-Dive into Top 5 Issues Identified

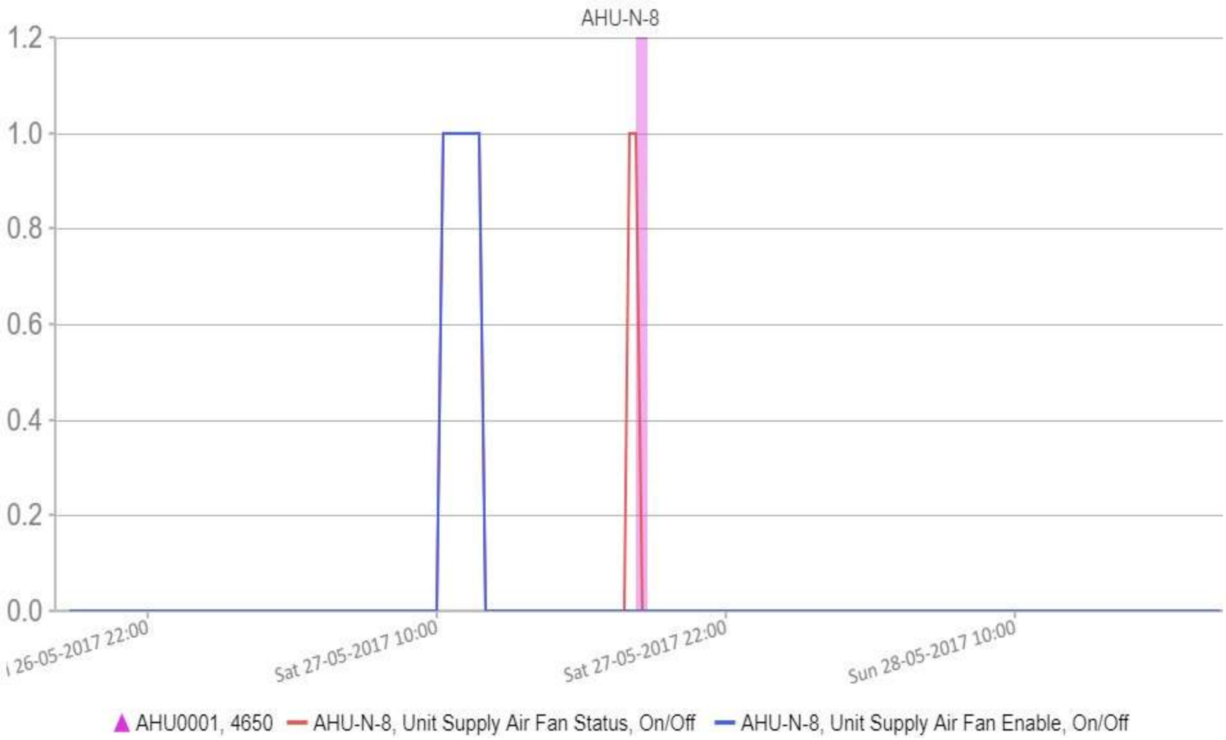
Issue: AHU0001 – Mismatch Alarm

Figure 8. ACE Platform (99 Elizabeth Street) – Issue ID: AHU0001

Alert evaluated at 2017-05-27 6:33:35 PM
AHU0001
The alarm is generated when the status feedback does not correspond with the output command status for longer than a defined time delay period.

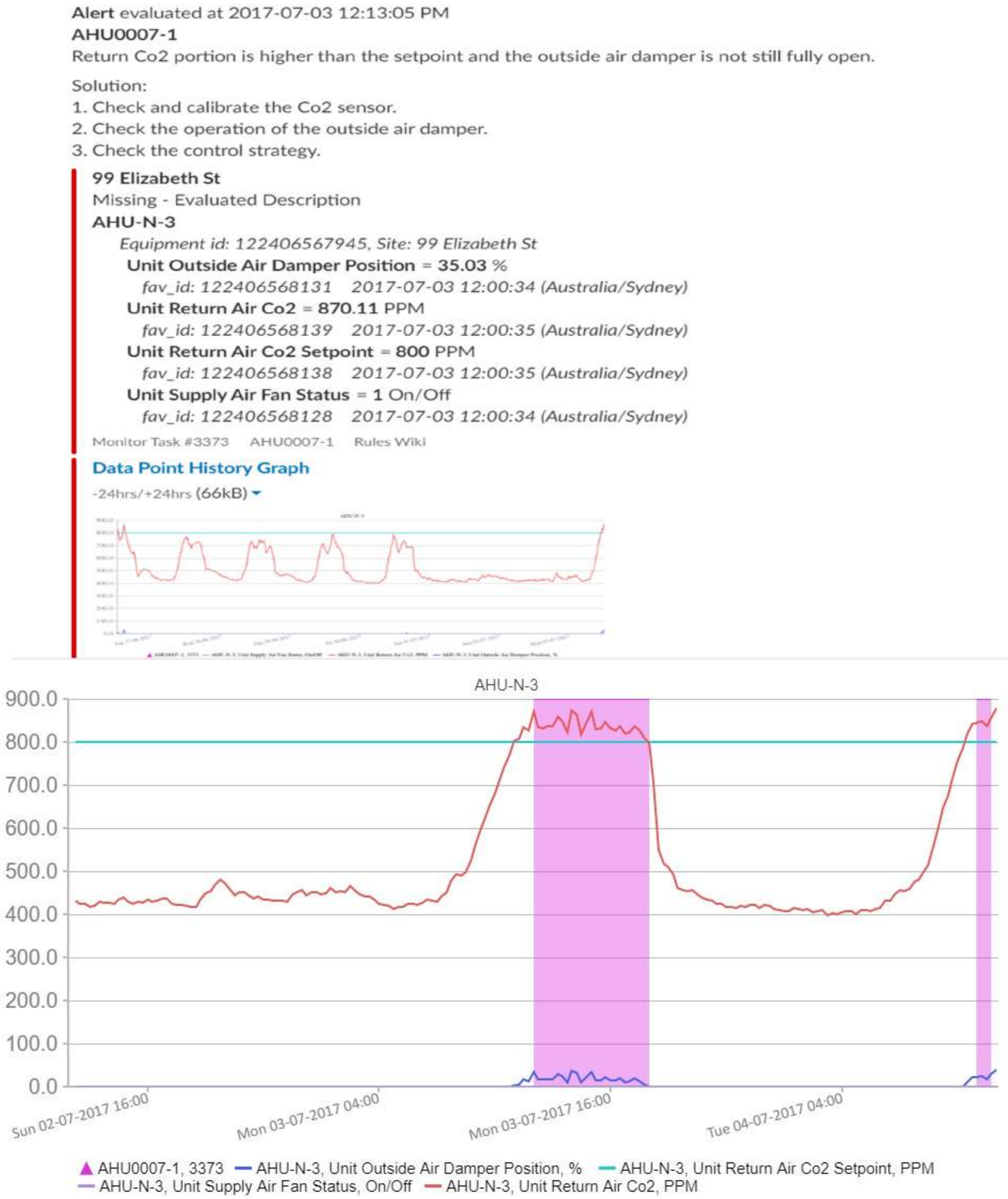
Solution:
1. Check the status switch.
2. Check and ensure that AHU's fan is not manually overridden.

99 Elizabeth St
AHU Supply Air Fan Feedback: 1 Does Not Match AHU Supply Air Fan Command: 0
AHU-N-8
Equipment id: 122406567960, Site: 99 Elizabeth St
Unit Supply Air Fan Enable = **0** On/Off
fav_id: 122406568352 2017-05-27 18:16:30 (Australia/Sydney)
Unit Supply Air Fan Status = **1** On/Off
fav_id: 122406568353 2017-05-27 18:16:30 (Australia/Sydney)
Monitor Task #4650 AHU0001 Rules Wiki



Issue: AHU0007-1 – High CO_2 parts per million (ppm)-MOAD

Figure 9. ACE Platform (99 Elizabeth Street) – Issue ID: AHU0007-1



Issue: AHU0008-1 - Low Supply Air Static Pressure

Figure 10. ACE Platform (99 Elizabeth Street) – Issue ID AHU0008-1

Alert evaluated at 2017-05-16 10:10:31 AM

AHU0008-1

Air handling unit supply air static pressure is not tracking the supply air static pressure setpoint when the air handling is On.

Solutions:

1. Check and ensure that fan is operating at it's maximum speed and is not manually overridden.
2. Check and calibrate the static air pressure sensor.
3. Check and ensure that the fan belt is not loose or is not dislocated.
4. Check and ensure that the current static air pressure setpoint matches the design/commissioning value obtained based on the spaces' air flow requirements.
5. Check and ensure that the fan is not undersized for the current required static air pressure setpoint.

99 Elizabeth St

Missing - Evaluated Description

AHU-N-13

Equipment id: 122406567975, Site: 99 Elizabeth St

Unit Supply Air Fan Enable = **1** On/Off

fav_id: 122406568578 2017-05-16 10:05:33 (Australia/Sydney)

Unit Supply Air Fan Speed = **100** %

fav_id: 122406568580 2017-05-16 10:05:33 (Australia/Sydney)

Unit Supply Air Fan Status = **1** On/Off

fav_id: 122406568579 2017-05-16 10:05:33 (Australia/Sydney)

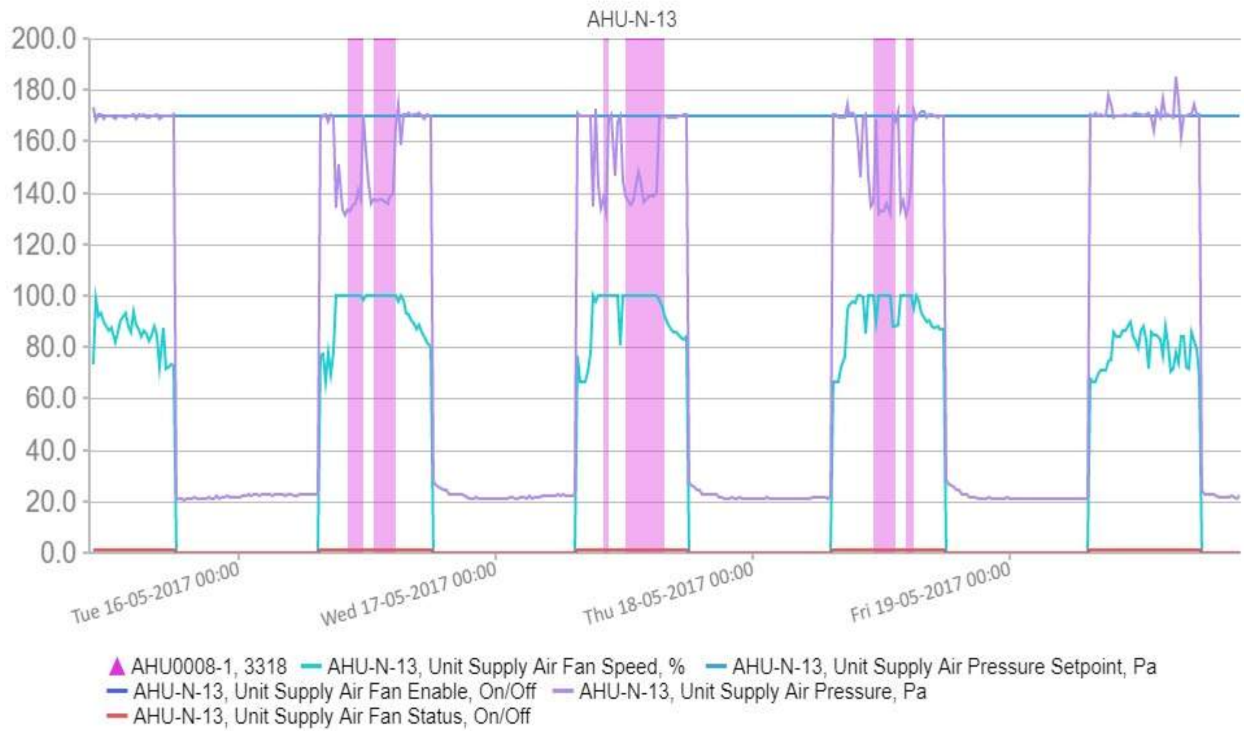
Unit Static Air Pressure = **133.44** Pa

fav_id: 122406568587 2017-05-16 10:05:33 (Australia/Sydney)

Unit Static Air Pressure Setpoint = **170** Pa

fav_id: 122406570743 2017-05-16 10:05:35 (Australia/Sydney)

Monitor Task #3318 AHU0008-1 Rules Wiki



Issue: AHU0008-2 - High Supply Air Static Pressure

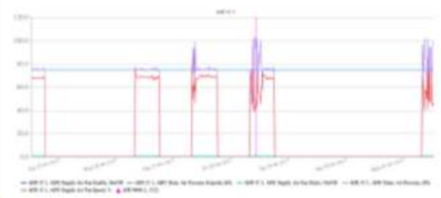
Figure 11. ACE Platform (99 Elizabeth Street) – Issue ID: AHU0008-2

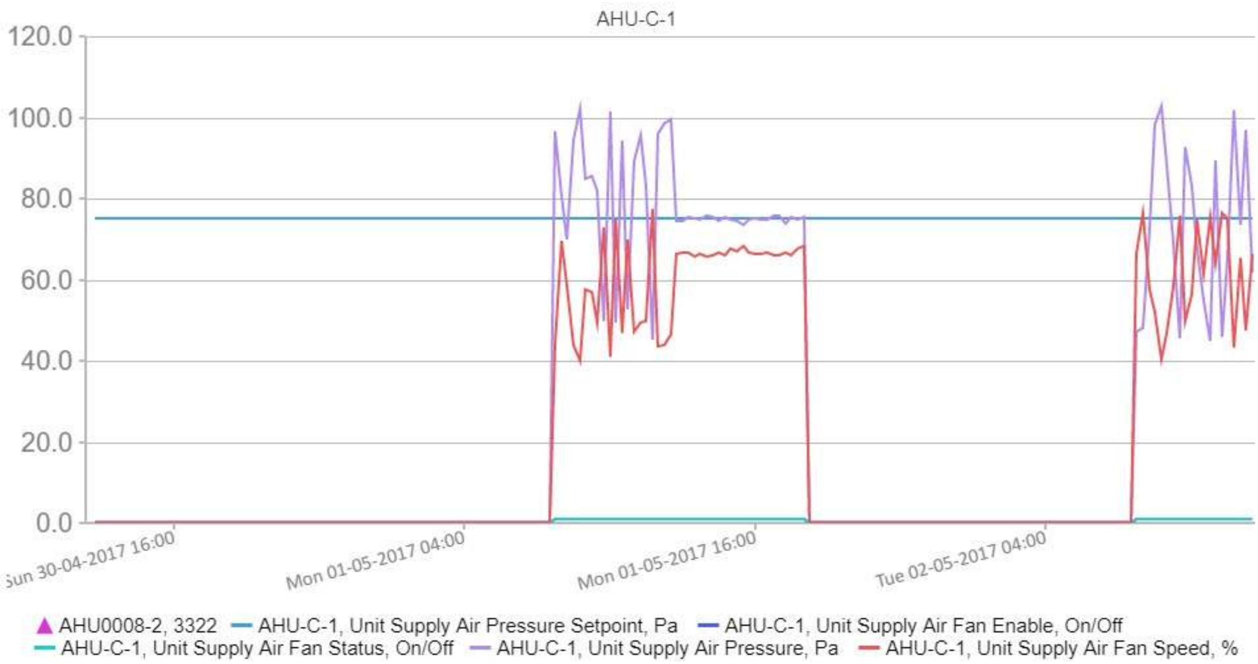
FDD Rules Engine APP 12:41 PM
Evaluated at 2017-05-01 12:41:47 PM
AHU0008-2
Air handling unit supply air static pressure is not tracking the supply air static pressure setpoint when the air handling is On.

Solutions:
1. Check and ensure the fan is not operating at it's maximum speed and is not manually overridden.
2. Check and calibrate the static air pressure sensor.
3. Check and ensure that the current static air pressure setpoint matches the design/commissioning value obtained based on the spaces' air flow requirements.
4. Check and ensure that the fan is not oversized for the current required static air pressure setpoint.

99 Elizabeth St
Missing - Evaluated Description
AHU-C-1
Equipment id: 122406567942, Site: 99 Elizabeth St
AHU Supply Air Fan Enable = 1 On/Off
fav_id: 122406567957 2017-05-01 12:30:03 (Australia/Sydney)
AHU Supply Air Fan Speed = 46.45 %
fav_id: 122406567959 2017-05-01 12:30:03 (Australia/Sydney)
AHU Supply Air Fan Status = 1 On/Off
fav_id: 122406567958 2017-05-01 12:30:03 (Australia/Sydney)
AHU Static Air Pressure = 99.58 kPa
fav_id: 122406567966 2017-05-01 12:30:05 (Australia/Sydney)
AHU Static Air Pressure Setpoint = 75 kPa
fav_id: 122406567967 2017-05-01 12:30:05 (Australia/Sydney)
Monitor Task #3322 AHU0008-2 Rules Wiki

Data Point History Graph
-24hrs/+24hrs (69kB)





Issue: AHU00013-WLT - Supply Air Temperature Poor Control

Figure 12. ACE Platform (99 Elizabeth Street) – Issue ID: AHU00013-WLT

FDD Rules Engine APP 5:54 PM
Alert evaluated at 2017-06-01 5:53:57 PM
AHU00013-WLT
The alarm is generated since AHU's supply air temperature is not within +/-1°C of the supply air temperature set-point when AHU is operating.

Solutions:
1. Check and calibrate the supply air temperature sensor.
2. Check the operation of the chilled and hot water valves.
3. Check the CHWV and HWV control strategy.
4. Check the chilled water or hot water leaving temperature and their set-points.

99 Elizabeth St

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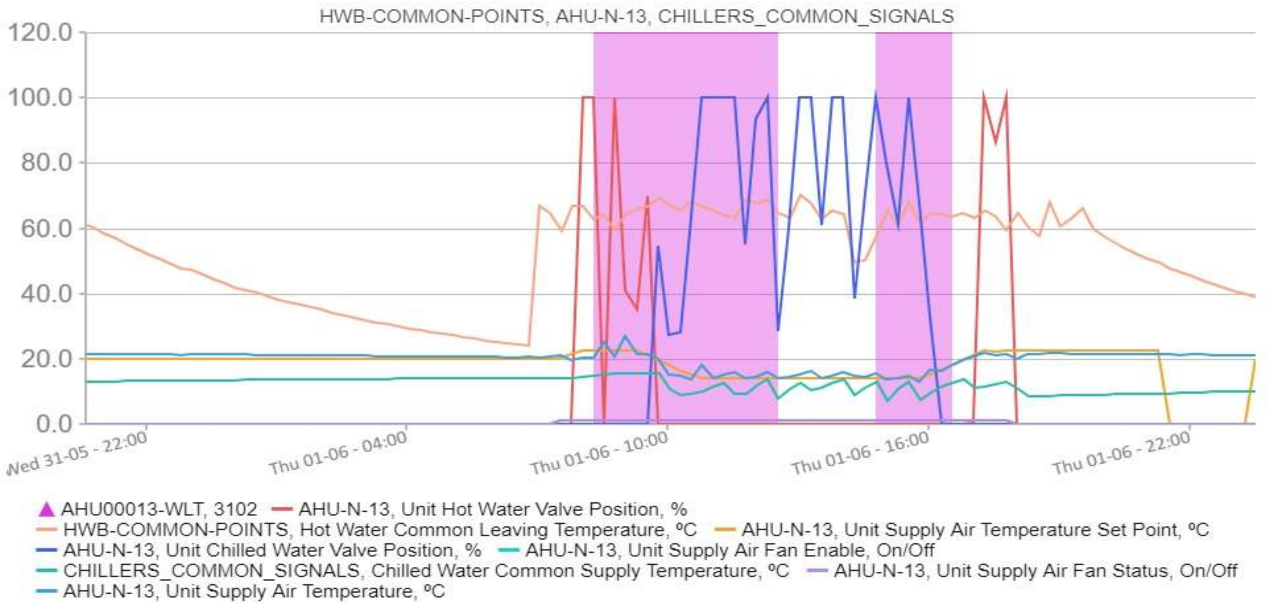
AHU-N-13
Equipment id: 122406567975, Site: 99 Elizabeth St
Unit Chilled Water Valve Position = **0** %
fav_id: 122406568576 2017-06-01 17:47:39 (Australia/Sydney)
Unit Hot Water Valve Position = **100** %
fav_id: 122406568577 2017-06-01 17:47:39 (Australia/Sydney)
Unit Supply Air Fan Enable = **1** On/Off
fav_id: 122406568578 2017-06-01 17:47:39 (Australia/Sydney)
Unit Supply Air Fan Status = **1** On/Off
fav_id: 122406568579 2017-06-01 17:47:39 (Australia/Sydney)
Unit Supply Air Temperature = **21.30** °C
fav_id: 122406568585 2017-06-01 17:47:40 (Australia/Sydney)
Unit Supply Air Temperature Set Point = **22.50** °C
fav_id: 122406568586 2017-06-01 17:47:40 (Australia/Sydney)

CHILLERS_COMMON_SIGNALS
Equipment id: 122406568110, Site: 99 Elizabeth St
Chilled Water Common Supply Temperature = **13.10** °C
fav_id: 122406569838 2017-06-01 17:48:34 (Australia/Sydney)

HWB-COMMON-POINTS
Equipment id: 122406568135, Site: 99 Elizabeth St
Hot Water Common Leaving Temperature = **59.50** °C
fav_id: 122406568031 2017-06-01 17:48:28 (Australia/Sydney)



ACE Platform (99 Elizabeth Street) - Demonstration of Outcomes

Annual Energy Summary

Table 5. ACE Platform (99 Elizabeth Street) - Annual Energy Summary *

Time Period	Electricity Saving (%)	Gas Saving (%)
July 2016 to July 2017	8.3%	13%

* Note: Reported reductions were achieved on top of occupancy increasing from 50% to 100%.

NABERS Rating

- Took building from 1.5 stars (indicative) to 5 stars (official rating) in 24 months, for $48,000 in OPEX, with no CAPEX.
- Our target was 4.5 stars.

Thermal Comfort Improvements

Reduced tenant hot & cold temperature-related complains to less than 5% (verified by client).

Note: All savings numbers presented in this case study have been verified by the client (i.e. building owner and/or facility manger).

END OF CASE STUDY

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Results

ACE Platform
by CIM Enviro

Table 1. Part II Evaluation Criteria

#	Evaluation Criteria	Score	Reported Rating
	FM Reported Metrics and Feedback – Qualitative		
1	- Ease of solution implementation and implementation effort required by *Facility Manager* (with consideration of building size, HVAC system complexity, and BMS interfacing requirements beyond non-standard networking protocols e.g. BACnet).	91-100% (combined score from all demonstration buildings under implementation)	BEST IN CLASS
2	- Clarity and understanding of FDD solution reports, and quality of service-related communication provided by *FDD Solution Provider.*	91-100% (combined score from all demonstration buildings under implementation)	BEST IN CLASS
3	- Level of support or service provided by *FDD Solution Provider* (beyond reporting) to facilitate further investigation of potential faults or to aid investigation by *Facility Manager* and/or HVAC maintenance contractors.	91-100% (combined score from all demonstration buildings under implementation)	BEST IN CLASS
	FDD Performance Metrics – Quantitative		
4	- Number of correctly identified faults% score (0 correctly identified faults = 0% score)	91-100% (exemplar demonstration building)	BEST IN CLASS
5	- Number of missed faults (0 missed faults = 100% score)	91-100% (exemplar demonstration building)	BEST IN CLASS
6	- Number of false alarms (incorrectly identified faults or non-faults) (0 false alarms = 100% score)	91-100% (exemplar demonstration building)	BEST IN CLASS
	BONUS Metric – Optimisation Opportunities		
	- Number of HVAC optimisation opportunities identified (beyond scope of evaluation criteria)	The CIM Enviro FDD solution identified a leading number of HVAC system and BMS control optimisation opportunities as part of their reporting requirements.	BEST IN CLASS

Note: Only the ratings (AVERAGE; ABOVE AVERAGE; EXCELLENT; BEST IN CLASS) have been presented in this Part II of the final report. Absolute scores will be kept confidential by CSIRO due to commercial sensitivities.

Reference

WALL J. AND GUO Y (2018). EVALUATION OF NEXT-GENERATION AUTOMATED FAULT DETECTION & DIAGNOSTICS (FDD) TOOLS FOR COMMERCIAL BUILDING ENERGY EFFICIENCY – FINAL REPORT PART I: FDD CASE STUDIES IN AUSTRALIA, RP1026, LOW CARBON LIVING CRC, FEB 2018, PP 68.

WALL J. AND WHITE S. RP1026 - EVALUATION OF NEXT-GENERATION AUTOMATED FAULT DETECTION & DIAGNOSTICS TOOLS FOR COMMERCIAL BUILDING ENERGY EFFICIENCY - PARTNER PARTICIPATION PROTOCOL V2.0.