



# Automated fault detection for persistent energy savings in commercial buildings

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CSIRO ENERGY TECHNOLOGY  
[www.csiro.au](http://www.csiro.au)

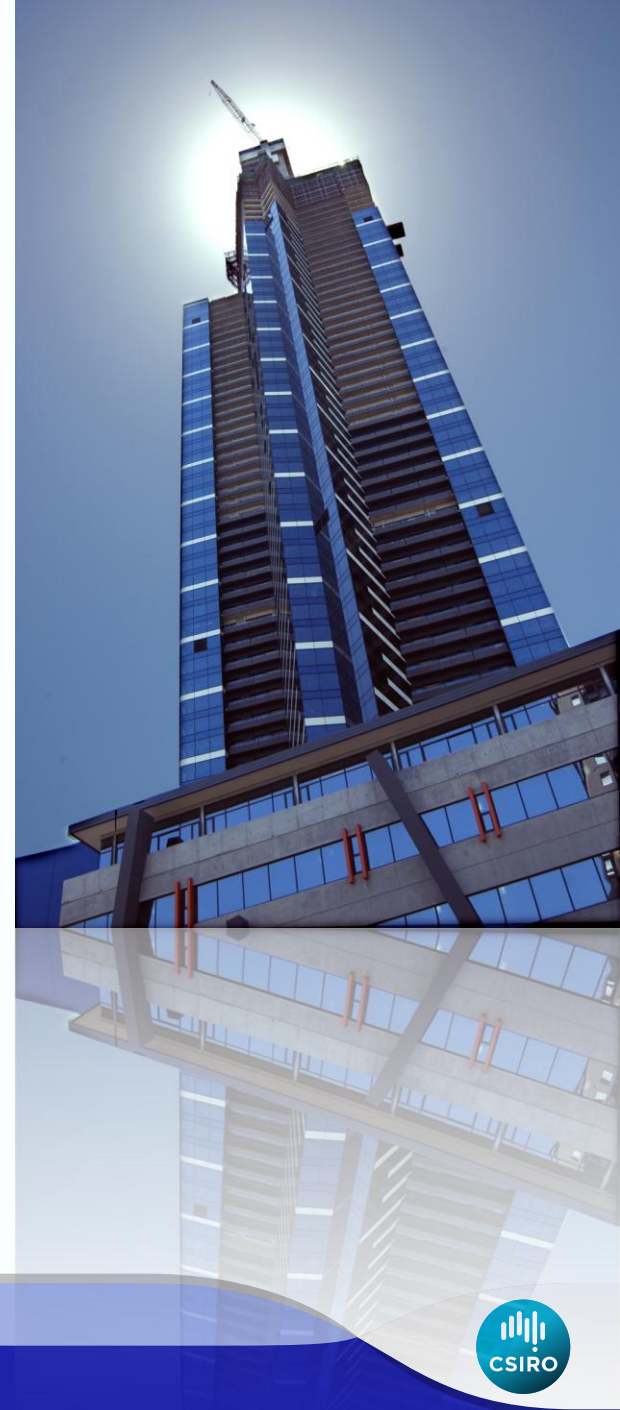


2013 Australian summer study on energy efficiency & decentralised energy  
Brighton Le Sands, Sydney



# Overview

- Emerging HVAC Technologies for energy efficiency
- Commissioning of HVAC systems / potential savings
- Fault detection and diagnostics (FDD) methods
- Automated tools for FDD
- CSIRO evaluation of automated FDD tools
- Case studies
- Next steps



# Performance optimization and diagnostics technology options

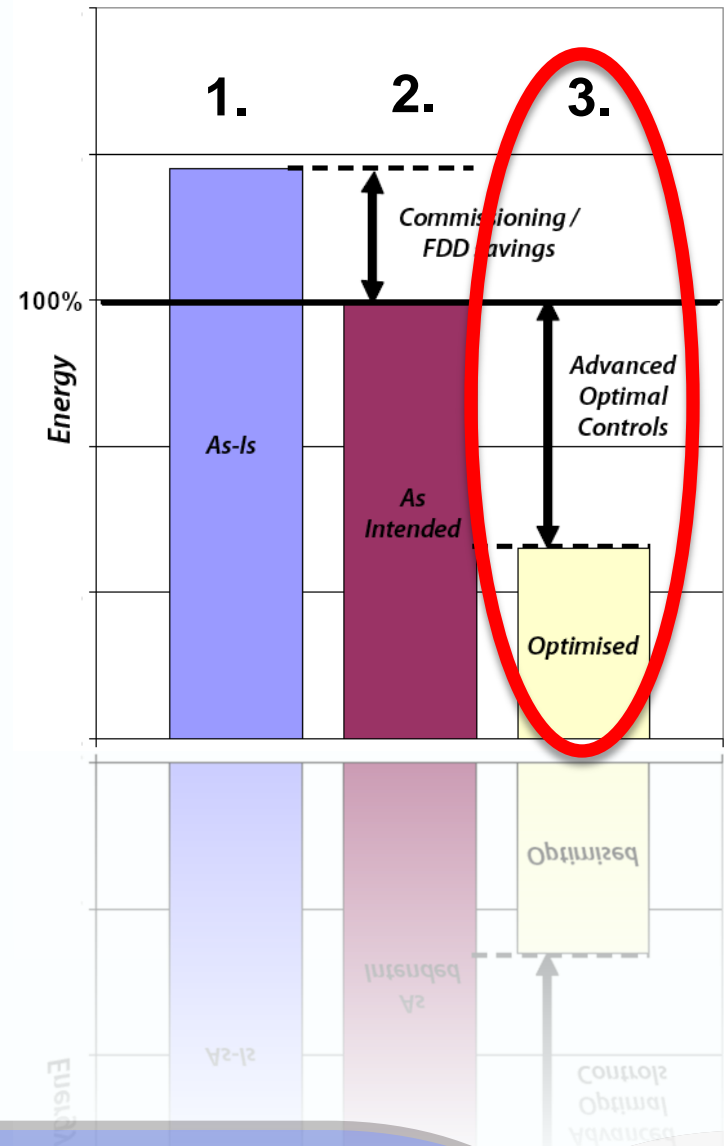
Option	Potential Savings	Availability
Demand-Controlled Ventilation	10%	Commercially available
Duct-Leakage Diagnostics	7%	R&D / Emerging
Retro Commissioning	13%	Commercially available
Ongoing Commissioning/FDD	17%	Commercially available / Emerging
Building Energy Information Systems	20%	Commercially available
Packaged Rooftop Air Conditioner FDD	13%	R&D / Emerging

(source: Goetzler et al., 2011)




# Benefits of Commissioning

- Properly commissioned and 'tuned' building systems are important...
  - Improved Energy Performance
  - Reduced maintenance needs
  - Increased equipment life
  - **Maximises impact from optimal controls!**



# Building Commissioning

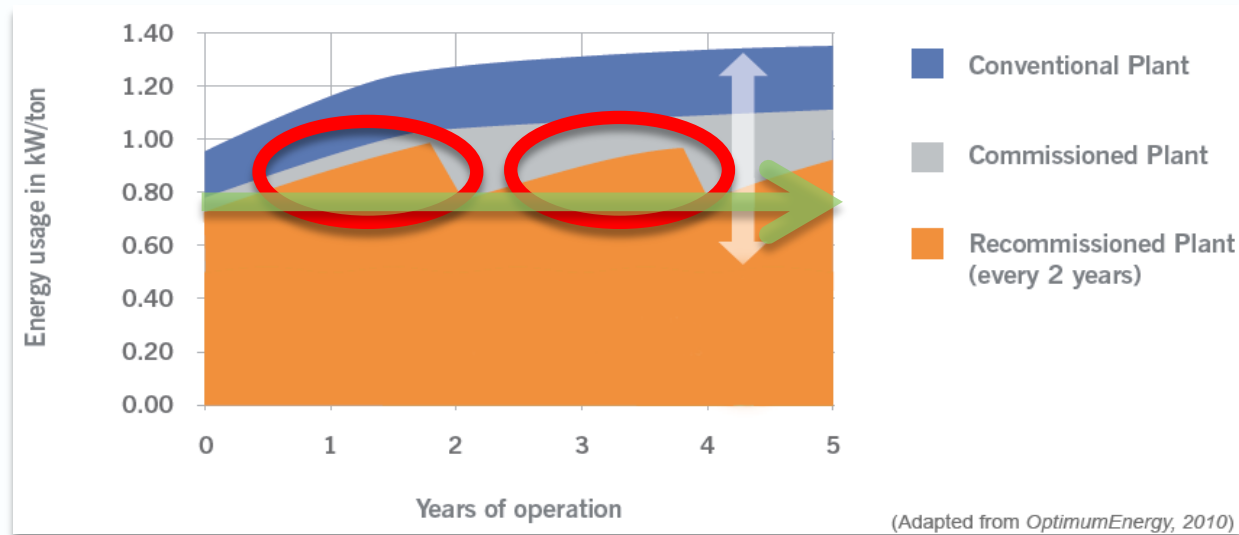
- End Goal: Ensure energy systems are performing as per their design intent or “as best they can”.
- Types of building commissioning (Cx)
  - **Initial Cx:** Design  Post Handover / Fine-tuning
  - **Re Cx:** perform commissioning procedures for existing buildings during their lifetime following the initial commissioning.
  - **Retro Cx:** set of procedures, like an extensive tune-up, that are applied to buildings that have been changed or have never been commissioned.
  - **Ongoing Cx:** a more automated commissioning process that is performed and evaluated on a frequent or continuous basis.
- Best practise Cx guides:
  - AIRAH DA27
  - CIBSE Cx Codes
  - ASHRAE Guidelines (**new Standard 202P Cx Process to be released 2013**)

# Potential Savings from Existing Building Cx

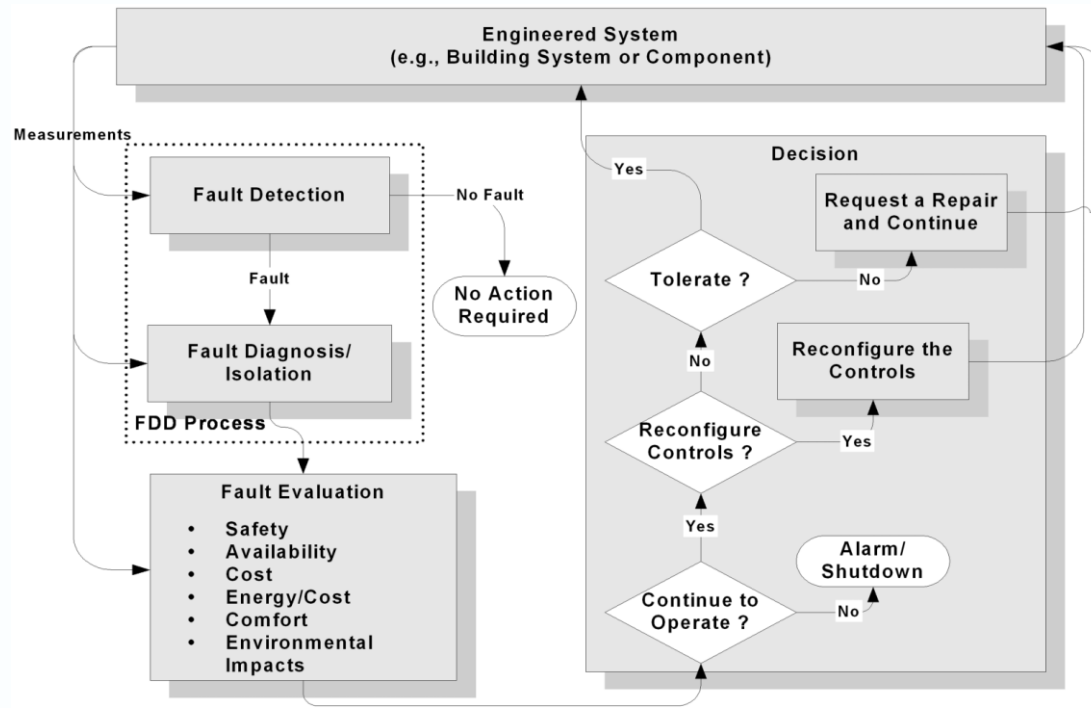
- U.S. building commissioning meta-analysis (source: Mills, 2009)
  - 16% median whole-building energy savings in existing buildings
  - payback time of 1.1 years.
- NSW OEH Energy Saver Program - building tuning/recommissioning practices
  - 5-10% savings of their utility cost (source: AIRAH Discussion Paper - Transition to Low Emission HVAC&R, 2013)
  - simple payback is less than 2 years, some less than 1 year
- Common HVAC fault types
  - Stuck and leaking chilled and hot water valves
  - Stuck and leaking air dampers
  - Leaking air ducts, blocked air filters
  - Sensor calibration (drifts, offsets)
  - Oscillating local control loops
  - Faults on Air handling fans, Pumps, VSDs

# Persistent Energy Savings?

- Excess energy consumption between re-commissioning cycles
- How can we ensure persistent energy savings?
  - Re-commissioning procedures - labour intensive, perceived as expensive
  - Expert building operator monitoring 24/7
  - Automate elements of the commissioning process
    - Automated Fault Detection & Diagnostics (AFDD) tools
    - Automated Ongoing Cx tools



# Generic FDD Process for Building Systems

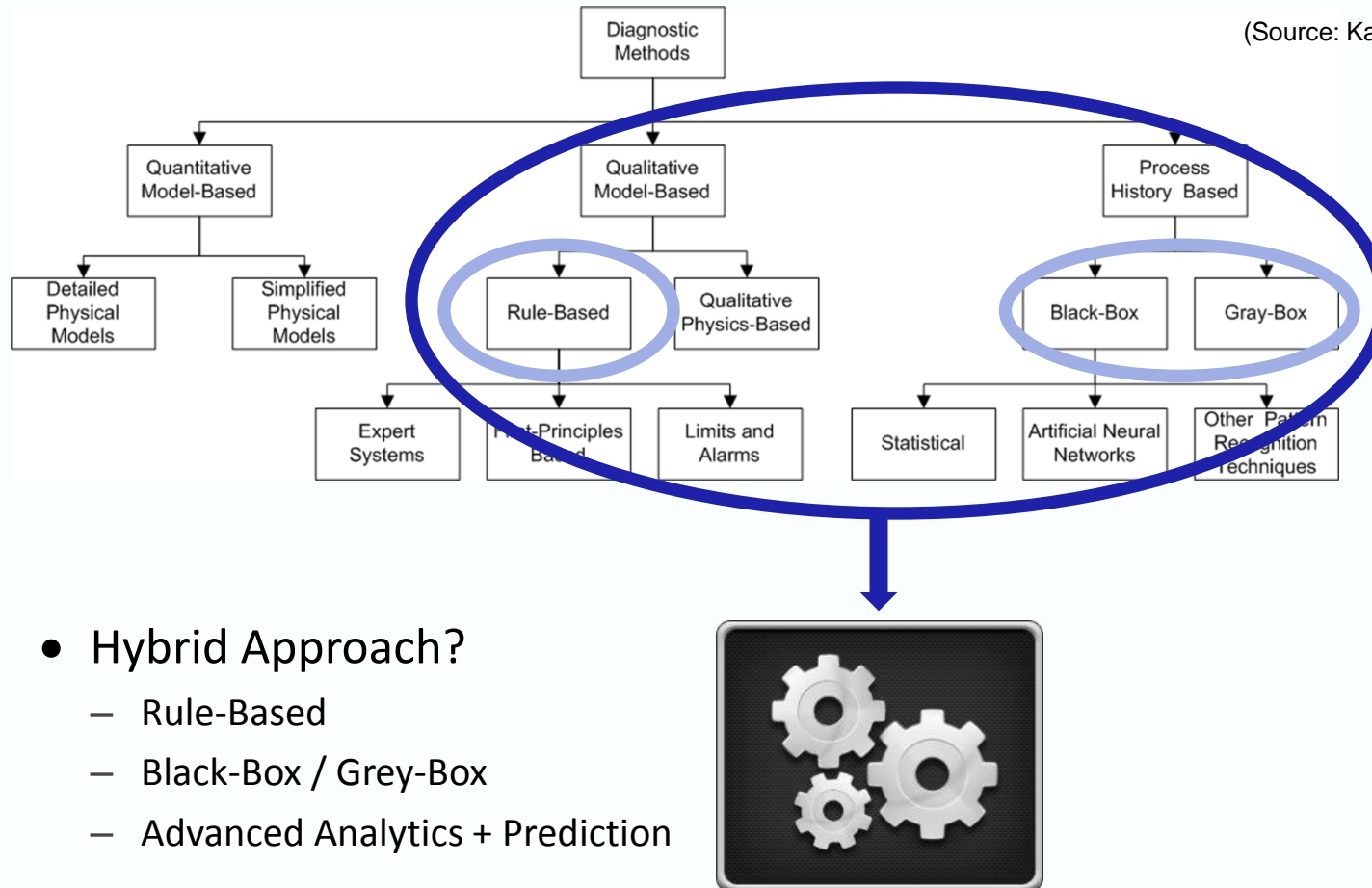


- Measurement Data: BMCS, EMCS, smart meters, wireless sensors, weather
- Detect faults in systems, sub-systems and components
- Isolate the cause(s) of the fault
- Suggest remedial actions / reconfigure controls



# Classification of FDD Methods

(Source: Katipamula & Brambley, 2005)



- Hybrid Approach?

- Rule-Based
- Black-Box / Grey-Box
- Advanced Analytics + Prediction

# What are AFDD tools?

- Sophisticated algorithms/expert rules- exists as software
  - Stand-alone or online (SaaS / Cloud)
- Connects to existing data sources:
  - Building Management & Control System (BMCS)
  - Smart meters / Energy Management & Control Systems (EMCS)
  - Wireless Sensors
  - Weather data
- Continually analyse operational data and compares with known rules/models
  - E.g. every 15mins, determine potential faults every hour
- Can provide certainty about operational problems and wasted energy
- For building operators it can be the difference between **I think** and **I know!**

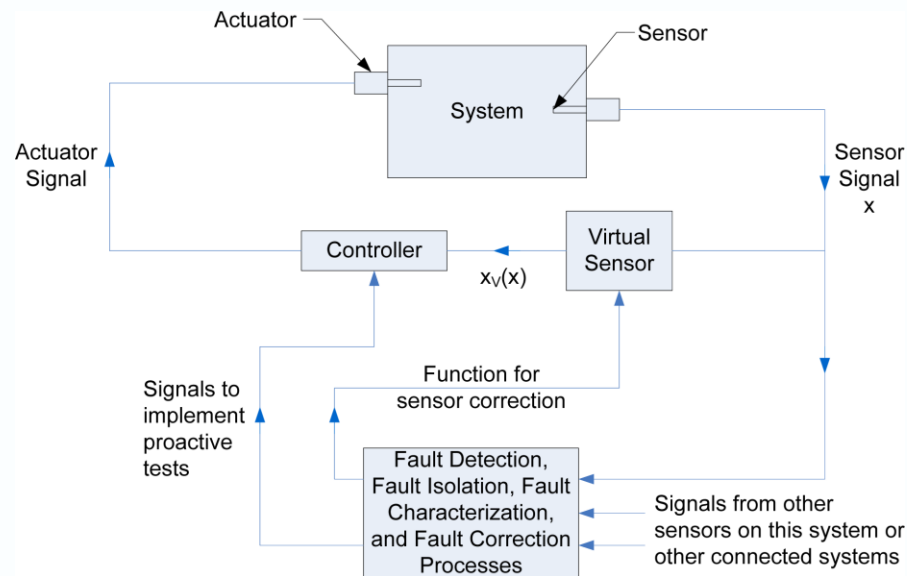
# Automated FDD Functionality

- Monitoring and Visualisation
- Fault Detection
  - Detect faults in systems, sub-systems and components
  - Energy Analytics, Estimate Energy Wastage
- Fault Diagnostics
  - Isolate the cause(s) of the fault
  - Suggest remedial actions
  - Prioritise based on severity or energy wastage
  - Condition monitoring
- Automated Cx
  - Automatically re-tune / re-calibrate controls
- Non-Energy Benefits:
  - Improved occupant comfort, indoor air quality
  - Reduced equipment size, reduced noise
  - Reduced maintenance needs, extended equipment life



# Automated Ongoing Commissioning

- Automated Commissioning work by Brambley, Katipamula *et al.*
  - ‘Self-correcting’ controls
  - After a fault is detected, automatically adjust controls to compensate
  - May require a re-design of BMCS control logic
  - Not commercially available (R&D)



# Emerging Automated FDD Tools

- AFDD tools emerging...

- PACRAT
- Infometrics (Cimetrics)
- Enforma (Arch Energy)
- APAR & VPACC (NIST)
- DABO (ADMS Technologies)
- SCIWatch (Scienergy)
- Skyspark (Skyfoundry)
- Panoptix Continuous Diagnostics Advisor (Johnson Controls)
- (Ezenics)
- (Coppertree Analytics)
- Synergy (Fieldiagnostics)
- Accenture
- Tririga (IBM)
- Clockworks (KGS Buildings)
- (Iconics)
- (Glacial Energy)



(source: Skyfoundry)



(source: Johnson Controls)



(source: ADMS Technologies)




# CSIRO Evaluation of AFDD Tools

- CSIRO undertaking initial evaluation of commercially available AFDD tools
- Currently evaluating 2 tools:
  - DABO (ADMS Technologies)
  - SkySpark (SkyFoundry)
- Additional tools being considered for implementation:
  - ClockWorks (KGS Buildings)
  - Panoptix Continuous Diagnostics Advisor (Johnson Controls)
- CSIRO seeking Government / Industry support for comprehensive evaluation
  - Lab testing: AHRAE 1312-RP Fault Simulation Tool
  - Real building case studies: CSIRO Energy Centre, others buildings to be identified
  - **Outcome (shared IP): Cost-benefit analysis – quantify cost, implementation effort, data requirements, FDD performance, energy savings ...**

# Case Study - DABO

- DABO™ (Diagnostic Agent for Building Operators)

- Distributed by ADMS Technologies 
- Initially developed by CanmetENERGY (Natural Resources Canada)
- Stand alone software application
- Rule-Based FDD
  - over 800 expert rules
  - more than 275 performance indicators

- Advertised Features:

- Ongoing commissioning reports
- Energy metering, HVAC, water-system and lighting-control efficiency tracking
- Hourly fault detection diagnostics (FDD)
- Detailed performance dashboard

Understand your  
**BUILDING'S  
PERFORMANCE**

- ✓ System Tracking
- ✓ Fault Detection & Diagnosis
- ✓ Ongoing Commissioning
- ✓ Energy Monitoring



(source: ADMS Technologies)

# Case Study - DABO

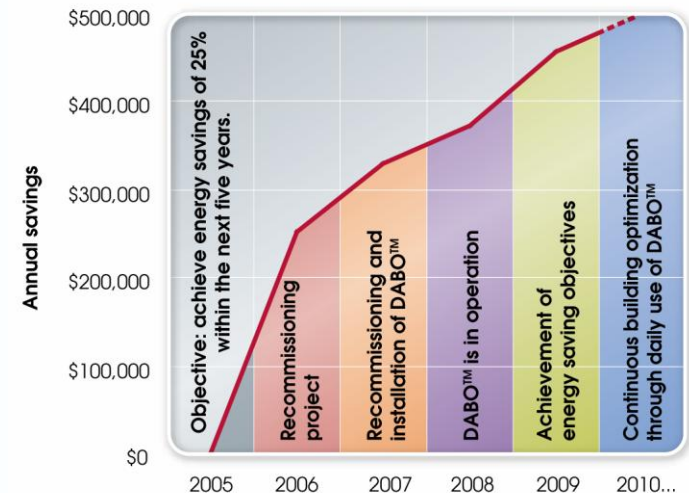
- Building: Palais des congrès de Montréal, Montréal Canada
  - 130,000 m<sup>2</sup> Convention centre
  - Annual energy bill: \$2 million CAD



(source: ADMS Technologies)

Daily Analysis of Individual Components	Optimization of Systems over Time
<p>At the Palais des congrès de Montréal, regular consulting of DABO™ screens in 2008–2009 <b>resulted in the detection of 211 faults</b> that would have been difficult to detect otherwise. For example:</p> <ul style="list-style-type: none"> <li>▪ Inverted connections on a three-way valve installed on an heat recovery loop</li> <li>▪ Unnecessary start-up of several HVAC systems during unoccupied periods</li> <li>▪ Leaking heating and chilled water valves</li> <li>▪ Defective or undersized humidifiers</li> <li>▪ Decalibrated sensors</li> <li>▪ Simultaneous heating and cooling</li> </ul>	<p>By consulting historical data and analyses provided by DABO™, Palais des congrès de Montréal employees and the Consulting Engineers Pageau Morel <b>optimized most of the building's mechanical and electrical components, such as:</b></p> <p>107,000-L/s outdoor air supply system with:</p> <ul style="list-style-type: none"> <li>▪ 22 supply/exhaust systems</li> <li>▪ 30 HVAC systems (H-type)</li> <li>▪ 50 VAV terminal boxes</li> </ul> <p>Cooling and heating systems:</p> <ul style="list-style-type: none"> <li>▪ Cooling and heating plants</li> <li>▪ Distribution systems</li> </ul>

- Detection of 211 HVAC faults in 1<sup>st</sup> year
- Achieved a persistent 25% energy savings





# DABO – Screen Shots



(source: ADMS Technologies)

DABO™, Building Automation System: CSIRO [jdbcodbc:DABO\_CSIRO] Database is updated: 2012-05-18 10:09:35

Object View Dashboard Assistant Reports Tools Help

### Symptoms detected details

AHU-02 - 2013-01-31 at 15h

**Symptom 802:** Critical: Supply air temperature out of normal scale range.

**Mode:** Mechanical Cooling

**Failure(s) that may have caused this symptom:**

**Failure 3:** Supply air temperature sensor

**Suggested Action:** Verify calibration of temperature sensor For help, you can call ADMS @ 1-866-299-7517 Ext. 2 or email support@ADMS-Tech.com

**Impact:** Possibility of overcooled or overheated air temperature causing improper room temperature control and increased terminal reheat if applicable

**Symptom 806:** Critical: Supply air humidity out of normal scale range.

**Mode:** Mechanical Cooling

**Failure(s) that may have caused this symptom:**

**Failure 7:** Supply air humidity sensor

**Suggested Action:** Verify calibration of humidity sensor For help, you can call ADMS @ 1-866-299-7517 Ext. 2 or email support@ADMS-Tech.com

**Impact:** Improper safety humidifier control operation, possibility of condensation in duct work, improper humidity level in zone, possibility of occupant incomfort

**Print**

0.2.34  
0.2.35  
0.2.40  
0.2.41

Free and Mec.Cooling    Mechanical Cooling    Not Stable    Undetermined

On    Warm Up

# Case Study - ClockWorks



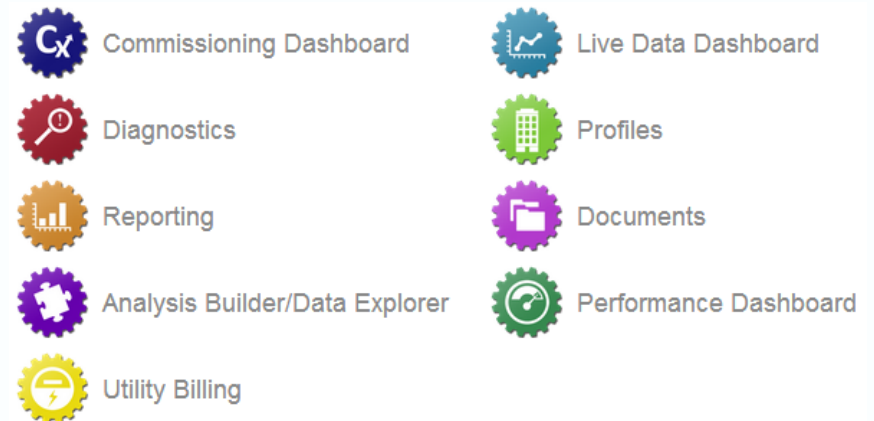
- ClockWorks

- Developed and distributed by KGS Buildings
- Cloud-based software application
- Rule-Based FDD



- Key Advertised Features:

- Automated Diagnostics
- Cross-Platform Data Integration
- Customizable Reports
- Secure Enterprise-Level Network
- Access Anywhere
- Unlimited Cloud-Based Storage
- Link to External Management Systems



# Case Study - ClockWorks



- Building: Research laboratory, Boston U.S.
  - 41,806 m<sup>2</sup> (5-year-old)

Building Summary	
Location	Massachusetts
Use Type	Research Lab
Size	450,000 sq. ft.
Monitored Systems	Central and Zone Ventilation System

Project Summary	
Project Status	Ongoing
Setup Cost	\$23,190.00
Maintenance Cost (annual)	\$35,407

Savings Summary	
Potential savings from faults found (annual)	At least \$165,000

- Building: Office Building , Massachusetts U.S.
  - 17-story multi-tenant office building

Building Summary	
Location	Massachusetts
Use Type	Office
Size	17 Floor Tower
Monitored Systems	HW Primary Loop, CHW Primary Loop, Large Air Handlers

Project Summary	
Project Status	Ongoing
Setup and Engineering Cost	\$65,000
Maintenance Cost (annual)	\$2,316

Savings Summary	
Expected Incentive Award	\$32,000 - \$44,000
Potential savings (annual)	\$60,000 - \$75,000

# ClockWorks – Screen Shots



Siân's Account | Logout Home | Admin | KGS Admin | System Admin | Help Client: [ ] Module: Goto module...

### Create Expression

Building	Equipment Class	Equipment	Analysis	Start Date	Notes Summary	Cost (\$)	C	E	M
BLD					<b>Notes: PROBLEM: HEATING OCCURING WHILE COOLING COIL VALVE IS OPEN</b> <ul style="list-style-type: none"><li>- The supply air temperature was more than 3 deg F higher than the mixed air temperature while the cooling coil valve was open, for a total of 24 hrs over the analysis period.</li></ul>				
W					<b>Possible Causes:</b>				
W					<ul style="list-style-type: none"><li>- Leaking heating coil valve.</li><li>- Stuck cooling coil valve.</li><li>- Temperature sensor error.</li></ul>				
W					<b>PROBLEM: HEATING OR PREHEATING AND COOLING VALVE OPERATING SIMULTANEOUS</b>				
W					<ul style="list-style-type: none"><li>- The heating or preheating valve is commanded to be open at the same time as the cooling valve is commanded to be open..</li></ul>				
					<b>Possible Causes:</b>				
					<ul style="list-style-type: none"><li>- Error in control sequences.</li><li>- Temperature sensor error causing valve(s) to be controlled incorrectly.</li></ul>				
					<b>PROBLEM: EXCESS OR SIMULTANEOUS HEATING AND COOLING</b>				
					<ul style="list-style-type: none"><li>- The preheating coil and/or cooling coil are either providing excess heating or cooling or operating simultaneously.</li><li>- This may waste around \$978 and 79220 kBTUs over 1 day(s).</li></ul>				
					<b>Possible Causes:</b>				
					<ul style="list-style-type: none"><li>- Valve is not seating properly and is leaking.</li><li>- Valve is stuck.</li><li>- Temperature sensor error or sensor installation error is causing improper control of the valves.</li></ul>				

Save

# Summary & Next Steps

- Commissioning / fine-tuning key to low-energy buildings
- Automated Fault Detection and Diagnostics (FDD) tools are emerging....
- Automated Commissioning (self-correcting controls) at R&D stage
- Case Studies and literature showing Auto. FDD energy savings potential 5-40%
- CSIRO looking to perform comprehensive evaluation of Automated FDD tools commercially available
  - Initial evaluation looking at 2+ tools (2 more being investigated)
  - Seeking Government / Industry support for larger evaluation in Australian context
  - Cost-benefit analysis – quantify cost, implementation effort, data requirements, FDD performance, energy savings ...
- Automated FDD Tools could be key to **high impact persistent energy savings!**

# Thank you

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# Initial Cx Resources

(additional slides)

- AIRAH application manual DA 27 - Building Commissioning, 2011
- ASHRAE
  - ASHRAE Guideline 0-2005 - The Commissioning Process
  - ASHRAE Guideline 1.1-2007- HVAC&R Technical Requirements for The Commissioning Process
  - ASHRAE Standard 202P - Commissioning Process for Buildings & Systems, estimated released 2013
- CIBSE Commissioning Codes:
  - Code A: Air Distribution Systems, Code B: Boilers, Code C: Automatic Controls, Code L: Lighting, Code M: Management, Code R: Refrigeration, Code W: Water Distribution Systems
- BSRIA Soft Landings Framework  
<http://www.bsria.co.uk/services/design/soft-landings/anz/>

# Ongoing Cx / FDD Resources

(additional slides)

- DOE EEB-HUB Project (ongoing)  
See: <http://www.eebhub.org/>
- IEA ECBCS Annex 47 - Annex 47 Cost Effective Commissioning of Existing and Low Energy Buildings (completed 2005-2010)  
See: <http://www.ecbcs.org/annexes/>
- PIER Advanced Automated HVAC Fault Detection and Diagnostics Commercialization Program. (completed 2006)  
See: <http://www.archenergy.com/pier-fdd/default.htm>
- IEA ECBCS Annex 40 - Commissioning of Building HVAC Systems for Improving Energy Performance. (completed 2001-2004)  
See: <http://www.ecbcs.org/annexes/>