Final Scientific Technical Report

INTEGRATED BUILDING MANAGEMENT SYSTEM (IBMS)

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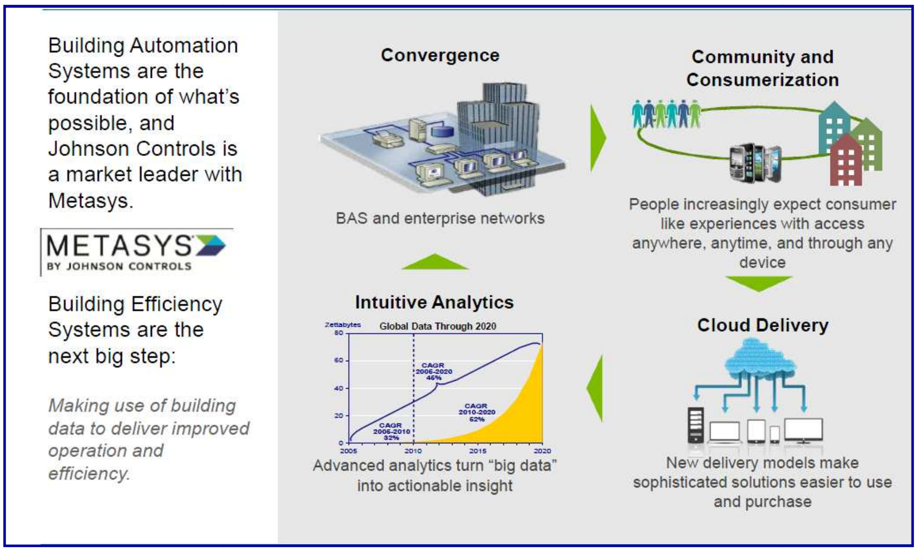
Executive Summary

This project provides a combination of software and services that more easily and cost-effectively help to achieve optimized building performance and energy efficiency. Featuring an open-platform, cloud-hosted application suite and an intuitive user experience, this solution simplifies a traditionally very complex process by collecting data from disparate building systems and creating a single, integrated view of building and system performance. The Fault Detection and Diagnostics algorithms developed within the IBMS have been designed and tested as an integrated component of the control algorithms running the equipment being monitored. The algorithms identify the normal control behaviors of the equipment without interfering with the equipment control sequences. The algorithms also work without interfering with any cooperative control sequences operating between different pieces of equipment or building systems. In this manner the FDD algorithms create an integrated building management system.



Comparison of Actual Performance to Project Objectives

The project achieved its objectives to develop an Integrated Building Management System (IBMS) which can integrate disparate building systems to increase energy efficiency, comfort and lower maintenance costs. The system integrates automated fault detection and building automation system data to accomplish this.

Project Activity Summary

Phase I: Development of the Project Management Plan (PMP)

Task 1.0 – Project Management Plan (PMP)
Initial PMP submitted 9/10/2010 with subsequent updates over the life of the project.

Task 2.0 – Project Kickoff Meeting
A JCI team, including Principal Investigator, Principal Project Director and Business Officer traveled to NETL in Morgantown, WV on October 6, 2010 to participate in the DOE kick-off meeting which consisted of a DOE briefing and JCI review of project and questions.

Task 3.0 – Identify Prototype and Proof Of Concept (POC) Test Sites
Prototype test sites were identified in February, 2011 to include Johnson Controls buildings (three buildings on 2 different campuses) and multiple buildings at Georgia Tech in Atlanta, GA.

The identification and acceptance of POC test sites for the JCI Panoptix™ solution, which includes the work done under this grant, was completed by JCI's Product Management team. These sites included Miller Park in Milwaukee, WI and University of Minnesota, Minneapolis, MN.

Task 4.0 – Phase I Project Briefing
Our Phase I Project Briefing was presented on January 11, 2011 to the DOE.

Phase II: Applied Research on the Integrated Building Management System

Task 5.0 – Develop Integrated Control and Fault Detection Algorithms

A literature search and review was done to understand the state of the art of energy management systems, sustainability, integrated control and fault detection and diagnostics. This review helped to identify approaches and algorithms developed by others. Information on algorithms was used in conjunction with prior internal intellectual property developed by the Johnson Controls.

An Intellectual Property (IP) search was performed to ensure that the IBMS does not infringe on protected work by others. IP assessment work was completed by the JCI legal group and was monitored through the term of this project. IP related to grant work was tracked to allow management through the terms defined in the IP Waiver. The Johnson Controls IP Assessment form (BE-PDP-FR-03) was used to identify IP.

The Fault Detection and Diagnostics algorithms developed under this grant have been designed and tested as an integrated component of the control algorithms running the equipment being monitored. The algorithms identify the normal control behaviors of the equipment without interfering with the equipment control sequences. The algorithms also work without interfering with any cooperative control sequences operating between different pieces of equipment or building systems.

Using Matlab, a software package for numerical computations, code was developed for the Fault Detection and Diagnostics algorithms. The developed code allowed the input of test data vectors and provided the outputs in the form of preliminary user interface concepts. Historical data was taken from buildings to test the algorithms. This provided an early way to verify that the algorithms perform as expected. However, using historical test alone does not guarantee that all of the desired test scenarios are available. Certain scenarios may not have naturally occurred in the data sets for the buildings. To enhance the coverage of the testing, , Matlab was also used to execute existing **equipment and plant** models for the purposes of creating additional test data. Through the use of models, it is possible to create many different types of equipment failures and inefficiencies. The test vectors can create precise fault scenarios and expected results. The data from the models can be generated at faster than real time which allows more test scenarios to be created. Using the test data, automated testing was used to be able to easily retest algorithms with a suite of test vectors with expected results. As the algorithms are modified or enhanced, the test suite is extended and all the tests are rerun to verify the new feature works and did not adversely affect previous functionality.

A Project Performance Report was developed and was delivered to the Project Management office per plan.

Task 6.0 – Capture Business, Customer, and System Requirements

The objective of this task was to define customer expectations, document a clear product definition, and develop a realistic business case.

Work products completed for this task include, but are not limited to:

Business plan development
Aggregated Kano Scoring
Customer Concept Value Focus Groups
Customer Concept Value Qualitative Testing
Energy Star Benchmark Report
Internal Concept Workshops
VSR (Vision, Scope and Requirements) document
Requirements identification – Customer, User, Business

Engineering assessment was done and documented within multiple engineering conceptual design documents. Other tools used to perform the assessment included, but are not limited to simulation, modeling, early-prototyping, sketches/drawings, and use cases.

Critical System Requirements in product and functional specifications were identified and submitted to the DOE. The Critical to Quality requirements (CTQ's) have been monitored through the development life cycle and satisfy business requirements.

Task 7.0 – Phase II Project Briefing
DOE Project Briefings II and III were delivered on April 3, 2012

Phase III: Prototype Product Development of the Integrated Building Management System

Task 8.0 – Create Concept Design

Agile software development spanned work as described in Tasks 8.0, 9.0 and 13.0 and accounted for progress through Phases III and IV through each sprint (3 week period of work). JCI applied the Scrum*methodology through this project. A cloud based open platform prototype was developed. The prototype was remotely hosted in what is known as the "Staging" environment and used to automatically and continuously collect building data. The building data was automatically normalized for consistency and stored for use by applications.

Multiple applications were developed that are hosted on the infrastructure and can use the data according to their respective goals. Some of these were:

> **Continuous Diagnostics Advisor** – an application that constantly monitors building systems to detect problems that waste energy and impact tenant comfort, helping optimize operational performance, identify cost and energy efficiencies, and prevent equipment failures.
>
> **Custom Analyzer** – an application that provides a highly flexible capability to analyze trend data. It allows the viewing of data from multiple buildings and types of equipment, making it easy to conduct comparative analysis among multiple buildings, floors of a building or even specific pieces of equipment.
>
> **Energy Performance Monitor** - an applications which automates the process of measuring and verifying the savings that result from the implementation of an energy efficiency improvement project. Based on an industry standard approach to measurement and verification known as International Performance Measurement and Verification Protocol (IPMVP) Option C (Whole Building Retrofit), Energy Performance Monitor uses actual measured data from utility meters, building systems, and business applications, as inputs to a baseline that you create. This information helps monitor the performance of energy efficiency projects.

Carbon and Energy Reporter - an application that tracks and report energy use, utility cost, and greenhouse gas (GHG) emissions across and an owner's facility portfolio. In addition, the application helps validate utility bills and forecast utility use and cost. Data can be reviewed for a single building, or for a group of buildings, and allows for comparison between current and historical data.

By using the prototype system, facility managers were given a single integrated way to view their building and system performance. This provided a way to test both the infrastructure and applications from a functional standpoint as well as a way to gain feedback as to the business value of the system.

See **Figure 1 High Level Architecture** below for the layout of the prototype system.

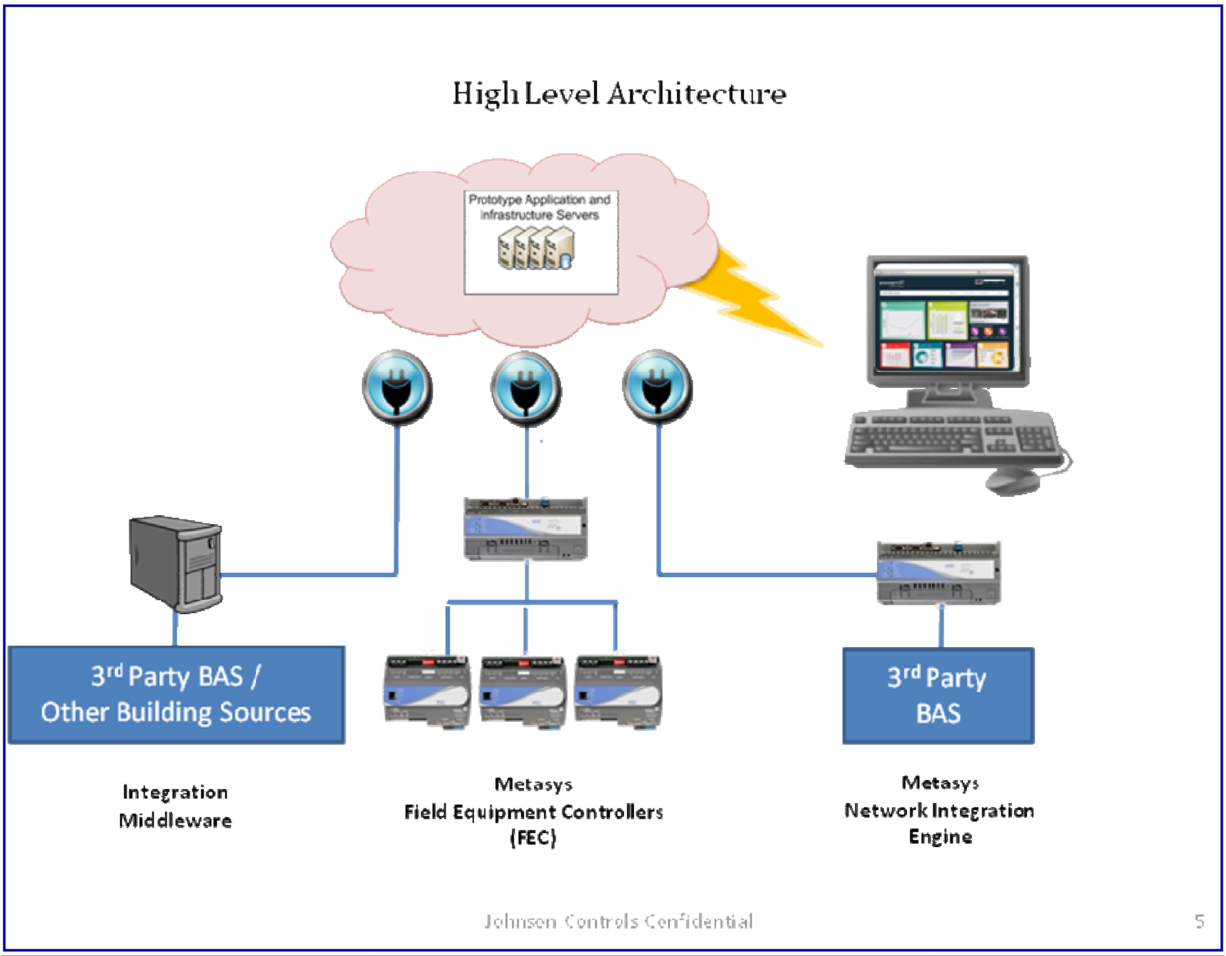


Figure 1 High Level Architecture

Task 9.0 – Develop Application and Fault Detection Features

The Fault Detection algorithms developed in Phase II were re-factored (using auto code generation capabilities when possible) for use within the prototype environment. This involved making them compatible with the cloud based environment and connecting them seamlessly to the infrastructure. The applications were then able to use the normalized building data for their respective functions and present the results in a single place.

Test data from Phase ii was entered into the system to validate that the results were identical. This verified that the integration of the algorithms into the prototype did not change the intended behavior of those algorithms. This also allowed testing of the prototype from the point of the normalized data storage all the way through the application to the final presentation of results.

Internal tools were developed to facilitate easy commissioning of building systems into the prototype and ultimately, the product. These software tools help identify assess available equipment within the facility, enter physical building information (floors, rooms, etc) and map equipment data to the system.

Task 10.0 – Test Application Functionality at Customer Facility
The prototype system installation of two prototype sites was completed in September and October, 2011, with a total test period of approximately 5 months. Building data was continuously taken, normalized and stored in the cloud based prototype. The fault detection algorithms executed automatically against the building data to detect faults and operational issues with the buildings. The results from this were presented to the user through the user interface for the application. The user was able to use the software to manage all or specific areas of the configured buildings and investigate the discovered issues.

Several key benefits were drawn from the prototype testing:

1) The prototype allowed the complete "end to end" testing of the system from the building and equipment controllers, through the data collection, through the applications and to the user interface.

2) Usability feedback from facility managers was taken and used to reinforce or modify the user interface design and visualization.

3) Data collection metrics were taken to assess if there was any impact to the building automation system.

4) Performance analysis of the system in a full scale environment.

5) Identification of bugs in the system. Root causes were identified and update code was deployed to the cloud based prototype. The use of a cloud based system allows easy updates to be made available to multiple customers. Changes only need to be made at a central location creating little to no work required at the customer's site.

Engineering worked with facility personnel to investigate discovered equipment or building issues and to determine the root cause. Additionally, operations team worked with facility personnel to configure the various facilities and help understand preferences from the facility manager point of view. The internal commissioning tools were used which provided an opportunity to enhance or modify them as needed.

Task 11.0 – Verify Critical System Requirements are met

System Tests were executed to verify compliance with the critical system requirements. The tests are intended and designed to be run repeatedly with each new revision of the software. In this fashion, software updates and revisions do diminish the quality or functionality.

Task 12.0 – Phase III Project Briefing

DOE Project Briefings II and III were delivered on April 3, 2012

Phase IV: Proof of Concept (POC) Development of the Integrated Building Management System

Task 13.0 – Design and Development of the System

Based on the results of the Prototype testing and using an agile software development process, the prototype software was modified and enhanced to correct bugs and add new features or functionality. In the agile development process, a prioritized backlog of work items was maintained. The prioritization is set by the Product Management in alignment with the business objectives. Results and feedback from the prototype testing were used to set these priorities. This focused the efforts on providing the maximum customer value and avoided expending cost or resources on items with lesser customer value. Periodic (and frequent) demonstrations of the working software were held to allow stakeholder and opportunity to assess progress and provide business level feedback.

During this phase, the deployment architecture was extended to include a production environment. The deployment architecture contains multiple levels such that any software revisions are deployed on lower level systems prior to being moved to production. All of the environments are hosted in the cloud. The deployment process and software tools were developed to successfully move from one environment to the next on the path to the production deployment. These were designed to be automated wherever possible to eliminate manual errors.

Task 14.0 – Install POC system in Customer Facility

The installation of two POC sites, Miller Park in Milwaukee, WI and University of Minnesota, Minneapolis, MN, was completed in February and March, 2012, with a total test period of approximately 3 months.

The system was configured to run against multiple test sites containing various building and campus types. Similar to the prototype testing, building data was continuously taken, normalized and stored for use with applications. The fault detection algorithms executed automatically against the buildings, detecting faults and operational issues with the buildings. Results from this were presented to the user through the user interface for the application.

The JCI Operations team and Customer Success Center trained the personnel from the test site's facility departments. In addition, they worked with the personnel to help configure the system according to each person's individual preferences. The system allows a particular user to customize their view of their own facility or facilities. For example, using the available widgets and the fault displays, the user can focus on a particular building, floor or piece of equipment, etc. This allows efficient management of the system as it can highlight specific items from a large amount of data. Current and historical data from the equipment can be viewed to help investigate building issues.

Task 15.0 – Validate the Performance of the system

The system performance was monitored for the infrastructure and the applications. JCI operations team and Live Guides collaborated with the customer to assess results and customer value and to acquire feedback. Similar to the prototype testing, the key benefits of the testing were focused around "end to end" testing, usability feedback, assessment of impact to building systems and full scale performance. The critical to quality requirements were validated to make sure they were still in compliance.

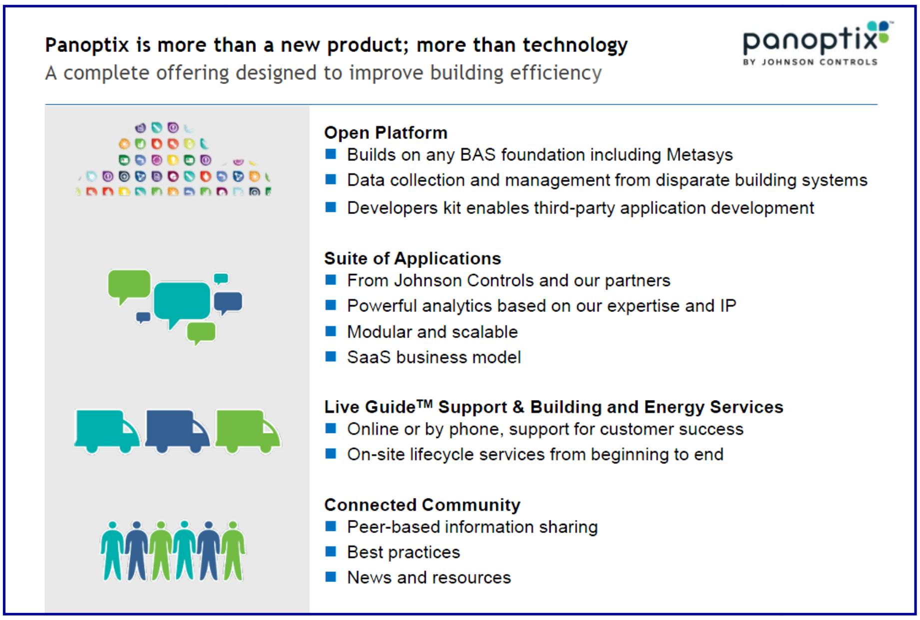
Testing at the Proof of Concept sites continues. At some sites, the initial testing was limited to certain portions of the campus or complex. The system is now being extended to additional buildings and areas. The continuation of the testing permits more analysis of the system in different seasons and under a variety of load conditions. For example, some types of faults in building typically occur in the summer months (cooling season) while others are more common in the winter months (heating season).

Task 16.0 – Phase IV Project Briefing
DOE Project Briefing IV was completed on September 18, 2012.

Products Developed

The JCI solution is an open-platform, cloud-hosted application suite with an intuitive user experience. This solution simplifies a traditionally very complex process by collecting data from disparate building systems and creating a single, integrated view of building and system performance.

It is also able to constantly monitor building systems. When a fault is detected, notifications appear on a dashboard. Detected issues such as abnormal energy consumption, anomalies in peak demand, poor VAV and AHU performance, and chiller efficiency issues can identify problems that can lead to premature equipment failure. This information is being delivered through Johnson Control's new offering, Panoptix™, specifically in the Continuous Diagnostics Advisor application which provides the fault detection capability.



Through the monitoring of existing building systems Continuous Diagnostics Advisor can detect problems that waste energy, create comfort problems, or might lead to premature equipment failure. When Continuous Diagnostics Advisor detects a fault, it runs diagnostics to determine the cause of the fault. This information helps customers prioritize repairs and retro-commissioning activities in a building. To perform automated fault detection for equipment, Continuous Diagnostics Advisor uses the following detection methods:

- **Peer Analysis –** detects equipment that is operating statistically differently than similar equipment in a peer group, thereby identifying which piece of equipment is having problems.

- **Rules-Based Analysis –** detects faulty equipment by using a standard set of rules available to all customers. As an example, a standard rule for a VAV Box is VAV-SD Absolute Flow Error. When this rule is used, a fault occurs when the Supply Flow Error is greater than a percentage of the Flow Setpoint. The fault check runs after a 15-minute occupancy delay and continues until the Zone is Unoccupied. To function properly, this rule requires that the Occupancy, Supply Flow Setpoint, and Supply Flow points of the VAV Box are mapped to Continuous Diagnostics Advisor.

- **Meter Analysis** – detects abnormal consumption (energy) or peak demand (power) by reviewing historical data for a meter, identifying days that have similar patterns, and then identifying when either total consumption and/or peak demand for a specific day is statistically different than the meter's typical behavior.

The system information is easily accessible through any Web browser so you can monitor the performance of a single piece of equipment, the entire building, or all the assets in a campus or portfolio around the world.

Through configurable, mobile device-friendly dashboards and customizable widgets the user is able to customize data views and reports that will help monitor equipment and easily create reports based on provided filter options.

As the product is deployed as a SaaS, continuous 3 weeks cycles occur to which our Proof Of Concept customers have access to. This has allowed the customer to subscribe to our continuously improving applications while engaging in a strong feedback loop with our support organization to address issues as soon as possible. This process has been instrumental in the Proof Of Concept testing cycle as JCI prepares to deploy to external customers.

Website: **www.johnsoncontrols.com/ panoptix**