A Guide for Specifying Performance Monitoring Systems in Commercial and Institutional Buildings

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Synopsis

This paper describes a guide for specifying performance monitoring systems that was developed as part of jointly funded CEC PIER-DOE project intended to assist commercial and institutional building owners in specifying what is required to obtain the information necessary to initiate and sustain an ongoing commissioning activity. The project's goal was to facilitate the delivery of specific performance related information to the benefit of both commissioning providers and building operators. A number of large-building owners were engaged in order to help create 'market pull' for performance monitoring while producing a specification that met their needs.

The specification guide and example specification language addresses four key aspects of performance monitoring:

- performance metrics
- measurement system requirements
- data acquisition and archiving
- data visualization and reporting

The paper describes key aspects of the guide including how measurement accuracy requirements relate to the performance metrics that are used in both troubleshooting and routine reporting. Guide development activities and related tech-transfer efforts are also presented.

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Introduction

Those who evaluate the performance of buildings and their energy using systems have long known that it takes the attention of a knowledgeable and dedicated team to obtain the quality of data necessary to determine how well a building is actually performing as well as identify means for improving it. This team may include a measurement analyst, instrumentation vendors, an installation contractor and the owner's staff. The problem is that buildings are not designed for measuring their performance. This is particularly true of flow. It is also believed that obtaining such data is a luxury; that it is not needed for system control or day to day operations.

But, as systems become inherently more complex with the advance of technology and energy costs continue to rise, owners require better information to benchmark the performance of their building inventory and energy using systems and to troubleshoot problems. This is complicated by the fact that few specifying engineers and installation contractors are trained to understand good measurement practice, thus driving costs up when they are specified. It is hoped that building a case for such systems, whether they are applied as part of the direct digital control system or an energy information system, and providing some insight into best practices will promote their use, help educate the user and drive costs down.

A specifications guide and example specification language for performance monitoring systems has been developed to assist commercial and institutional building owners in specifying what is required to obtain the information necessary to initiate and sustain an ongoing commissioning activity. The intent is to provide more focused information, thus benefiting both commissioning providers and building operators. The advantage of working with large building owners was the opportunity to create 'market pull' for performance monitoring while producing a specification that met the needs of these owners.

The guide and example specification language addresses four key aspects of performance monitoring:

- performance metrics
- measurement system requirements
- data acquisition and archiving
- data visualization and reporting

Development of the guide involved producing a draft general performance monitoring specification in collaboration with several large building owners. It was then reviewed by a number of interested stakeholders, including specifying engineers, manufacturers and building owners and operators. The specification was then revised and used as a resource in a number of projects involving large government and commercial buildings and campuses. Feedback from these efforts prompted the project team to convert the general spec into a specification guide. Material was also developed and submitted to ASHRAE for inclusion in Guideline 13: Specifying Direct Digital Control Systems. A brief summary of these activities is provided.

Overview of a Performance Monitoring System

Purpose

The primary purpose of the performance monitoring system is to provide facility managers and operators with the means to easily assess the current and historical performance of the building/facility as a whole, and its significant energy consuming systems and components. The performance monitoring system includes not only the needed sensors, wiring and data acquisition device, but also the means to calculate, display and archive resultant parameters. The monitoring system can be contained within a direct digital control (DDC) system or as a separate stand alone energy information system (EIS) or as a combination of the two. DDC also offers a viable platform for implementing a performance monitoring system, which can provide facility managers and operators with the means to easily assess the current and historical performance of the building/facility as a whole, and its significant energy consuming systems and components. The system can be installed as part of a new construction project or as part of a DDC system installation or upgrade project in an existing building.

What's required?

Increased number of monitoring points

Performance monitoring requires installation and programming of additional monitoring points, including measured, virtual and calculated values, which are not required for control. Whole building energy, equipment power, air and water flow and local weather are among the measurements required. By themselves these measurements provide invaluable insight to how a building, system, or piece of equipment is operating. But, when combined together in a specific calculated value known as a performance metric, they provide building staff the means to track building and system performance over time and to identify and diagnosis potential and current problems by comparing them with expected values or benchmarks. These monitoring points and performance metrics need unique identifiers in order to be able to compare similar parameters across a system, building or campus. To be of optimum use to building managers and operators, the performance monitoring system should also provide benchmarks that define the range of expected performance for each performance metric.

Improved sensors and through system accuracy

Anytime calculated values are used for comparison with itself over time or with similar values from other buildings, systems or equipment, there should be concern about the quality or certainty of the underlying measurements. The quality of any measurement is affected by the following:

- attributes of the sensor,
- any signal conditioning if present,
- the data acquisition system's infrastructure including analog-to-digital converter and the wiring connecting it with the sensor,
- any calibration corrections that are applied,

- installation techniques and field conditions.

Accuracy, precision, linearity, drift or stability over time, dynamic or rate of response, range, turn-down, sample or scan rate, resolution, signal-to-noise ratio, engineering unit conversion and math functionality, and data storage and retrieval frequency are all terms used to describe the quality of the measurement system and its components.

It is believed that a higher level of measurement rigor than that typically provided in DDC systems is required to provide sufficient data quality over time for identifying / establishing the specified performance metrics and benchmarks.

Enhanced data management and graphical data display capabilities

In order to visualize both current and historical data that may extend over years in a seamless fashion, a more robust data management system is required as well as improved data visualization techniques. Recommended capabilities include:

- Unique point names
- Animation and hot links
- Defined data tables
- Multiple group trend plots
- Special plot types: XY, carpet, load frequency distribution

Benefits of a Performance Monitoring System

Monitoring main electricity and natural gas meter(s) data enable building staff to track building electricity and natural gas use by time of day, facilitating management of peak loads and identification of unnecessary equipment operation during unoccupied periods. It also enables monitoring of power quality supplied to the building and power factor of building load.

Monitoring chilled water plant equipment power meter data enables building staff to track and manage chiller contributions to peak load and monitor chiller health.

Monitoring building chilled water flow meter and chilled water supply and return temperature data along with plant power enables the monitoring system to calculate the actual heating and cooling delivered by plant chillers. This information is important for a number of reasons. It is used to track and manage growth in chiller capacity requirements that can impact occupant comfort. It also aids in the detection of anomalous loads that increase operating costs. These measurements enable the tracking of chiller plant efficiencies, which allows the identification of more efficient operating strategies. It also enables the detection of degradations in performance that indicate the need for maintenance in order to minimize operating costs and maximize equipment life.

The use of a high quality weather station provides reliable measurement of outside air wet-bulb temperature, which enables the most effective use of free cooling, thus minimizing chiller use. Reliable measurement of outside wet bulb temperature enables proper cooling tower operation and maximizes chilled water plant efficiency.

Advanced data calculations and data displays provide operators with effective, standardized ways of viewing the performance of the building and the HVAC system, including comfort. Careful grouping of plots puts all the information required to monitor and, if necessary, troubleshoot, each different part of the HVAC system on a single screen. This makes it easier to spot and diagnose faults before they become problems, reducing hot and cold calls and O&M costs. This makes it easier to operate the building, freeing up stationary engineers to meet other tenant needs.

Recommended Performance Monitoring Requirements

The most significant driver for selecting appropriate performance metrics is energy use and the key parameters needed to identify opportunities available to improve performance. LEED Existing Buildings has simplified this for the user by identifying key points to measure. LEED New Construction and ESCO type projects, if they include measurement and verification of the expected energy savings, require specific measurements to be taken in order calculate performance over time. Related metrics are then employed in order to track and sustain performance. The key is to start simple and move toward more advanced performance evaluations as confidence in obtaining value from the effort is achieved.

To help the user Table 1 lists recommended performance monitoring requirements for 3 grades of performance monitoring based on building types and user needs: basic, intermediate and advanced.

- Basic: typically applied to a single building which may have built up systems including air handlers, boilers and a chilled water plant; owner desires essential monitoring requirements
- Intermediate: typically applied to conventional buildings with built up systems which include air handlers, boilers and a chilled water plant; owner desires progressive monitoring requirements
- Advanced: typically applied to exotic buildings, campuses or critical facilities with special requirements, which have complex systems such as co-generation or self generation; owner desires sophisticated monitoring requirements.

These metrics are detailed in Appendix C of the specification guide. The owner or his/her representative should reconfigure this list and resulting specification as needed to meet specific owner project requirements.

Table 1 – Recommended Performance Monitoring Requirements

Requirement	Class 1 - Basic	Class 2 - Intermediate	Class 3 – Advanced Diagnostics
Data Displays			
Equipment/ System Graphic	Floor plan with zone temperatures; system graphic with performance data; equipment graphic	Add performance data to equipment graphic	
Data Tables	Building air handler summary table, metrics results table	Expand building air handler summary table, add floor zone table, expand metrics results table to include additional metrics	Expand metric results table to include additional metrics
Time Series Group Trend Plots	System performance plots	Add equipment performance plots	Add system and equipment diagnostic plots
XY Group Trend Plots	1. ChW Plant Delta-T, ChW Plant tons vs. OA Temp 2. ChWPlant kW vs. ChWPlant tons 3. ChW Plant kW/ton vs. OA Temp, OA Wb Temp, ChW Plant tons 4. HVAC Power vs. OA Temp, OA Wb Temp, ChW Plant tons 5. Total Gas Flow vs. OA Temp 6. OA Temp Fraction vs. OA Damper Fraction 7. Whole Bldg Electric EUI; Whole bldg HVAC electric only EUI; Whole Bldg Natural Gas EUI , Whole Bldg Water EUI vs. Avg. Daily OA Temp	Add XY plots: 1. Chiller kW/ton vs. CondEWT, Chiller tons 2. Chiller kW vs. Chiller tons 3. ChW Plant Delta-T, ChW Plant tons vs. OA Temp-ChW 4. Whole bldg HVAC electric only EUI, Total Boiler Gas EUI Whole Bldg Lighting EUI, Whole Bldg Plug EUI vs. Avg. Daily OA Temp	Add X-Y plot diagnostics: 1. Avg Daily ChW Supply Temp, Daily ChW Plant Eff, Daily Total ChW Plant Electric Usage vs. Avg Daily OA Temp-ChW 2. Avg Daily Boiler Eff , Daily Total Blr Heating System kBtus, Daily Total HVAC Gas Usage (cu. ft.), Daily Total HVAC Gas Energy (kBtus) vs. Avg Daily OA Temp-HoW 3. Daily Total Air Handler Volume, Avg Daily Air Handler Eff, Daily Total Air Handler Electric Usage vs. Avg Daily OA Temp-AH 4.Avg Daily Building Power vs. Avg Daily OA Temp 5. Daily HVAC EUI vs. Avg. Daily OA Temp, Avg Daily OA Temp-AH 6. Avg. Bldg AH VFD Freq, Avg. Bldg Duct Static Pressure vs. OA Temp
Points			
Measured	OA Temp; OA WB-Temp; Main Power; Main Natural Gas Flow	Add: Air Handler # Duct Static Pres; SA-Ho Static Pres if dual duct;	Add: RTU # Gas Flow; HVAC Heater # Gas Flow

	Main Water Flow Chiller # Power; Other ChW plant equipment power; Plant ChW (loop #) ChWST; Plant ChW (loop #) ChWRT; Plant ChW (loop #) flow (gpm); Air handler # MA Temp, RA Temp, SA Temp Air handler # SF & RF power; Air handler # flow (cfm); Zone temperatures	Terminal Unit # SA Flow, SA Temp, add SA HD Temp, SA HD Flow if dual duct Lighting Circuit # Power; Plug Circuit # Power; RTU # Power; Other HVAC equipment power; Chiller # ChWST; Chiller # ChWRT; Chiller # ChW flow (gpm); Boiler # gas flow; (Boiler #) HoWST; (Boiler #) HoWRT; (Boiler #) HoW flow (gpm); Air Handler # SF VFD freq (Hz); Plant CondW (loop #) S Temp; Plant CondW (loop #) R Temp; Plant CondW (loop #) Flow (gpm)	
Virtual	Air Handler # OA Damper %, Return Damper %, SF Mode, SF status, ChW Valve %, SA Temp Sp, add SA-Ho Temp, SA-Ho Temp Sp, HoW Valve % if dual duct	Chiller # ChWS Temp Sp AH# Duct Static Pres Sp, VFD Speed Sp, SA-Ho Static Pres Sp if dual duct; Terminal Unit # Clg Temp Sp, Htg Temp Sp, Clg PID %, Htg PID %	
Calculated – Whole Building	Avg. Daily OA Temp; Whole Bldg Peak Power; Whole Bldg Electric EUI; Whole Bldg Natural Gas EUI; Whole Bldg Water EUI	Add: Avg. Bldg Duct Static Pressure; Total HVAC Electric Power; Whole Bldg Lighting Power; Whole Bldg Plug Power; Whole Bldg HVAC Electric-only EUI; Whole Bldg Lighting EUI; Whole Bldg Plug EUI	Add: Avg. Daily OAT-ChW; Avg. Daily OAT-Blr; Avg. Daily OAT-AH; Avg. Daily building power (kW) Total HVAC Demand; Whole Bldg HVAC EUI
Calculated – Chilled Water	ChW Plant (loop #) Delta T; ChW Plant Power; ChW Loop # tons; Total ChW Plant tons; ChW Plant Efficiency (kW/ton)	Add: Chiller # tons; Chiller Efficiency (kW/ton); Total Chiller Power; Total ChW Plant Heat of Rejection (tons); Chilled water Plant Heat Balance	Add: Avg. Daily ChW Supply Temp; Daily Total ChW Plant Electric Usage; Daily ChW Plant Energy; Max Daily ChW Plant Energy; Avg. daily ChW Plant Efficiency;

Calculated Natural Gas Equipment		Add: Total Boiler Gas Flow; Total Boiler Gas EUI; Boiler # Output (Btu/hr); Boiler # Efficiency (COP); Total Boiler Output; Total Boiler Efficiency (COP)	Add: Total RTU Gas Flow; Total HVAC Gas Flow; Daily Total HVAC Natural Gas Usage; Daily Total HVAC Gas Energy; Max daily HVAC Gas Energy; Total HVAC Natural Gas EUI; Avg. Daily Boiler Efficiency
Calculated – Supply Air	AH# Outside Air Temp Faction; AH# Outside Air Damper Fraction; Total Air Handler Power; Total Air Handler Volume; Air Handling System Specific Power (kW/cfm)	Add: Inst. Avg. Bldg AH SF VFD Freq	Add: Daily Total Air Handler Electric Usage; Daily Total Air Handler Volume; Max Daily Air Handler Volume; Avg. Daily Air Handler Specific Power
Database Software	Sequel Server/ MS SQL Server 2000	Sequel Server/ MS SQL Server 2000	Time Series Database: OSI PI Server, Oracle, MS SQL Server 2005
Assumptions	Measurement of HVAC system equipment power is easily accomplished; System is capable of calculating time based metrics and displaying x-y plots.		

General Issues to Consider

Project Scope

If an owner desires to include performance monitoring as part of their project requirements, the specification will need to define the functional capability that is desired. This would include the necessary monitoring points and performance metrics; required through system accuracy, and enhanced data management and graphical data displays. Detailed example specifications are provided in Appendix D and Appendix G of the Guide. Appendix D is written in a general specification context while Appendix G is specifically adapted to ASHRAE Guideline 13: Specifying Direct Digital Control Systems.

Approaches – DDC System Install/Upgrade vs. EIS

Though direct digital control systems are not true data acquisition systems, they provide a reasonable platform for acquiring the required data, and calculating and displaying the resultant metric parameters, and storing them in a robust database. Special consideration should be given to performance monitoring applications, due to the additional bandwidth required to gather one minute data on all points. Access to historical data is limited to the size of memory and database type. Their most limiting factor is that most manufacturers do not provide the ability to display XY type plots.

Energy Information Systems on the other hand are 3rd party systems that use the latest database technologies to scavenge data from a variety of data sources including the DDC system, storing it on their own database, separate from the DDC system. They provide varying levels of data processing, analysis and data display.

System Rigor: Accuracy of the Measurement, Network Architecture, Sampling, and Data Recording, Archiving and Storage

The quality of any measurement is determined by the attributes of the sensor, any signal conditioning if present, the data acquisition system and the wiring connecting them, any calibration corrections that are applied, sensor installation and field conditions. Specifying higher quality sensors may be required when implementing a performance monitoring system in order to obtain desired accuracy and repeatability of measured and calculated performance metric indices. Sensor accuracy is also dependent upon proper sensor placement.

Performance monitoring applications require that the system be capable of performing a variety of math functions and calculations on an interval basis. Special consideration should be given to the network architecture of performance monitoring applications, due to the additional bandwidth required to gather one minute data on all points.

The level of measurement rigor suggested in the guide is intended to provide sufficient data quality over time for identifying / establishing the specified performance metrics and benchmarks in order to give facility staff the confidence to act on it. Through-system measurement accuracy goals for individual measurement points and metrics are provided in Table 2. Individual instrumentation requirements are suggested in the instrumentation subsection of the example specifications in order to meet these goals. Appendix B of the Guide provides a detailed list of system functionality and capabilities that should be considered when specifying a performance monitoring system.

Table 2 – Through-System Measurement Accuracy Goals

Measurement Point or Metric	Accuracy Goal
Outside ambient temperature (ºF)	0.2ºF
Outside ambient wet bulb temperature (ºF)	0.2ºF
Zone temperature (ºF)	0.5°F
HVAC electric only energy use (kWh)	1.5% of reading
Chilled, hot water temperature (ºF)	0.1ºF, if >= 5ºF delta T
Chilled, hot water delta temperature (ºF)	2% of reading
Chilled, hot water flow (gpm)	2% of reading, > 20-1 turndown
Natural gas flow (scfm)	2% of reading, > 10-1 turndown, w/ pressure and temperature compensation; Using an average heat content of the gas to convert to kBtu introduces a ~2% error
Air flow (cfm) *	5% of reading down to 10% of full scale, > 10-1 turndown

Measurement Point or Metric	Accuracy Goal
Power (kW)	2.0% of reading
Chiller cooling output (tons)	3% of reading
Chiller cooling energy (ton-hrs)	3% of reading
Boiler heating output (kBtu/hr)	3% of reading
Boiler heating energy (kBtu)	3% of reading
Electric energy use (kWh)	2.0% of reading
Total HVAC energy use (kWh) (includes air side, water side and natural gas)	3% of reading
Chiller performance (kW/ton)	4% of reading
ChW Plant performance (kW/ton)	4% of reading
Total boiler performance ($kBtu_o/kBtu_i$) (COP)	4% of reading
Total air handler performance (kW/cfm)	6% of reading
Net Usable Building floor area	2%

Data Visualization and Graphical Data Displays

The data visualization requirements of performance monitoring systems take the graphical data display requirements of the typical DDC system to another level. Much of the functionality required such as the ability to gather and display data has been there for some time, but has rarely been used to its fullest extent. Graphic data displays are valuable tools for presenting building performance results to the user. They are invaluable when used for commissioning HVAC systems and diagnosing problems. Data display types include campus, building, floor-plan, system and equipment graphic screens, logic block program sequence screens, time weighted point screens, tabular multi-point data screens, time series point trend plots, time series group trend plots and XY group trend plots. Not all DDC system manufacturers provide the capability to do XY plots. Example data displays are provided in Appendix H of the Guide.

Need for Point Naming Convention

As the shear number of points that can be made available to the user has climbed, DDC manufacturers and installing contractors have searched for ways to simplify the set-up graphics and sequences. This is particularly true where a significant number of similar unit types are present such as air-handler or VAV terminal box controls in a large building or campus. The temptation is to name each similar point the same and allow the page header to define the equipment. But, unless the header information is carried throughout the programming, the ability to compare similar points in data displays for commissioning and diagnostic purposes is thwarted. It is possible in systems that employ high-end database structures or use XML to map from one database to another such as in EIS products to not require unique point naming, but these are not common.

Until standard open system tools such as the BACnet Web services standard provide a proven capability to compare similar points, it is highly recommend for those users who intend to use their DDC system for performance monitoring to specify a point naming convention which required unique point names. This unique name should be required in all cases of its use:

drawings, graphics, sequences, alarms, etc. This is an excellent training aid that will reinforce to the user the relevance of each point and where it physically exists. An example point naming convention, which includes specific point names and block trends is provided in Appendix I of the guide.

Commissioning

Performance monitoring applications inherently increase the need for submittal review, instrument installation and programming checks and tests including point set-up and graphical data displays. Sensor and performance metric through system accuracy will need to be verified. This is one of the more difficult aspects of this effort. Data throughput and archive integrity should also be tested.

Training

It is very important that the building superintendent, facility management staff and the current HVAC maintenance contractor and tenants if necessary be trained in accessing DDC HVAC control system information, making adjustments to setpoints and schedule, responding to and adjusting alarms, adding new trends as needed and diagnosing minor system upsets using trend reports. When a performance monitoring system is added a more thorough review of why the system was installed and how to use and maintain it needs to be included in the training curricula. Particular attention should be given to utilizing the data, instrumentation and database maintenance, and adding new points, trends, trend groups and XY plots.

Guide Development

The research project's short duration did not allow sufficient time to fully evaluate the costs and benefits of implementing a performance monitoring system at participating sites. This would require a project of extended duration. The project team focused primarily on engaging interested owners and developing site specific specifications, which required a number of iterations. Actual installation costs are not yet known.

Overall, the project team interfaced with facility personal from 9 sites including state and federal facilities, university campuses and a private building. Additional effort was given to developing general specification language and obtaining review and feedback from a competent group of specifying engineers, manufacturers and building owners and operators and the subsequent development of the guide. Provided below is brief summary of activities at a few sites.

Government Office Building, Santa Rosa: the project team prepared a comprehensive set of performance monitoring capabilities that was integrated into the overall controls specification; new instrumentation will be installed once the expansion project construction phase of the new chilled water plant starts.

Government Office Building, Sacramento: the project team prepared a comprehensive set of performance monitoring capabilities that has been reviewed by staff and integrated into their overall retrofit project controls specification in preparation for a request for bids.

Commercial Office Building, West Sacramento: the project team prepared an initial and updated set of performance monitoring specifications; a series of bids were then solicited in order to obtain one that was most reasonable. It is hoped that the new monitoring capabilities will be installed soon as the Chief Engineer is anxious to use the new system to resolve an ongoing comfort issue.

Tech-Transfer Activities

The project team is engaged on a number of fronts to see that the information developed can be used. Activities include:

- Release 1 of the draft general specification for performance monitoring systems is listed as a reference in ASHRAE's Building Performance Scoping Study dated 1/14/2006.
- Release 1 was also used to prepare an example specification focused on chilled water plant monitoring for ASHRAE Guideline Project Committee 22P: Instrumentation for Monitoring Central Chilled Water Plant Efficiency.
- Updated material, including three new annexes, **Example Specifications for DDC Based Performance Monitoring Systems; Example Graphic Data Displays;** and **Alternate Point Naming Convention and Example Point Names and Group Trends,** was submitted November 2005 to ASHRAE's continuous maintenance process for consideration by the Standing Guideline Project Committee 13: Specifying Direct Digital Control.
- The specification guide is to be used by ASHRAE Technical Committee 1.4 Green Controls subcommittee to help develop a reference guide for LEED.
- The specification guide is to be used to develop a metering guide for building sub-metering CSU campuses for the California State University's Mechanical Review Board. It will also be shared with participants in the California Public Utility Commission's Monitoring Based Retro-Commissioning programs.
- Material from the specification guide is being considered for use in California's Title 24 Building Energy Efficiency Standards during the 2008 standards development process.
- The current draft for the specification guide can found at http://cbs.lbl.gov/performance-monitoring/specifications/.

Conclusions

Specifying and installing a performance monitoring system requires a level of rigor above that of the average installed DDC system. Performance monitoring systems are data dependent, requiring a more robust data acquisition capability than is typically used for control. This needs to be clearly specified.

The building owner and/or operator needs to have a good handle on what their data needs are. This includes desired performance metrics, point naming convention, data accuracy requirements and data displays and actionable objectives in how the data is to be used. The specification guide for performance monitoring systems described in this paper provides a context for determining these factors and example specification language for inclusion in a project request for bids.