Automated Diagnostics from DDC Data - PACRAT

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Synopsis

Trended Direct Digital Control (DDC) Data is a valuable resource. This data can be utilized to diagnosis common faults and problems with HVAC systems. The data can be used for many other purposes including:

- Characterization and documenting system performance
- Calculating energy cost and consequences of certain faults
- Prioritizing maintenance resources
- Benchmarking HVAC operations and maintenance for contracted maintenance
- Measuring and Verification of energy based performance contract
- Visualization of data
- Identifying problems during commissioning
- Continuous commissioning tool - Insuring investment in commissioning continues

PACRAT is a database software tool that allows users to effectively utilize trended data to diagnose system problems, characterize system performance, protect investments in energy projects, commissioning, and contracted maintenance services.

About the Authors

J. Jay Santos, P.E., is a principal and co-founder of Facility Dynamics Engineering. Facility Dynamics focuses in HVAC controls design, HVAC controls master planning, HVAC Diagnostics and Building commissioning. He teaches HVAC continuing education controls courses (Building Automation, DDC, Pneumatics) for the University of Wisconsin, North Carolina State, and the Energy Resource Station in Iowa. He developed a DDC User Guide. The Guide covers interoperability, architecture, hardware, and software issues in a standard format and generally assists owners/engineers design and select systems that meet their needs.

E. Lon Brightbill, P.E., is a principal and co-founder of Facility Dynamics Engineering. He has developed numerous software applications including PACRAT (Performance And Continuous Re-commissioning Analysis Tool) and CACEA (Controls and Commissioning Engineering Application). He is has managed commissioning projects including the $40 million HVAC upgrade to the Main Clinical Center at National Institutes of Health (NIH); $35 million M&E services expansion to the 24/7 United Parcel Service Data Center $65 million General Lab Building, Building 50 at the National Institutes of Health and numerous General Motors plants.

What is PACRAT?

PACRAT stands for Performance and Continuous Re-Commissioning Analysis Tool. It is a database software tool that utilizes recorded system operational data (trend data) for analysis to improve facility operations and planning. PACRAT processes data that has been recorded and stored by a computerized control system, an energy metering system, or any other data source (data loggers). PACRAT serves four basic functions:

- HVAC fault diagnosis
- Characterization and documentation of system performance
- Measuring, verification and metering tool
- Data visualization tool

Trended DDC data is an extremely under-utilized resource. Most of our larger facilities have some type/vintage of DDC/EMS system. These systems are easily capable of collecting and storing important historical data about the operation and performance of our HVAC systems. This data can be used for many different and useful purposes.

The automatic diagnostic analysis tool leverages the time of the typically overextended facility operator time by analyzing the data for operational anomalies. The systems characterization tool, characterizes actual system/space operating parameters so future assessments of space requirements do not have to be based on "guestimates" per industry handbooks that is currently the case. The measuring, verification, and metering tool can combine measured DDC data with actual or "virtual" meters to benchmark energy performance or present and analyze utility data. The data visualization allows more sophisticated data presentation than offered through the DDC system. This visualization allows owners/consultants personnel to better understand the facility, its characteristics and needs as well as allow them to make more informed decisions on its operation.

HVAC Fault Diagnostics

PACRAT is divided into system modules. In addition to an Air Handler module, there are chiller and hydronic modules. There are also boiler and VAV box modules under development.

The Air Handler system module consists of the following diagnostics:

- Mis-calibrated sensors
- Leaking Valves and associated wasted cost and false load
- Out of sequence coils and associated wasted cost and false load
- Fighting Coils and associated wasted cost and false load
- Suspect or failed sensors
- Failed outputs or those with a poor performance characteristic
- Unoccupied period operation (fan and ventilation) and associated wasted cost
- Inadequate ventilation rates along with the associated parameter statistics
- Missed free cooling opportunities (lack of economizer) and associated wasted cost
- Struggling system capacities and terminal outputs. This identifies the "tail wagging the dog" scenarios that often leads to very poor performance
- Deviations from defined set-point ranges
- Unstable control
- Degrading heat exchange surfaces

Note that when applicable, PACRAT calculates the energy cost waste of the anomaly (with full time of day rate schedule capabilities). This is crucial information for the typical facility professional and acknowledges the reality of facility operations today. Facility staffs are frequently undersized and the operator's "to-do-list" is never ending. PACRAT not only indicates the anomaly, but indicates the consequences of it so that operator can prioritize it effectively.

Characterization and System Performance Documentation (Reality Characterization)

The idea of analyzing actual characteristics/requirements vs. estimated requirements is extremely valuable and has been generally overlooked by the A/E design community. Now that the data is generally becoming available for the analysis, this should add an important aspect to any facility assessment. Whether determining the additional capacity needs due to an expansion, considering an energy-related project, or simply deciding what the optimal setpoint or reset schedule should be for a control loop, the actual data gives you the real answer. You can also use the data to determine the most efficient way of operating equipment such as characterizing chiller performance with lift and load. PACRAT includes a variety of standard characterization modules and allows you to define your own. Another important aspect is to characterize the spaces to better distribute capacity. No pre-construction "guestimate" is as good as the actual data. One example we found was the relatively high balance point of a space that based on the standard assumptions should have a lower one. This invalidated the study (which was certainly "correct" per the current "standard of care" for such studies) that indicated the addition of an airside economizer had an acceptable payback. The following represents some of the possible performance characterization that can be accomplished with this data:

- Indoor environment statistics including highs, lows, and averages of space temperature, humidity, CO2, ventilation rate, and load
- Space load profiles with time of day by type of daily period (occupied and unoccupied)
- Space load with outdoor air temperature by type of daily period
- Component energy uses and costs
- Output performance characteristics along with an associated histogram
- Hydronic system loads and temperature differences
- Chiller efficiencies (chiller only as well as with associated ancillary equipment)

Measurement, Verification and Metering Module

PACRAT also facilitates Monitoring and Verification (M&V). In some cases savings payments are based on “microscopic” calculations relating to the use of a specific component as opposed to the “macroscopic” comparison of the energy bills to a baseline. PACRAT supports both approaches. PACRAT can process the data and specifically report the savings based on actual data compared to the baseline. “Actual” data can be actual recorded consumption, or calculated consumption based on a components part load characteristic. With sufficient baseline data, PACRAT will create a baseline based on multi-dimensional parameters. Any recorded parameter can be used as a "dimension". For instance, a typical baseline will be created based on typical use at a particular time of day, on a particular type of day, at a particular outside air condition. Once the baseline is created, PACRAT can recreate what the energy would have been with baseline conditions and calculate the savings, and summarize it in a report. Features of this module include the ability to:

- Group meters in a hierarchical fashion to allow penetration into the details of the consumption
- Create "virtual meters" for well-defined operation of equipment. This saves the expense of installing a meter on a device for which you can accurately calculate the energy use based on a recorded parameter such as output to the device.
- Create multi-dimensional baselines (which is analogous to a "neural" approach). Any recorded parameter can be used as a dimension. Automatically recreates baseline use from current data and calculates and summarizes the data. There is no need to apply the typical linear regression over-simplification popular in many savings calculations tools. Two baselines can be created. One baseline is the pre-retrofit baseline, which is the basis for the savings. The other can be the post-retrofit baseline, which is the basis for "lack of savings" diagnostics.
- Create a "fabricated baseline". This is useful for energy projects based on predefined or assumed baseline operation and a "microscopic" savings calculation approach.
- Recreate costs of most utility rate schedules.
- Create reports to summarize typical interval demand histories available from most utility companies. These can be used to analyze the facility demand profiles.

Data Visualization

PACRAT provides a host of facilities for visualizing the data. The basic visualization tool is the ability to view the raw data graphically. You can assign the data to graphs and view them by date range with zoom in, zoom out, move ahead and move back facilities on each graph. The most useful implementation of this is the way PACRAT records when anomalies occurred. When it reports them it presents the range of time over which the anomaly occurred and allows you to jump directly to the visual representation of the data so you can immediately see the context in which the anomaly occurred.

Other visualization tools include graphing of the system characterization summaries, and scatter plots of two-dimensional data. Further PACRAT formats data for and opens Statistica where virtually any two dimensional or three dimensional scatter plot, surface plot, histogram, distribution plot, etc. can be run on just about any of the data values.

Applications for PACRAT

Facility Operations

PACRAT assists the operators by automatically diagnosing common problems that can occur in the system without being readily evident. It includes some "expert" system advice as to what might be the cause of the anomaly and how to resolve it. It documents system anomalies that may be temporary in nature. The summaries and visualization helps them better understand the system operation. In addition to operations and maintenance personnel, commissioning engineers and other service providers can also utilize this diagnostic module.

During the commissioning process, PACRAT can be used to identify anomalies that may not be identified during the normal commissioning process. Once set-up, it can also be used to "keep" the system commissioned by periodically running the diagnostics.

PACRAT provides valuable management information to the facility managers so that they will know if the facility is being operated as effectively as possible. As the managers are usually fiscally responsible for the facility operation, they need to know when energy is being wasted. Since they are also responsible for ensuring proper indoor environments, they need to know when the system is lacking. PACRAT provides this management information in concise summaries. The system data can be analyzed to benchmark system operational performance. This performance analysis information can then be used to evaluate effectiveness of maintenance by in-house staff or by contracted personnel.

Energy Management

Relative to the energy monitoring of the facility, PACRAT far surpasses the functionality of more traditional "macroscopic" energy consumption analysis tools as they pertain to system operation. With those tools, you find out at the end of the month that an energy waste has developed. However, you then have to figure out, on your own, why it occurred. In many cases

this will involve manually pouring through trend data, or extensively surveying the systems to find out why. PACRAT will not only identify the waste much earlier, but also tell you specifically why it is occurring and suggest how to remedy it.

PACRAT not only provides direct energy saving opportunity information, but it also provides the data necessary to make more informed and accurate energy cost and savings projections. Actual facility use can vary dramatically from that assumed in "standard assumptions" used to project energy savings. PACRAT provides detailed information that will facilitate more accurate "baseline models" of the facility to a resolution that cannot be obtained from energy bill calibration. The "monitoring and verification" functionality allows energy managers to easily document and track the results of energy projects. The hierarchical meter configuration allows you to penetrate into the utility uses to summarize and visualize the consumption patterns. This provides a powerful analytical tool.

Design Engineers

Designers can use the reality characterization functionality of PACRAT to fine tune the selection parameters of new systems. Frequently invalid design assumptions are applied to renovations of a new facility. As an example that occurs frequently, designers assume that the chilled water temperature difference typical for the system is what the coils were designed for (typically around 12°F). Data typically documents that it is much lower. This leads to less than optimum chiller and pump selection. This can lead to inappropriate equipment selection. Even if the data is recorded in some fashion it is typically so cumbersome to find, it is usually ignored.
In general, the design industry is on the horizon of a better way of doing business. In general, now that we have computers controlling our facilities, we can "listen to what are facilities are telling us" by recording actual parameters and using them to make better design decisions. PACRAT supports this approach.

Energy Service Companies

PACRAT can be implemented remotely. Data can be downloaded to the remote site for processing. Energy service companies usually have a financial interest in making sure the facility is operated optimally. Frequently energy measures are disabled or bypassed due to a temporary or mis-diagnosed problem. Even if the disable was justified for the temporary condition, it frequently is left disabled. PACRAT will keep the ESCO apprised of the inefficient operation or when energy performance measures are not be applied optimally.

Case Study

PACRAT was installed at the National Security Agency's OPS 1 Building. OPS 1 is a 1,200,000 square foot building served primarily by 32 Air Handling Units. PACRAT utilized trend data collected from an existing EMS system.

PACRAT identified $260,000 in annual energy waste (including unoccupied system operation) and $180,000 annual energy waste (not including unoccupied system operation). Approximately 40% of the energy savings were captured with just a few days of technician time. It also documented significant over-sizing due to "liberal" design assumptions. These design criteria were subsequently modified resulting in $800,000 in cost avoidance on a project under design.