Tuning Up the Retrocommissioning Process

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Synopsis

The approaches to retrocommissioning, or "tuning up," a building are as diverse as the problems from which buildings suffer. The approach may be totally different if the program goal is to obtain energy savings versus a goal of improving comfort or indoor air quality problems.

E M C Engineers, Inc. (EMC) recently participated in a utility sponsored program, in which the purpose was to use the retrocommissioning (RCx) process to restore building mechanical systems to optimum performance. The assumption was that energy savings, improved building comfort, and indoor air quality would be the natural by-product of getting the building systems working properly.

One benefit of the RCx program was the extended and detailed scope of the RCx process for the buildings analyzed. In executing the full scope of RCx services, we were able to evaluate the value of individual activities within the RCx process. The paper will present our observations on what aspects of the process worked well and which tasks added little value to the ultimate goal to optimize building performance. The observations will present insights to building owners and RCx service providers to the most efficient and cost effective methods for tuning up building operations.

The paper will benefit buildings owners and RCx providers by discussing the benefits and pitfalls of the RCx process. It will help the Owner to choose an optimized RCx scope of work to produce optimized building system.

About the Author

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Introduction

Retrocommissioning is defined as applying a systematic process to optimize the operation of existing building systems. The process is typically split into four main phases[1]:

- **Planning Phase**. Tasks consist of defining the owner's objectives and gathering data of the building systems. The goal of this phase is to create a concise and efficient plan for executing the detailed analysis required for the next phase.
- **Investigation Phase**. Main tasks include identifying opportunities to improve building operations and providing sufficient economic analysis to the owner to justify implementation.
- **Implementation Phase.** Involves implementing the recommendations made in prior phases. The work can be done by the facilities' maintenance staff, the RCx provider, or through outside contractors.
- **Verification or Hand-Off Phase**. Involves preparing documentation, verifying the results of implementation, and training facility maintenance staff.

Although retrocommissioning has been shown historically to produce an attractive economic payback, the challenge of the process is to maximize the efforts of the implementation phase. It is often necessary to invest sufficient time and scope in the planning and investigation phases to fully understand and justify the maximum number of opportunities. But given the fixed amount of resources available, a building owner would much prefer to invest those resources in implementing solutions.

If an RCx provider was able to execute a detailed RCx process, then the likelihood for identifying building problems would be increased. When shortcuts are taken in the process, opportunities may get missed.

Given all the different approaches to identifying problems in a building, which brings the most value to a building owner, especially when time and budget resources are limited?

Retrocommissioning Program

EMC recently participated in a retrocommissioning program sponsored by two California utility companies. This RCx program applied a detailed RCx process to 11 municipal government buildings, including 10 courthouses and one administrative building.

The goal of this RCx program was to optimize the mechanical systems within the building. In order to achieve that goal, a comprehensive scope was created by the owner. The scope included the following tasks.

- **Benchmarking Phase.** Obtaining and analyzing three years of utility data, and comparing the results against industry benchmarks.

- **Planning Phase.** Involved interviews with building mechanics, obtaining as-built information, and creating specific plan documentation for point to point testing, TAB verification, and mechanical assessments.
- **Prefunctional Testing Phase.** This phase actually contained two main activities, and was the most time intensive. The first activity included the field work necessary to complete point to point testing, air flow and water flow measurements, and mechanical assessments. The second activity included the economic analysis and creation of cost proposals to implement recommendations.
- **Implementation Phase.** Involved partnering with the owner, and with mechanical, TAB and controls contractors, to execute recommendations made in prior phases, ranging in complexity from replacing individual AHU dampers to upgrading controls system from pneumatic to direct digital control (DDC).
- **Functional Test Phase.** Involved working with a controls contractor to define the as-found control sequence and to verify the controls sequences using a systematic test procedure.
- **Final Report Phase.** Involved the revision of the energy models to show the results of the implemented measures. Protocols were also created for system level benchmarking so that the owner could monitor the energy use of their buildings and compare it to the expected optimized operation. Documentation in the form of Final Reports and Training Manuals were also created to summarize the final results of the RCx program.

Whole Building Benchmarking Phase

The purpose of the benchmarking phase was to obtain and document the historical energy use of each of the eleven buildings being considered in the RCx Program. Tasks included obtaining historical utility data, performing benchmarking calculations to determine energy performance, and preparing a Benchmarking Report to document findings.

Why Is Benchmarking Important?

Benchmarking is vital if the owner’s main goal during the retrocommissioning process is to produce energy savings. One of the most important reasons to benchmark a building is to quickly show the building owner if the potential exists for improvement in operational costs.

What Metrics in Benchmarking are Important?

A comparison of building performance can be shown in many ways, but can be condensed down to two basic approaches.

1. Compare the building performance against itself.

Annual comparison. Perform a comparison of the monthly energy bills for a minimum of two years. Then compare the energy use from year to year to see if significant changes occurred. It is important to normalize the data against the time period (usually a 30-day monthly period) to get a reasonable comparison from one year to the next, especially since utility bills are not usually reported for constant 30-day periods.

As an example, Figure 1 shows the normalized monthly natural gas use for 2002, 2003, and 2004 for one of the buildings analyzed in the program.

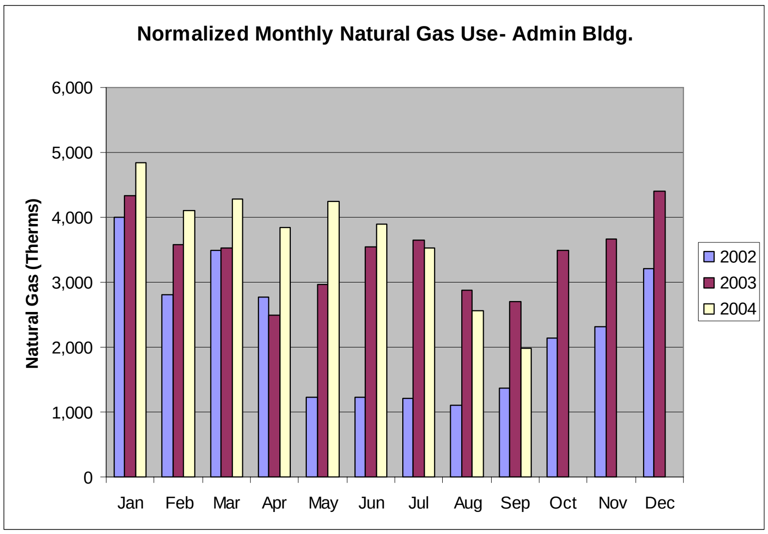

Figure 1. Monthly Comparison of Natural Gas Usage

It was noted that the natural gas usage has increased significantly between 2002 and 2004. Gas usage has increased nearly threefold during the summer of 2004 compared to 2002. It was instantly suspected that significant natural gas savings was possible in this building, and the investigation plan was tailored to find that savings.

Daily comparison. Another helpful benchmark involved comparing daily utility use from one season to another. Fifteen minute data was obtained from the electric utility company, and typical daily profiles were created for peak cooling and peak heating conditions. The benefit of analyzing daily electrical profiles was to estimate the disaggregation of major electrical systems.

- The **base load lighting and plug loads** were estimated by reviewing electrical demand during unoccupied periods.
- The **effect of central plant cooling** could also been seen by comparing the summer and winter peak electrical loads.
- The **building occupancy schedule** could be verified by analyzing daily load profiles.

Data normalized to weather. Another obstacle to reasonable comparisons is when the benchmark does not factor in the effect of weather from one year to the next. Therefore, normalizing utility data to weather factors such as heating degree-days can also add creditability to the benchmark results.

2. Compare the building against similar buildings. For the RCx program, ten different courthouses were investigated, ranging in building area from 70,000 to 600,000 ft^2. The energy use index (EUI) for each building was compared to each other, and is noted in Figure 2.

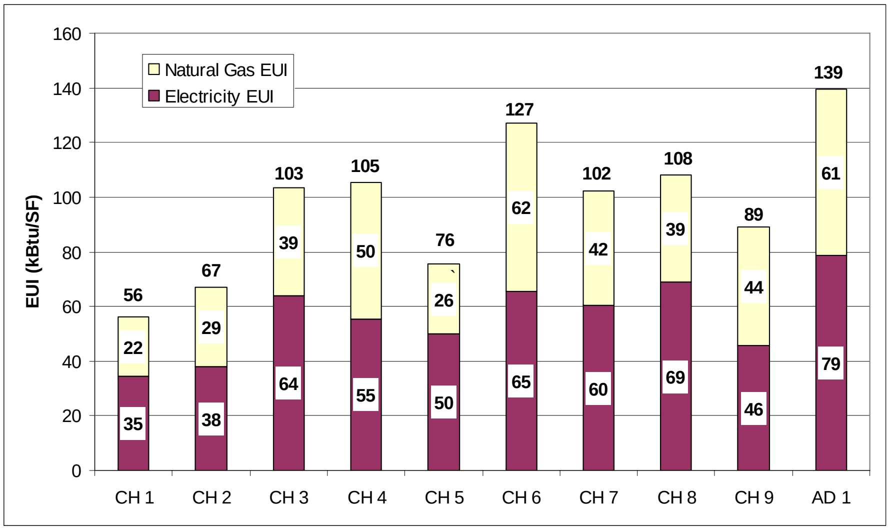

Figure 2. Energy Use Index Comparison – 10 Similar Buildings

Based on the results of the EUI calculation, it seemed reasonable to expect that buildings operating below 75 kBtu/ft^2 would set a reasonable target for energy usage for buildings with optimized systems. Total energy savings goals were set at the beginning of the project, based on the assumption that the final EUI for each building could be reduced to the levels of Courthouse 1 and 2 (between 50 and 65 kBtu/ ft^2 –year). This assumption proved to be reasonable, based on the results of the final energy savings calculations.

3. Compare the building to a regional or national database. The RCx program was fortunate to have 10 similar building types, which allowed for a reasonable EUI comparison. There are also regional and national building databases that can be used to give a building owner additional insight into the level of energy savings that could be expected.

For the RCx program, the buildings were compared against a regional and a national database. The regional benchmarking tool used was Cal-Arch[2]. The Cal-Arch benchmarking tool uses existing data from California's Commercial End Use Survey (CEUS), which is energy use information collected by California's major utilities. Figure 3 summarizes an example of an EUI comparison to the Cal-Arch database.

Building consumption can also be compared to national building databases such as Energy Star's Portfolio Manager[3], or the Commercial Buildings Energy Consumption Survey (CBECS)[4], which is based on the national survey conducted by the Energy Information Administration (EIA). Figure 4 summarizes the comparison of the baseline EUI of one building against the CBECS database.

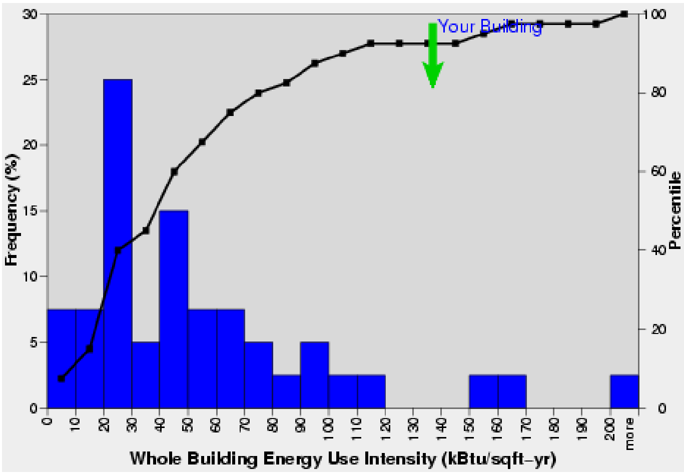

Figure 3. Cal-Arch (Regional Database) EUI Comparison

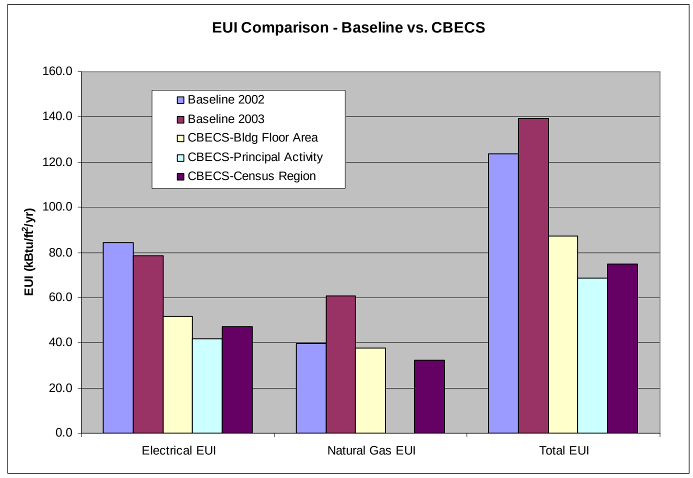

Figure 4. CBECS (National Database) EUI Comparison

The level of benchmarking required is dependent upon the extent to which the data can be used. The calculation and comparison of the EUI is valuable in setting energy savings goals and can help the building owner gauge the economic benefit of pursuing retrocommissioning. Comparison of utility data is also a helpful tool for identifying potential implementation opportunities. Calibration of utility data to baseline energy calculations is also a vital step in determining realistic energy savings.

Is There Value to System Level Benchmarking versus Whole Building?

Whole building benchmarking is often used at the beginning of the process in order to determine if the building has potential for retrocommissioning, and to provide economic information for the owner. During the initial phases of the RCx program, whole building benchmarking brought more value because of the ease of obtaining data from utility bills, the ability to obtain data that was more accurate, the ease of the EUI calculation, and the comparison against benchmarking databases which were typically based on the whole building.

The value of system level benchmarking came into play at the end of the RCx process. System level benchmarking is being used as a predictive tool to determine if the buildings are sustaining optimum performance in the future. Energy models, which were used to calculate implementation energy savings, were also able to calculate the expected energy consumption of the chiller, boiler, and HVAC fans individually, as a function of a common metric such as outside air temperature.

System level benchmarking can be a valuable predictive tool. However, the calculation of that benchmark is much more labor intensive. BAS software must be able to manipulate trended data to make the system level benchmark meaningful. There is value to the system level benchmark, but the owner must be willing to invest in achieving useful data, and must be committed to actively using it as a tool to sustain savings.

Planning Phase

The purpose of the planning phase is to gather information regarding the individual buildings through initial building walkthroughs, interviews with personnel familiar with building operation, and through the collection of appropriate documentation. This information is compiled in the Retrocommissioning Plan.

The planning phase is a necessary initial investigation step. The primary goal of this phase is to determine if the facility has sufficient opportunity to make the investment into detailed analysis worthwhile. Both the building owner and the RCx provider are not interested in "drilling a dry hole," or investing heavily in analysis of a building that is already running in an efficient manner. An experienced RCx provider can make a determination within a few field surveys whether the potential for those energy conservation opportunities exist.

In some retrocommissioning programs, the documentation required in the Retrocommissioning Plan can be onerous, and this phase alone can two to four weeks to complete. There is an opportunity to streamline the RCx process at this phase.

In the planning phase activities for the initial ten buildings surveyed, the following sections were contained in the RCx Plan Report.

- **Program Overview.** A listing of the major tasks required for each phase. This list is typically dictated by the scope of work of the program, and should be documented so that the building owner and RCx provider have the same expectations as to the scope of future investigation phases.
- **Building Description.** A detailed description of each mechanical building system, including a summary of nameplate information obtained during field surveys. Although this information must be gathered for use in future phases, a detailed system description in the Planning Report may not be necessary during the initial phase.
- **Preliminary Building Assessment.** This is the most important part of the RCx Planning Report. Are there opportunities worth pursuing in this building? It is important to give the building owner a sense of the energy conservation opportunities, along with a ballpark estimate of the economic impact of pursuing the projects.
- **Building Documentation.** This is a checklist of the documentation needed by the RCx provider. It is important that the RCx provider and owner work together to obtain the necessary documentation in a timely manner.
- **Site Assessment Forms.** These forms are typically good forms to use during the site interviews. However, documentation in a formal report may not be necessary.

In summary, the three most important functions of this phase are to quickly identify if opportunities exist, to estimate economic benefit, and to formalize the plan for developing the analysis in the subsequent detailed analysis phases. The RCx Plan will then present to the owner the recommendation to pursue these opportunities, layout the tasks required and the price to pursue it, and give sufficient reason to justify the investment.

A key to success is to involve and engage the facility maintenance staff as soon as possible. If the maintenance staff is not available, then consider having subcontractors available to jump on building repairs as soon as they are identified. Maintenance staff/subcontractors can be used immediately to perform tasks such as restoring operating schedules, repairing broken or disconnected damper actuators/linkages, and other minor repairs that can result in immediate energy savings.

Prefunctional Test Phase

The general approach to understanding the "as-found" equipment operation during the Prefunctional Testing phase is summarized in Figure 5 below:

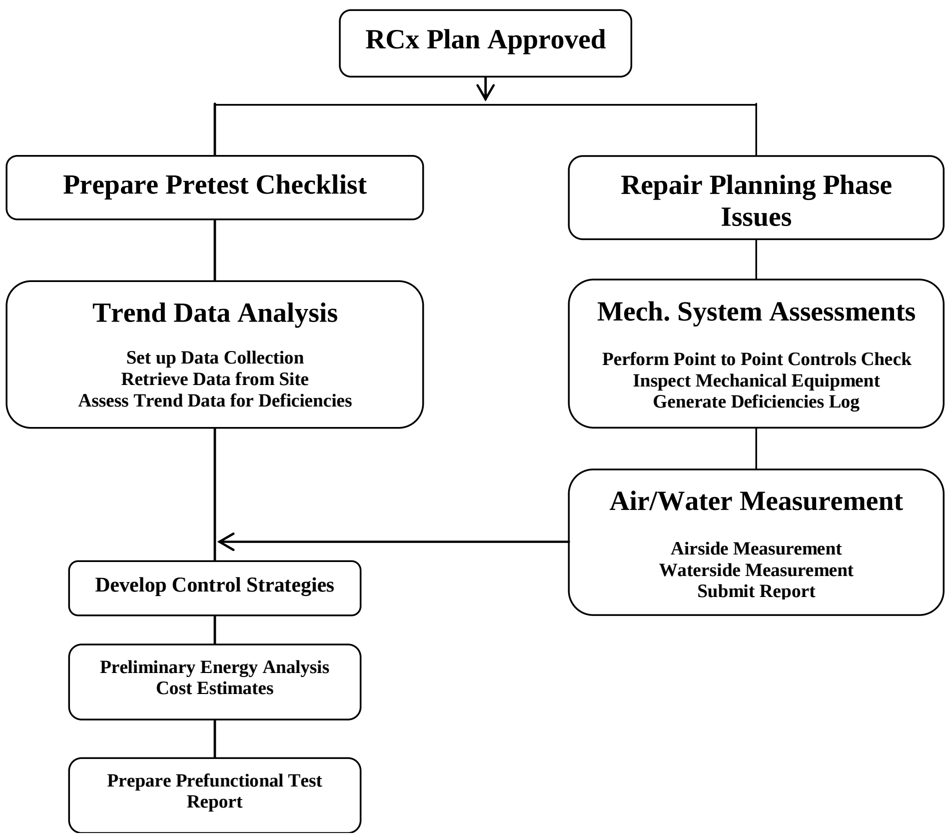

Figure 5. Prefunctional Test Phase Work Flowchart

<u>Question:</u> During the Prefunctional test phase, is point to point testing more important than data trending analysis? What sample should be performed for point to point testing?

Two different analytical paths were taken to fully test the operation of mechanical system components. One approach, the use of trend data to assess operational deficiencies, could be considered a "hands off" approach. The other approach, point to point testing, requires a "hands-on" approach to verifying component operation in the field. The following table summaries the benefits and disadvantages of each approach.

Trend Data Analysis ("Hands Off")	Point to Point Testing ("Hands On")
Benefits: • Does not require extensive field work. • System diagnostics are made easier. • Reveals interaction of system operation. • Reveals operation during unoccupied hours. • Results can be integrated into energy analysis. • Analysis tools are being developed to download and analyze trend data more efficiently.	**Benefits:** • Results in very reliable field data. • Results in better evaluation of equipment in the field. • Produces very specific punch list of deficient items. • More conducive for pneumatic controls. • Does not necessarily take longer to execute, especially considering the amount of time required to set up, execute and analyze trend data
Disadvantages: • Must have the appropriate BAS points available for proper trending, or should supplement with handheld data loggers. • Is difficult for pneumatic controls systems (requires data loggers). • Takes minimum of 7 days to gain adequate data set. • Uncertain input data could cause questionable results.	**Disadvantages:** • Extensive field work is required. • Higher cost/fee required for RCx. • More difficult to coordinate work in an occupied building. • "Hands on work" requires attention to safe work practices.

It is during the prefunctional testing phase that more deficiencies are missed because shortcuts are taken in the RCx process. An approach based on thorough point to point testing will discover more RCx opportunities, but will come at a higher price to the owner, especially since most point to point tests require more than one person to execute.

There should be an element of both approaches (trend data and point to point testing) in a comprehensive RCx program. If project schedule and budget will limit the prefunctional scope, then consider reducing the scope of the TAB activities and mechanical assessment to maximize this valuable exercise. If further scope reduction is required, then consider a sampling exercise, using the results of the trend analysis to lay out the most important points for point to point testing. However, a minimum amount of point to point testing may be important in order to validate the data received in the trends.

The type of control system will often dictate the prefunctional testing approach. Many RCx programs will not consider a building that maintains a high percentage of equipment with pneumatic controls because trending analysis is not usually cost effective. A RCx program that stresses energy savings will require some degree of data trending in order to form the basis of the energy savings analysis. Buildings with some degree of direct digital controls (DDC) are usually better candidates for retrocommissioning.

***<u>Question:</u>* Should TAB be involved in the process? Does an owner obtain value by performing TAB to prove terminal unit operation?**

The scope of the RCx program involved airside measurement of all supply, return, and exhaust diffusers, as well as capacity measurements of HVAC fans and water flow measurements at pumps and major coils.

TAB measurements on major mechanical equipment can provide valuable information on the operation of the system. Supply and return fan capacity measurements can be compared to design flow to confirm proper delivery of air quantities to the zones. Outside air quantities should also be measured in both full economizer and minimum outside air damper positions. If known, the TAB contractor should be directed to set the minimum outside air damper position to design quantities if the damper is found in a closed position. TAB contractors should also provide static pressure profiles of the major air handling units. These profiles can be used to identify problems in duct distribution, such as blocked ductwork or air devices, closed fire/smoke dampers, or dirty air filters.

Water measurement of pumps and major coils is also recommended. These measurements can often disclose design or operational problems. An example of an issue discovered during the program involved central chiller plants with chilled water and condenser water pumps set much higher than design conditions, which resulted in low temperature differences through the chiller bundles and inefficient performance.

The TAB process was also used to diagnose the operation of terminal units. Diagnostics were created based on the results of air flow and temperature measurements at the diffusers. While the air flow measurements were being taken at the diffusers, the TAB technicians were directed to measure supply diffuser discharge air temperatures in both cooling and heating modes. The technicians were also instructed to verify the operation and calibration of the thermostats since airflow measurements required manipulation of the thermostats in both heating and cooling modes.

Operation of the terminal units is often overlooked because of the amount of time required to test each box or each pneumatic thermostat. The process can be streamlined (if necessary) by just taking discharge air temperatures in heating and cooling modes. However, it is extremely important to create and execute a strict testing protocol. The chilled water, hot water and discharge air temperatures at the AHU must be set and documented before terminal boxes can be tested to ensure a meaningful temperature difference measurement in the various modes.

***<u>Question:</u>* Should a detailed mechanical assessment be included in the optimized RCx process?**

Detailed assessments were performed for all major mechanical equipment, using forms that were a hybrid of manufacturer's startup forms and commissioning prefunctional checklists. A service contractor was directed to assess equipment condition and document using the modified assessment forms.

Detailed deficiencies were produced for each facility based on the assessments, and were passed along to the owner. Many of the recommendations were considered lower priority, and were to be incorporated into future preventive maintenance work orders.

A detailed assessment may not provide the best economic payback to a building owner, unless the main goal of the RCx process is to address maintenance issues. Some amount of time is needed to create proper and appropriate forms for field crews, and to perform the assessments in the field. However, the assessment can be a good gauge of the effectiveness of an owner's preventive maintenance program.

There are features of mechanical assessments that are inexpensive, and bring value to the RCx process. Those tasks include:

- **Boiler tune-ups.** Boiler tune-ups were completed on boilers that were not slated for replacement. Tune-ups consisted of adjusting gas pressure and combustion air quantities, and verifying boiler controls. Flue gas analysis was performed to verify boiler efficiency for the baseline and post tune-up condition. Boiler efficiencies were typically improved 2 to 5%.
- **Chiller oil analysis**. Oil samples were taken for each chiller, and a spectrochemical analysis was performed by an independent laboratory agency. The analysis was performed to determine the condition of the equipment, and to search for three main categories of deficiencies, including the presence of **wear metals (iron), contaminants (silicon, dirt), and undesired additives (moisture).**

  For some chillers, recommendations were made for immediate maintenance work. For chillers that were in good condition, the analysis results will serve as a baseline document for analysis completed in the future.
- **Loop water analysis.** Chemical control tests were completed on field samples gathered from the water loops for hot water, chilled water, condenser water, and raw water makeup feeds. The levels of chemical inhibitor were verified, along with pH and mineral levels, which would give insight into the condition of the water treatment system and the interior of the piping.

Implementation Phase

The key to sustaining an optimum mechanical system is involving the facility maintenance staff into the RCx process as soon as possible. It can be a challenge for an outside consultant or contractor to gain the trust of maintenance personnel. As the outsider, the RCx provider is often "guilty until proven innocent." Here are some action items that may improve your chances.

- **Be a good listener**. Often years of building history can be discovered in a one hour interview with the maintenance staff. Also, the RCx provider may be able to help develop projects that have been on the maintenance staff's "wish list" for years.

- **Present a credible team**. Teaming with qualified service or controls contractors during field activities may help perception. If possible, be aware of the reputation of your team.
- **Present credible results**. Use trend data, TAB results, or lab test results to help support recommendations for implementation.
- **Use the chain of command**. If the maintenance supervisor is a proponent of the RCx process and the recommendations, there may be more accountability for the maintenance person to maintain it.
- **Explain the theory behind the change**. A maintenance person may not understand the theory behind an optimized control sequence, for example. Adequate training on the RCx process and the modifications is a necessary step to bring them up to speed.
- **Stand behind your service**. After implementation, systems may not work as intended all the time. Timely follow-up to warranty calls is important.
- **Help fill in the paperwork gaps**. Provide final documentation that is easy to understand. Thorough "as-builts" of the mechanical system and explanation of the RCx modifications may help make their job easier.

If the maintenance person does not buy into your program, that person could undo in five minutes what it took weeks to straighten out. An effective RCx program will not be sustained unless it is supported by the maintenance staff.

Functional Testing Phase

The purpose of functional testing is to provide a systematic review of the operation of the mechanical system. It is an inclusive and systematic process intended not only to optimize how equipment and systems operate, but also to optimize how the systems function together.

During the program, one of the largest benefits of the functional performance test was providing clear definition to the published control sequence. For the buildings in this program, several versions of control sequences are typically available, but the "as-built" sequence was not fully known. There was great value in comparing the written "as-built" sequence with the actual code loaded into the DDC controller. Often adjustments had been made in the code that affected equipment operation, without documentation to back it up.

It was also valuable to execute the functional performance test in conjunction with the controls contractor. As deficiencies were discovered during the tests, often minor programming changes could be made to address the problem right away.

Conclusion

An additional courthouse was added to the RCx program after the original ten buildings were nearly complete. The RCx scope of the additional building was streamlined based on some of the lessons learned from previous buildings. Some of the modifications, which were based on lesson learned throughout the RCx program, include:

1. The original benchmarking, planning, and prefunctional phase was combined into one investigation phase.
2. Benchmarking tasks were reduced to the calculation of the energy use index and the monthly utility bill comparison for 2004 against 2005. Compilation of the utility bills was required in order to calibrate the energy model used to calculate energy savings.
3. Planning phase tasks were reduced to the creation of forms required for field survey activities, including:
    a. **Monitoring plan**. Created to determine the DDC points required for trending, and the location of independent data loggers to cover gaps in the data required.
    b. **Survey forms.** Used during interviews with building maintenance staff and during initial field surveys to capture mechanical equipment nameplate data.
    c. **Point to point tests**. Controls points lists were obtained in order to determine the analog and digital points that were to be tested.
    d. **Functional performance tests**. A customized test procedure was created based on the available control sequence.
4. A two-week investigation phase survey was used to gather equipment information, perform point to point testing of DDC and pneumatics systems, and functional testing of the central plant. Controls contractors were used to assist with the testing, and to make minor repairs of failed controls components and programming modifications on the spot.
5. A TAB contractor was used to measure fan capacities and pressure profiles for the major AHUs. Minimum outside air damper positions were set to match design conditions. Water measurements were also taken on main hydronics pumps and minor balancing was accomplished. Testing of terminal units and zone pneumatic thermostats were not included in the scope of work.
6. Estimators for the controls contractor were brought in at the end of the investigation phase survey in order to understand the scope of the repairs required.

The RCx project benefited because efficiencies were gained by combining tasks. The project schedule was improved by combining work of several different phases. A detailed deficiency log was created in short order because of the detailed testing procedures. Many deficiencies were corrected during the initial surveys because of the partnership between the RCx provider, facility maintenance and outside contractors. Building comfort and indoor air quality was improved because of controls and TAB adjustments. Energy savings was immediately gained because the RCx process stressed the correction of obvious deficiencies, not just investigation.

Bibliography

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3. ENERGY STAR's Portfolio Manager is available at: http://www.energystar.gov

4. Commercial Buildings Energy Consumption Survey (CBECS)[4], based on the national survey conducted by the Energy Information Administration (EIA), is available at: http://www.eia.doe.gov/emeu/cbecs/