Retrocommissioning Handbook

for Facility Managers

Prepared for the Oregon Office of Energy

By Portland Energy Conservation, Inc. (PECI)

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Purpose of the Handbook

The purpose of this handbook is to provide building owners and managers with basic information about the retrocommissioning process and help them receive maximum value from commissioning existing buildings. It discusses commissioning terminology, how to get started, the phases and steps in the retrocommissioning process, roles and responsibilities of the team members, costs, benefits, how to increase cost effectiveness and more. It is written specifically for facility managers of public buildings and those who are interested in obtaining cost-effective operation and maintenance (O&M) improvements that do not entail a large capital investment. This is not a detailed how-to manual for commissioning service providers, although it may give them useful insight in understanding the owner's and manager's role and expectations for the project.

Objectives of the Retrocommissioning Process

Commissioning of existing buildings or "retrocommissioning," is a systematic process applied to existing buildings for identifying and implementing operational and maintenance improvements and for ensuring their continued performance over time. Retrocommissioning assures system functionality. It is an inclusive and systematic process that intends not only to optimize how equipment and systems operate, but also to optimize how the systems *function together*. Although retrocommissioning may include recommendations for capital improvements, the primary focus is on using O&M tune-up activities and diagnostic testing to optimize the building systems. Retrocommissioning is not a substitute for major repair work. Repairing major problems is a must before retrocommissioning can be fully completed.

The following have been identified by owners as the primary objectives for retro-commissioning a project:

Bring equipment to its proper operational state
Reduce complaints
Reduce energy and demand costs
Increase equipment life
Improve indoor air quality
Increase tenant satisfaction
Improve facility operation and maintenance
Reduce staff time spent on emergency calls

Definition

Existing-building commissioning, also known as retrocommissioning, is an event in the life of a building that applies a systematic investigation process for improving or optimizing a building's operation and maintenance. It may or may not emphasize bringing the building back to its original intended design. In fact, the original design documentation may no longer exist or be relevant. The goals and objectives for applying the process, as well as the level of rigor, may vary depending on the current needs of the owner, budget, and condition of the equipment. The retrocommissioning process most often focuses on dynamic energy-using systems with the goal of reducing energy waste, obtaining energy cost savings, and identifying and fixing existing problems.

Retrocommissioning Process

Retrocommissioning Stages, Phases and Activities

PRE-IMPLEMENTATION STAGE

1. Project Selection

(a) Select project

(b) Muster support and gather information

2. Planning phase

(a) Develop project goals and scope

(b) Develop team

(c) Select and hire a commissioning provider

3. Investigation phase

(a) Review facility documentation

(b) Develop the commissioning plan and hold the scoping meeting

(c) Perform a site assessment

(d) Develop an initial list of findings

(e) Develop and present an interim report

(f) Develop the diagnostic monitoring and test plans

(g) Implement diagnostic monitoring and test plans

(h) Select the most cost-effective opportunities for implementation

IMPLEMENTATION STAGE

4. Implementation phase

(a) Implement recommendations

POST-IMPLEMENTATION STAGE

5. Final adjustment

(a) Retest and remonitor

(b) Update building documentation, including O&M manuals, if applicable

(c) Train operators

6. Project hand-off

(a) Final report

(b) Follow-up tasks

1. PROJECT SELECTION

a. Select project

Some buildings or groups of buildings make better candidates for retrocommissioning than others. Owners of multiple buildings may want to develop a spreadsheet to better understand, compare, and prioritize their building stock according to which sites present the most opportunity for improvements. These buildings should be first in line for retrocommissioning. The most broken buildings may not be the most attractive, while newer buildings may offer the most savings or benefit for the least cost.

The following bullets provide some guidance for selecting buildings for retrocommissioning.

- An unjustified, high energy-use index
- Persistent failure of equipment and/or control system (Worn out, old equipment should be replaced before the commissioning begins)
- Tenant complaints
- Indoor Air Quality problems
- Any other reasons that warrant building retrocommissioning

b. Muster support and gather information

To make the project a success the building owner must secure management commitment and support for the project, secure support of motivated and available building staff, ensure tenant cooperation, allocate adequate time frame and budget. The collection of building documentation should begin almost immediately after the project has been approved for implementation.

The gathering of the building documentation should include:

General building description (See Appendix D)
Drawings relevant to the systems scheduled for commissioning, especially control drawings
Sequences of operation for all or most equipment
Energy-efficient operating strategies for all or most equipment
Equipment list with nameplate information for all or most equipment
O&M manuals for all or most equipment
TAB reports
PM logs for all or most equipment
Energy bill (electric and gas) information for at least 12 months along with a rate schedule

2. PLANNING PHASE

a. Develop project goals and scope

The retrocommissioning process begins by defining in writing the goals for the project and clearly communicating those goals to the team that is carrying out the work. Often the main goal for commissioning an existing facility is to obtain cost savings from improving the operation of the building's energy-using equipment, given the current operating requirements. Identifying and eliminating potential indoor air quality and comfort problems is also often high on the list of retrocommissioning objectives. The following example lists the objectives for an actual retrocommissioning project:

- Obtain and verify cost-effective energy savings. Verification will require limited performance monitoring of selected building systems.

- Identify and recommend improvements to operational strategies and maintenance procedures, focusing on those measures that sustain optimal energy performance and reduce operating costs.
- Identify HVAC-related health and safety issues as they present themselves during the normal course of the commissioning work.

b. Develop team

A team will be responsible for achieving the goals defined for the project. This team will typically require two teams initially working together: a facilities team and a commissioning team. The teams can be small as long as needed skills and authority are represented on each. These two teams must join to become the project team. The facilities team must have the authority to obtain acceptable contractor services, if needed, and to interface with them. Since the facilities team and commissioning team must handle many functions, it is the owner's responsibility to bring the overall team together. The Commissioning Provider may have varying levels of involvement in this process depending on the level of trust and confidence established. Ultimately the project team should consist of only those people most critical to accomplishing the work.

For buildings with in-house staff, one of the most important team member(s) is the building operator assigned to work with the Commissioning provider. Ideally, the operator should have in-depth knowledge of the building control systems, understand how and why equipment and systems are currently operated and maintained, and have access to historical data.

The Commissioning provider must bring troubleshooting, problem solving, diagnostic monitoring, testing, and analysis expertise to identify problems with building systems that must be solved to meet project goals. The commissioning provider must also challenge the use of current equipment, practices, or methods that may be causing problems and identify useful and cost-effective solutions for the problems.

c. Select and hire a commissioning provider

Currently, there is no certification process for commissioning providers. In absence of certification, it is necessary to determine if a provider has the experience needed to provide appropriate retrocommissioning services. Appendix A contains two forms for defining the required experience of a Commissioning provider. These sample forms can be customized to reflect the needs of a specific project.

The typical approach for seeking commissioning services includes:

Evaluating experience with buildings having problems similar to that under consideration
Requesting and contacting references
Evaluating ancillary skills such as diplomacy, negotiation, communications, meeting facilitation, listening, investigation, and reporting abilities
Considering the following factors:
Is commissioning a core business or a primary business component of the firm?
Are any work samples such as final commissioning reports available for review?
Are there any lists of Commissioning providers available from local utilities or state and local government organizations?
Is the firm a full member of the Building Commissioning Association (BCA)?
It is important that the skills of the Commissioning provider match the goals and scope of the project. For example, if improving indoor air quality (IAQ) is the primary objective for the

retrocommissioning, then the individual hired for the job must be skilled at investigating and solving IAQ problems.

Initial identification of acceptable Commissioning providers may occur through a Request for Qualifications (RFQ) process. The RFQ allows evaluation of qualifications without detailed definition of the work to be accomplished. In this way, the desired work scope can be developed more fully while a group of qualified firms and their references are being established and contacted.

Large or complex projects often dictate the use of a Request for Proposal (RFP) from the group of potential providers. Appendix B contains a checklist of factors to consider when putting together an RFP.

As part of an RFP, the owner or manager should provide a list of expected products or deliverables resulting from the retrocommissioning process. The number and type of deliverables depends on the scope of the project. Appendix C lists several possible deliverables that may be required.

The primary deliverables include:

Retrocommissioning Plan
Master List of Deficiencies
Potential Improvements
List of Recommended Capital Improvements for Further Investigation
Final Report

If the project is large or complicated, a pre-proposal meeting, including a site visit to the facilities included in the scope of the project, may be necessary. This approach allows the selected group of Commissioning providers a chance to see the facility and ask critical questions they may have concerning the project. It also tends to “level the playing field” so that each party has the same information when developing their bids.

3. Investigation Phase

The primary tasks for the investigation phase are, understanding how and why building systems are currently operated and maintained, identifying deficiencies and potential improvements, and selecting the most cost effective “fixes” to implement. This phase of the project looks at all aspects of the current O&M program and practices as well as the management structures, policies, and user requirements that influence them. It may include interviewing management as well as building personnel, reviewing current O&M practices and service contracts, spot testing the equipment and controls, and trending or electronic data logging of pressures, temperatures, power, flows, and lighting levels and use.

The investigation phase is generally the most time consuming and expensive part of the retrocommissioning process. The investigation phase includes six steps:

a. Review facility documentation

Once the Commissioning provider has been hired the process of facility review should begin. The commissioning provider uses the documentation during the investigation phase of the project for developing the site assessment form and the diagnostic and functional test plans that may be required to verify equipment performance.

b. Develop the commissioning plan and hold the scoping meeting

After reviewing the building documentation and gaining a clear understanding of the project goals, the commissioning provider has the primary responsibility for developing the plan and seeking significant input and review from the owner and owner's staff. Including the building operating staff during plan development facilitates their desire to see the process succeed. The plan usually includes the following:

General building information and contact (name, address, telephone numbers, etc.).
Project goals
Building description (brief)
Project scope
Roles and responsibilities
Schedule (for primary tasks)
Documentation
Investigation scope and methods
Implementation phase requirements
Project hand off

The scheduling of project work should coincide with the project goals. For example, if there is an increased number of complaints regarding cooling, then the diagnostic testing should be scheduled during peak cooling conditions. The plan should be viewed as a flexible document that may include some schedule changes during the course of the project.

Generally, the Commissioning provider facilitates the scoping meeting with the plan as the primary focus. The scoping meeting brings all of the team members together to review, discuss, and agree to the retrocommissioning plan. The primary role of the owner or manager is to reiterate the objectives for the project and show support for the retrocommissioning plan. Each team member's responsibilities are discussed and the schedule is agreed to. The scoping meeting sometimes includes others who have vested interest in the project (such as a local utility) but are not directly responsible for performing work on the project.

c. Perform a site assessment

The goal of the site assessment is to gain an in-depth understanding of how and why the building systems and equipment are currently operated and maintained and what building staff and occupants consider as the most significant problems. Most projects require the Commissioning provider to develop a formal site-assessment document that includes a detailed building staff interview regarding operating strategies and an in-depth site survey of equipment condition. Appendix E contains sample assessment forms. Assigning building operators who have an historical knowledge of the building and expertise in the control systems expedites this task. Due to their familiarity with the building and its systems, O&M staff may already have most of this information on hand. Filling out the assessment forms helps them organize this information and better target their retrocommissioning activities. The site assessment addresses the following major issues:

Overall building energy use and demand and areas of highest energy use and demand
Current design and operational intent and actual control sequences for each piece of equipment included in the project
Equipment nameplate information and maintenance issues (broken dampers, dirty coils, sensor calibration, etc.)
Current schedules (setpoint, time-of-day, holiday, lighting, etc.)
The most severe control and operational problems
Location of the most comfort problems or trouble spots in the building

Current O&M practices

Depending on the scope of the project, the site assessment can take one to several days to complete. It is common for many problems and obvious corrections to reveal themselves during the site assessment. It may be cost effective to have the assigned building operator make minor adjustments and repairs as the site assessment progresses. These “field fixes” should be summarized on the Master List of Deficiencies and Improvements (the Master List is discussed below) and documented on the applicable site assessment form. Engineering calculations can often be applied later to determine the value of these adjustments and repairs.

The assessment is meant to uncover the best opportunities for optimizing the energy-using systems and improving O&M practices. It provides the starting point for evaluating the effectiveness of improvements and O&M activities. It also provides a basis for recommending where diagnostics and testing may be appropriate. Diagnostic testing helps to better pinpoint problem causes and verify that a problem does exist.

d. Develop an initial list of findings

Concurrent with the site assessment, the Commissioning provider begins to develop a Master List of Deficiencies and Improvements. This Master List is one of the most significant deliverables from the retrocommissioning process and ultimately becomes an important decision making tool for the facility manager and building staff. Every finding from the investigation phase is summarized on the Master List, including those adjustments and repairs made during the course of the investigation process. At a minimum, the list should include the name of the system or piece of equipment, a description of the deficiency or problem, and a suggested solution. Appendix F contains a sample Master List.

To better understand the deficiencies and problems, the owner or manager may require the Commissioning provider to categorize them according to type or source. For example, problems may fall into four primary categories: maintenance, operation, design, or installation. Understanding where the more costly problems fall helps management to understand where organizational improvements may be needed. For example, several problems falling under the “installation” category may indicate a need for the owner to require commissioning for future new construction or new equipment installations. Such problems may also suggest taking a hard look at who is providing the installation service. If the majority of problems are maintenance-related this may indicate a need for additional staff, more training, or a better managed service contract.

e. Develop and present an interim report

During the site assessment, the commissioning provider begins to develop a master list of O&M improvements for possible implementation. The list includes the name of the system or piece of equipment involved a description of the issue or problem, and a suggested solution. The list of opportunities and recommendations generated during the initial site assessment is submitted to the Facility Manager and owner for review, prior to developing a monitoring and testing plan.

f. Develop the diagnostic monitoring and test plans

The information gained from the site assessment may indicate that it will be necessary to obtain more complete and exact data on when and how systems are actually operating, since the assessment may only identify suspected areas for improvement. If more information is needed, the Commissioning provider develops the necessary diagnostic monitoring and test plans.

Diagnostic monitoring and testing allows the Commissioning provider to observe temperatures along with critical flows, pressures, speeds, currents of the system components under typical operating conditions. By analyzing this information, the Commissioning provider determines whether the systems are operating correctly and in the most efficient manner. Three typical diagnostic methods are Energy Management Control System trend logging, stand-alone portable datalogging, and manual functional testing. Often, a combination of these methods is used. To get an idea of the level of rigor involved in these tests, see Appendix G, which contains a sample diagnostic monitoring plan and trend logging plan, and Appendix H, which contains sample functional test plans for a centrifugal chiller and a variable frequency drive.

g. Implement diagnostic monitoring and test plans

The Commissioning provider and the owner's representative schedule the implementation of the diagnostic monitoring, testing, and the associated preparatory work. Preparing for monitoring and testing may include checking and calibrating control points such as temperature sensors. When possible, to reduce project costs, the facility staff should complete the calibration work under the direction of the Commissioning provider. In addition, if dataloggers are used, facility staff can usually assist in the installation and removal of the loggers. The trendlogging plan may be carried out by the facility staff, but may require assistance from the controls vendor, particularly on developing, formatting and downloading computer files for analysis by the Commissioning provider. Results from monitoring, via trend logs or dataloggers are provided in annotated graphical or columnar format for reporting purposes.

The Commissioning provider usually directs the functional tests. Facility staff, a control vendor, or other appropriate parties assist with the hands-on operation of the equipment being tested. The Commissioning provider documents manual testing and observed results on the test plan forms. The forms also describe the piece of equipment or system and the detailed test procedures.

After diagnostic monitoring and testing are completed, the findings are analyzed and checked against the site-assessment information. Any resulting changes, additional deficiencies, or potential improvements are summarized on the Master List.

h. Select the most cost-effective opportunities for implementation

Once the site assessment and diagnostic testing are complete and the Master List is filled out, owners decide which items on the list provide the most benefit and effectively meet the project objectives. For some projects, managers often want to implement the entire Master List but may need to prioritize the improvements according to cost effectiveness. For example, in some buildings it may be more cost-effective to implement plant-related control strategies before performing more labor-intensive fixes, such as fine tuning of an air-side economizer. To help with this decision making process, the Commissioning provider generally completes an analysis of the opportunities and makes recommendations for implementation based on which improvements are most cost effective. It's not unusual to expect a simple payback of 18 months or less for the recommended improvements that produce energy savings. The savings generated from these improvements can sometimes pay for other improvements that have less quantifiable benefits.

Many retrocommissioning improvements are straightforward and owners can confidently expect benefits from them. In such cases, the building management and staff may not need any savings verification to justify implementation. Other improvements such as those related to comfort, IAQ, and equipment malfunction may not have easily quantifiable benefits, but facility staff often want to implement them because they simply want their building to "work right." The building management and staff always make the final decision on which deficiencies and improvements to address first.

Investigation phase deliverables

The site assessment is often the primary, if not the only product, coming out of the project. Some projects only require completion of the investigation phase, making the assessment and Master List the primary deliverables. The assessment generally includes gathering information on the condition of equipment including equipment nameplate information as well as the operating strategies. Appendix E provides sample assessment forms for a pump. In many cases, it is not necessary to require the entire assessment as a deliverable. For example, if the building does not have an adequate current list of equipment with nameplate information, the maintenance or equipment condition part of the assessment becomes the main deliverable. Alternatively, if the building lacks written control strategies, the operating part of the assessment is valuable for developing this missing information in-house. However, if the assessment findings are the most important product, then the Master List alone adequately fulfills this requirement and the site assessment may be dropped from the deliverable list.

The following lists typical deliverables for the investigative phase:

- Short-term diagnostic monitoring and functional test plans
- The Master List of deficiencies and potential improvements (Master List)
- Completed site-assessment forms (optional)
- Completed functional tests
- List of repairs, adjustments, and other improvements made during investigation
- List of selected improvements for immediate implementation including costs and ROIs (estimates of return on investment)

4. IMPLEMENTATION PHASE

During the investigation phase, several of the simple, obvious, and less expensive repairs and improvements are usually completed. During the implementation phase, the more complicated and expensive ones are completed. This section discusses implementing recommendations and verifying the results, along with some important issues to consider during these activities.

a. Implement recommendations

A primary goal for most retrocommissioning projects is to actually implement the major cost-effective improvements so that results can be realized. Although the investigation phase provides important information and products, unless improvements are actually put in place, the retrocommissioning process remains incomplete. Depending on their availability and expertise, the implementation process may be carried out by in-house O&M staff. However, in some cases the implementation may require outside help. For example, hiring a controls contractor may be necessary if in-house staff lacks the expertise, access, or time required to make control strategy changes at the program level.

Retaining the Commissioning provider through the implementation phase, whether the implementation work is done in-house or outsourced, is a choice worth considering. Because the Commissioning provider has an intimate knowledge of the building systems and needed improvements, having the Commissioning provider develop an Implementation Plan and supervise the implementation may ultimately save time and reduce costs. In addition, it is necessary (and highly recommended) that some functional retesting be performed after implementation. Retesting is discussed in more detail below. Through the retesting process, the Commissioning provider ensures that the improvements are working as expected and that they positively affect other systems and equipment as well as the building occupants. It is not unusual for the retesting to uncover related or hidden problems that could lead to more benefits.

5. Final Adjustment

a. Retest and remonitor

Once an improvement or "fix" is completed, retesting to confirm that the effected equipment is operating properly can be done with EMCS trending, manual testing, or datalogging. In some cases, it may be necessary to use a combination of these methods. For example, retesting might involve manual tests of the function of repaired items such as damper motors or valves to verify that they stroke properly, followed by EMCS trending or datalogging to determine that they are modulating to maintain the desired setpoint at the appropriate times.

It is often desirable and enlightening to reinstall several if not all the dataloggers (or re-initiate the original EMCS trends) and remonitor operations to obtain several days of post-implementation data. The data is then compared to the original data (pre-implementation data) in order to confirm that the combination of improvements are integrated and have the desired overall positive effect for the building. This technique can also be used to benchmark the final performance of the improvements. This benchmarking information can then be used to establish criteria or parameters for tracking whether or not the improvements are performing properly throughout the life of the equipment or systems.

Retesting and remonitoring may also reveal the need for further improvements. Often fixing one deficiency uncovers other opportunities, leading to more savings or improved comfort. At this point it is also important to use any of the applicable port-test and monitoring data to check and adjust the original energy savings estimates to make them as accurate as possible.

b. Update building documentation

The following tasks should be completed by the commissioning provider as appropriate to the project:

- One line drawing schematics of each system investigated.
- Finalize the O&M plan outline, including the examination of and enhancement of current maintenance or service contract procedures.
- Develop a list of required O&M documentation and a systems operations manual, including full written sequences of operation for equipment that still may be missing documentation of its sequences.
- Develop an energy-efficiency plan.
- Develop guidelines for implementing a preventative maintenance plan.
- Develop a comprehensive training plan or recommendations for appropriate building staff to attend training in general O&M concepts and for specific equipment and systems. This will include both building operators and facility managers or owners.
- Develop guidelines and recommendations for incorporating an energy accounting and tracking system. Include benchmarks for whole building energy use and primary plant equipment efficiency tracking.
- Develop a list of operational strategies for the owner to incorporate in the future.

- Develop an operations assessment program and systems tune-up and recommissioning schedule.

c. Train operators

The commissioning provider, either provides the training himself or, ensures that contractor/manufacturer provides adequate training to accomplish high proficiency of the operating staff. Besides that, the training may also address the other areas of the building operation that are of particular concern to the Owner.

6. Project Hand-off

a. Final report

The commissioning provider prepares a final report. The owner may specify what information the report should include. Ideally, the final report contains the following:

- Executive summary
- Project background
- The retrocommissioning plan
- The “Master List” of improvements with a description of which improvements were implemented
- A cost/savings analysis for the estimates of savings and the actual improvement costs for each improvement implemented
- List of capital improvements recommended for further investigation
- The completed operations initial site assessment forms
- The EMCS trending plan and logger diagnostic / monitoring plan and annotated results
- All completed functional tests and results
- Recommended frequency for recommissioning by equipment type with reference to tests conducted during initial commissioning.
- Complete documentation of revised or new strategies adopted to optimize systems operation along with the rationale that lead to selection of these strategies.
- A Systems Manual that includes:
  - A brief “design” narrative of all systems investigated (brief description of the system, it purpose and general operation), with corrected and created sequences of operation.
  - A description of and rationale for all energy-saving features and strategies with operating instructions and caveats about their function and maintenance relative to energy use.
  - Recommendations for recalibration frequency of sensors and actuators by type and use.
  - Specific recommendations regarding seasonal operational issues that affect energy use.
  - A list of all user adjustable setpoints and reset schedules with a discussion of the purpose of each and the range of reasonable adjustments with energy implications. Include a schedule frequency to review the various setpoints and reset schedules to ensure they are at current relevant and efficient values.

- ➢ A list of time of day schedules and a schedule frequency to review them for relevance and efficiency.

b. Other tasks

If necessary, the commissioning provider schedules and performs deferred testing (seasonal testing). If the owner intends to recommission the facility in the future, the commissioning provider develops a recommissioning plan and schedule.

Participants and Responsibilities

Retrocommissioning is a team effort. Depending on the project scope, however, the retrocommissioning team may simply consist of the commissioning provider and a designated member of the operating staff. Budget considerations and the characteristics of the project may dictate the number of team members and their responsibilities. For cost-effectiveness, the retrocommissioning team should be streamlined to fit the complexity of the project. The owner should consult with the commissioning provider about the makeup of the team. The commissioning provider can review the scope of work and advise the owner on how to consolidate roles and tasks to best meet the needs of the project.

OWNER/FACILITY REPRESENTATIVE

The most significant role of the building owner or owner's representative is to support the commissioning provider's efforts to accomplish the work. Other responsibilities may include:

- Determining the project's budget, schedule, and operating requirements
- Determining the objectives of the project and communicating them to the team members
- Hiring the Commissioning provider and other members of the project team
- Assigning appropriate in-house staff to the project
- Defining the building protocols (see discussion in section above titled Planning Phase)
- Defining the lines of communication between the team members
- Working with the Commissioning provider to establish the commissioning plan and how to best leverage existing resources to streamline the project and reduce costs
- Supporting the Commissioning provider by facilitating communication between the Commissioning provider and other project team members as needed
- Informing the building occupants of the intended retrocommissioning work as needed
- Requiring and reviewing progress reports and meeting notes
- Attending training sessions and commissioning meetings when appropriate

BUILDING OPERATOR/O&M STAFF

Assign building operators to assist with (or at least observe) as much of the retrocommissioning as possible to improve their understanding of the equipment and control strategies. This will enable them to retest or recommission systems periodically as part of their ongoing O&M program. Appendix I contains strategies for O&M staff may use for increasing cost effectiveness. The following list includes tasks that building operators are typically responsible for, depending on their skill level:

- Gathering and updating building documentation
- Providing detailed input into the initial assessment and investigation process
- Performing appropriate preventive maintenance and commissioning-generated checklist tasks prior to any diagnostic or functional testing
- Installing and removing short-term diagnostic monitoring equipment
- Gathering trending information from the EMCS as required
- Assisting with the performance of manual functional testing as needed
- Attending project meetings and training as required

COMMISSIONING PROVIDER

The commissioning provider's tasks and responsibilities depend on the scope of the project, the budget, and the skill of the building O&M staff. Typical retrocommissioning responsibilities include:

- Identifying what documentation, drawings, data, and other information will be required
- Developing a building-specific commissioning plan
- Developing agendas and facilitating all commissioning meetings
- Submitting progress reports and commissioning meeting notes to the project and facility manager as determined by the owner
- Performing detailed on-site assessment of the present maintenance practices and operating strategies noting all possible deficiencies and improvements
- Understanding the warranties and service contracts that are in place and how they can be leveraged on the project
- Developing monitoring and testing plans
- Performing short-term diagnostic monitoring, using EMCS trend logging where appropriate
- Developing, overseeing, and documentation of functional test procedures as needed
- Developing "Master Lists" of deficiencies and improvements
- Recommending system or energy-efficient capital improvements for further investigation
- Prioritizing the most cost-effective improvements for implementation for existing systems
- Supervising implementation of the selected improvements
- Performing post-installation monitoring and testing activities as needed
- Calculating the estimated energy savings based on the before-and-after short-term energy measurements
- Assisting in operators training, as needed
- Submitting a final report and all specified deliverables

CONTRACTORS AND MANUFACTURER REPRESENTATIVES

Installing contractors, maintenance service contractors, controls contractors, and manufacturer representatives can be important contributors to the commissioning of existing equipment, especially when equipment is relatively new, still under warranty, or under contract for service by a manufacturer's representative or a particular service contractor. In some cases, one firm may have installed the system as a manufacturer's representative and hold the service contract for the system. This is often true for control systems and large plant equipment such as chillers and boilers.

If equipment is still under warranty or under a service contract, it is important that the responsible company or individual be brought on the team early in the process. Contractor or manufacturer responsibilities mainly consist of performing the hands-on testing of the system that they have installed or serviced, especially if a warranty will be void if anyone else manipulates the equipment. They may also be responsible for fixing any deficiencies that are found during the retrocommissioning process. Compensation for these parties depends on the extent of the service contract or warranty coverage.

Some owners do not have full or even part-time building operators, or may have building operators with minimal skills or time. These owners often use service contracts to cover most of their HVAC, controls, and electrical systems. In such cases, the service contractor may take on retrocommissioning tasks that building operators would usually perform. The contractor may be requested to perform certain scheduled preventive maintenance tasks to coincide with the needs of the commissioning project, as well as assist in performing the hands-on testing, diagnostics, and adjusting and calibrating of equipment. Controls contractors may contribute by assisting with trend logs and EMCS programming tasks.

The controls contractor may be an essential player on the commissioning team because he or she is often the most familiar with the building's control sequences and programming. Control technician expertise with the system can expedite the incorporation and testing of new or improved control strategies for the building. Although enlisting the time of a control technician may be expensive; limiting their assistance can reduce the overall cost-effectiveness of the project.

DESIGN PROFESSIONALS

Depending on the age of the equipment and systems involved, and whether there is a new installation occurring during the retrocommissioning process, design professionals may or may not be involved in the project. Design professionals are rarely involved in a pure retrocommissioning process unless the Commissioning provider needs additional expertise regarding design issues that are uncovered during the investigation process. In such cases, the design engineer (perhaps the engineer who designed the original installation) may be brought on the team as a consultant to help resolve the issues. When commissioning a new installation is part of the project, the responsible designer for the new equipment and system should be part of the commissioning effort.

TESTING SPECIALISTS

Testing specialists may need to join the retrocommissioning team depending on the needs of the project. Special equipment such as variable-volume fume hoods may require special testing expertise. Although the Commissioning provider typically writes the test procedures, the testing may be carried out by others who are experts in their field. Testing, adjusting, and balancing (TAB) professionals may be asked to verify water or air flows using special equipment if the retrocommissioning identifies possible air or water balance problems. Some Commissioning providers are also test engineers and are fully equipped to perform almost any type of test required. However, this is unusual. Most Commissioning providers are skilled at performing fundamental HVAC functional tests and calibration exercises, but rely on other professionals or test experts for more complicated testing. Appendix J contains a typical list of commissioning tools.

Resources

ASHRAE Professional Development Seminar, An Integrated Approach to Building Commissioning, 1998.

Building Commissioning, the Key to Quality Assurance, U.S. Department of Energy, 1998.

Energy Information Administration (EIA) 1995. *Commercial Buildings Energy Consumption and Expenditures 1992*. DOE/EIA-0318(92). Washington, D.C.

Herzog, P., *Energy-Efficient Operation of Commercial Buildings: Redefining the Energy Manager's Job*, McGraw-Hill, 1996.

Sharp, T. R., *Energy Benchmarking in Commercial Office Buildings*, Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings (4): 321-329, 1996.

Web Sites Containing Commissioning Information

Building Commissioning Association http://www.bcxa.org

Oregon Office of Energy www.energy.state.or.us/bus/comm/bldgcx.htm

Appendix A: Commissioning Firm Experience

FILL OUT A SEPARATE FORM FOR EACH FIRM ON THE TEAM

Company Name | Contact Person | Title

Address | City | State / Prov | Zip / Postal Code

Telephone | Fax | E-Mail

Description of Business

Commissioning Activities

Percentage of overall business devoted to commissioning services _______%

How long has the firm offered commissioning services ______________years

Average number of commissioning projects performed each year: ______________projects

Is the firm a full member of BCA? ______________

Systems or technologies for which firm has provided commissioning services (check all that apply)

- ❑ Pkg. or split HVAC
- ❑ Chiller system
- ❑ Boiler system
- ❑ Energy Mgmt. Sys.
- ❑ Variable Frequency Drives
- ❑ Lighting Controls
- ❑ Daylighting
- ❑ Electrical, general
- ❑ Electrical, emerg. power
- ❑ Envelope
- ❑ Fire/Life Safety
- ❑ Plumbing
- ❑ Commercial refrigeration
- ❑ Telecommunications
- ❑ Thermal Energy Storage
- ❑ Labs & Clean Rooms
- ❑ ________________

Number of registered engineers on staff who have directed commissioning projects: __________

The firm has provided commissioning services in the following: (check all that apply)

Building Sector	**New Construction Major Renovation**	**Existing Building Tune-up**	**Equipment Replacement**
• Office or retail	❑	❑	❑
• Grocery	❑	❑	❑
• Hospitals	❑	❑	❑
• Laboratories	❑	❑	❑
• Schools or universities	❑	❑	❑
• Industrial / Manufacturing	❑	❑	❑
• Special purpose–prisons, museums, libraries, etc.	❑	❑	❑

COMMISSIONING TASK EXPERIENCE LISTING ON SIMILAR PROJECTS

FILL OUT A SEPARATE FORM FOR EACH FIRM ON THE TEAM

KEY:

Design Review:	Reviewed design and provided comment during design phase	Data/Trending:	Used dataloggers or EMS trend logs for testing
Cx Plan:	Wrote the commissioning plan	Training:	Developed or approved staff training
Specifications:	Wrote commissioning specifications for construction team	Review O&Ms:	Reviewed completed O&M manuals
Funct. T. Plans:	Wrote functional test procedures	CP in firm:	Commissioning provider was part of the firm
Witnessed FT:	Witnessed and documented functional tests	Supervised CP:	Supervised commissioning provider subconsultant to the firm
Hands-on Tests:	Performed functional tests (hands-on)	Worked w/CP:	Worked with a commissioning provider hired by others

				(Enter "X" if by own firm, "S" if by subconsultant)											
				Commissioning Tasks Performed									**Management**		
Project Name, Date Bldg Size & Type (New/Exist)	**City & State Owner Contact Title and Phone**	**Name & Role of Persons(s) Assigned to Project by Firm** (identify any subconsultants)	**Systems Commissioned** (Identify if tested by subsconsultants)	Design Review	Cx Plan	Specifications	Funct. T. Plans	Witnessed FT	Hands-on Tests	Data/Trendings	Training	Review O&Ms	CP in firm	Supervised CP	Worked w/CP

Appendix B: Request for Proposal (RFP) Checklist for Retrocommissioning Services

The checklist contained in this appendix is a guide for individuals tasked with developing an RFP for commissioning services for existing buildings. It is not a comprehensive checklist for developing an entire RFP from start to finish, but includes items specific to retrocommissioning that will help obtain a *realistic* proposal.

✓ RFP Checklist for Retrocommissioning Services

- ❑ Include clear objectives and assign priority to each has (energy, comfort, building control, etc.)
- ❑ Provide information about the building. At minimum include:
  - A brief building description
  - Square footage
  - A general HVAC description (central plant as well as distribution systems for both heating and cooling); controls system description
  - A list of major equipment, including number and age of each type
  - A brief renovation, retrofit, and equipment replacement history
  - A building use description
- ❑ Provide as much information on the trending capabilities of the EMCS as possible. Ideally, a complete points list should be provided. This increases the bidders' ability to more accurately budget the data acquisition tasks. Also, state whether the system can be accessed remotely (by modem).
- ❑ Provide a list of available up-to-date building documentation.
- ❑ Include as complete a scope of work as possible. State the type of commissioning expected (existing-building, new equipment, or combined new and existing systems). If it is unclear what the scope of work can realistically include, allow step one of the project to address developing a detailed scope of work. Or, hire an experienced commissioning consultant to help develop the scope of work for inclusion in the RFP. The scope of work should include a list of equipment needing commissioning. Also, clearly state for each phase of the project (planning, investigation, implementation, and integration) what the in-house building staff's and/or service contractor's responsibilities include and what the commissioning provider responsibilities include. (For guidance, refer to Appendix I.)
- ❑ If the preferred data acquisition methods are known (datalogging, trending, functional testing) state them, otherwise specifically ask that the bidder detail their approach on these issues.
- ❑ Indicate what is expected for each of the retrocommissioning phases (planning, investigation, implementation, and hand-off). It is especially important for the bidders to know whether the contract proceeds through the implementation phase or ends with the investigation phase (detailed site assessment).
- ❑ Request the Commissioning Provider's general approach and a skeletal commissioning plan for the project.
- ❑ List the specific support that the Commissioning Provider can expect from the facility staff and service contractors (particularly the controls vendor) and give the skill level of each of the facility staff. State how much testing and investigation can be done by facility staff.
- ❑ When requiring savings calculations/estimates, state the desired method for completing the work (qualitative ranking of measures for implementation using expert judgment, cost estimates and engineering calculations of savings, costs from actual bids and bin or computer simulations of savings).
- ❑ Any cost or energy savings calculations or estimates required of the Commissioning Provider prior to implementation and after post-verification should be clearly stated with the desired method.
- ❑ List the required Commissioning Provider qualifications and qualifications for any subcontractors.
- ❑ Request work examples from previous projects (final report, Master List of Findings etc.)
- ❑ List the RFP selection criteria.
- ❑ Give a cost range for the project.
- ❑ Provide a list of required deliverables (see section titled "Selecting a Commissioning Provider").
- ❑ Other RFP checklist items: ____
- ❑ ____

Appendix C: List of Possible Deliverables for a Retrocommissioning Project

Phase	Activities	Primary products/deliverables[a]
Project Selection	1. Selecting project 2. Mustering support and gathering facility documentation	
Planning	1. Developing and communicating objectives 2. Choosing team and hiring commissioning provider	
Investigation	1. Reviewing and updating building documentation and historical utility data 2. Developing retrocommissioning project plan and holding scoping meeting 3. Performing site assessment 4. Developing Master List of deficiencies (repairs) and potential improvements 5. Developing short-term diagnostic monitoring plans 6. Performing functional testing, diagnostics and trending 7. Selecting most cost-effective opportunities for implementation	• Retrocommissioning project plan (including project objectives and scope) • Scoping meeting minutes Short-term diagnostic monitoring and functional test plans • Master List of deficiencies and potential improvements (known as the Master List) • Completed assessment forms and diagnostic test results • List of selected improvements for immediate implementation
Implementation	1. Implementing improvements	• Completed repairs and improvements (noted on revisions to Master List)
Final Adjustment	1. Retesting and remonitoring 2. Updating building documentation, if applicable 3. Training operators	• Final estimated cost and energy savings calculations for energy-efficiency and cost-saving improvements • Revised or upgraded building documentation (if required as part of project • Training videos or text materials
Handoff	1. Completing final report 2. Maintaining investment by developing recommissioning plan, training, and performance tracking 3. Holding project closeout meeting	• Final report • Recommended capital improvements for future investigation • Recommissioning plan or schedule

[a] All phases should include progress reports and minutes from meetings.

Appendix D: Building Information Summary

Appendix D contains a list of typical building characteristics that can be placed in a spreadsheet or a database for comparing multiple buildings. This is useful for owners with multiple facilities who are interested in gaining a preliminary understanding of their building stock regarding retrocommissioning opportunities.

BUILDING IDENTIFICATION (NAME OR NUMBER)

General Information

- ✓ Building Type (e.g., Office, Warehouse, Hospital)
- ✓ Number of Occupants
- ✓ Size (Gross Square Feet)
- ✓ Year of Construction
- ✓ Year of Last Renovation

Building Equipment

- ✓ Central Heating Plant (Boilers)
- ✓ Central Cooling Plant (Chillers)
- ✓ Packaged Units
- ✓ District Heating
- ✓ District Cooling
- ✓ Computer Energy Management System
- ✓ Age of Primary Heating Equipment
- ✓ Age of Primary Cooling Equipment

Energy Data

- ✓ Annual Hours of Operation
- ✓ kWh per year
- ✓ Annual Electric Use in kWh per Square Foot
- ✓ Peak Demand for Last 12 Months
- ✓ Natural Gas ccf per Year
- ✓ Annual Gas Use in BTU per Square Foot
- ✓ BTU per Square Foot per Year all Fuels
- ✓ District Heating (lbs. of Steam per Year)
- ✓ District Cooling (TN Hours per Year)
- ✓ Average annual BTU per Square Foot for region or city for similar type buildings

Appendix E: Sample Site-Assessment Forms

Assessment forms help guide the interview process with building staff which occurs during the investigation phase of the project. Site assessment forms are developed for each piece of equipment and system that is selected for retrocommissioning. The forms may address either operation or maintenance issues or both depending on the scope of the project. The site-assessment is an *information gathering exercise*. Minor repairs and simple improvements may be implemented during the assessment, however the major problem solving and improvement recommendations generally occur at the end of the investigation phase, after all the information and data are analyzed.

Sample Site-Assessment Form (Interview)

General O&M Questions

Has your heating system always met load? ☐ Yes ☐ No

Under what conditions has your heating system not met load?

What was the solution to this problem:

Has your cooling system always met load? ☐ Yes ☐ No

Under what conditions has your cooling system not met load?

What was the solution to this problem:

Do you feel you have any HVAC equipment that is undersized? ☐ Yes ☐ No

If yes, explain:

How do you compensate for the undersizing?

Do you feel you have any HVAC equipment that is oversized? ☐ Yes ☐ No

If yes, explain:

How do you compensate for the oversizing?

Is the building mechanical equipment (fans, pumps, etc.) scheduled to start up simultaneously or is the start-up staged?

What HVAC adjustments do you make to unoccupied areas or spaces (turn off HVAC, adjust thermostat to minimum heating and cooling, close off diffuser, etc.)?

In your opinion, is the building HVAC system well balanced? ☐ Yes ☐ No

If no, explain:

Explain the method of humidification for the building:

Are there any problems with the humidification method (explain)? ☐ Yes ☐ No

Explain the method of dehumidification for the building:

Are there any problems with the dehumidification method (explain)? ☐ Yes ☐ No

From what areas in the building do you receive the most complaints (explain nature of complaints)?

What is your worst building problem and how do you deal with it?

Comments and Notes:

Sample Site Assessment Form for Domestic Hot Water

What is the temperature setpoint for each of the building's hot water heaters?

Heater ID	Area Served	Temperature Setting	Reason for Setting

- Explain method of domestic hot water control? ______________________________
____
____
____

- If hot water is preheated, explain method? __________________________________
____
____
____
____

- Do the recirculating pumps run continuously? ______________________________

Notes, Comments, and Observations:

Summarize deficiencies and possible improvements on Master List

Sample Pump Assessment Form

Pump Control Questions:

Circle or explain what function the pump serves:

Condenser Water   Chilled Water   Secondary Chilled Water   Heating   Water
Secondary Heating Water

Other ____

Pump ID #: ____

- What causes the pump to initially start? ____________________
- What causes the pump to cycle? ____________________
- How is capacity controlled (VFD, etc.)? ____________________
  (If a VFD is used attach VFD Assessment Form to the appropriate Pump Form)
- If applicable, what is the differential pressure control point? ____________________
- If there is a lead/lag strategy, explain: ____________________
- If pumps are staged, explain: ____________________

Notes, Comments, and Observations:

(Summarize deficiencies and possible improvements on Master List)

Pump Assessment Forms Cont.:

Pump Nameplate Information

Use N/A for not applicable and N/O for not obtainable or available.

Pump Function: **(Heating water, condenser, etc.)**				
Pump ID or Number				
Pump Manufacturer				
Model Number				
Serial Number				
Age				
Impeller size				
Head pressure				
Suction Pressure				
Discharge Pressure				
GPM				
Motor Manufacturer				
Motor Model #				
Phase				
Volts phase to phase	Nameplate: Measured:	Nameplate: Measured:	Nameplate: Measured:	Nameplate: Measured:
Volts phase to ground	Measured:	Measured:	Measured:	Measured:

Pump Function: **(Heating water, condenser, etc.)**				
RLA each phase	Nameplate: Measured:	Nameplate: Measured:	Nameplate: Measured:	Nameplate: Measured:
kW	Measured:	Measured:	Measured:	Measured:
Power Factor	Measured:	Measured:	Measured:	Measured:
HP				
RPM				

Notes, Comments, and Observations:

Pump Assessment Forms Cont.:

Pump Maintenance Checklist

Check if okay; enter comment number if deficient. Document comments by number in form provided below checklist. Use N/A for not applicable and N/O for not obtainable or available.

Pump ID				
General condition good (clean and appear well maintained)				
No unusual noise or vibration				
No water leaks				
Thermometers on supply and return.				
Pressure gauges installed across pumps and functioning (if so, record pressures)	Suction: Discharge:	Suction: Discharge:	Suction: Discharge:	Suction: Discharge:
Pump rotation correct				
Properly balanced				
Strainers in place and clean? State when strainers were last cleaned				
Piping properly insulated				
Piping generally in good condition				
Valves in good condition - no leaks				
Water treatment in place and operating				

Number	**Comment**

Summarize all deficiencies and possible improvements on the Master List.

Appendix F: Sample Master List

This list summarizes the findings from the investigation phase of the project and is a primary product or deliverable resulting from the retrocommissioning process. The following Master List was created for an actual project and is offered here only as an example. The equipment and systems listed and the related findings would differ for other buildings. Under "Type," O=operation, M=Maintenance, and D=design.

Sample: Master List of Deficiencies and Potential Improvements

Item #	Equipment or System ID	Description of Finding	Recommended Improvement	Type	Status
1	All Plant Equipment	Manual start up and shut down of boilers, chillers, pumps. Automatic scheduling not incorporated.	Include and implement automatic scheduling for plant equipment using optimum start, incorporate setup and set back strategies.	O	Done. Testing for clg equip. deferred until clg season.
2	Boiler Control	Control strategy for loss of boiler not programmed.	Add programming to allow automatic start up of 2nd boiler on loss of 1st boiler.	O	Done.
3	Chillers 1 and 2	Lacks interface with EMCS - (see also #2).	At minimum, allow EMCS to enable and disable the chiller and add monitoring points for water temperatures and run status.	O	Done. Retest deferred until clg. season.
4	Chillers 1 and 2	Chilled water reset capability not used.	At minimum, allow the chiller's integral controls to reset chilled water temperature. (See manufacturer's instructions.)	O	Reset installed through EMCS system.
5	Chillers 1 and 2	Energy tracking	Add points to EMCS to allow energy and demand tracking for both chillers.	O/M	Done.
6	Chillers 1 and 2	Chillers do not operate in parallel per original design intent.	Have design engineer and chiller mfg. review present chilled water system. Request a proposal for design changes necessary to allow chillers to stage as a lead/lag system.	D	Design referral. Design review in process.
7	Chiller 1 and 2	High demand on start up.	Consider employing soft start through EMCS or integral controls.	O	Soft start added to chiller start up.
8	EMCS	Trending not installed.	Add trending capabilities to EMCS to improve building staff troubleshooting abilities.	O/M	Done.
9	Heat/Cool Change over	Manual change over between heating and cooling.	Add points needed to incorporate automatic change over strategy.	O	Done.
10	Chilled Water Pump, P-1	Pump is possibly oversized. Piping is possible undersized.	Investigate sizing of the pump. Check amps against nameplate during full load conditions. Review piping.	D	Pump review done. Piping design referral. Review in process.

Sample: Master List of Deficiencies and Potential Improvements (con't)

Item #	Equipment or System ID	Description of Finding	Recommended Improvement	Type	Status
11	Condensate Pump inside AC-1	Pump located inside of AC-1 may cause high discharge air temperatures.	Investigate possible relocated pump or venting it to mech. room. (Does the pump run continuously?) Ref. 11/14/96 meeting fax.	M	Insulated for temporary solution.
12	Cooling Tower Fans	Diagnostics show tower cycles on primary fan only. Pony motor not working.	Troubleshoot CT to determine staging problem. Repair so pony motor cycles as 1st stage.	M/O	Done.
13	Cooling Tower Control	Integral chiller control for staging cooling tower fans not used. Temperature bulb for sump may be poorly located.	Investigate using the chiller capability of staging the cooling tower fans based on condenser differential refrigerant pressure. If present strategy is kept, relocate temperature bulb lower in pan and closer to outlet.	O	Delta P Strategy not appropriate. Staging from sump temp. better method. Bulb relocated.
14	Cooling Tower 3-way Valve	According to functional tests, the valve doesn't modulate to maintain condenser water temperature, as it should.	Troubleshoot problem and repair so valve modulates as designed.	D/M/O	Repaired. This will be rechecked as part of the design review and PM recommissioning.
15	Heating System	Data shows heating water supply temperatures between 80 and 90°F.	Investigate. Normally heating water temps are between 140 and 180°F	O	Resolved with new reset schedule.
16	Plant Instrumentation	Pressure and temp gauges missing from plant piping.	Install pressure and temperature gauges on chiller, boiler, and pumps as needed to facilitate maintenance and troubleshooting.	M	As time and budget permits for building staff.
17	East Primary Air Unit AC-1	Data shows inconsistent control of supply and mixed air. Steam valve erratic during temps below 35 deg. F.	Correct through EMCS.	O	Done.
18	West Primary Air Unit AC-12	Data shows erratic control of supply air and no drop in supply air temp when chillers were on.	Investigate. Remonitor during second round of diagnostics by measuring mixed air temp also.	O	Retest in clg season.
19	AC-13 (Multizone Unit)	Data shows wide swings in hot and cold deck temperatures resulting in poor control of space temperatures.	Improve control through EMCS. Investigate damper and valve functions.	O/M	Done. Retest shows correction successful.
20	AC-13 (Multizone Unit)	Data shows poor economizer control.	Improve economizer control through EMCS. Investigate damper function. Consider enthalpy control using EMCS.	O/M	Same as 18.

Sample: Master List of Deficiencies and Potential Improvements (con't)

Item #	*Equipment or System ID	Description of Finding	Recommended Improvement	Type	Status
21	All Air Handlers:	TOD scheduling not used.	Include and implement TOD scheduling. Stagger start time at occupied target and following power loss.	O	Scheduled from plant equip. through EMCS.
22	Air Handler AC-1s OSA Preheater	Preheat coil is not functioning properly. Present averaging bulb sensor (input for controlling the steam valve) was found to have 70% of its sensing element outside of the unit.	Relocate averaging bulb sensing element to read temperature of air stream. Ensure freeze protection operates to shut OSA damper when OSA conditions dictate. Check control strategy through EMCS.	M/O	Done. Averaging bulb relocated.
23	Air Handler AC-11 through 18	OSA dampers not controlled to take advantage of economizer capability	Program system and add humidity sensors (outside and inside) to employ enthalpy control for economizing. At minimum use dry bulb control.	O	Done. 11, 13, 15, 18 fine tuned.
24	AC-15 and 18	Data shows AC-15 OSA damper always closed and AC-18 opening partially some of the time.	Improve economizer control with EMCS program and investigate damper function. (See also above #22).	O/M	Same. Done.
25	Air Handlers AC-4,5 and 10	No air side economizing.	Add actuators to OSA and RA dampers along with EMCS points and program to take advantage of economizer function.	O/D	10 are done. Others dependent on AC-1. Design review in progress.
26	VAV Operation and Control for west conf. space.	VAV boxes are secured open and the VFD is circumvented. Test need for duct heaters.	Consider reinstituting the VAV system using the VFD. Repair reheat if they are needed.	M/O	Done. VFD working. Reheats not needed.
27	OSA Temperature Sensor	Calibration issue.	Check calibration of OSA temperature sensor, relocate, and properly shield if needed.	M/O	Relocated to roof using weather resistant type sensor and shielding. Done.
28	EMCS	Facility staff did not receive adequate training on EMCS.	Provide 40 hours of training to facility staff using original specification. Train building staff to present data in graphical format.	O	40 hours of training specified and complete.
29	Domestic Hot Water	High water temperature (140).	Lower domestic hot water to 110°F for restrooms and 120°F for showers. Kitchen needs for hot water have priority over this strategy.	O	Presently, higher temp needed for kitchen. Point of use water heater to be installed in kitchen.

Appendix G: Sample Diagnostic Monitoring and Trending Plans

These plans are developed by the commissioning provider. Building staff may assist in their implementation, depending on the scope of work. The examples provided are intended to give the reader a sense of the level of rigor involved in the retrocommissioning process.

- **Datalogger Plan**

Appendix G contains two pages of a sample datalogger plan for a typical commercial office building. The datalogger plan lists all of the dataloggers for the project, their location and what information they are recording.

- **EMCS Trending Plan**

Appendix G also contains a sample EMCS trending plan for implementation by either building staff or the controls contractor.

Datalogger Plan for Short-Term Diagnostic Monitoring

Project Name: ___________________________________

Brand Name of dataloggers: ___________________

Run-Time Parameters:

Start Date __________________________________

Start Time _________________________________

Stop Date __________________________________

Stop Time _________________________________

Duration___________________________________

Sampling Frequency _________________________

Storage Frequency __________________________

Total Loggers ______________________________

Total Points ________________________________

Each logger has four separate modules. Each module can be programmed separately to gather data on temperature, pressure, or current. Below are the first two pages of the logger plan for Building One.

Logger 1:

Equipment Name	Point Name	Measurement	Type module	Units	Min.	Max.
Chiller - 1	Leaving Chill. Water	Water	Temp.	^{o}F	32	212
Chiller - 1	Entering Chill. Water	Water	Temp.	^{o}F	32	212
Chiller - 1	Chil. Pump -1	Current	400 mV AC	Amps	0	0
Chiller - 1	Cond. Pump -1	Current	400 mV AC	Amps	0	0

Logger 2:

Equipment Name	Point Name	Measurement	Type module	Units	Min.	Max.
Chiller - 2	Leaving Chill. Water	Water	Temp.	^oF	32	212
Chiller - 2	Entering Chill. Water	Water	Temp.	^oF	32	212
Chiller - 2	Chil. Pump -2	Current	400 mV AC	Amps	0	0
Chiller - 2	Cond. Pump -2	Current	400 mV AC	Amps	0	0

Logger 3:

Equipment Name	Point Name	Measurement	Type module	Units	Min.	Max.
AC-13	Hot Deck	Temperature	Temp.	^oF	32	212
AC-13	Cold Deck	Temperature	Temp.	^oF	32	212
AC-13	Mixed Air	Temperature	Temp.	^oF	32	212
AC-13	Return Air	Temperature	Temp.	^oF	32	212

Logger 4

Equipment Name	Point Name	Measurement	Type module	Units	Min.	Max.
Cooling Tower	Primary Fan Motor	Current	400 mV AC	Amps	0	0
Cooling Tower	Pony Motor	Current	400 mV AC	Amps	0	0
Cooling Tower	Sump	Water	Temp.	^oF	32	212

Logger 5:

Equipment Name	Point Name	Measurement	Type module	Units	Min.	Max.
Ambient Outside	Outside Air Temp.	Temperature	Temp.	^{o}F	32	212
Ambient Outside	Outside Humidity	Relative Humidity	Humidity	RH	0	100

Logger 6

Equipment Name	Point Name	Measurement	Type module	Units	Min.	Max.
Boiler -1	Pump	Current	400 mV AC	Amps	0	0
Boiler -2	Pump	Current	400 mV AC	Amps	0	0
Boiler -1	Forced Draft Fan	Current	400 mV AC	Amps	0	0
Boiler -2	Forced Draft Fan	Current	400 mV AC	Amps	0	0

Sample EMCS Trending Plan

Building staff is responsible for entering and initiating the trends using the building's energy management control system (EMCS) per this plan. Calibration of critical sensors should be completed no more than two weeks prior to initiating trends. Trending and the short-term datalogging are done simultaneously. The trend data are then compared to the data gathered by the portable dataloggers to determine whether the EMCS is working correctly. Trend data are also used to augment the short-term diagnostics for verifying sequences of operation and schedules. This trend plan will be used during both pre-implementation of the improvements and during post-implementation. Any changes to the plan for post-implementation are noted in *italics*. The following outlines the trend plan for Office Building One.

Plant Equipment

Description of Trend Point	**Number of Points Per Trend**
Outside air temperature	(1)
Outlet or leaving water temperature from the tower for both chillers (cond. water return)	(2)
Chilled water supply temp from both chillers	(2)
Hot water converter for secondary loop - entering and leaving water temperatures for each	(4)
Hot water converter steam valve position for each	(2)
Sub-Total	**11**

Air Handlers

Name	**Tag Number**	**Description of Trend Point**	**Number of Points Per Trend**
East AC	1	Mixed air temp	(1)
East AC	1	Supply air temp	(1)
East AC	1	Preheat valve position	(1)
East AC	6	Supply air temp	(1)
West AC	13	Hot deck and cold deck temp (multizone)	(1)
West AC	15	Supply air temp	(1)
West AC	15	Chilled water valve position	(1)
Sub-Total			**(7)**

Appendix H: Sample Functional Performance Tests

Appendix H contains a sample functional test for a centrifugal chiller and a variable frequency drive (VFD) on a pump. These tests are developed by the commissioning provider and can be more or less detailed and comprehensive depending on budgets and project objectives. Facility staff may assist with the hands-on operation of the equipment tested.

Sample Functional Test for Centrifugal Chiller

Functional Performance Test

Building:	**Commissioning Provider:**	**Phone:**
Date:	**Mfg. or Contractor:**	**Phone:**

Special Instructions:

Before performing this test, make sure that the normal PM tasks have been completed for the chiller and the following related equipment has been observed or functionally tested to prove proper operation:

- Chilled water pumps
- Condenser water pumps
- Cooling towers

Be sure all related pumps and cooling towers are operable and enabled.

Set leaving chilled water temperature to specified temperature.

If test is not being performed on or near design-day temperatures, false load the chiller.

If an energy management control system (EMCS) interfaces with this chiller, make sure all sensors are calibrated and properly located.

Use monitoring (dataloggers) and EMCS trend logging whenever possible to demonstrate proper operation of the equipment (this can be used in lieu of manual functional testing) and attach the output to this form.

Electrical

Check for voltage imbalance. Maximum allowable imbalance is 2%.

At the main disconnect for the compressors, measure the voltage of each phase and use the following method to determine the percent imbalance:

Phase A + Phase B + Phase C / 3 = Average Voltage

The percent voltage imbalance is then:

100 (Avg. Voltage – Lowest Phase) / the Average Voltage = % of Imbalance

Measured Voltage for Compressors

Phase A:	Phase B:	Phase C:

Percent Imbalance ____________ The percent imbalance is acceptable Yes/ no

Comments and Calculations:

General

Check operation or status of each. Enter comment number if deficient, and document comments by number in form provided below checklist. Use N/A for not applicable and N/O for not obtainable or available.

Checklist Item	Number
Test condenser water flow and chilled water flow	
Test interlocks to pumps	
Test starter for dynamic limits and timers	
Oil heater safety inhibits starting	
Check chilled water recycle mode (if applicable)	
Chilled water pump stays on	
Other (list):	

Number	Comment

Test control panel for manual function.

- **Do readouts match actual values?.. ☐Yes / ☐No**
- **Is refrigerant alarm and room ventilation adequate?.. ☐Yes / ☐No**

Confirm energy performance over load range. Compare results to manufacturer's data using the attached table. If using dataloggers for this test, attach the readouts and explanation verifying proper performance. Otherwise proceed with manual test as follows:

Take three sets of data at 10-minute intervals. Tolerances from specified values should not exceed 1 degree F for temperature and 5% for flow. Repeat if necessary until system stabilizes and the differences between the three readings are less than the limits.

Chilled Water	Interval 1	Interval 2	Interval 3
LWT (F)			
EWT (F)			
Delta T			
Flow in GPM			
EW Pressure (PSI)			
LW Pressure (PSI)			
Evap. Leaving Refrigerant Temp.			

Condenser Water	Interval 1	Interval 2	Interval 3
LWT (F)			
EWT (F)			
Delta T			
Flow in GPM			
EW Pressure (PSI)			
LW Pressure (PSI)			
Condenser Leaving Refrigerant Temp.			

Electricity	Interval 1	Interval 2	Interval 3
Watt meter output			

Calculate the average test data and enter the results into the following table along with the manufacturer's performance data:

Based on the average test data, calculate the capacity using the following formula:

CAP in cooling tons = (chilled water delta T) * (chilled water flow rate) / 24

Check operation or status of each. Enter comment number if deficient, and document comments by number in form provided below checklist. Use N/A for not applicable and N/O for not obtainable or available.

Chilled Water	Manufacturer's Data	Average Test Data	Comment #
LWT (F)			
EWT (F)			
Delta T			
Flow in GPM			
EW Pressure (PSI)			
LW Pressure (PSI)			
Evap. Leaving Refrigerant Temp.			
LWT (F)			
EWT (F)			
Delta T			
Flow in GPM			
EW Pressure (PSI)			
LW Pressure (PSI)			
Condenser Leaving Refrigerant Temp.			
KW			
BTU/h or Cooling Tons			
kW per Ton =			

Number	Comment

- **Was any unusual noise or vibration observed?.. ☐Yes / ☐No**
- **Were amperage fluctuations observed?.. ☐Yes / ☐No**
- **Vane steady (not hunting)? .... ☐Yes / ☐No**
- **Capacity is according to design? .... ☐Yes / ☐No**
- **kW per ton is according to design? .... ☐Yes / ☐No**

Part Load Test

Confirm energy performance over load range. Compare results to manufacturer's data using the attached table. If using dataloggers for this test, attach the readouts and explanation verifying proper performance. Otherwise proceed with manual test as follows:

Chiller may need to run for one hour with temperature and flow rate stabilized before performing this test. Watch amperage readings while load is being reduced. Amperage should be steady when recorded.

Take three sets of data at 10-minute intervals. Tolerances from specified values should not exceed 1 degree F for temperature and 5% for flow. Repeat if necessary until system stabilizes and the differences between the three readings are less than the limits.

Chilled Water	Interval 1	Interval 2	Interval 3
LWT (F)			
EWT (F)			
Delta T			
Flow in GPM			
Evap. Leaving Refrigerant Temp.			

Condenser Water	Interval 1	Interval 2	Interval 3
LWT (F)			
EWT (F)			
Delta T			
Flow in GPM			
Condenser Leaving Refrigerant Temp.			

Electricity	Interval 1	Interval 2	Interval 3
Wattmeter Output			

Calculate the average test data and enter the results into the following table along with the manufacturer’s performance data:

Based on the average test data, calculate the capacity using the following formula:

CAP in cooling tons = (chilled water delta T) * (chilled water flow rate) / 24

Chilled Water	Manufacturer's Data	Average Test Data
LWT (F)		
EWT (F)		
Delta T		
Flow in GPM		
EW Pressure (PSI)		
LW Pressure (PSI)		
Evap. Leaving Refrigerant Temp.		
LWT (F)		
EWT (F)		
Delta T		
Flow in GPM		
EW Pressure (PSI)		
LW Pressure (PSI)		
Condenser Leaving Refrigerant Temp.		
KW		
BTU/h or Cooling Tons		
KW per Ton =		

- **Was any unusual noise or vibration observed?.. ☐Yes / ☐No**
- **Were amperage fluctuations observed?.. ☐Yes / ☐No**

Chilled Water Reset

If a reset strategy is employed, a test should be developed to demonstrate that the strategy works correctly. Use monitoring equipment or EMCS trend logging whenever possible and attach output demonstrating the reset strategy.

Training

- **Are the staff responsible for operating the chiller adequately trained?..................... ☐Yes / ☐No**

Explain:

O&M Plan

- **Has an acceptable O&M Plan been put into place? .... ☐Yes / ☐No**

Briefly describe the O&M plan:

The following items need correction:

- **Are eddy current tests conducted every 5 years? .... ☐Yes / ☐No**

Variable Frequency Drive (VFD) Pump

Secondary Hydronic Pump Application

Functional Performance Test

Commissioning Team:

Commissioning Provider: ____

EMCS operator: ____

VFD technician: ____

HVAC technician: ____

Owner's rep.: ____

Pump ID:_____

____**Chilled water** (CHW) **secondary** ___**Hot water secondary** (HW)

Design max.: Hp: ____ GPM: ______ Head _____ Ft

VFD brand and model: ____

The following functional performance test is for a VFD controlling a variable flow hydronic system to a **constant** differential pressure (DP). ***A check-mark denotes compliance.***

I. Documentation Verification

___ Review the design documents and the specifications if available.

___ Verify that the VFD ___description, ___specifications, ___technical and troubleshooting guide and the installation, ___programming record and ___balance reports are on-site. From the design documents determine: Location for the DP measurement:

____

Control strategy for the pump:____

____

II. VFD Installation

Differential Pressure Sensor

Actual location of DP measurement____

The measurement should ideally be taken across the coil of the last branch.

Complies?

____

Pressure Offset (Po) Conversion: psi x 2.31 = ft H_2O

DP pump is being controlled to: _______feet [A].

Pressure rise across pump at design conditions (from balance report): _______feet [B]. Pressure offset, Po, [A] ÷ [B]= _______.

Optimally, Po should be 0.3 or less in order for the VFD and pump to be able to respond to small pressure changes and realize adequate energy savings. If Po is greater than 0.4, the DP sensor is probably located too close to the pump.

Complies? ____

Balancing to Lowest Pressure

Review the HVAC balance report and verify that the system was balanced so the VFD controls to the lowest possible DP (from the capacity test). The controlling DP from the balance report is _________feet. At design, the corresponding VFD frequency or pump RPM from the balance report is: Pump-1 ________; Pump-2 _______; Pump-3 _____. The corresponding flow from the balance report is_______GPM. Refer to the capacity test at the end of this form for details.

Balanced to lowest DP? ____

General Issues

___ Verify that any power quality mitigation measures required from the specifications have been completed.

___ Verify that there are no 3-way coil valves that may negate the value of the VFD by allowing flow to bypass the coil.

___ Verify that the acceleration and deceleration ramp time of the VFD is between one and four minutes. Actual ramp time: up _____min. down _____min. (short ramp times will result in "hunting" and excess modulation by the VFD; typical ramp times are 1 to 4 minutes)

___ Verify that each VFD has been integrated into the EMCS as per specification.

___ Verify that the EMCS monitors the DP.

___ Verify that minimum flow bypass of 2-way valve, if present, has flow less than 2% of design flow.

III. Functional Performance Test

This test is not intended to verify that the coil valve is functioning properly, but rather that the VFD is functioning properly.

1. Design Flow by Test and Balance (TAB). Record in Condition 1 in Table 1 the speed, DP, and total supply flow at design conditions from the TAB report.

2. Intermediate Flow (coil valves partially open). Intermediate flow will occur when current conditions are such that the system is not in full cooling or full heating, nor at minimum flow. Read the speed, DP, and the total supply flow in the secondary loop and record in Condition 3 in Table 1.

If the conditions are not in an "intermediate" position, change all space temperature set points to 4 degrees below the actual temperature in the space, for CHW pumps, or 4 degrees above for HW pumps (circle one) to simulate an approaching of thermostat satisfaction and take readings.

3. Design Flow (coil valves full open). Using the (EMCS) or other means, change all space temperature set points to at least 10 degrees below the current space temperature for CHW pumps, or 10 degrees above for HW pumps, so that the entire HVAC system supplied from these pumps is in full cooling (or heating, as appropriate, circle) in all zones. Observe that all coil valves are to their design maximum position (from the TAB report). Wait at least 20 minutes for lag time while observing:

___ Does the first lag pump turn on (after a delay) when the lead pump exceeds its ______ gpm design flow?

___ Does the 2nd lag pump turn on (after a delay) when the sum Lead + Lag 1 exceeds the sum of their design, *AND* the DP drops to 80% or _____ feet?

Read the speeds, DP and the total supply flow and record in Condition 2.

4. Minimum Flow (Coil valves shut). Change all space temperature set points to be equal to the actual space temperatures to simulate a satisfied condition, driving the boxes to their minimum and the coil valves closed. Wait at least 25 minutes.

___ Do the lag pumps sequentially turn off (with a delay) when the flow is less than the design of all *running* pumps?

___ Does the last pump shut off appropriately?

Take the frequency, pressure and flow readings and record in Condition 4.

IV. Analysis

Table 1.

Condition	Secondary Pump No.	**Speed** (Hz or RPM) Reading	**Speed** (Hz or RPM) Average	**DP at Sensor** (psi) Reading	**DP at Sensor** (psi) Average	**Total Flow** (gpm)
1. At design flow by TAB	**Lead**					
	Lag-1					
	Lag-2					
2. At design flow (during commissioning)	**Lead**					
	Lag-1					
	Lag-2					
3. At intermediate flow (during commissioning)	**Lead**					
	Lag-1					
	Lag-2					
4. At no flow (during commissioning)	**Lead**					
	Lag-1					
	Lag-2					

Conversion: 0.434 x ft H_2O = psi

2.31 x psi = ft H_2O

1. In Table 1, average the speed and the DP for all pumps at each of the four conditions.

2. If the speed at Condition 1 (TAB test) is not within 10% of the current test at Condition 2, all the boxes may not have been driven wide open during the commissioning test, or the readings were taken before the lag time was complete. Investigate and repeat tests as appropriate.

   ___Less than 10% variance?

3. During operation of lead-lag pump combinations, the average DP readings at all four conditions should remain within 10% of each other. If there is more than a 10% variance, the sensor may be faulty. Note that during lead-lag pump transition, the DP may appropriately vary by as much as 20%.

   ___Less than 10% variance?

4. **___At no flow, Condition 4, is the flow and DP zero?**

5. **___For the total flow readings in Table 1, are the values in Condition 2 > 3 > 4?**

6. **___Collaborative Trending**

   The system operation will, will not (circle) be trended to further verify the proper operation of the VFD. Points to be trended are listed in the Trending Request Form.

   ___From studying the trends, is the VFD is functioning properly?

7. **Additional tests.** Refer to the chilled water systems sequence of operations tests for further collaboration on the VFD performance.

V. Training

___The building staff are adequately trained to operate and maintain the VFD. Comments:

VI. O&M Plan

___An acceptable O&M plan has been put into place. Describe:

VII. Capacity Test

To ensure that energy use is minimized, the hydronic system must be balanced at design conditions at the lowest possible differential pressure (DP) possible. This requires that the lowest possible DP at the sensor be found that will allow the delivery of design flow through the valve most difficult to satisfy. This system minimum DP is what the VFD should control to. This is accomplished by changing the temperature setpoint for all zones to 55F for cooling coils or 85F for heating coils, causing all AHU coil valves to be calling for full cooling or heating, as applicable. Each coil's flow is then measured against the design flow. The coil that is receiving the lowest fraction of design is identified. The current DP at the controlling sensor is noted. A calculation is made, giving the DP required at the sensor to allow the identified most critical coil to meet its design flow. The equation is $DP_2 = DP_1 \times Q_2^2 / Q_1^2$. Where Q_1 = actual or fraction of design flow during capacity test. Q_2 = design flow or 1.0 if using fractions. DP_1 = DP at sensor. DP_2 = DP to control to. It is noted that if all coils were calling for full cooling simultaneously, the pump could not maintain the new DP_2 value, due to diversity pump size reduction having been made by the design engineer.

Summarize deficiencies and possible improvements on Master List

Appendix I: Strategies for Increasing Retrocommissioning Cost Effectiveness

Thorough preparation and participation by building staff prior to and throughout the project reduces overall costs. This section introduces strategies that in-house building staff can use for streamlining the project and increasing the effectiveness of the Commissioning Provider's time.

1. Gather building documentation
2. Perform appropriate preventive maintenance
3. Perform simple repairs and improvements as the project progresses
4. Perform diagnostic monitoring and functional tests
5. Implement selected improvements and repairs

These strategies should be planned as appropriate and introduced to the building staff before putting the retrocommissioning process into action. If the project, due to size or complexity, requires using a bid process for obtaining commissioning services, the request for proposals should state which of the tasks discussed below are in-house building staff responsibilities. This helps the bidders understand what to expect from the owner's staff and develop their budgets accordingly.

GATHER BUILDING DOCUMENTATION

Compile an *up-to-date* building documentation package prior to the retrocommissioning process. If this is not done ahead of time, the Commissioning Provider will need to gather this information. This packet should be available on-site and include as much information as possible including:

- Drawings relevant to the systems targeted for commissioning (preferably "As-Built" drawings if accurate)
- O&M manuals
- Testing, adjusting and balancing (TAB) reports
- Original design documentation
- An equipment list with nameplate information, dates of installation, and submittals including pump curves and fan curves
- List of outside service contractors regularly used
- Copies of current service contracts
- Control system documentation, such as sequences of operation, special control strategies, control diagrams, points list, control program or code, etc.
- Energy-efficient operating strategies,
- Energy bill (electric, gas, steam, chilled water, etc.) or energy accounting information for at least the last 24 months along with a rate schedule, unit price, or supply contract information for each energy type, and
- Water and sewer usage and billings.

It is possible that some of the information will not be readily available, such as pump curves, fan curves, and written sequences of operation. However, the more documentation that in-house staff can update and compile, the less time the Commissioning Provider will spend obtaining this information. Performance curves are generally available from the original installing contractor or the equipment manufacturer. Have the nameplate information, including the serial number and date of installation, available when contacting either of these parties. Appendix C contains a typical checklist of documentation required as part of retrocommissioning.

PERFORM APPROPRIATE PREVENTIVE MAINTENANCE

Special care should be taken to make sure that all in-house staff or an outside maintenance service contractor completes scheduled preventive maintenance (PM) work before retrocommissioning begins. For example, if retrocommissioning occurs during the cooling season, the annual PM tasks for the cooling plant and systems should be completed before commencing with the project. It is not cost-effective to hold up the retrocommissioning process because of dirty filters, loose belts, broken dampers, or loose electrical connections. These are typical preventive maintenance tasks that do not require a Commissioning Provider to find and recommend fixing. The Commissioning Provider's time is better used helping the building staff find and solve operating, design, and installation problems rather than equipment-care deficiencies.

PERFORM SIMPLE REPAIRS AND IMPROVEMENTS AS THE PROJECT PROGRESSES

Depending on the skill level of the building staff, they can perform a number of improvements and repairs as the project progresses. Completing simple repairs and adjustments discovered during the early part of the investigation phase increases the effectiveness of the diagnostic monitoring and testing. For example, there is no sense in waiting to calibrate or relocate a sensor, or fix a binding damper only to have the diagnostic and testing phase of the project indicate, once again, that this is a problem. Also, finding an effective solution to a problem is often accomplished through a series of "fixes" occurring over the course of the project. Often what appears as a simple problem, once fixed, may allow the diagnostic testing to uncover a larger but more subtle problem, which can then be fixed. These "simple fixes," no matter how minor they appear, should be logged on the "Master List of Deficiencies and Potential Improvements" (this list is discussed in more detail in the section titled "Investigation Phase").

Note that if energy and/or energy-related cost savings are retrocommissioning objectives, it may be important to ensure that energy and cost baselines are well established prior to performing any significant repairs or improvements.

PERFORM DIAGNOSTIC MONITORING AND FUNCTIONAL TESTS

It is often appropriate and cost-effective to have the most motivated and interested building staff assist with the short-term diagnostic monitoring, trend logging, and functional testing that occurs during the investigation phase of the project. This helps reduce project costs and provides the building staff with a learning experience that they can reapply later. If building staff are trained to initiate trend logs using the building's EMCS, a Commissioning Provider can reduce time spent on the task and the owner will not need to hire a controls contractor to do the trending. Building staff may also assist with the installation and removal of portable dataloggers used for short-term diagnostics and assist with carrying out functional test plans. This also reduces costs and gives the building staff exposure to different approaches to troubleshooting problems and investigating and verifying equipment performance.

IMPLEMENTING SELECTED IMPROVEMENTS AND REPAIRS

Depending on availability and expertise, O&M staff may be enlisted to implement the selected repairs and improvements. Using in-house staff to perform these tasks reduces costs. Hiring an outside contractor to implement major repairs and improvements may cause the payback to increase to the point where the project is no longer cost effective. The success of this cost-reducing strategy hinges on in-house staff training, knowledge, and willingness to carry out the work. Existing workloads of O&M staff should be analyzed to determine how schedules and workloads will be shifted to accommodate any additional work.

Appendix J: Commissioning Tools Checklist

The following is a list of tools typically used for commissioning:

INSTRUMENTS

- ❑ Air flow measurement instrument-flow hood and/or manometer
- ❑ Pressure gauges
- ❑ Ammeter
- ❑ Multi-meter
- ❑ Portable data loggers
- ❑ Light meter
- ❑ Tachometer
- ❑ Combustion analyzer
- ❑ Digital thermometer with various types of probes
- ❑ Psychrometer
- ❑ Hydronic pressure measurement instrument
- ❑ Flow meter
- ❑ Extra batteries
- ❑ Two-way radios

HAND TOOLS

- ❑ Cordless drill and bits
- ❑ Allen wrenches
- ❑ Duct tape
- ❑ Extension cord
- ❑ Flashlight
- ❑ Hairdryer
- ❑ Hot and cold chemical packs
- ❑ Pliers, wrenches, vice grips, etc.
- ❑ Pocket knife
- ❑ Ladder
- ❑ Screwdrivers
- ❑ Sockets and driver
- ❑ Nut drivers
- ❑ Rags
- ❑ Flexible mirror

MISCELLANEOUS

- ❑ Tape recorder
- ❑ Camera and film and/or video camera and tape
- ❑ Calculator
- ❑ Test forms
- ❑ Phone list
- ❑ Building documents, files
- ❑ Business cards
- ❑ Clipboard, paper, pens, pencils
- ❑ Personal protective equipment