Commissioning for Green Building Projects

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Kent W. Peterson, PE, FASHRAE, MCIBSE, LEED®AP
ASHRAE Presidential Member
P2S Engineering, Inc.
kent.peterson@p2seng.com
Learning Objectives

• Understanding the requirements for commissioning green building projects
• Understanding enhanced commissioning activities
• Understanding roles and responsibilities
• How to write functional test requirements
• How to assist in ensure control system design can be commissioned
• Understanding principles behind commissioning solar PV systems
Assuring Quality

• The theory that a good design and a good contractor will deliver fully functional systems without commissioning ignores reality for most projects

• Many systems in buildings do not perform as intended by the designer or expected by the building owner
Problems will be Discovered ...

- Hot water valve motion impeded by piping layout [EMC no date (a)]
- Exhaust fan hardwired in an “always on” position [Mittal and Hammond 2008]
- Zone damper actuator arm broken (no temperature control) [Martha Hewett, MNCEE]
- Rust indicates poor anti-condensation heating control setpoints in supermarket refrigeration cabinet [Sellers and Zazzara 2004]
- Inadequate fan cooling and excessive fan power due to poor fit between the light fixture and ducting, causing significant duct leakage [Martha Hewett, MNCEE]
Problems will be Discovered ...

Damage to brick façade of pool building due to lack of proper sealing and air management [Martha Hewet, Minnesota Center for Energy and Environment (MNCEE)]

Building envelope moisture entry [Aldous 2008]

Air leakage in an underfloor air-distribution system [Stum 2008]

Photosensor (for daylight harvesting) shaded by duct [Deringer 2008]

Photosensor “sees” the electric lamps rather than task-plane illumination [Deringer 2008]

Failed window film applications
Sources of Problems

• A design that wouldn’t work properly if built exactly as designed
• Those that arise from deviations from the design intent for the building
• Those that arise from construction problems independent of the design intent
What is Green Building?

• It is the practice of using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and deconstruction

• Designed to reduce the overall impact of the built environment on human health and the natural environment
Green Building Principles

• Optimize site / existing structure potential
• Optimize energy use (renewable energy)
• Protect and conserve water
• Reduce environmental impact of materials
• Enhance indoor environmental quality
• Optimize operational and maintenance practices
What is Building Commissioning?

• The Commissioning Process is a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria.
  – ASHRAE Guideline 0

• The process is performed specifically to ensure that the finished facility operates in accordance with the owner’s documented project requirements and the construction documents

• It begins in pre-design and continues through design, construction, and occupancy of the facility
Cx as an Integrated QC Process

• Defining quality early and ensuring that quality goals are being met at all phases of a project are necessary to provide a building owner with a finished product that satisfies the owner’s overall goals and objectives.

  – The CxA role is to assist the owner in defining their operation and energy goals, to provide review and feedback to the owner and design team at key milestones and to work with the construction team to validate and document system operation.

  – Commissioning, like quality, shouldn’t be an afterthought at the end of a project. Instead it should be integrated into the project from the beginning to ensure that quality is addressed throughout the project.
Commissioning Goals

- Define and document requirements clearly
- Verify and document compliance
- Establish and document commissioning process tasks
- Deliver buildings and construction projects that meet the owner's needs
- Verify that operation and maintenance personnel and occupants are properly trained
- Maintain facility performance across its life-cycle
Why Building Commissioning?

• There is an increasing need for buildings to demonstrate performance of green building metrics
  – Concerns about design claims
  – Helps owner understand building system performance and metrics
• There is also a recent trend to demonstrate performance over the life of the building
Commissioning Benefits

• Satisfied occupants & stakeholders
• Systems perform as intended
• Lower energy use and cost
• Early detection of potential problems
• Better building documentation
• Trained building operators
• Lower operation and maintenance cost
• Reduced contractor callbacks
• Improves maintainability of equipment/systems

Occupant Needs

Pre-Design

Design

Construction

Occupancy & Operation
What Commissioning is NOT

• Test and Balance
• Start-up
• Plan review
• Design
• Contract Administration
• Inspection
History

• G. Edwards Deming developed TQM in the late 50’s and early 60’s then improved the process in the 70’s
• Europe, Australia and Asia had a process that some US companies wanted to utilize
• ASHRAE Committee GPC-1 was organized in November 1984
• ASHRAE Guideline 1 was published in 1990
History

• ASHRAE Guideline 1 is now in its 3rd revision which was approved for publication in June 2007
• ASHRAE started looking at other systems in 1991
• Total Building Commissioning document is being developed by ASHRAE and NIBS
ASHRAE Guidelines

• ASHRAE Guideline 0-2005, The Commissioning Process
  – Describes the commissioning process capable of verifying a facility and its systems meet the owner’s project requirements

• ASHRAE Guideline 1.1-2007, The HVAC Commissioning Process
  – Describes the technical requirements for the application of the commissioning process that will verify HVAC systems achieve the owner’s project requirements
Total Building Commissioning Process

ASHRAE Guideline 0-2005: The Commissioning Process

ASHRAE Guideline 1.1-2007
HVAC&R Technical Requirements for The Commissioning Process

NIBS Guideline 3-2006
Exterior Enclosure Technical Requirements for The Commissioning Process

Guidelines 2-200X & 4-200X through 14-200X
Technical commissioning guidelines dealing with structure, electrical, lighting, interiors, plumbing, etc.
Why is Commissioning Green Building Systems so Critical?

• Systems found in buildings are very complex, dynamic systems
  – Unique
  – Built on-site
  – Built by hand
  – Thousands of independent components

• Owners of green buildings expect the building to deliver the environmental benefits and improved indoor environment
Systems Commissioning

- Verifies operation of components under various conditions
- Verifies interaction between systems and subsystems
- Documents performance of systems to design criteria
- Instructs building personnel on proper operation of systems
Project Cost & Savings

- Potential Savings
- Cost to Fix

Project Timeline

- Concept
- Design
- Construction
- O&M
Key Elements of Success

• Committed owner and team
• Commissioning Authority present early in project
• Team approach to design & construction
• Early O&M personnel involvement
The Commissioning Process
The Commissioning Process

• The Commissioning (Cx) Process involves steps that are integrated into every phase of the project:

PRE-DESIGN  DESIGN  CONSTRUCTION  OCCUPANCY & OPERATION

• Commissioning is NOT just testing at the end!
Cx: Pre-Design Phase Objectives

- Document/Review Owner’s Project Requirements
- Scope & budget for commissioning
- Select Commissioning Authority
- Create Commissioning Plan
Cx: Design Phase Objectives

- Document/Review Basis of Design
- Refine scope of commissioning
- Perform Cx Focused Design Reviews
- Update Commissioning Plan
• Include commissioning requirements in construction documents
  – Develop commissioning specifications
  – Develop construction checklists and functional performance test procedures
  – Define format and content of systems manual
  – Define training requirements
Cx: Construction Phase Objectives

- Update Owner’s Project Requirements
- Update Commissioning Plan & schedule
- Review Submittals against Cx Plan, OPR, and BOD
- Review control sequences
- Update construction checklists
- Update functional performance test procedures
- Document construction observations
- Develop Systems/O&M Manuals
Cx: Construction Phase

Objectives

• Train O&M Personnel
• Complete Construction Checklists
• Perform Functional Performance Testing (FPT)
• Document deficiencies found during FPT’s (Issues Log)
• Correct deficiencies and retest
• Prepare Final Report
• Provide ongoing guidance to assist Operations and Maintenance to achieve OPR
• Complete Seasonal Testing
• Document lessons learned
• Complete warranty follow-up
CxA Qualifications and Responsibilities
Relationship with CxA
Cx Authority Qualifications

- Individuals who possess a high level of experience in the following areas:
  - Energy systems design, installation and operation
  - Commissioning planning & process management
  - Hands-on field experience with energy systems performance, interaction, start-up, balancing, testing, troubleshooting, operation, and maintenance procedures
  - Energy systems automation control knowledge
Cx Authority

• Determine what the owner really wants and develop the owner’s project requirement document (OPR)
• Assist the engineer in developing the basis of design (BOD)
• Verify the right systems are being installed
• Review the design documents for Cx
Cx Authority

- Work with all the other team members
- Document the entire project
- Develop the commissioning plan
- Develop the commissioning specifications
Cx Authority

• Conduct the Cx meetings
• Communication is key!
• Review the submittals for compliance with OPR
• Review warranties for the record
• Write pre-functional checklists
Cx Authority

- Operational Testing
  - Ensure proper installation
  - Functional Performance Testing to measure performance
  - Verify system capacities
  - Verify control strategies
  - Validate energy performance

- Verify the operation of the systems
Cx Authority

- Building Operator Training
  - Determine training requirements
  - Systems focus
  - How to operate systems
  - How to maintain systems
Commissioning Documentation
Cx Documentation

• Owner’s Project Requirements (OPR)
• Basis of Design
• Contract Documents
• Commissioning Plan
• Design and Submittal Reviews
OPR / BOD

• The Owner shall document the Owner’s Project Requirements (OPR).
  – The design team shall develop the Basis of Design (BOD)
  – The CxA shall review these documents for clarity and completeness
  – The Owner and design team shall be responsible for updates to their respective documents

Why is this important?

_The OPR and BOD provide an informed baseline and focus for validating systems’ energy and environment performance_
OPR / BOD (continued)

• Owner’s Project Requirements (OPR)
  – The OPR should detail the functional requirements of a project and the expectations of the building’s use and operation as it relates to the systems to be commissioned

• Basis of Design (BOD)
  – The BOD shall provide a narrative describing the design of the systems to be commissioned and outlining any design assumptions that are not otherwise included in the design documents
OPR (continued)

- **Owner and User Requirements**
  - The primary purpose, program, and use of the proposed project. Overarching goals relative to program needs, future expansion, flexibility, quality of materials, and construction and operational costs.

- **Environmental & Sustainability Goals**
  - Specific environmental or sustainability goals.

- **Energy Efficiency Goals**
  - Overall project energy efficiency goals relative to local energy code or ASHRAE Standard or LEED. Goals or requirements for building siting, landscaping, facade, fenestration, envelope and roof features that will impact energy use.
OPR (continued)

• Indoor Environmental Quality Requirements
  – For each program/usage area the intended use; anticipated occupancy schedules; space environmental requirements (including lighting, space temperature, humidity, acoustical, air quality, ventilation and filtration criteria); desired user ability to adjust systems controls; desire for specific types of lighting; and accommodations for after-hours use.

• Equipment and System Expectations
  – The desired level of quality, reliability, type, automation, flexibility, and maintenance requirements for each of the systems to be commissioned.
  – Provide any specific efficiency targets, or desired technologies.
OPR (continued)

• Building Occupant and O&M Personnel Requirements
  – Describe how the facility will be operated, and by whom.
  – Describe the desired level of training and orientation required for the building occupants to understand and use the building systems.
Basis of Design (continued)

Owner’s Project Requirements

What

Basis of Design

How
Basis of Design (continued)

• Primary Design Assumptions
  – including space use, redundancy, diversity, climatic design conditions, space zoning, occupancy, operations and space environmental requirements

• Standards
  – including applicable codes, guidelines, regulations, and other references that will be followed

• Narrative Descriptions
  – including performance criteria for the HVAC&R systems, lighting systems, hot water systems, on-site power systems, and other systems that are to be commissioned
Cx Specifications

• Develop and incorporate commissioning requirements into the construction documents
  – Commissioning team involvement
  – Contractors' responsibilities
  – Submittals and submittal review procedures for Cx process/systems
  – Operations and maintenance documentation, system manuals
  – Meetings
Cx Specifications (continued)

• Develop and incorporate commissioning requirements into the construction documents
  – Construction verification procedures
  – Start-up plan development and implementation
  – Functional performance testing
  – Acceptance and closeout
  – Training
  – Warranty review site visit
Commissioning Plan

- Commissioning Program Overview
  - General project information
  - Systems goals and objectives to be commissioned
  - Commissioning scope
    - Systems to be commissioned
    - Sample amount
    - Monitoring requirements
Cx Plan (continued)

- Commissioning Team
  - Team members, roles and responsibilities
  - Communication protocol, coordination, meetings and management
  - Commissioning specifications anticipated

- Estimated project commissioning schedule with start dates and end dates
Cx Plan (continued)

- Description of commissioning process activities
  - Documenting the Owner’s Project Requirements
  - Preparing the Basis of Design
  - Pre-functional checklists and startup procedures
  - Developing systems functional test procedures and verification procedure
  - Verifying systems performance
  - Reporting deficiencies and the resolution process
  - Accepting the building systems
Cx Plan (continued)

• Description of Commissioning Process Activities (continued)
  – Documenting the commissioning review process
  – Reviewing contractor submittals
  – Developing the systems manual
  – Verifying the training of operations personnel
  – Reviewing building operation after final acceptance
Installation and Functional Performance Tests

• The purpose of commissioning is to verify the performance of commissioned systems as installed to meet the OPR, BOD, and contract documents.
  – Installation inspection
  – Systems performance testing
  – Evaluation of results compared to OPR/BOD
Commissioning Report

• Complete a summary commissioning report
  – The summary report should include confirmation from the CxA indicating whether individual systems meet the requirements of the OPR, BOD, and Contract Documents

• Executive summary of the process and the results of the commissioning program – including observations, conclusions and any outstanding items
Commissioning Report (continued)

• A history of any system deficiencies identified and how they were resolved – including any outstanding issues or seasonal testing scheduled for a later date

• Systems performance test results and evaluation (any other supporting information can be compiled as a Cx record but is not required in the summary report)
• Enhanced commissioning could also provide:
  – A summary of the design review process with comments and responses
  – A summary of the submittal review process
  – A summary of the O&M documentation and training process
Commissioning Report (continued)

- Electronic Cx Report recommended
Commissioning for Green Building Rating Systems
Systems to be Commissioned

• The scope of work is usually determined by the owner; however, the following systems/equipment may be included:
  – Mechanical Systems
    • HVAC&R (Heating, Ventilation, Air Conditioning, & Refrigeration)
    • Indoor Air Quality Systems
    • Pumping/Piping Systems
    • Plumbing Systems
      – Domestic hot water
    • DDC Controls (Software and Hardware)
    • Energy and Water Measurement Devices
Systems to be Commissioned

– Electrical Systems
  • Power Distribution
  • Switchgear
  • Grounding
  • Lighting and lighting control

– Specialty Electrical Systems
  • Security and Fire Alarm Systems
  • Voice/Data Systems
  • Standby Power Systems
  • Daylighting Controls
Systems to be Commissioned

– Building Envelope
  • Thermal and moisture integrity
  • Building envelope pressurization
– Renewable Energy Systems
– Irrigation Systems
BEAM Plus for New Buildings v1.1

• EU 10 Testing and Commissioning
  – Commissioning Specifications
    • 1 credit for provision of appropriate specifications and cost provisions in contract documents detailing the commissioning requirements for all systems and equipment that impact on energy use and indoor environmental quality.
  – Commissioning Plan
    • 1 credit for the appointment of a commissioning authority and provision of a detailed commissioning plan that embraces all specified commissioning work.
BEAM Plus for New Buildings v1.1

• EU 10 Testing and Commissioning (continued)
  – Commissioning
    • **1 credit** for ensuring full and complete commissioning of all systems, equipment and components that impact on energy use and indoor environmental quality.
  – Commissioning Report
    • **1 credit** for providing fully detailed commissioning reports for all systems, equipment and components that impact on energy use and indoor environmental quality.
  – Independent Commissioning Authority
    • **1 BONUS credit** for engagement of an independent commissioning authority in the Testing and Commissioning process.
Commissioning Requirements

LEED Building Design & Construction 2009

EA: Prerequisite 1
- Fundamental Building Systems Commissioning

EA: Credit 3
- Enhanced Commissioning
LEED 2009 Fundamental Cx Tasks

Task 1: Cx Authority Selection
Task 2: Develop OPR/BOD
Task 3: Cx Requirements in CDs
Task 4: Develop & Implement Cx Plan
Task 5: Verify Installation & Performance
Task 6: Cx Summary Report
LEED 2009 Enhanced Cx Intent

• Begin the commissioning process early during the design process…and execute additional activities after systems performance verification is completed.
LEED 2009 Enhanced Cx Tasks

Task 1: Cx Authority Selection
Task 2: Design Reviews
Task 3: Submittal Reviews
Task 4: Systems Manual
Task 5: Training
Task 6: Operations Review after Occupancy

The CxA must perform these tasks
Task 1: Cx Authority Selection

- Prior to the start of the construction documents phase, designate an independent CxA to lead, review, & oversee the completion of all commissioning process activities.
  - The CxA shall have documented commissioning authority experience in at least two building projects
  - The individual serving as the CxA shall be independent of the work of design and construction; not an employee of the design firm, though they may be contracted through them; not an employee of, or contracted through, a contractor or construction manager holding construction contracts; and can be a qualified employee or consultant of the Owner.
  - The CxA shall report results, findings and recommendations directly to the Owner
  - This requirement has no deviation for project size
Task 2: Design Reviews

• The CxA shall conduct, at a minimum, one Cx design review of the OPR, BOD, and design documents prior to mid-construction documents phase and back-check the review comments in the subsequent design submission.
  – Clarity, completeness and adequacy of OPR
  – Verifying all issues discussed in OPR are addressed adequately in BOD
  – Reviewing design documents for achieving the OPR and BOD and coordination of commissioned systems

• Additional reviews by the CxA, throughout the design and construction process may be advisable and appropriate depending on the project duration, phasing, complexity and the Owner’s requirements.
Task 3: Submittal Reviews

- The CxA shall review contractor submittals applicable to systems being commissioned for compliance with the OPR and BOD. This review shall be concurrent with the A/E reviews and submitted to the design team and Owner.
  - Meeting the OPR and BOD
  - Operation and maintenance requirements
  - Facilitating performance testing

- The CxA review of contractor submittals does not, typically, substitute or alter the scope or responsibility of the design team’s obligations to approve or reject submittals.
Task 4: Systems Manual

- Develop a systems manual that provides future operating staff the information needed to understand and optimally operate the commissioned systems.
- Provide a Systems Manual in addition to the O&M Manuals submitted by the Contractor. The Systems Manual generally focuses on operating, rather than maintaining the equipment, particularly the interactions between equipment.
## Task 4: Systems Manual (continued)

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<td>Final version of the BOD</td>
<td>A/E</td>
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<tr>
<td>System single line diagrams</td>
<td>A/E</td>
</tr>
<tr>
<td>As-built sequences of operations, control drawings and original setpoints</td>
<td>Contractor</td>
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<tr>
<td>Operating instructions for integrated building systems</td>
<td>Contractor</td>
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<tr>
<td>Recommended schedule of maintenance requirements and frequency, if not already included in the project O&amp;M manuals</td>
<td>Contractor</td>
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<tr>
<td>Recommended schedule for retesting of commissioned systems with blank test forms from the original Commissioning Plan</td>
<td>CxA</td>
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<tr>
<td>Recommended schedule for calibrating sensors and actuators</td>
<td>Contractor</td>
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</tbody>
</table>
Task 5: Training

- Verify that the requirements for training operating personnel and building occupants are completed.
- Based on the particular project, establish and document training expectations and needs with the Owner. Ensure that operations staff and occupants receive this training and orientation.
- Pay particular attention to new or uncommon sustainable design features that may have a potential to be over-ridden or removed because of a lack of understanding. Document that the training was completed according to the contract documents.
Task 5: Training (continued)

- Common Training Topics
  - General purpose of system (design intent)
  - Use of O&M manuals
  - Review of control drawings and schematics
  - Startup, normal operation, unoccupied operation, seasonal changeover, manual operation, control setup and programming troubleshooting, and alarms
  - Interaction with other systems
  - Adjustments and optimizing methods for energy conservation
  - Special maintenance and replacement sources
  - Occupant interaction issues
  - System response to different operating conditions
Task 6: Occupancy Review

- Assure the involvement by the CxA in reviewing building operation within 10 months after substantial completion with O&M staff and occupants. Include a plan for resolution of outstanding commissioning-related issues.

- The CxA should coordinate with the Owner and the O&M staff to review the facility and its performance 8 to 10 months after handover of the facility.
Task 6: Occupancy Review (continued)

• Any outstanding construction deficiencies or deficiencies identified in this post-occupancy review should be documented and corrected under manufacturer or contractor warranties.

• The CxA review of the building operation with operations staff and occupants should identify any problems in operating the building as originally intended. Any significant issues identified by the CxA that will not be corrected should be recorded in the systems manual.
EA Credit 3: Completion Submittals

• Submittal Documentation
  – This credit is submitted as part of the Construction Submittal
    • Provide the name, firm and experience information for the CxA
    • Confirm that the 6 required tasks have been completed
    • Provide a narrative description of the results of the commissioning design review, implementation of the systems manual and training, and the plan for the review of building operation at 8 to 10 months
# LEED 2009 Commissioning Tasks

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<td>EA C3, Task 1</td>
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<td>Owner’s project requirements,</td>
<td>2. Document owner’s project requirements; Develop basis of design</td>
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<td>Owner or CxA Design team</td>
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<td>6. Conduct commissioning design review prior to mid-construction documents</td>
<td>EA C3, Task 2</td>
<td>CxA</td>
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<td>7. Review contractor submittals applicable to systems being commissioned</td>
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<td>8. Verify installation and performance of commissioned systems</td>
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<td>9. Develop systems manual for commissioned systems</td>
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<td>O&amp;M training</td>
<td>10. Verify that requirements for training are completed</td>
<td>EA C3, Task 5</td>
<td>Project team or CxA</td>
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<td>Substantial completion</td>
<td>11. Complete a summary commissioning report</td>
<td>EA P1, Task 6</td>
<td>CxA</td>
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<tr>
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<td>12. Review building operation within 10 months after substantial completion</td>
<td>EA C3, Task 6</td>
<td>CxA</td>
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</table>

Although EA Prerequisite 1 does not require the CxA to be on the project team until just before the equipment installation phase, if brought in earlier, the CxA can help the owner develop the project requirements and assist with other important commissioning tasks.

Some commissioning tasks can be performed by the owner or other project team members, however, the review of the owner’s project requirements and basis of design must be performed by the CxA. For EA Prerequisite 1, Fundamental Commissioning, this may be performed at any time before verification of equipment installation and acceptance.
LEED 2009 Fundamental Cx
Systems to be Commissioned

• HVAC&R systems and associated controls
• Lighting and daylighting systems
• Domestic water systems
• Renewable energy systems
LEED 2009 Enhanced Cx Systems to be Commissioned

- Same systems as Fundamental Cx
- Owner may elect to include other systems, such as:
  - Building envelope
  - Storm water management system
  - Irrigation
# LEED BD&C 2009 Reference Guide

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<th>EAc3 Task #</th>
<th>Task Description</th>
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<th>If you are meeting EAp1 &amp; EAc3</th>
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<td>1</td>
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<td>Owner or Project Team</td>
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<td>2</td>
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<td>Document Owner’s Project Requirements (OPR)</td>
<td>Owner</td>
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<td>2</td>
<td></td>
<td>Develop Basis of Design</td>
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<td>3</td>
<td></td>
<td>Incorporate commissioning requirements into the construction documents</td>
<td>Project Team or CxA</td>
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<td>2</td>
<td></td>
<td>Conduct commissioning design review prior to mid-construction documents</td>
<td></td>
<td>CxA</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Develop and implement a commissioning plan</td>
<td>Project Team or CxA</td>
<td>Project Team or CxA</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Review contractor submittals applicable to systems being commissioned</td>
<td></td>
<td>CxA</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Verify the installation and performance of commissioned systems</td>
<td>CxA</td>
<td>CxA</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Develop a systems manual for the commissioned systems</td>
<td></td>
<td>Project Team or CxA</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Verify that the requirements for training are completed</td>
<td></td>
<td>Project Team or CxA</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Complete a summary commissioning report</td>
<td>CxA</td>
<td>CxA</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Review building operation within 10 months after substantial completion</td>
<td></td>
<td>CxA</td>
</tr>
</tbody>
</table>

*Project Team = Owner, Architect, Engineer and/or Builder*
Guidance on Functional Performance Testing
**Functional Performance Test**

- Test of the dynamic function and operation of equipment and systems using manual (direct observation) or monitoring methods
  - Functional testing is the dynamic testing of systems (rather than just components) under full automatic operation
  - Systems are tested under various modes, such as during low cooling or heating loads, high loads, component failures, unoccupied, varying outside air temperatures, fire alarm, power failure, etc.
  - The systems are run through all the control system’s sequences of operation and components are verified to be responding as the sequences state.
Commissioning HVAC Systems

• While simple in concept, HVAC systems are actually complex applications of technology and physical principles that must function in a dynamic environment to meet the changing requirements of the loads and occupants they serve

• Attempt to explore all the operating conditions and possible failures when writing the functional performance tests
Writing a Functional Test

• Preparation Element
  – Purpose
  – Equipment needed
  – Precautions
  – Documentation
  – Acceptance criteria
  – Contractor coordination

• Planning Element
  – Prerequisites
  – Procedures
  – Exit Strategy
  – Return to normal
Writing a Functional Test

• Prerequisites for functional tests typically includes:
  – Sensor calibration
  – Pre-functional tests
  – Start-up
  – Test and balance, and
  – All control sequences tested and validated by contractor
Roles and Responsibilities During Testing

• Must decide whether Cx provider or installing contractor performs/executes test procedures
  – Should be stipulated in the specification so that each contractor can bid accordingly

• Things to consider...
  – Liability issues
  – Warranty issues
  – Contractor cost to perform test (discuss with owner during design-phase Cx)
A Good Test Process Begins with a Good Specification

- Stipulate all roles/responsibilities in the appropriate sections
- Specify key testing acceptance criteria
  - Critical if looking to verify energy performance
- Specify post-occupancy/monitoring
  - Identify points that will be monitored and specify sample rates
  - Making this requirement stringent may help in eliminating DDC systems with system architectures that make trending/monitoring more difficult
Testing Objectives

• System Functionality
  – Setpoint and control sequences programmed correctly
  – Does system function per the sequence of operations?

• System Performance
  – Are control loops stable?
  – Are time/staging delays adequate to prevent short cycling?

• Energy Performance
  – Longer-term monitoring and calibration of building model
  – Verify benchmarks established in OPR
  – System diagnostics and optimization
  – Benchmark future system operation
Testing Objectives

• Test system functionality and monitor system performance
  – Cost effective method may be to verify that all systems function and can operate safely (i.e. adequate ventilation; deliver conditioned air to spaces; all safeties work) and then monitor building operation to let the building “tell you” if there are operational problems

• Energy performance
  – Useful approach to develop operational benchmarks and enhance the persistence of proper system operation over time
  – More costly and time consuming but may be able to pay for itself based on optimized sequences and fixing operational problems
Establishing Testing Priorities

• Test all equipment
  – If required by owner/spec
  – May be warranted in critical applications
    • Cleanrooms
    • Laboratories
    • Hospitals

• Test based on representative sample
  – Select 20% to 30% for initial testing
  – Select additional 20% to 30% if X% of initial sample fails
  – Can be selective in testing subsequent samples if a specific problem reoccurs
Functional Testing Guide

• PECI has an online Functional Testing Guide at www.peci.org/ftguide/
  – Test guidance documents
  – Checklist tool and testing directory
  – Control system design guide
The information in this Functional Testing Guide can help commissioning providers to:

– Understand how to test from a systems perspective
– Identify common problems and the root causes of these problems
– Customize test procedures to meet the needs of their specific projects
– Understand why a specific test sequence is being executed
– Understand the possible outcomes and necessary precautions during testing
– Qualitatively understand the costs and benefits of testing
Functional Testing Checklist Tool and Test Directory

Functional Testing Checklist Tool

**Checklist Tool**

The Checklist Tool contains abbreviated checklists of key commissioning test requirements, preparations, and cautions for the systems and components covered in the Functional Testing Guide (FT Guide). Each checklist provides useful links to information found in relevant sections of the FT Guide and the Control System Design Guide. Using the checklists are a quick way to evaluate an existing functional test, as well as a portal into the FT Guide for supporting information.

![View Checklist Tool](image)

Functional Test Directory

**Test Directory**

The Test Directory contains direct links to each of the 95 publicly-available prefunctional checklists, functional test procedures, and test guidance documents referenced in the Functional Testing Guide (FT Guide). Each test is categorized based on the system module in which it occurs in the FT Guide.

![View Test Directory](image)
Functional Test Directory

• Test Library
  – 95 publicly available tests
    • Pre-functional checklists
    • Functional testing
    • Testing guidance documents
  – Test are also categorized by system type
  – All tests can be downloaded and saved as Word documents
Control System Design and Review are Critical to Commissioning Success
A Controls Process
Gone Insane

Start new project

Avoid getting out in the field

Profess no knowledge of DDC

Develop statement of intent and performance spec

Bid project and select low bidder

Receive control shop drawings

Profess no knowledge of DDC

Verify statement of intent pasted into shop drawings

Note that all loops should be PID

Approve tests that will guarantee efficient performance

Note that all systems shall be Cx’ed for efficient operation

Profess no knowledge of DDC

Receive draft Cx functional tests

Approve drawings reflecting intent & latest technology
Documenting Critical Details can be Important

• Obvious to HVAC designer ≠ Obvious to a non-HVAC savvy programmer
• Statement of intent ≠ successfully implementing stated intent
• Detailed narrative sequences
  – Document design intent
  – Improve persistence
  – Capture expert knowledge
  – Begin to cure the insanity
Thinking a New Way; Addressing the Details

- Actuator sequencing
- Independent safeties
- Setpoint reset
- Critical setpoints
- System arrangement
- System psychrometrics
- Transient conditions

- Normal positions
- Failure positions
- External controls
- O&M and Cx points
- Setpoint adjustability
- Control algorithm
- Alarms
Transient Conditions and System Stability

• Systems stability
  – Steady state = Easy
  – Transients = Hard

• Schedules
• Equipment failures
• Power outages
HVAC Designer Attributes

• Required
  – Knowledge of fundamental physical and HVAC principles
  – Ability to think logically

• Desirable
  – Intimate knowledge of DDC control systems
  – Desire to get out into the field
Narrative Sequence Bottom Lines

• HVAC designers are familiar with HVAC fundamentals and know how to think logically
• Detailed narrative sequences communicate the designer’s knowledge to the control system vendor, the commissioning team and the operating team
• The HVAC designer knows more about the details of DDC control than they think
Curing the Insanity

1.**Develop a narrative sequence**
2.**Bid project and select an informed low bidder**
3.**Receive control shop drawings**
4.**Profess knowledge of HVAC and logical thinking**

Start new project

- Avoid getting out in the field
- Approve tests that will verify design intent and optimize systems
- Communicate design intent and the need for test to verify it
- Profess knowledge of HVAC and logical thinking

Receive draft Cx functional tests

- Verify details are addressed
- Note that all loops should be PID
- Approve drawings reflecting details & latest technology
A DDC System Architecture Resource

- Generic, on-line system architecture information
  - Configuration
  - Equivalency
  - Performance specs

- Sensor technology resource
  - DDC primer
  - Sensor tutorial

www.ddc-online.org
Specifying DDC Requirements

• Shop drawings
  – Include a requirement for a system architecture and system layout shop drawing
  – Require one drawing per AHU or system
  – Require control logic diagrams
• Require commissioning support
  – All necessary software
  – Remote access capability
Specifying DDC Requirements

- Analog sensors
  - Specify accuracy by application
  - Specify resolution by application
A Resource for Understanding Sensor Requirements

Point List Specification Guidance


Recommendations for:
- Monitoring requirements
- Accuracy
- Point name conventions
Specifying DDC Requirements

• Specify requirements the system architecture must support
  – Trending requirements
    • Sampling rate
    • Archiving
    • Commissioning and normal operations
Specifying DDC Requirements

• Specify requirements the system architecture must support
  – Specify response times
  – Elapsed time between alarm occurrence and annunciation
  – Elapsed time for change of setpoint to update
  – Elapsed time for start/stop command to initiate
  – Elapsed time for a change of value or state to update
  – Elapsed time for a graphic to refresh and update 10 points
Specifying DDC Requirements

• Specify controller application requirements/acceptable applications
  – Application specific secondary controllers
    • Terminal units
    • Small unitary equipment
  – Fully programmable primary controllers
    • Air handling systems
    • Central plants
Specifying DDC Requirements

• Specify software requirements
  – What do you need to be able to do?
    • Monitor, supervise control, edit and add points
    • Change set points, timing parameters, and loop-tuning constants in all control units
    • Enter programmed start/stop time schedules
    • View alarms and messages
    • Modify existing control programs in all control units
    • Upload/Download programs, database, etc.
Specifying DDC Requirements

- Specify software requirements
  - How is the system programmed?
    - Line code
    - Graphic programming
    - Off-line simulation capabilities
Specifying DDC Requirements

- Specify software requirements
  - Specify graphic capabilities
    - How do you penetrate the data base?
    - Floor plans or directory tree?
    - One per system or one per typical system?
    - Summary tables or not?
    - Engineer’s system diagrams or theirs?
Specifying DDC Requirements

• Specify software requirements
  – Diagnostic capabilities
    • Alarm settings
    • Response instructions?
    • Smart alarms?
Specifying DDC Requirements

• Specify commissioning and set-up requirements
  – Who sets up the trends and what are the requirements?
  – Who sets up the schedules and what are the requirements?
  – What must be in place prior to commissioning?
  – How will coordination with the Testing and Balancing Contractor be accomplished?
  – How many re-tests are allowed and what are the penalties for excessive commissioning failures?
Point Lists
Complimenting the Specs and Defining Key Requirements

• Concepts
  – Level the playing field
  – Define requirements
• Control
• Monitoring
• Diagnostics

• Important Elements
  – System and service
  – Point name/Identifier
  – Sensor requirements
  – Alarm requirements
  – Trending requirements
Curing the Insanity

- Develop a narrative sequence, defined specs and point list
- Bid project and select low bidder from a level playing field
- Receive control shop drawings

- Start new project
- Verify details are addressed
- Note that all loops should be PID

- Avoid getting out in the field
- Approve tests that will verify design intent and optimize systems
- Communicate design intent and the need for test to verify it
- Receive draft Cx functional tests
- Approve drawings reflecting details & latest technology

- Profess knowledge of HVAC and logical thinking
- Profess knowledge of HVAC and logical thinking
The Integration and Coordination Cx Meeting

• Consider accomplishing the final approval for the control system drawings via a meeting with:
  – Controls contractor
  – Owner
  – Designer
  – Other interested parties

• Topics to be discussed at this meeting include:
  – Point names
  – Alarms and setpoints
  – Graphics
  – Control sequences
Early Team Integration = Savings

• Changes before programming - EASY! (low cost or no cost)
• Changes after programming - HARD! (EXPENSIVE!)
A DDC System Design Resource

- ASHRAE Guideline 13
- Available for download at www.ASHRAE.org
An On-line Commissioning Resource

California Commissioning Collaborative: www.CaCx.org
Enabling Success with the Controls Process

- Own knowledge of HVAC and logical thinking
- Develop a narrative sequence, defined specs and point list
- Bid project and select low bidder from a level playing field
- Receive control shop drawings
- Own knowledge of HVAC and logical thinking
- Start new project with a field perspective
- Develop an interest in how systems work
- Approve tests that will verify design intent and optimize systems
- Communicate design intent and the need for test to verify it
- Own knowledge of HVAC and logical thinking
- Eagerly anticipate draft Cx functional tests
- Approve drawings reflecting details & latest technology
- Verify details are addressed
- Verify appropriate control algorithms
Commissioning Costs and Schedule Impacts
Commissioning Budget

• Cx fees range 2-4% of systems commissioned
  – 0.5 – 1% of total project construction cost
  – Depends on scope and project size

• How to minimize?
  – Make Cx part of the project expectations from the start
  – Involve building operations and maintenance staff in the commissioning process
Cx Performance Benchmarks

Based on 643 Buildings Surveyed

July 21, 2009

Lawrence Berkeley National Laboratory: http://cx.lbl.gov
Cx Projects are Cost-Effective

Based on 643 Buildings Surveyed


July 21, 2009

Lawrence Berkeley National Laboratory: http://cx.lbl.gov
Cx Scheduling

• Schedule Cx activities throughout
  – Involve Cx provider early
  – Begin Cx process in the design phase
  – Allow for iterative design refinement
  – Allow time to correct deficiencies found by testing

• Try to schedule Cx activities to not be on the critical path at the end of the project
Commissioning
Conclusions
Cx Positive Impacts

• Provides quality control
• “Bridges the gap” between design, construction and operation
• Verifies that Design Intent is met
• Monitors construction compliance
• Assures systems operate as intended
• Validates performance measurements
• Better operator training
Cx Benefits

• Reduced design errors & omissions
• Improved construction efficiency & coordination
• Reduced construction change orders
• Improved energy efficient performance
• Improved indoor environmental quality
• Improves quality and performance of green buildings
Conclusions

- There are many challenges in commissioning
- Challenges have to be addressed
  - straight on
  - early
  - fully
- Experience has shown that the commissioning benefits are worth the effort and cost
Albert Einstein

“Insanity: doing the same thing over and over and expecting different results”
Additional Information

- Become an **ASHRAE** member!
- ASHRAE (www.ashrae.org)
  - Guideline 0
  - Guideline 1
- Portland Energy Conservation Institute (www.peci.org)
- Building Commissioning Association (www.bcxa.org)
- Commissioning Specialists Association (www.csa.org.uk)
Additional Information

• US Green Building Council LEED (www.usgbc.org)
• BEAM Standards (www.hk-beam.org.hk)
• Commissioning Specialists Association (www.csa.org.uk)
ASHRAE’s Commissioning Process Management Professional (CPMP) Certification Program
ASHRAE Commissioning Process Management Professional

- Designed & developed in collaboration with APPA, BCA, IES, NEBB, SMACNA, and TABB

- Purpose of program:
  - To assist building owners, developers, standards writing agencies, and others in assessing the capability of individuals to manage the whole building commissioning process with the owner

- Purpose of exam:
  - To evaluate an individual’s ability to manage the commissioning process
ASHRAE Commissioning Process Management Professional

• For more information on ASHRAE’s Certification Programs
  – Visit www.ashrae.org/certification
  – E-mail certification@ashrae.org
What is PV Commissioning?

• A quality oriented process for achieving, verifying and documenting that the performance of PV system and assemblies meet defined objectives and criteria
Elements of PV Commissioning

- Verification that installation is complete, safe and aesthetically acceptable
- Verification that all components of system are robust and permanent
- Verification of system performance and proper system operation
- Documentation of as built conditions and required acceptance documentation
- Establishing performance benchmarks
- Training of owner personnel on basic system operation
PV Commissioning Process

• Preparation of required documentation, checklists, testing procedures, expected performance requirements and basis of design
• Incorporation into specifications and bid documents
• Specifying requirements for commissioning timeline
• Identifying responsible person or entity for commissioning
• Training owner on basic system operation
PV Commissioning Timeline

• Should be considered throughout the course of the PV installation project
• Should be planned during the design phase
• Should be built into system costs
• Should be carried out at end of construction and repeated as desired after project completion
• Ensure that weather is good and time-of-day is appropriate (for right irradiance)
• Conducted after burn-in period (especially for thin film amorphous silicon panels)
Who Commissions?

- Should represent the system owner
- Should be able to act independently in owner’s interest without conflict
- Should be an outside commissioning specialist for large projects
- Engineer or system designer could be used for smaller projects
- Must have sufficient knowledge about PV systems
Documentation Required

• As built drawings
• Cut sheets of modules and inverters
• Commissioning specifications
• Equipment manuals
• Forms for rebate programs or incentives
Commissioning Tasks

• Verify installation is complete
  – Are all components permanently and correctly installed?
  – Is all wiring complete and correct?
  – Is permanent utility power connection complete?
  – Are monitoring systems correctly wired?
  – Are most recent punch list items completed?
Commissioning Tasks

• Verify installation is safe
  – Has the permit been signed off?
  – Are mechanical and structural systems adequate and built to plans?
  – Is waterproofing, if required, completed satisfactorily?
  – Has the electrical design been adapted correctly?
    » Working clearances are met
    » Metallic surfaces are grounded correctly
    » Wire and conduit size installed are per plans
Commissioning Tasks

• Verify installation is robust and permanent
  – Ensure all outdoor equipment is designed to withstand the elements and environment
  – Ensure dissimilar materials are isolated to prevent galvanic corrosion
  – Ensure fasteners are stainless steel and steel rack elements are hot dipped galvanized or better
  – Wiring and conduit is suitable for their location
  – NEC required labeling is provided
  – No visual damage to modules
Commissioning Tasks

- Document as-built conditions
  - Photo document all existing installations
    » Arrays, conduit runs, disconnects, inverters
    » Main interconnection
  - Module layout matches roof plan drawing
  - Module string layout matches as-built string diagram including consistency of wiring and string numbering
  - Document model number and quantity of modules, inverters, combiner boxes, disconnects and monitoring system
Commissioning Tasks

• Documenting Performance
  – Most difficult and most important aspect of a commissioning a PV system
  – Involves documenting and comparing:
    • Expected performance
    • Actual performance
Determining Expected Performance

Expected System Performance ($P_E$)

$$P_E = P_{STC} \times K_I \times K_T \times K_S$$

- $P_{STC}$ - Standard DC output power of panel
- $K_I$ - Irradiance factor
- $K_T$ - Cell temperature factor
- $K_S$ - System derating factor
Determining Expected Performance

**Peak DC Power Output (P_{STC})**
Product of Panel STC DC rating and number of modules installed as part of the system

\[ = \text{Panel STC Rating} \times \text{number of modules} \]

For Example:

*Panel STC Rating*: 230 W STC rating

*Number of Modules*: 100

*Total DC Power Output*: 23000 W or 23 kW
Determining Expected Performance

Irradiance Factor ($K_I$) =

\[
\frac{\text{Actual measured irradiance}}{\text{STC irradiance (1000 W/m}^2\text{)}}
\]

For Example:

Actual measured Irradiance: 800 W/m$^2$

STC Irradiance: 1000 W/m$^2$

Irradiance Factor: 0.8
Module Cell Temperature Factor ($K_T$) = \[ 1 + C_T \times (T_C - T_{STC}) \]

- $C_T$ - Module temperature coefficient of power
- $T_C$ - Actual cell temperature in Celsius
- $T_{STC}$ - Standard Test Condition cell temperature (25°C)

For Example:
- $C_T$ -0.003/°C – 0.005/°C
- $T_C$ 35°C
- $T_{STC}$ 25°C
- $K_T$ 0.97
Determining Expected Performance

System Derating Factor ($K_S$) – is a product of all of the system efficiencies and following sub factors

- Module mismatch
- Inverter efficiency
- Module soiling
- Module name plate tolerance
- Wiring losses
- Shading
- Tracking efficiency
- Age
Determining Expected Performance

• System Derating Factor ($K_s$)
  – Module mismatch: 0.97 is representative unless the system uses individual module power point tracking devices, such as microinverters or dc-to-dc power optimization devices, in which case the mismatch is eliminated and this subfactor becomes 1.0
  – Inverter efficiency: A value in the 0.94 to 0.96 range is typical for most modern high efficiency grid-tied inverters
  – Module soiling: 1.0 assuming the system being commissioned is brand-new, there is no need to derate for soiling
  – Module nameplate tolerance: It is reasonable to use 0.99 or better for most high-quality module manufacturers
  – Wiring losses: 0.98 include dc wiring losses and connection losses up to the inverter, where instantaneous power output measurements are usually made
Determining Expected Performance

• System Derating Factor ($K_s$)
  – Shading: If the array is shaded at all, proper verification of performance output is very difficult. Make sure it is not shaded during commissioning.
  – System availability: During commissioning there is no need to derate for availability; the system must be operating (available) when taking power measurements.
  – Tracking efficiency: Trackers should be in perfect working order during commissioning. Since irradiance values are taken in the module plane, this factor is irrelevant regardless.
  – Age: A brand-new system has yet to experience any age related degradation.
Documenting Actual Performance

• Megger test each home run
• Measure $V_{OC}$ of each string
• Measure $I_{MP}$ for each string
• Inverter startup sequence
• Cell temperature
• Irradiance
• Inverter AC Power output
Documenting Actual Performance

• PV Cell Temperature
  – Measure at the beginning and at the end of performance measurement
  – Measure in different places on a module and in a variety of locations throughout the array
  – Take average of all measurements in degrees Celsius
Documenting Actual Performance

• Irradiance and Inverter AC Output
  – Take 15 minutes of averaged irradiance and AC output
  – Locate pyranometer
    • to have the exact azimuth and the tilt angle as the modules
    • to not shade any modules
  – Make sure readings on the pyranometer and the inverter are taken with in few seconds of each other for a total of three readings
  – Document readings of pyranometer in W/m² and inverter in W or kW with variation of less than 2%
## Documenting Performance Test Results

<table>
<thead>
<tr>
<th>Inverter #</th>
<th>Quantity of modules</th>
<th>STC watts per module</th>
<th>Total STC watts</th>
<th>System derating factor ($K_a$)</th>
<th>Irradiance factor ($K_i$)</th>
<th>Temp. factor ($K_t$)</th>
<th>Predicted watts ac</th>
<th>Measured watts ac</th>
<th>Measured/predicted watts ac</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td>215</td>
<td>3,870</td>
<td>0.89</td>
<td>0.84</td>
<td>0.962</td>
<td>2,789</td>
<td>2,975</td>
<td>107%</td>
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<tr>
<td>2</td>
<td>36</td>
<td>215</td>
<td>7,740</td>
<td>0.89</td>
<td>0.84</td>
<td>0.962</td>
<td>5,575</td>
<td>5,931</td>
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<tr>
<td>3</td>
<td>36</td>
<td>215</td>
<td>7,740</td>
<td>0.89</td>
<td>0.85</td>
<td>0.962</td>
<td>5,600</td>
<td>6,027</td>
<td>108%</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>215</td>
<td>7,740</td>
<td>0.89</td>
<td>0.84</td>
<td>0.962</td>
<td>5,597</td>
<td>6,042</td>
<td>108%</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
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<tr>
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<td>6,941</td>
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<td><strong>Total</strong></td>
<td>234</td>
<td>215</td>
<td><strong>50,310</strong></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td><strong>37,667</strong></td>
<td><strong>40,129</strong></td>
<td><strong>107%</strong></td>
</tr>
</tbody>
</table>
Performance Verification

• Compare expected performance data with actual performance data
• Readings should be within 5% the system design for successful performance test of the system
Acceptance Certification Documents ...

- System is safe
- Actual performance of system is within 5% of expected performance
- PV system operates in normal grid tie mode when presented with normal conditions such as in the presence of sun and utility power
Training

• Physical walkthrough of entire system notifying disconnect locations procedures
• Inverter operation including any display screens and status lights
• Monitoring systems
• Operation manuals and warranties
Conclusion

• Commissioning PV system ensures:
  – Owner project requirements are met
  – Equipment and systems are installed according to contract document, manufacturer’s instructions and minimum accepted industry standards
  – Performance of equipment and systems are maximized
  – Owner’s operating personnel are adequately trained

• Results in increased revenues and incentives

• Performance based incentives, feed in tariff and local codes will drive commissioning market
For Further Information

• SolarPro
  – www.solarprofessional.com
  – PV System Commissioning (Oct/Nov 2009)

• PVWATTS
  – www.nrel.gov/rredc/pvwatts/

• California EPBB Rebate Calculator
  – www.csi-epbb.com/
Thank You for Your Participation!