NCBC 2005
MAY 4-6
NEW YORK NY
GRAND HYATT
13th National Conference On Building Commissioning

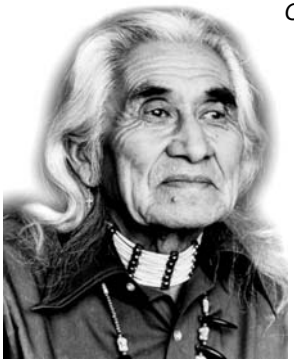
Session 17: Construction Phase Commissioning: It's Not Just Testing

Commissioning Findings from Design Review and Construction Observation

David Sellers
Senior Engineer, Technical Manager
PECI

"… Sometimes, the Magic Works and Sometimes It Does Not"

Chief Dan George as Old Lodge Skins in Little Big Man



A Problem in the Making

White cloud at the *combustion air intake* of a boiler on a common flue with other boilers =

- Condensing flue gas inside
- Carbonic acid
- Corrosion
  - Heat transfer surfaces
  - Combustion air system
  - Combustion air fan
  - Controls
  - Casing

A Problem in the Making

Major Damage to 8 Boilers During Temporary Operation!

How Could This Happen?

- Commissioning Included From Early Design Phases
- Major Construction
- Experienced Design and Construction Team
- Owner Heavily Involved in Construction
- Problem Identified Early
- Problem Discussed Frequently
- Potential for Damage Acknowledged By All

- My answer:

I don't really know, but "sometimes the magic works and sometimes, it does not".

This Begs the Question:

What Makes the Magic Work?

Starting Early Helps the Magic Work

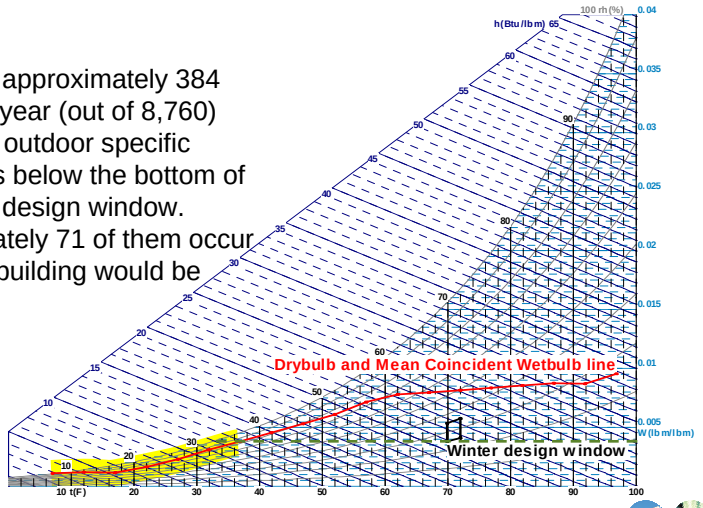
The Owners intent to provide a high quality internal environment leads the commissioning provider to ask a question during a design review meeting:

Do we really need to humidify in Seattle?

Hmmmm, lets think about that for a minute ….

Seattle + Winter = Mild and Moist

There are approximately 384 hours per year (out of 8,760) where the outdoor specific humidity is below the bottom of the space design window. Approximately 71 of them occur when the building would be operating.



Looking Humidification in the Bigger Picture

- Lost
  - Absolute assurance that indoor humidity will not be below 25 - 30% for 70-100 hours per year
- Gained
  - $100,000 savings in first cost
  - $6,000 savings in annual operating cost

What Made the Magic Work?

Technical Stuff

- Being aware of the environment
- Commissioning

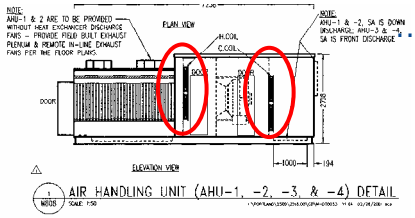
Non-Technical Stuff

- Thinking outside the box
- Flexibility

Does Fixed in Design Mean its Fixed?

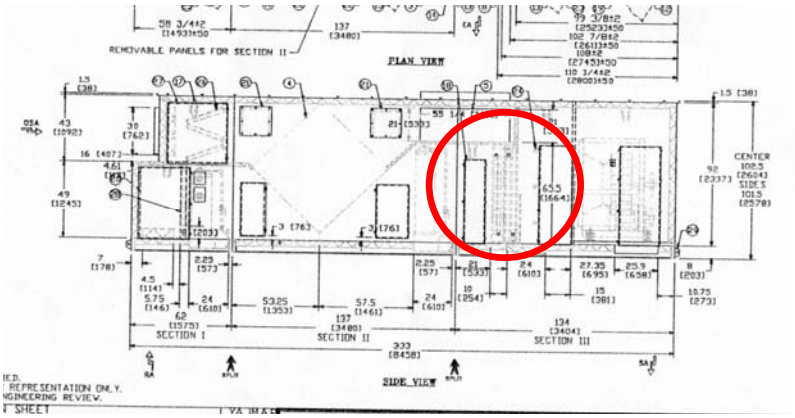
Design review identified critical 100% Outdoor air AHU design issues:

- Desirability of maximum face area
- Need for access
- Need for space for freezestat
- Preheat vs. warm up issues



… and the construction drawings reflected these comments

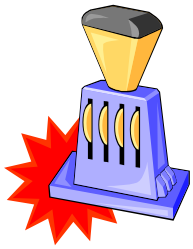
The Shop Drawing Reflects a Problem



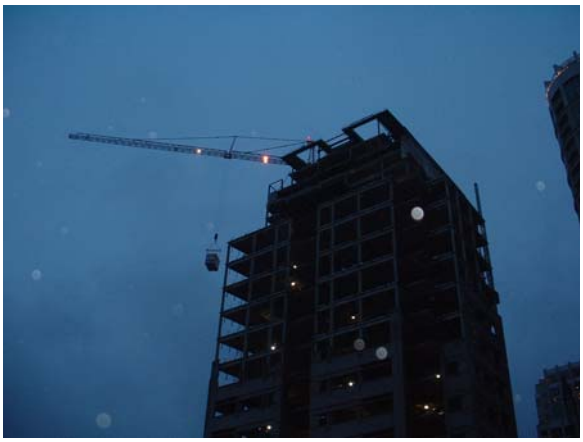
Note the lack of space between the coils!

Shop Drawing Mark-ups

- Note coil problem and other issues
- “Approved as Noted” to maintain schedule



The Equipment Arrives on Site …



… and a Problem Arrives With It

Coil connections match the uncorrected shop drawings, not the construction drawings

The Issues

- Freezing Issues
  - Equipment failures
  - Climate extremes
- Access issues
  - Maintenance
  - Sensor installation
- Operational issues
  - Potential nuisance shut downs
  - Draining the coil

The Good News

- The problem was solved with out major modification or expense via:
  - Focusing on solving the problem rather than assessing blame
  - Flexibility on the part of the Owner, Designer, and Contractors
  - Thinking “outside the box”

The Solution

- Use a feed-forward control strategy to operate the preheat valve based on entering conditions rather than leaving conditions
- The chilled water coil backs up an evaporative cooling process, so keep the coil drained
- Start-up and continuous commissioning to make sure it all works

What Made the Magic Work?

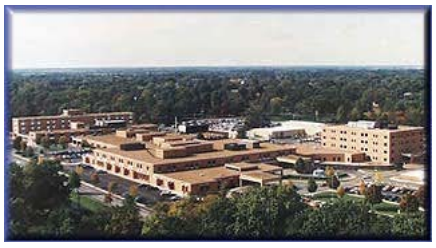
Technical Stuff

- Being aware of the environment
- Commissioning ||
- Technology

Non-Technical Stuff

- Thinking outside the box
- Flexibility ||

Making the Magic Work Requires Attention on Many Commissioning Fronts



Out of sight, out of mind in the Midwest

- 100 kW of electric snow melt installed at the new Emergency Room entrance
- No energy management system tie-in

Design phase Cx lapse

Images courtesy www.memhosp.com and www.squared.com .

Making the Magic Work Requires Attention on Many Commissioning Fronts

Images courtesy www.memhosp.com and www.squared.com .

The commissioning process

- Turned on during a snow storm
- Success – No snow or ice at the ER entrance!
- Forgot to turn it off after the storm

Construction phase Cx lapse

- No utility bill tracking program

Ongoing Cx lapse

Making the Magic Work Requires Attention on Many Commissioning Fronts

Images courtesy www.memhosp.com and www.squared.com .

Long term results

- No snow or ice at the ER entrance all winter
- Dry sidewalks after a thunderstorm in July

Ongoing Cx insight

- 2,400 kWh per day for months!

Cash flow lapse

The Solution

- Turn off the snow melt in the summer
- Add a pilot light to the contactor
- Be more aware of what's going on

What Made the Magic Work?

Technical Stuff

- Being aware of the environment
- Commissioning |||
- Technology||

Non-Technical Stuff

- Thinking outside the box
- Flexibility ||
- Taking action

Making the Magic Work Requires Training

- Owner requirement
  - AHU starters have “Test” – “Off” – “Auto” switches
  - Safeties (including the freeze-stat) over-ridden in the “Test” position for trouble-shooting purposes

Images courtesy www.eatonelectrical.com.

Making the Magic Work Requires Training

- Engineer’s push-back
  - Prefer no safety over-rides
  - If non-negotiable, then spring return from test

Images courtesy www.eatonelectrical.com.

Making the Magic Work Requires Training

- The result
  - Frozen coil
- The reason
  - Lack of training on spring return feature
  - A crescent wrench clamped to the switch tang holding the switch in the test position

Images courtesy www.eatonelectrical.com.

The Solution

- Train the operators
- Re-think compromise on critical issues

What Made the Magic Work?

Technical Stuff

- Being aware of the environment
- Commissioning |||
- Technology||

Non-Technical Stuff

- Thinking outside the box
- Flexibility ||
- Taking action

What Made (or would have made) the Magic Work?

Technical Stuff

- Being aware of the environment
- Commissioning |||
- Technology||

Non-Technical Stuff

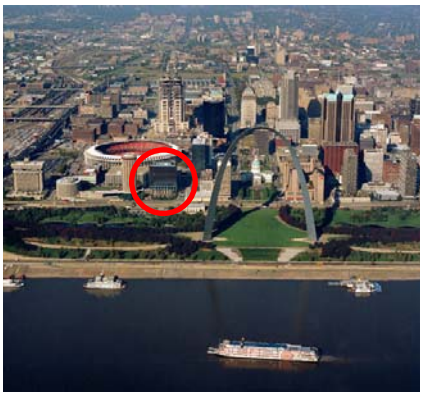
- Thinking outside the box
- Flexibility ||
- Taking action
- Courage of convictions

Magic Worked
|||

Magic Didn't Work
||

Knowledge Makes the Magic Work

- Mid-1980's vintage Midwest high rise (13 floors)
- Engineered smoke control cycle
  - Shuts down and isolates some units
  - Runs others to pressurize or exhaust fire floor
- Control system addresses smoke damper interlocks
  - Analog discharge static limit control
  - Limit switches



Test Results – Initial Engineered Smoke Cycle Functional Test

- Smoke damper closure triggered by fire alarm. ☑
- Fan shutdown triggered by smoke damper limit switch. ☑
- Smoke dampers close in less than 1 minute (5 seconds). ☑
- Duct is leak free. ☒
- Duct pressure rating is good. ☑
  - Ray Baltimore (control fitter) notes that the duct pressure gauge indicated 6 inches w.c. before we heard the bang; duct pressure class is 4 inches w.c.

Control System Design Didn't Address:

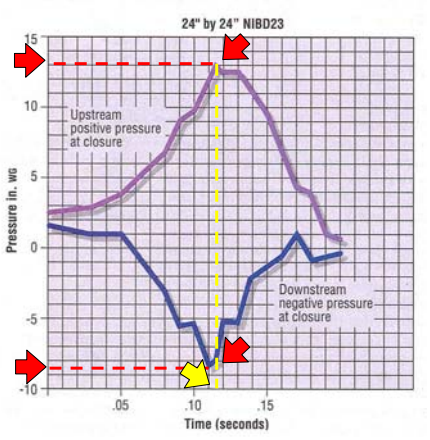
Pneumatic actuator speed

- The control designer probably should have thought of this
- (The control designer was me)

Air hammer

- The control designer never heard of this until Tom (graciously) said "*WE* must have air hammered the duct!"

Control System Design Didn't Address:



Images courtesy Ruskin's catalog

Air hammer

- The control designer never heard of this until Tom (graciously) said "*WE* must have air hammered the duct!"

See the FT Guide supplemental information for Chapter 13 – Distribution to learn more about air hammer and how to prevent it

The Solution

- Train the control designer/commissioning technician about air hammer (beyond having him blow the duct apart).
- Add restrictor tees to the bleed ports of the solenoids serving the actuators to slow them down on the close stroke.
- Zip screws
- Angle iron

What Made (or would have made) the Magic Work?

Technical Stuff

- Being aware of the environment
- Commissioning ~~||||~~
- Technology |||
- Knowledge

Non-Technical Stuff

- Thinking outside the box
- Flexibility ||
- Taking action
- Courage of convictions
- Try to look on the bright side

Magic Worked |||

Magic Didn't Work |||

Lesson's Learned Make the Magic Work
(Although some take a while to sink in)

- Mid-1980's vintage Midwest low-rise (6 floors)
- Combination fire/smoke dampers isolate return ceiling from return shaft on fire alarm

Photo is not of the actual damper but of a similar arrangement but with an electric actuator

- Control system addresses the potential for problems
  - Restrictors installed on the pneumatic actuators
  - Field personnel trained
  - Return static limit switches contemplated
    - Eliminated due to budget
    - *"What could go wrong on the return side with the actuators slowed down, right?"*

A Little Pressure Over A Lot of Area is What Can Go Wrong

- Air supplied to the dampers to hold them open for temporary AHU operation
- Fire alarm installation in progress
  - Fire alarm not powered up
  - Fire alarm relays energize solenoids to open dampers
    - Solenoid tubing connections temporarily reversed so non-energized solenoids hold dampers open
    - Condition placarded and discussed at job meeting

Test Results – Fire Alarm Panel Power-On Test

- Fire alarm panel inadvertently energized. ☑
- Return shaft smoke dampers start to slowly close. ☑
- Commissioning tech and control fitter on 3rd floor note "whooshing" sound. ☑
- Ceiling tiles begin to drop from the grid around the return shaft as the shaft wall deflects. ☑
- Commissioning tech and control fitter on 3rd floor put two and two together. ☑
- Commissioning tech and control fitter exchange brief remarks about the situation. ☑
- Control fitter makes mad dash to rooftop mechanical room and pulls disconnects on the air handling systems, averting disaster. ☑
- Commissioning tech buys control fitter a 6 pack. ☑
- Commissioning tech gets permission to purchase static limit switches. ☑

What Made (or would have made) the Magic Work?

Technical Stuff

- Being aware of the environment ||
- Commissioning 𝍸 |
- Technology ||||
- Knowledge ||

Non-Technical Stuff

- Thinking outside the box ||
- Flexibility ||
- Taking action ||
- Courage of convictions ||
- Try to look on the bright side
- Being in good physical shape

Magic Worked ||||

Magic Didn't Work |||

Magic May Not Work if Things Are Cast in Concrete (But it may keep them from becoming that way!)

- Northwest Regional Training Facility and Warehouse
  - LEED Gold
  - Radiant slab heating
  - Turn-key project
  - Aggressive construction schedule
- Contractor concerned about radiant slab pour
  - Tubing located to miss future floor penetrations
  - Tubing supported to prevent damage during pour
  - Plan of action to detect and repair damage during the pour
  - Plan of action to document tubing installation before the pour

Contractor Requests Cx Support on the Morning of the Concrete Pour

Contractor responsibilities

- Tubing installed ☑
- Concrete ordered and on the way ☑
- Worry ☑

Cx verification checks

- Tubing layout matches plans ☑
- Tubing layout documented ☑
- Tubing installed per manufacturers recommendations ☑
- Plan of action to detect and repair leaks in place ☑
- Perimeter insulation in place ☒

Solution

- Send concrete trucks back
- Continue to breath normally
- Install insulation

What Made (or would have made) the Magic Work?

Technical Stuff

- Being aware of the environment ||
- Commissioning 𝍸 ||
- Technology ||||
- Knowledge |||

Non-Technical Stuff

- Thinking outside the box ||
- Flexibility ||
- Taking action ||
- Courage of convictions ||
- Try to look on the bright side
- Being in good physical shape
- Luck

Magic Worked

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Magic Didn't Work

|||

Magicians Make the Magic Work

- Water feature pump targeted for impeller trim during MRCx
- Motor failure leads to motor replacement with a lower speed, lower horsepower motor

Magicians Make the Magic Work

- Water feature pump targeted for impeller trim during MRCx
- Motor failure leads to motor replacement with a lower speed, lower horsepower motor

Original	Replacement
15 hp	7-1/2 hp
20 amp	8 amp
1760 rpm	1180 rpm

Magicians Make the Magic Work

- Water feature pump targeted for impeller trim during MRCx
- Motor failure leads to motor replacement with a lower speed, lower horsepower motor

Motor replacement cost - $1,000

Estimated savings per year - $4,000

Magicians Make the Magic Work

- Water feature pump targeted for impeller trim during MRCx
- Motor failure leads to motor replacement with a lower speed, lower horsepower motor
  - Water feature aesthetics maintained
  - Preserves operation at "sweet spot" vs. impeller trim
  - Captures savings with normal maintenance expenditure

Magicians Make the Magic Work

What Made (or would have made) the Magic Work?

Technical Stuff

- Being aware of the environment ||
- Commissioning 𝍸 |||
- Technology 𝍸
- Knowledge ||||

Magic Worked

𝍸 |

Non-Technical Stuff

- Thinking outside the box |||
- Flexibility ||
- Taking action ||
- Courage of convictions ||
- Try to look on the bright side
- Being in good physical shape
- Luck
- Leadership and enthusiasm

Magic Didn't Work

|||

Buildings Are Prototypes

- Complex interactive machines
- Built and operated in a highly dynamic environment
- Built under tight time and budget constraints
- Incorporate constantly changing and evolving technology

A Few Problems Shouldn't Be A Surprise…

They Should Be Anticipated!

Design and Construction Phase Commissioning…

Part of the Magic that Solves or Prevents Problems…

… and, it Works More Often Than Not!

But, Its More than Just Saying You're Doing It

Technical Skills are Essential

- Familiarity with Commissioning
- Knowledge of the Fundamentals
- Familiarity with the Technology
- Being aware of the Environment

Other Skills Can Be *Extremely* Useful

- Thinking outside the box
- Flexibility
- Being Proactive
- Trusting Yourself
- Optimism
- Leadership and Enthusiasm

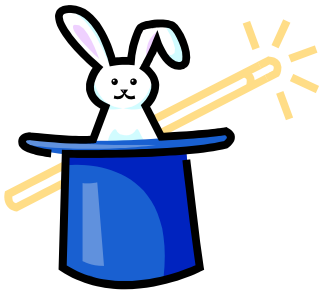
… and being open to good fortune can't hurt!

Try Some "Magic";

Make

- Trouble-free verifications
- Smooth start-ups
- Long term benefits

appear on your projects



Thanks for Attending!

Good Luck with your Projects

NATIONAL 13th CONFERENCE ON BUILDING COMMISSIONING

Session 23 – New Commissioning Tools from a Collaborative Research Project

What is the Functional Testing Guide and How are We Enhancing It?

David Sellers
Senior Engineer, Technical Manager
PECI

Origins of the Functional Testing Guide

- Research and Development Project
  - California Energy Commission's Public Interest Energy Research Program (PIER)
  - U.S. Department of Energy
  - Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems
- Original Goal
  - Compile a library of functional tests
  - Identify the gaps

Origins of the Functional Testing Guide

- Research and Development Project
  - California Energy Commission's Public Interest Energy Research Program (PIER)
  - U.S. Department of Energy
  - Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems
- PG&E's Commissioning Test Protocol Library
  - Focused on a similar goal
  - Reviewed 400+ functional tests
  - Compiled a library of publicly available tests
  - Not all testing requirements fully covered
  - Missing theory behind the tests

Origins of the Functional Testing Guide

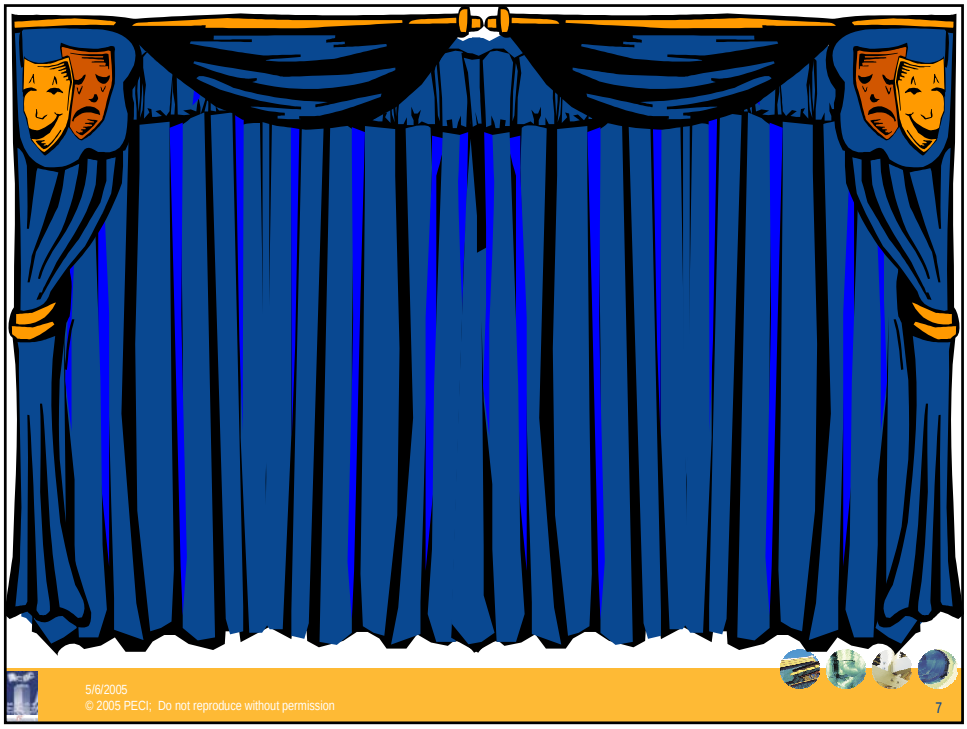
- Research and Development Project
  - California Energy Commission's Public Interest Energy Research Program (PIER)
  - U.S. Department of Energy
  - Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems
- NCBC 2000 Round Table Discussion
  - Should the project be re-focused?
  - What should the new focus be?

Origins of the Functional Testing Guide

- Research and Development Project
  - California Energy Commission's Public Interest Energy Research Program (PIER)
  - U.S. Department of Energy
  - Lawrence Berkeley National Laboratory's High Performance Commercial Building Systems
- Revised Goal
  - Complement the CTPL with a testing guideline
    - CTPL says *how* to test
    - FTG says *why*
      - Base on fundamentals
      - User adapts as needed
    - Provide cost benefit information
    - Begin to fill CTPL gaps
    - Provide a development framework

Released at NCBC 2003

- CD's
  - NCBC
  - PG&E training classes
- Download from:
  - http://buildings.lbl.gov/hpcbs/FTG
- Judging user acceptance
  - Feedback form at download
  - Word of mouth
  - LBNL survey



Enter, stage right: the STAC* Project

- Project Goal – Enhance the FT Guide based on user feedback
  - Develop the *Integrated Control and Operation* Chapter
  - Expand the Guide
    - Pumping Systems
    - Chiller/Condenser Systems
    - Boiler Systems
- Project Goal - Address barriers to the widespread uptake of Cx
  - Enhance the FT Guide
  - Add tests to the FT Guide
  - Provide Cx and RCx training
  - Develop/deploy a functional test checklist tool

*State Technologies Advancement Collaborative

Parallel FT Guide Development Paths, Comprehensive FT Guide Structure

STAC Sponsored *Functional Testing Basics* and *How to Write and Develop a Test* Chapter

STAC Sponsored Tools and RCx and Cx Training Based on the FT Guide

Test Specifications	Test Specifications	Test Specifications	Test Specifications
Air Handling Systems (Current FTG)	Pumping Systems (Current FTG)	Chiller and Condenser Systems (Current FTG)	Boiler Systems (Current FTG)
Organized by System Components	Organized by System Components	Organized by System Components	Organized by System Components
Benefits and Tips Tables	Benefits and Tips Tables	Benefits and Tips Tables	Benefits and Tips Tables
Fundamentals and Theory Discussion			
Links to CTPL* Tests			

Integration Tests

DOE Sponsored *Integrated Control and Operation* Chapter

*PG&E's Commissioning Test Protocol Library

Current Status

DOE Project

- Final Drafts
  - Integrated Control and Operation Chapter
  - Integration related tests
    - Recovery from power outage
    - Fire and smoke damper
    - Building pressurization
    - Relative calibration
  - Benefits and Tips Tables
    - Pumping Systems
    - Chiller/Condenser Systems
    - Boilers
- June 2005 Release

Current Status

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  - Benefits and Tips Tables
    - Pumping Systems
    - Chiller/Condenser Systems
    - Boilers
- Late May 2005 Release

STAC Project

- Research Conducted on the Use of the current FT Guide
- Top 25 Most Desirable Test Additions Identified

Top 25 Most Desirable Additions

(By rank)

1. Pump Performance Test
2. Freezestat Test
3. Evaporatively Cooled AHU Test
4. AHU Safeties And Integrated Operation Test
5. Valve Leak-by Test
6. Smoke/Fire Damper Test
7. Packaged Rooftop Units Test
8. Generic "Build Your Own Procedure" Form Test
9. Demand Controlled Ventilation Test
10. Visual Envelope Inspection Test
11. Discharge Temperature/Pressure Reset Interaction Test
12. Building Pressurization Test
13. Radiant Slabs Test

Top 25 Most Desirable Additions
(By rank)

14. Heat Recovery Ventilator Test
15. Power Failure Recovery Test
16. Steam Boiler Test
17. VAV Flow/System Integration Test
18. High Turn Down Ratio Test
19. Loss Of Control Network Communications Failure Mode Test
20. Air-cooled Dx Condenser Test
21. Stairwell Pressurization Test
22. Underfloor Supply Plenum Test
23. Heating Hot Water System Integration Test
24. Condensing Hot Water Boiler Test
25. Fluid Coolers Test

Current Status

DOE Project

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  - Benefits and Tips Tables
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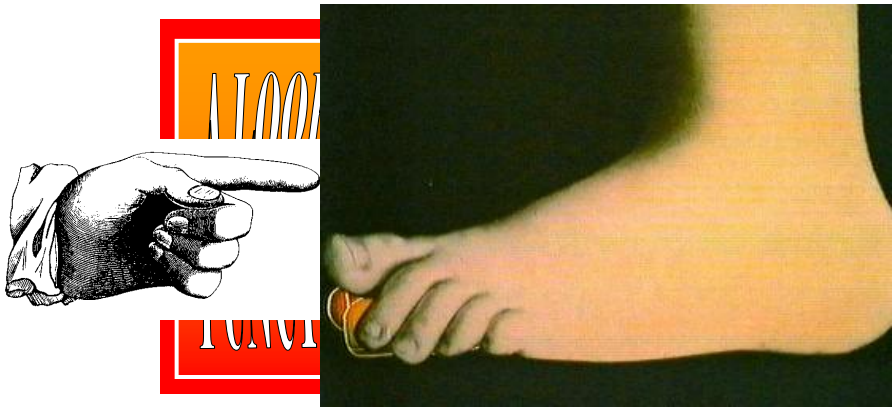
    - Boilers
- Late May 2005 Release

STAC Project

- Research Conducted on the Use of the current FT Guide
- Top 25 Most Desirable Test Additions Identified
- Training curriculum developed
- Functional testing checklist tool
- Work to date released with the DOE June 2005 release
- Work still in progress will be released next year



Content Organization

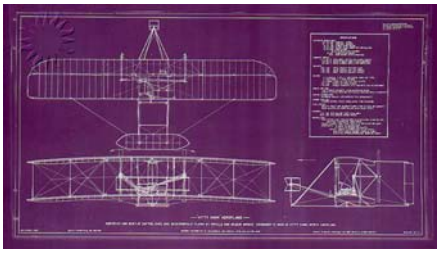
- How to Use the Guide Chapter
  - Navigation
  - Commissioning process
- Introduction to Functional Testing
  - System concept
  - Elements common to all functional tests
- Individual component chapters
  - Move through AHU from inlet to exhaust
  - Integration issues

A Work in Progress

- Not all chapters fully developed in the first release
  - All chapters contain ***basic*** information
    - Testing benefits table
    - Testing field tips table
  - Some included supplemental information
    - Design related issues
    - Theory and details
  - Some include proposed development path

Using the FT Guide for Design Phase Cx

A successful test has its foundation in a good design



Reviewing the Design

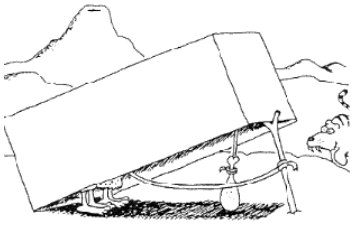
Integrating design intent with operating reality

- Non-design conditions
- Non-steady state issues
- Operation and maintenance issues

Planning the Test

- Developing a commissioning plan
- Developing specifications
- Developing sample tests and first drafts
- Identifying additional design issues

Using the FT Guide for Construction Phase Cx



"Shhhh, Zog! … Here come one now!"

Proper design execution the key to success.

Reviewing shop drawings

Integrating design intent with operating reality

- Actual configuration vs. specified
- Actual performance vs. specified
- Actual accessories vs. specified

- Fixing things on paper is more cost effective than fixing them with a cutting torch

Monitoring Construction

Setting things up for success from the start

- Proper assembly
- Proper field application
- Accessibility for maintenance and inspection

Verifying Integrated Construction

Bringing the integration perspective to construction observation

- Assessing the installation of assemblies involving multiple trades and disciplines
- Verifying things that are hidden by subsequent construction

Planning the Test

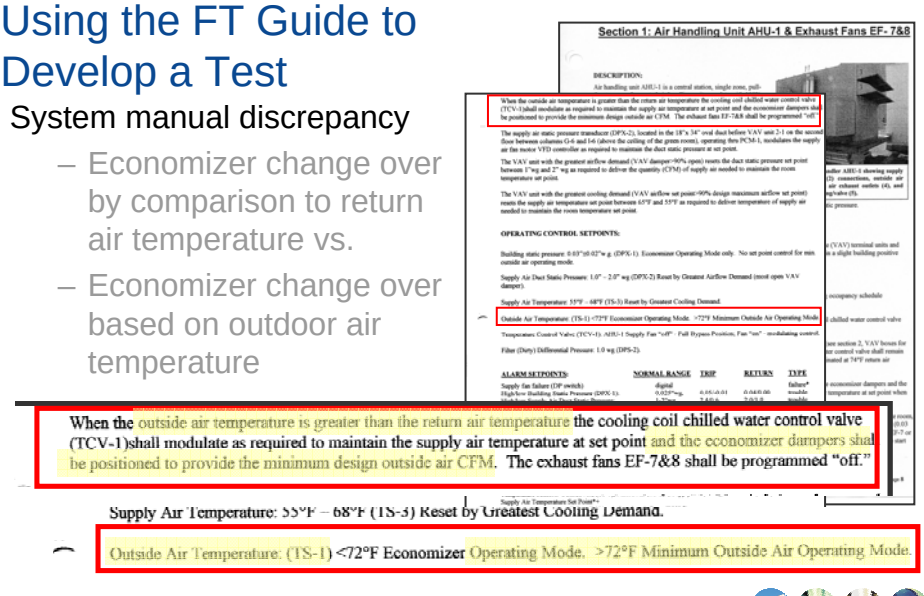
Identifying potential weak spots and/or critical performance issues

- Potential field improvements prior to testing
- Future testing and verification targets

Using the FT Guide to Develop a Test

System manual discrepancy

- Economizer change over by comparison to return air temperature vs.
- Economizer change over based on outdoor air temperature


Section 1: Air Handling Unit AHU-1 & Exhaust Fans EF- 7&8

When the outside air temperature is greater than the return air temperature the cooling coil chilled water control valve (TCV-1)shall modulate as required to maintain the supply air temperature at set point and the economizer dampers shall be positioned to provide the minimum design outside air CFM. The exhaust fans EF-7&8 shall be programmed "off."

Supply Air Temperature: 55°F – 68°F (TS-3) Reset by Greatest Cooling Demand.

Outside Air Temperature: (TS-1) <72°F Economizer Operating Mode. >72°F Minimum Outside Air Operating Mode.

How the Guide Might Help

- Understand economizer theory
  - General operating theory
  - Related parameters like minimum outdoor air and building pressurization
  - Typical components
  - Control strategies
  - Typical problems

How the Guide Might Help

- Understand economizer change over strategies
  - Approaches
  - Determining a set point
  - Equipment

How the Guide Might Help

- Provide a test template
  - Start with an existing CTPL test
  - Development options
    - Use the existing test on the fly
    - Quickly modify the existing test
    - Modify and format to your "look"
    - Use trending

Using the Calculation Appendix

Image courtesy of the Fan Equipment Company website

Fan Energy: A Function of Head and Flow

$$P_{Fan} = \frac{Q \times SP}{K \times \eta_{Fan} \times \eta_{Motor} \times \eta_{Drive}}$$

Where:

P_{Fan} = Horsepower into the motor serving the fan

Q = Flow rate in cubic feet per minute

SP = Static pressure in inches water column

K = Units conversion constant = 6,356

η_{Fan} = Fan static efficiency

η_{Motor} = Motor efficiency

η_{Drive} = Drive efficiency

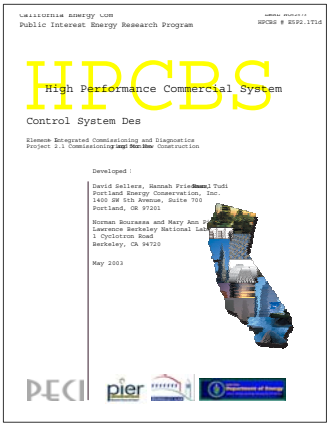
Fan Energy Savings

- Overview
  - Identifying energy savings
  - Troubleshooting
- Equations
  - Horsepower
  - Energy
- Additional Savings
  - Fan heat
  - Other resources
- Examples

The Control Design Guide; Part of the Package

Design/Operation Synergy

- Targeted at Designers
- Provides support for Commissioning Providers



Design Process and Point Selection Information

- Design process example
- Design aids
  - Spreadsheets for valve and damper sizing and scheduling
  - Standard details that can be opened in AutoCAD®
  - Quality improvement ideas
- Control points
- Monitoring points
- Safety points
- Sensor Selection
  - Calibration
  - Accuracy
  - Installation

System Configurations and Point List Recommendations

- Common system types
- Sample system diagram
- Point list recommendations
  - Starting point for construction documents
  - Control cost estimating tool
  - Design review tool for a Cx provider