HVAC Controls & Commissioning

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Overview

- Controls Design Process
- State of Controls Industry
- Planning DDC Systems
- Key Specification Issues
- Control Strategies
- The Commissioning Process
  - Definitions & Terminology
  - Process/Scope
  - LEED Requirements
  - Issues
- Fault Detection & Diagnostics
  - Performance Verification

HVAC Design Process

- Owner hires Architect or Architect Engineer
- Architect hires M/E/P Engineer
- HVAC Engineer skilled as sizing and selecting systems
- Typically has not kept up with Controls
- Controls is small portion of overall budget/project
- Many Options
- Many times, works with a vendor or reuse templates

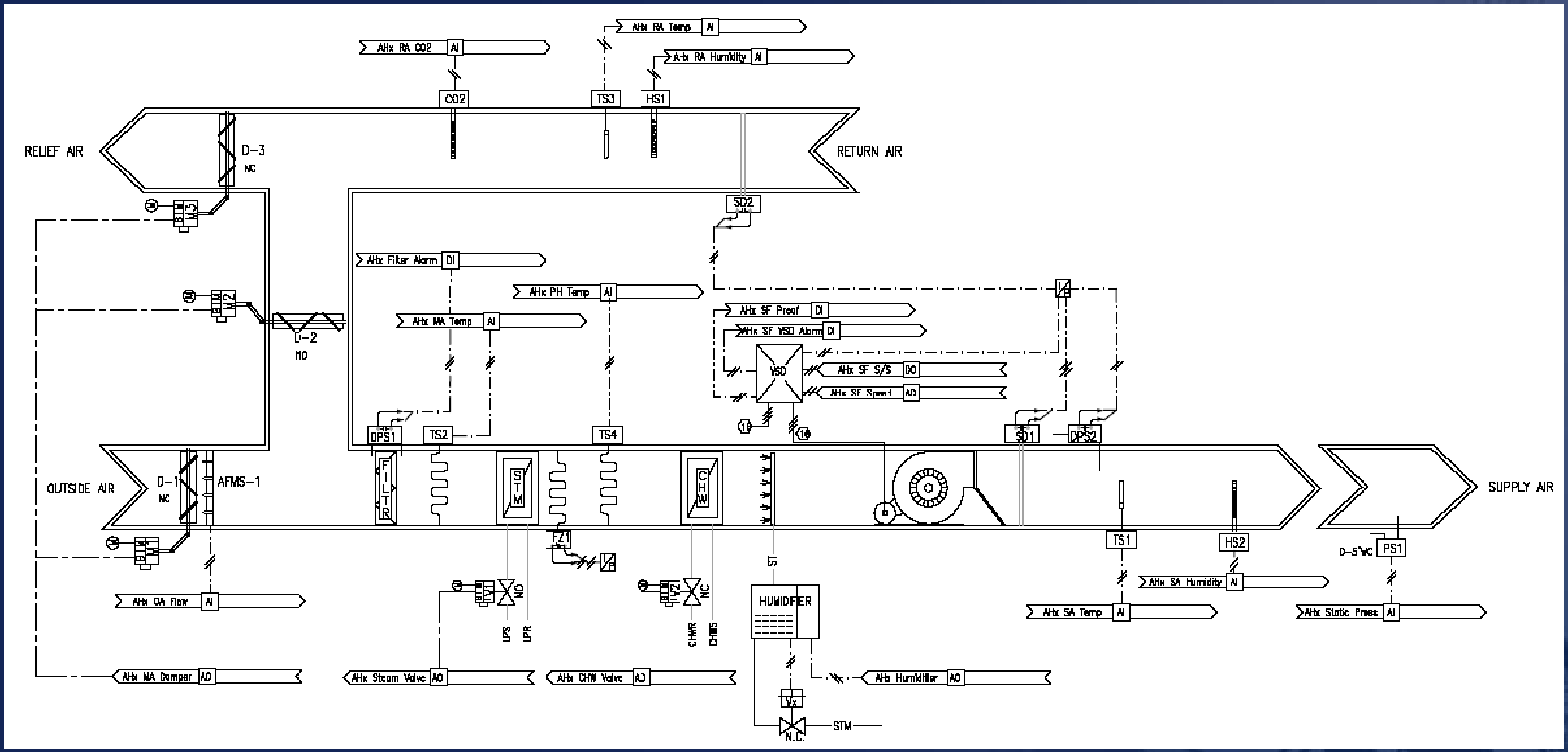
Controls Design - Current Practice

- HVAC Controls are Performance Specified (low liability)
- Specifications aren’t very specific
- Controls are typically “Design/Built” by 3rd tier subcontractor
- Application Engineer for vendor is key
- Documentation quality varies
- Resources are limited, enforcing good specs are a challenge
- Training is critical
- Difficult to get a system to work as planned
- Commissioning becomes necessary

Essence of a Building Control System

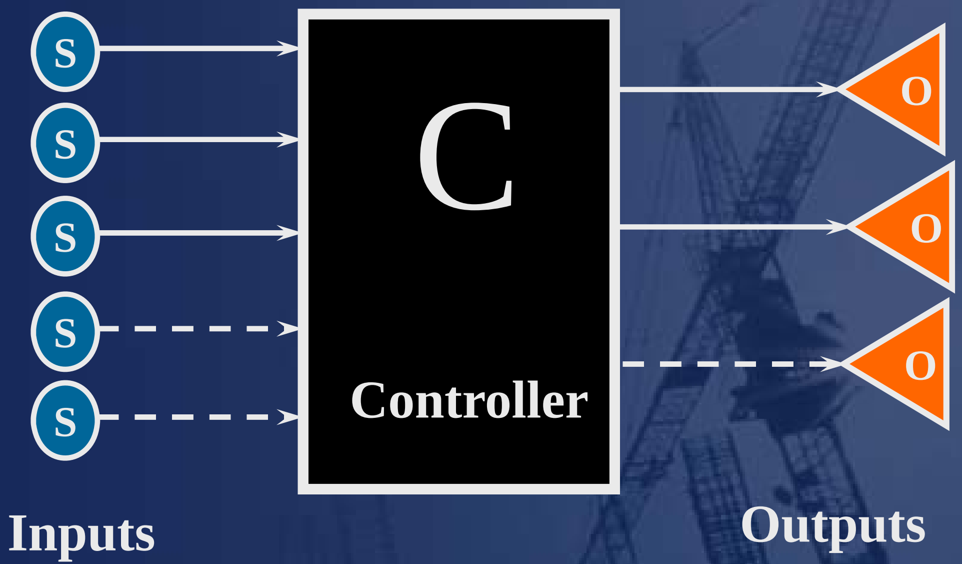
- Stuff
  - Sensors
  - Controlled Devices
  - Controllers
  - Interface Devices
  - Networks & Wiring
- People
  - Programming
  - Installation
  - Quality Control
- Tools
  - Software
  - Documentation
  - Training

Typical Documentation - Schematic

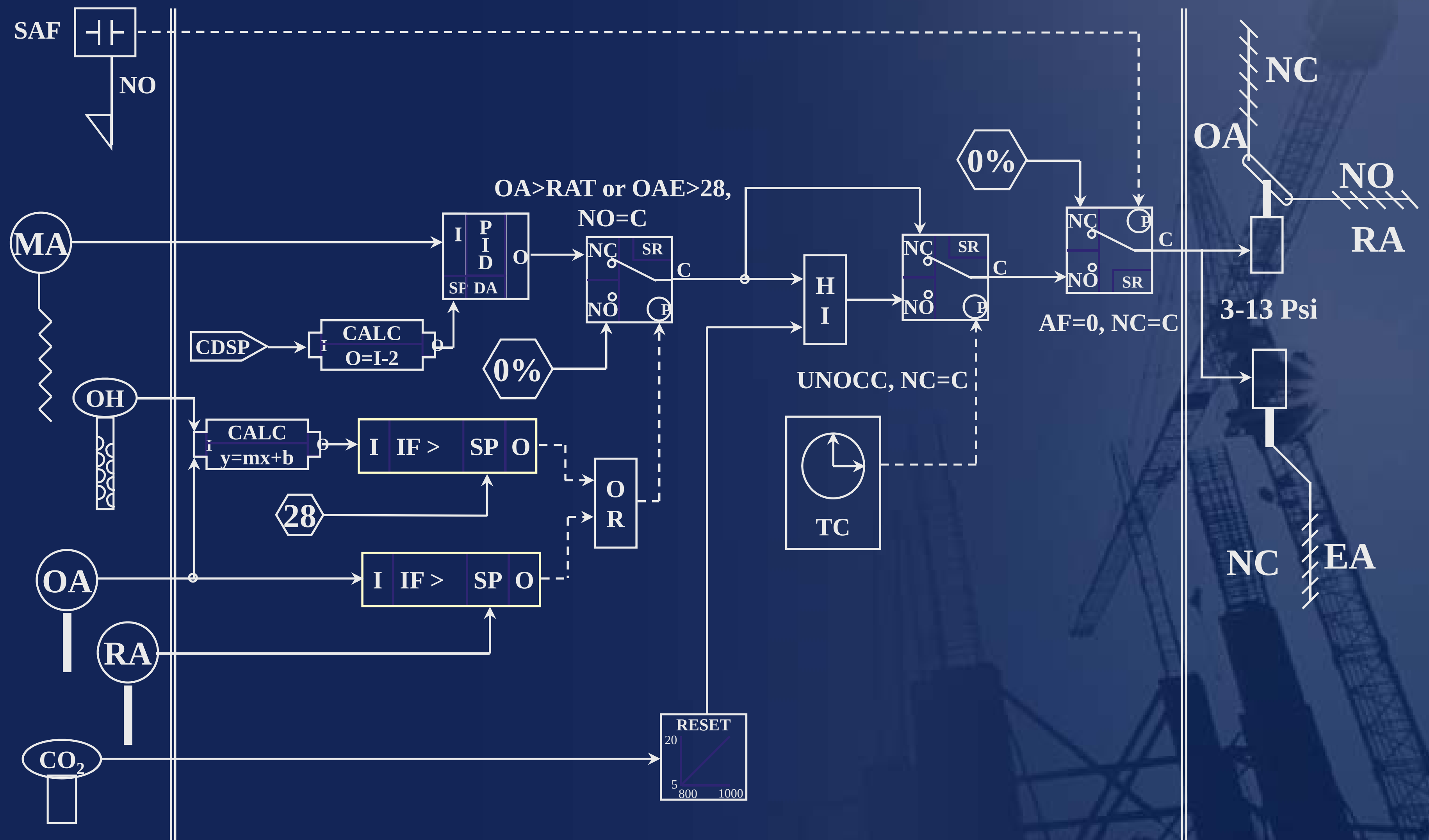


Typical Documentation

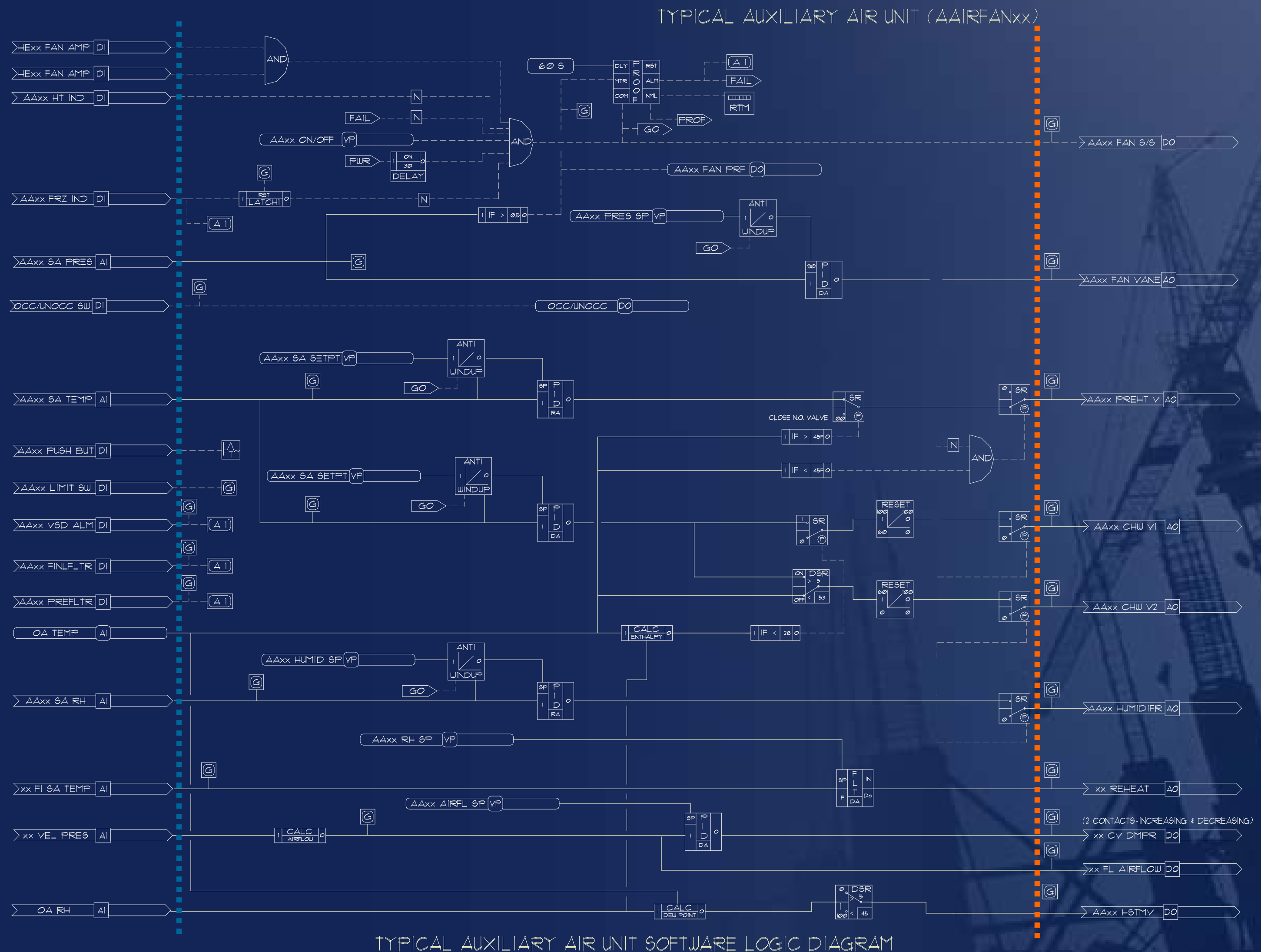
- Points List
- Programming
  - Line Code
  - Graphical Program
- Sequence of Operation
  - Original
  - Control Engineer
  - Operator Version
  - Current Operation



Logic Diagram (mixed air)



Control Logic Diagram (AHU)



Practical Issues

- Resource Limitation – consulting, installing, owner
  - Education/Training Required
  - Experience Based Learning
- Numerous Proprietary DDC Systems already in place
- Open Protocol Issues – good potential - new complication
- Other Design Issues
  - Specifications not specific (trend is for less detail)
  - All Controllers aren’t created equal

Master Planning of DDC Systems

- System Architecture
  - What is the size of the requirement?
  - Is there a requirement for remote communications?
  - What is already installed?
  - What are the growth plans?
  - What are the priorities?
- Controllers
  - What type of systems are to be controlled?
  - What are the requirements for each system?

Master Planning of DDC Systems

- Operator interfaces
- Equipment interfaces
- EMS interfaces
- Remote communication details
- Integration
- Backward compatibility

Master Planning of DDC Systems

- Personnel
  - Project Managers
  - Procurement Issues
  - Inheritor's
    - Level of Independence
    - Training

Owner's Input

- Be realistic
- Good controls projects just don't *happen*
- Consider developing a controls master plan
- Demand (and pay for) better (more prescriptive) controls designs
- Technical career track for control techs
- Develop control standards

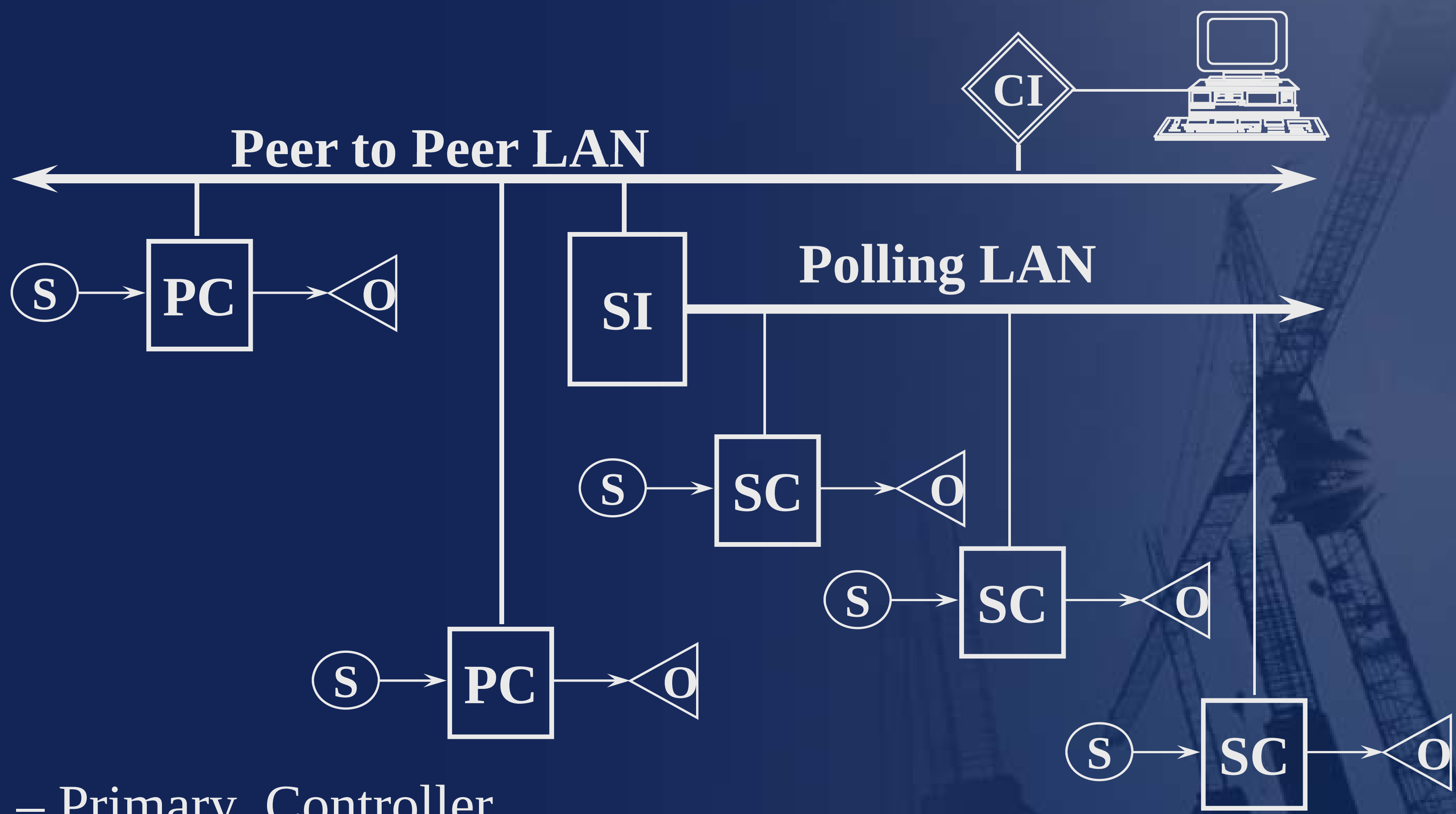
Criteria for Quality Specifications

- Prescriptive, Prescriptive, Prescriptive
  - The more well defined the specification, the easier (in theory) the commissioning
  - More functional testing, less refereeing
  - Enforcement
    - Design Phase
    - Submittals
    - Installation
- DEFINITIONS

Key Specification Issues

- System Architecture
- Control Hardware
- Interoperability/Integration
- Software
- System Setup

Typical DDC Architecture



PC – Primary Controller
SC – Secondary Controller
SI – Supervisory Interface
CI – Communication Interface

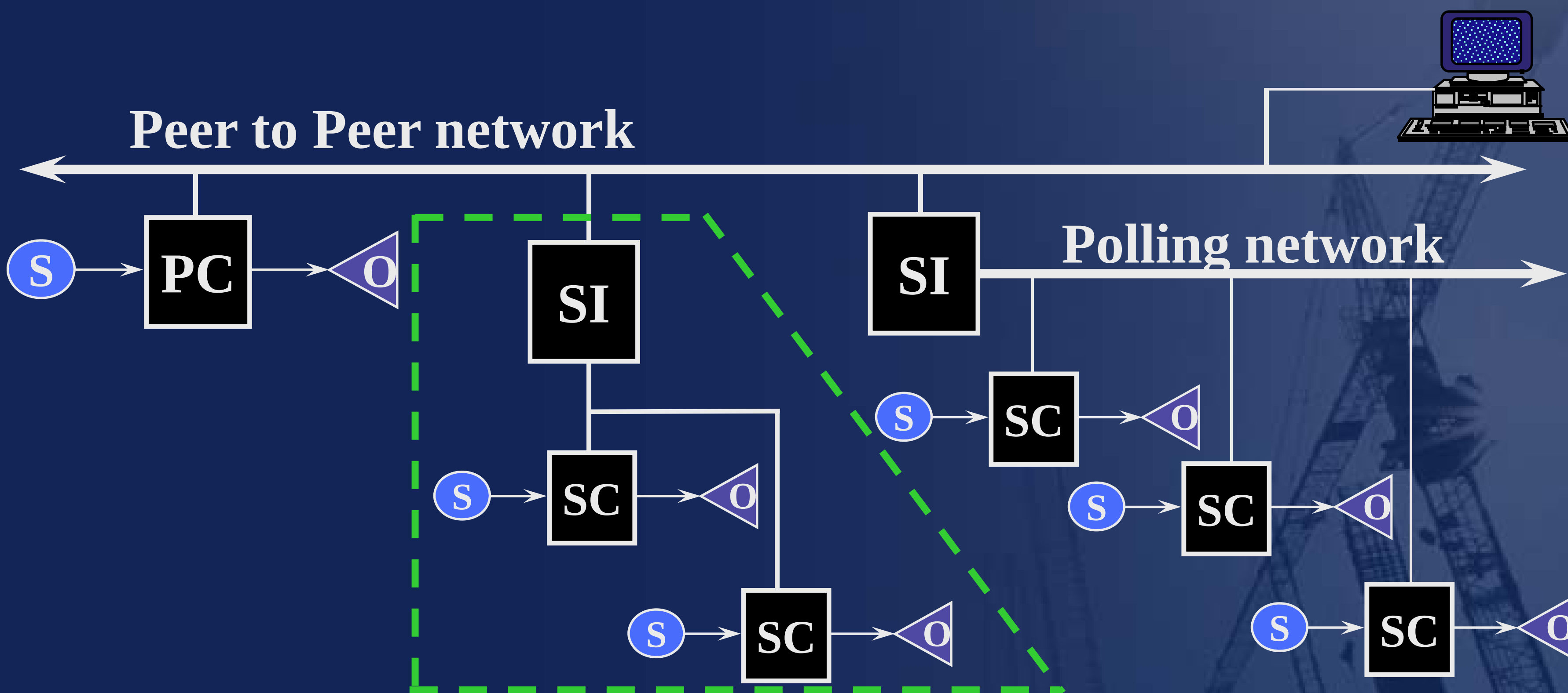
Key Specification Issues

- System Architecture
  - Robustness for project
    - Maximum Configurations
      - Especially on lower level networks
    - Peer to Peer versus Polling networks
    - Performance specify event criteria
      - Speed of alarm, command, status, graphic update, etc.
  - Capability of trending
    - Long term
    - Commissioning related
    - Impact on normal control functions

Key Specification Issues

- Control Hardware
  - Specify controllers for applications
  - Know potential bidders limitations
  - Design system around that reality
  - Consider 4 application categories
    - Peer to Peer only
    - Secondary controller on very limited polling network
    - Secondary controller on limited polling network
    - Terminal controller on limited polling network

Controllers Types



- PC – Primary Controllers
- SC – Secondary Controllers
- SI – Supervisory Interface

Key Specification Issues

- Interoperability, interface to existing systems and procurement limitations, criteria
  - Define terms
  - Make sure interoperability goals are realistic
  - Procurement issues
  - Define level of integration to existing
  - If interoperability is desired to a high degree, research capabilities of vendors further
  - If interoperability is being used as a procurement solution, reconsider
  - If all these interoperability criteria are met, review one more time

Key Specification Issues

- Software
  - Numerous software programs are needed for full functionality of DDC system
  - Vendors package these differently
  - Difficult to keep up
  - Specify vendor provide all software to perform common functions
    - Add hardware, edit database
    - Alarming, trending, reporting
    - Graphics, programming, upload/download, etc.

Key Specification Issues

- System Setup
  - Capabilities are one thing…
  - Setup is another
  - Details of the capabilities of trending, scheduling, alarming, password protection, graphic software are typically not discriminators
  - Focus on setup of these features
  - Easier to enforce if defined

Control Strategies

- Overall Concepts
  - Not a "one size fits all world" relative to sequences of operation
  - Need to be designed for the application (including the personnel)
  - Involve operations personnel in process
  - Standard sequences are good
  - Sequences need to be designed not design/built
  - Commissioning can be a catalyst for this discussion

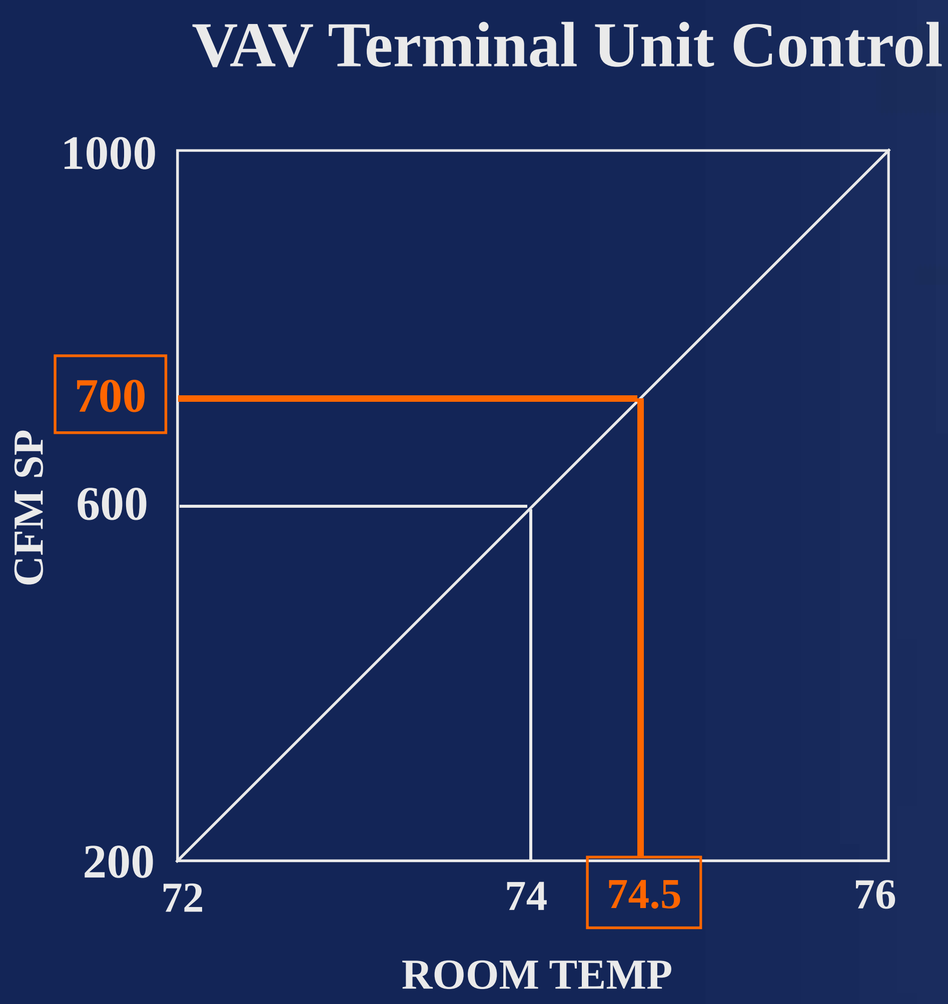
Specific Control Strategies

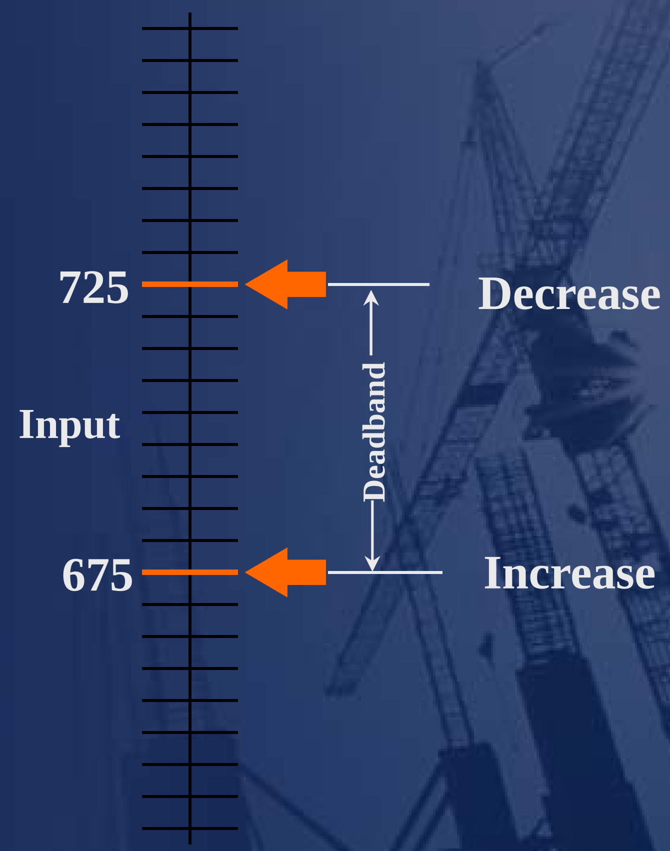
- Basic
  - On/off equipment scheduling
  - Occupied/unoccupied setback setpoints
  - Coordinated subsystem control
    - Coordinated sequences (heating/cooling)
    - Maximizing free cooling before mechanical cooling
  - Appropriate setpoints
    - Zone
    - Central Systems
    - Ventilation rates

Measurement

- If we can’t measure it, we can’t control it….
- Significant Figures
  - Flow = 754.24 cfm
  - RA Enthalpy = 24.566 Btu/lb
  - SP = 1.24 in
  - RAH = 54.53%
- Control Response of these measurements
  - Two-position
  - Proportional
  - PI, PID
  - Floating

Floating Control Example





Energy Control Strategies

- Reset Strategies
  - Demand Control Ventilation
    - CO_2 based
  - Cascade Control
    - Terminal Unit Demand resetting Static Pressure
    - Chilled water valve position resetting secondary pump speed
  - Unoccupied Operation
    - Ventilation
    - Zone Air flows
    - Lab Air flows
- Demand Control Strategies

Persistence

- Sequences should take into account the probability of performance persisting….
  - Simplify, or….
  - Educate and train
- An analogy…..
  - Information Technology Resources (new business)
    - 20 Years ago
    - Today
  - HVAC (DDC) Resources (old business)
    - 20 Years ago
    - Today

The Commissioning Process

- **What Is Commissioning?**
  - **Quality assurance process that ensures that:**
    - Owner’s needs and facility requirements are identified before design
    - Building systems are installed and perform interactively according to the design intent
    - Building systems are efficient and cost effective and meet the owner’s operational needs
    - Installed systems are operable and maintainable
    - Installation is performance-tested and verified
    - Complete and extensive O&M and Training documentation is provided to the Owner
    - Operators and facility staff are adequately trained and equipped to maintain building.
  - **It serves as a tool to minimize post-occupancy operational problems. It establishes testing and communication protocols in an effort to advance the building systems from installation to full dynamic operation and optimization.**

The Commissioning Process (cont.)

- Commissioning is a systematic, documented process for ensuring that building systems perform as designed and meet the owner's needs
- Act of Putting Into Service
- ASHRAE Guideline 0, Guideline 1
- PECI Cx Documents (www.peci.org)
- Other Cx Related Organizations – Certifications
  - BCA
  - SMACNA
  - NEBB
  - AEE
- Process needs to be customized to meet the needs of the organization and the project

The Commissioning Process (cont.)

- Not Construction Administration
- Not Construction Management
- Not Supervised Start-up
- Not Quality Control for the Contractor
- Validation and Verification of Installation, Performance
- Performance Validated from devices to components to subsystems and systems
- Focus is on
  - Functional Testing
  - Documentation
  - Training
  - HVAC, Controls and Dynamic Electrical
  - Other Specialty Systems critical to application (lab controls, security)

Cx-Specific Scope & Tasks

- **Design-Phase Cx Tasks**
  - Design Team puts language into specs and plans to better define the roles and responsibilities
  - Develops Cx Plan and Specifications
  - Review Owner's Project Requirements (OPR), Basis of Design (BOD)
  - Review Documents for with Functional/Operable perspective
  - Commissioning Authority (CA) is typically an independent party who serves as Owner's rep to insure Design Team properly takes Cx into account
  - Ideally, CA is retained during the Design Phase to assist in Contract Document development
- **Bid-Phase Cx Tasks**
  - Communicate Cx requirements to bidders
  - Bidding Contractors adequately account for Cx in their bids

Cx Tasks (cont'd)

- Construction-Phase Cx Tasks
  - Contractor develops Submittals (CA reviews of key submittals)
  - Contractors develop Start-Up Documentation (CA reviews/accepts). Contractor then performs startup according to these documents (Checklists/Initial Tests)
  - CA develops Functional Performance Tests (FPTs) based on Contractor Submittals of specific equipment and intended sequence of operation
- Acceptance-Phase Cx Tasks
  - CA and/or Contractors performs FPT on systems and equipment to insure optimal performance
  - CA reviews/Contractors compiles O&M Documentation Set
  - CA reviews/CA, Contractors and Design Team conduct Owner Training Program
- Warranty/Off Season Phase
  - Off Season, End of Warranty Visit

LEED Requirements

- Fundamental Commissioning (EA Prerequisite 1)
  - Designate a CA
  - Review Owner's Project Requirements (OPR), Basis of Design (BOD)
  - Incorporate Commissioning Requirements (specs)
  - Develops Cx Plan
  - Verify Installation and Performance of systems
    - Functional Performance Testing
    - HVAC
    - Lighting
    - Domestic Hot Water Systems
    - Renewable Energy Systems
  - Complete a Summary Commissioning Report

LEED Requirements

- Enhanced Commissioning (EA Credit 3 – 1 point)
  - Designate an Independent CA (prior to start of CD's)
  - In addition to OPR & BOD review, Conduct a review prior to "mid-CD phase", back check comments
  - Review submittals of commissioned systems
  - Develop systems manual
  - Verify Training
  - Participate in Warranty/Off-Season phase

LEED requirements for CA

- Fundamental Cx > 50k sf
  - Independent Consultant
  - Owner
  - “Disinterested” employee/subcontractor of A/E, CM, GC
  - CM (not holding construction contracts)
- Enhanced Cx
  - Independent Consultant
  - Owner
  - “Disinterested” subcontractor of A/E
  - CM (not holding construction contracts)
  - Same CA for the Fundamental and Enhanced CA
- Documented Cx Experience on at least 2 projects

Cx Plan and Specifications

- The key Contract Documents for Cx are the Cx Plan and Sections 15995/16995
- Cx Plan
  - A 'new' document that details complete roles and responsibilities for the entire Cx Program
  - Typically considered part of the Contract Documents
  - 'Living' document that is updated throughout the process
- Section 15995 – HVAC and Mechanical Systems Commissioning
  - Specification as to the Contractor's role in Cx
  - Requires coordination with individual equipment sections
  - Also Section 159xx – Controls Systems Commissioning

Other Cx-Related Contract Documentation

- Other Division 15 Sections
  - Design Team needs to include Cx-related paragraphs in individual equipment specifications relating to Start-Up and FPT, O&M Submittals, and Owner Training
- Other Divisions
  - Division 16 – Similar to Division 15 (Lighting and Controls, UPS, ATS, other dynamic electrical systems)
  - Division 1 – submittals, documentation, re-testing consequences
  - Other equipment/Divisions – Elevator/escalator, etc.
  - Building envelope
  - Separate Division (17?) for Commissioning
  - New CSI Format has Cx throughout

Commissioning Plan

- Contents
  - Overview of Cx Scope and Process
  - Parties Involved
  - Roles and Responsibilities of above
  - Task Definition
    - Coordination Meeting
    - CA Review of Submittals
    - Construction Inspections
    - Action List
    - Identification & Resolution of Deficiencies or Additional Work Req'd
    - Start Up Checklist Development
    - Contractor Notification
    - Execution of FPT's, FPT Participation
    - Training Procedures
  - General Functional Performance Tests

Parties/Responsibilities

- Commissioning Authority (CA)
  - Directs/documents the overall process
  - Performs or directs FPT
  - Insures O&M Docs and Training are adequate
- Design Team (Architect/Engineer)
  - Incorporate Cx requirements into Contract Documentation
- General Contractor and Subs
  - Mechanical, Electrical
  - Controls/Building Automation
  - TAB and Specialty
- Owner Representatives
  - Project or Construction Managers
  - Design and/or O&M Engineer
  - Facility Operators and Controls Techs

Start-Up Documentation

- Contractor carries responsibility for Start-Up
- Start-Up Documentation includes Checklists and/or Tests
- Documentation can be developed by…
  - Contractor/subs
  - CA
  - Contractor developed/CA approved (most common)
- Start-Up Responsibility and Witnessing
  - Contractor responsible for Start-Up Check/Test
  - Typically only major system startups are witnessed by CA/Owner
  - Also hydrostatic tests, flushing, duct cleaning, duct leak tests
  - Usually witnessed by CA/Owner Rep
- It all depends on the Contract
  - Most common approach: Contractor develops the draft Start-Up Documentation based on actual equipment – CA Reviews

Functional Performance Tests (FPTs)

- The detailed and thorough testing of building systems and their interactions with components and other systems to validate that system performance meets requirements.
- Requires all interrelated systems have completed successful Start-Up by Contractors and QC done
- TAB completed and results are available
- FPTs are typically developed by the CA
  - Requires specific equipment Submittal information
  - Usually developed/finalized during Construction Phase
- Involves extensive testing of control sequence of operation
- Testing involves use of the BAS (and some assistance from the Controls Contractor)
- FPT 'Pass/Fail' typically defines Acceptance by Owner

Issues

- Cx Scope
- When does CA get involved in the project?
- How well is Cx defined in documents?
- Depth of Cut?
- How well are sequences defined?
- What is the CA's Cx process?
- Who conducts the FPT's
- Increased Focus on Training and Documentation
- Certification
- Schedule Impacts
- Getting to Functional Testing
- Cost

Cx Scope

- Breadth
  - HVAC, Lighting (LEED), Dynamic Electrical
  - Specialty appropriate for project
  - Already covered by others
- Depth
  - 100% Central Systems
  - Sampling in zones
- Project Overhead
- Pre-functional testing involvement
- LEED requirements
- Other project/client specific requirements

Issues

- When is CA Involved
  - Early Design
  - Late Design
  - Construction
- How well is Cx Defined
  - Nebulous (i.e. demonstrate all and everything to anyone's satisfaction
  - Prescriptive Good – Well defined, reasonable process
  - Prescriptive Bad – Overly complex, unrealistic
  - Everything in Between
  - Serious Cost Consequences
- Breadth and Depth of Cut –
  - Scope of Work (Large vs. Small /Complex vs. Simple)
  - Breadth (Mechanical, Controls, Tab, Dynamic Electrical)
  - Depth (Sampling?)

Issues - Sequences

- **Clarify Sequences of Operation**
  - A very important (and often understated) aspect of system performance
  - CA must develop FPT's based on sequences
  - Hard to do with generic performance based sequences
- **Clarify other gray areas of specifications**
  - Open protocol, interoperability requirements
  - Controller "robustness"
  - Performance criteria
- **Sequence of Operation**
  - POOR Example: "Sequence chillers on and off as required to maintain setpoint and provide efficient operation"

Issue's – What's the CA's Process

- CA's Process
  - Estimating Impact
  - How involved are various parties in the process
  - Subcontractor involvement?
  - How much additional paper?
  - Electronic/IT requirements
  - Who conducts FPT's (next slide)
  - How "grey" are the requirements?

Issues – Who Conducts FPT’s

- Hands-On Approach
  - Requires more experienced CA staff – sometimes not possible
  - Require ability to manipulate systems hardware and controls
  - CA assumes increased responsibility
  - For multiple equipment of like kind, Contractors participate in first few for efficiency
- Hands-Off Approach
  - Witness the procedure following FPT
  - More common
  - Requires detailed FPT’s in Specifications
  - Requires coordination between CA and subcontractors
  - Usually results in stricter adherence to the FPT

Issues – Training & O&M Documentation

- Training
  - Depends on when CA got involved
  - Could add increased submittal, coordination and documentation of Training
- Documentation
  - More Requirements
  - Documentation of Pre-functional testing, QC Process
  - Usually more extensive
  - Look for more electronic submissions

Issues – Certification

- 6 Certifications currently
  - Building Commissioning Association
  - NEBB
  - AEE
  - AABC
  - TABB
  - University of Wisconsin
  - ASHRAE?
- Certify a Process
- One size does not fit all
- Varied approaches
- Owner's are becoming educated on Commissioning
- Commoditize?

Issues - Scheduling

- Should not be managed as a single task
  - HVAC Commissioning
  - Electrical Commissioning
- Needs to be broken down into multiple systems
- Controls Contractor manpower
  - To finish job
  - To demonstrate Cx (hands-off process)
  - To react to punch list and Cx deficiencies
- Consequences for missing early milestones
- Can’t have everything ready in parallel

Getting to Functional Testing

- Biggest Challenge
  - Document Pre-functional testing requirements
  - Judging *Reality*
  - Consequences of *Reality*
- Resolve of Owner
- What’s best for the project
- Financial Impacts
  - Owner
  - Contractor
  - CA

Issues – Cost

- "It depends"……
  - Breadth of Project (HVAC, Controls, Electrical, Specialty…)
  - Project Overhead (Quantity of Meetings)
  - Start-up Attendance
  - Remote access capability
  - Efficiency of Project Management
  - Performance of Contractors
  - Allowance for contingencies & retesting
  - Depth of Cut (Sampling)
  - Scope of Report/Training/O&M Manual Review
  - Who conducts the detailed Functional Testing

Fault Detection & Diagnostics (FDD)

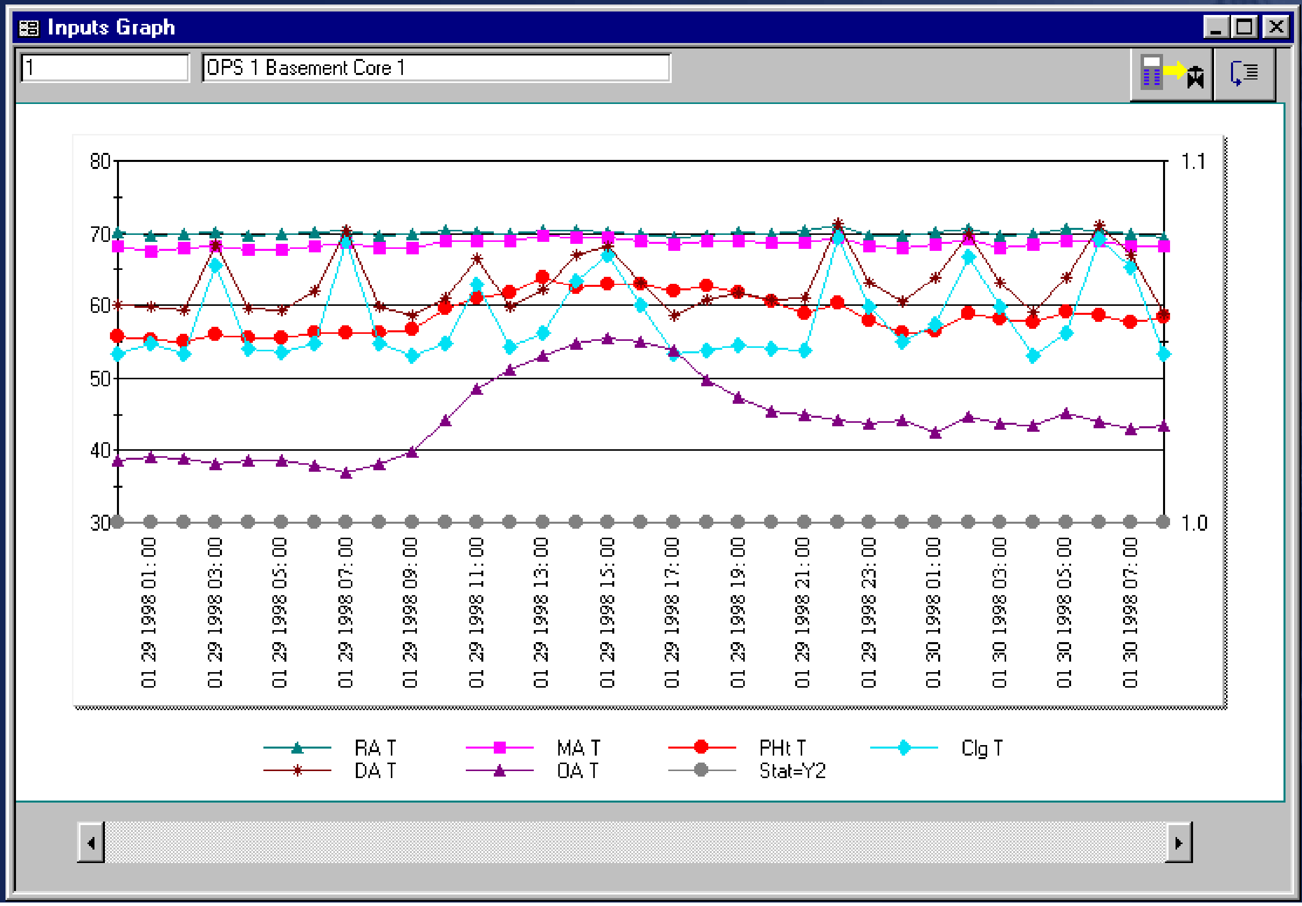
- Tapping An Existing Resource
- DDC systems can trend data useful for system operational analysis
- Generally Under-Utilized
  - Data's been historically cumbersome to acquire
  - Hard to automatically analyze
- Operational Data
  - Historical - "Yesterday's" to "Last Years"
  - Real Time – Current Sample
- Compliment an EMCS, Not Duplicate it
  - Control Systems - Real Time Alarms & Failures

Data Interpretation

- Data Visualization
  - Helpful to supplement a diagnostic
  - Resources are limited that can provide diagnostics
  - Expensive to diagnose manually full time (24/7)
- Facility Managers DO NOT need more data
  - They need the data analyzed and interpreted so they can act and/or plan – INTERPRETATION
  - AUTOMATED DIAGNOSTIC
- Current DDC systems in concert with "Expert" diagnostic program can provide interpretation

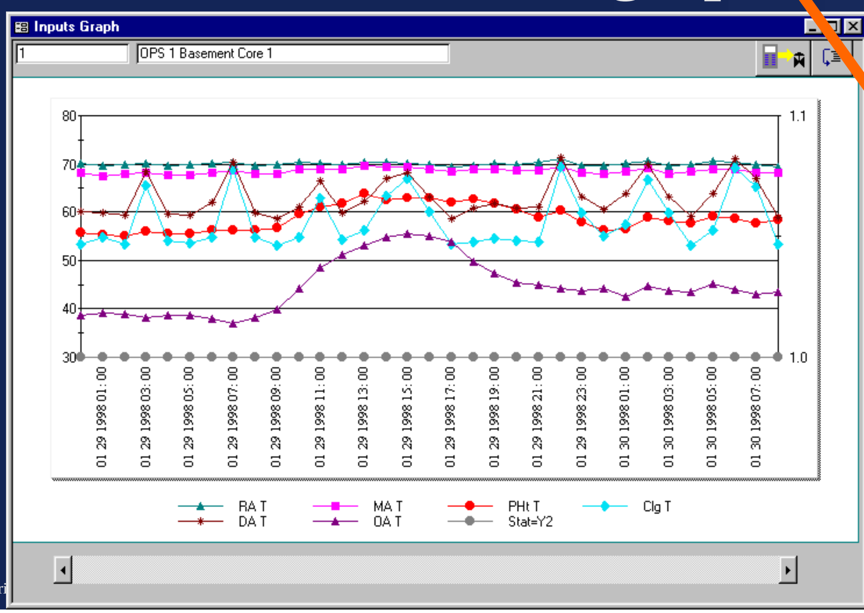
Data Visualization

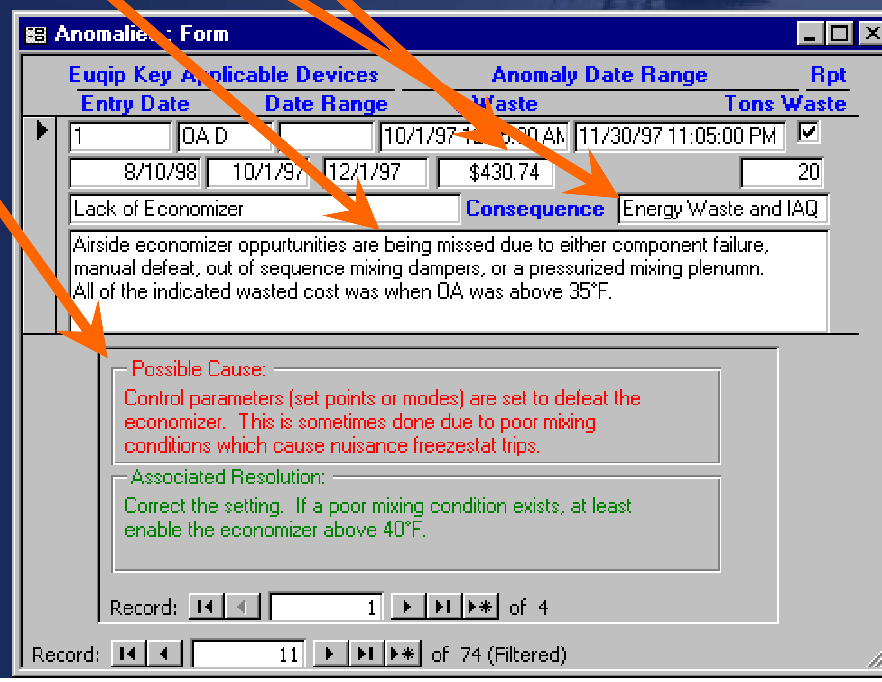
- Requires system knowledge or visualization
- Requires historical record (trending)
- Requires Diagnostician



Automated Diagnostics

- **Pertinent and Important Information Reporting**
  - Energy Cost Waste
  - Consequences
  - Applicable Details
  - Expert Help
  - Sort and filter anomalies on any parameter
  - Link to data graph





Why Mine Historical Data?

- To **Save Energy** by:
  - Identifying wasteful operation
  - Identifying optimal operating strategies
  - Identifying the most efficient equipment
- To **Save Installation Costs** by using feedback to provide more optimal designs
- To **Provide Better Service** by
  - Prioritizing repairs and improvements
  - Monitoring the effectiveness of the operating group
  - Identifying problem areas and systems
- To **Plan More Effectively** by using the feedback to more accurately predict future needs

Why Mine Historical Data?

- To Document Performance and IAQ by extracting and saving the key metrics
- To Optimize Energy Purchases by using load profile information
- To Quantify Results of Energy/Cost Saving Projects by comparing new use to baseline
- To Account for/Distribute Uses and Costs by summing uses and calculating costs
- To Predict Eminent Peaks by using the historical data to predict operation
- To Feed Other Business Processes/Information Systems by characterizing the data exchanging the results
- To Effectively Retro-Commission a facility
- To Facilitate Post Occupancy Evaluations

Uses of Historical Data

- Automated Diagnostics
  - Look for improper system operation
  - Look for poor performance based on excursion from
    - set thresholds
    - statistical projection from baseline data
    - calculated performance
  - PRIORITIZATION IS KEY

Uses of Historical Data

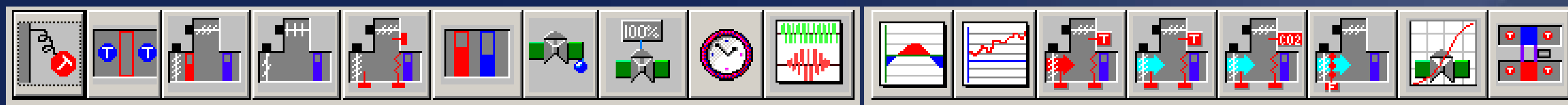
- Performance Characterization
  - Environmental Stats
  - Meter Uses and Costs
  - Peak Loads
  - Load/Demand Profiles and distributions
  - Efficiencies, Performance Maps
  - Output Characteristics

Uses of Historical Data

- Visualize Performance
  - Various views of the interval data
- Measurement and Verification
  - Precise and Specific basis for Savings on Energy Performance Contracts
  - Documenting savings of an energy project
- Predicting Demand and Usage

Automated Diagnostics

AHU Modules



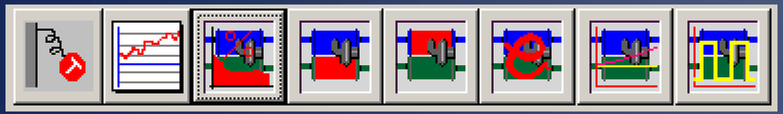
- Failed or suspect sensors
- Mis-calibrated/coordinated sensors
- Out of sequence coils and associated wasted cost and false load
- Missed free cooling opportunities (lack of economizer) and associated wasted cost
- Fighting Coils and associated wasted cost and false load
- Leaking Valves and associated wasted cost and false load
- Space Over-conditioning
- Excess Heat Recovery
- Excess Cycling of Fan
- Struggling system capacities
- Unoccupied period operation (fan and ventilation) and associated wasted cost
- Unstable and Oscillating Control
- Deviation from setpoint
- Inadequate ventilation rates along with the associated parameter statistics
- Failed outputs or those with a poor performance characteristic
- Excess Ventilation and wasted cost
- Lack of Heat Recovery
- Override Operation
- Extensive Custom Analysis Capability

Automated Diagnostics

- **Zone/VAV Terminal Modules**
  - Failed or suspect sensors
  - Mis-calibrated/coordinated sensors
  - Out of sequence coils and associated wasted cost and false load
  - Fighting Coils and associated wasted cost and false load
  - Leaking Valves/Dampers and associated wasted cost and false load
  - Space Over-conditioning
  - Struggling system capacities including VAV Terminal limits
  - Unstable and Oscillating Control
  - Deviation from setpoint
  - Failed outputs or those with a poor performance characteristic
  - Override Operation
  - Extensive Custom Analysis Capability
  - Fighting Companion Zones

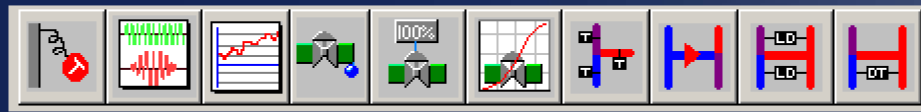
Automated Diagnostics

- **Chiller Module**



  - Failed or Suspect Sensors
  - Poor Chiller Load Factor
  - Poor/Degrading Heat Exchange surfaces
  - Lack of Chiller Output/Degrading Efficiency
    - Can use either DOE 2 methodology for projecting chiller performance or historical data
  - Struggling Capacity/Deviation from Setpoint
  - Excessive Cycling
  - Out of Range Refrigerant Cycle Parameters
    - Equations for characterizing various refrigerants is embedded
  - Override operation
  - Custom Analysis

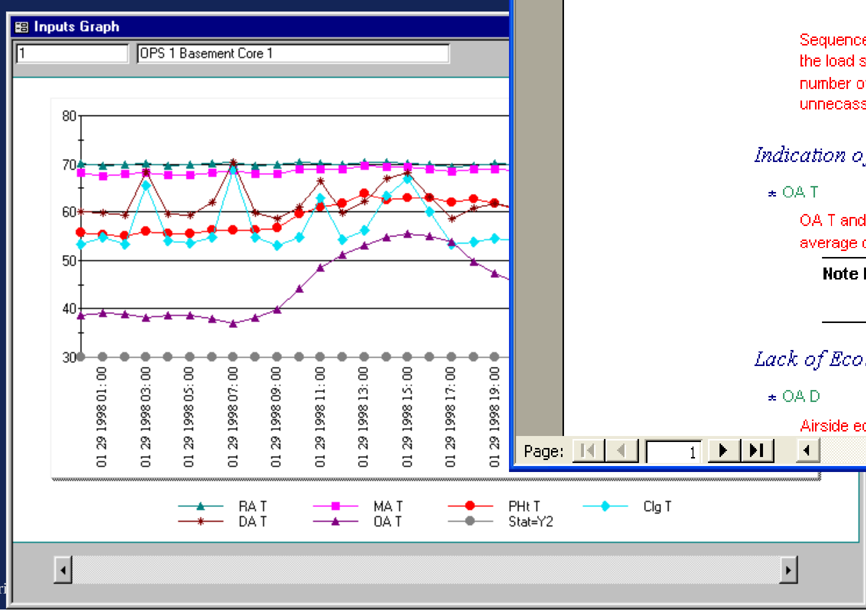
Automated Diagnostics

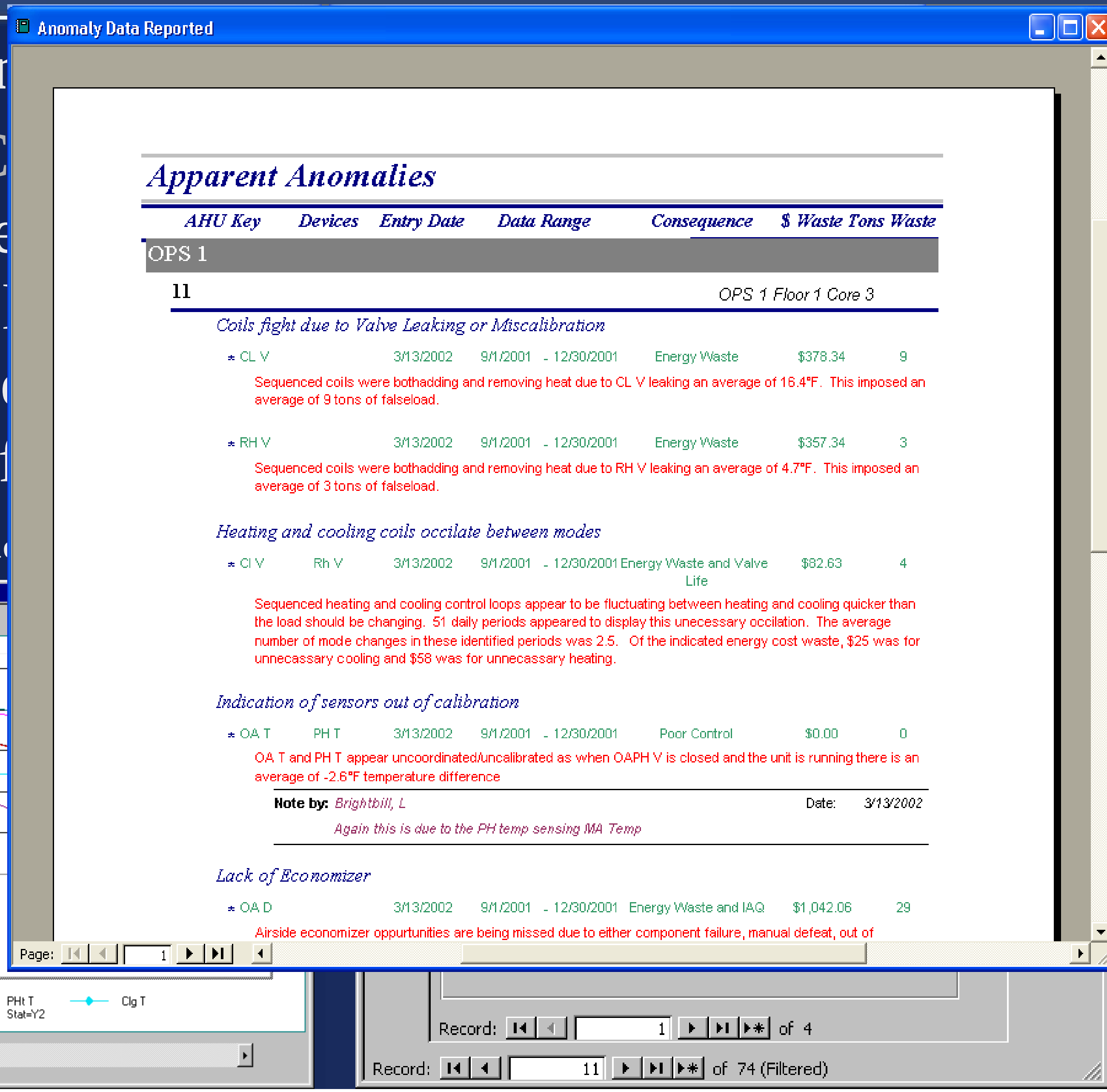


- Hydronic System Module
  - Failed or Suspect Sensors
  - Poor Temperature Difference
  - Reverse Bridge Flow
  - Unstable Control
  - Sensor Mis-calibration
  - Failed Output or Poor Characteristic
  - Loop Overpressure
  - Struggling Valve or Pump control
  - Primary-Secondary Meter Coordination

Automated Diagnostics

- **Pertinent ar**
  - Energy C
  - Conseque
  - Applicabl
  - Expert He
  - Sort and f
  - Link to da





Anomaly Data Reported

Apparent Anomalies

AHU Key	*Devices*	*Entry Date*	*Data Range*	*Consequence*	*$ Waste*	*Tons Waste*
OPS 1						

11 OPS 1 Floor 1 Core 3

Coils fight due to Valve Leaking or Miscalibration

Devices		Entry Date	Data Range	Consequence	$ Waste	Tons Waste
CL V		3/13/2002	9/1/2001 - 12/30/2001	Energy Waste	$378.34	9

Sequenced coils were bothadding and removing heat due to CL V leaking an average of 16.4°F. This imposed an average of 9 tons of falseload.

Devices		Entry Date	Data Range	Consequence	$ Waste	Tons Waste
RH V		3/13/2002	9/1/2001 - 12/30/2001	Energy Waste	$357.34	3

Sequenced coils were bothadding and removing heat due to RH V leaking an average of 4.7°F. This imposed an average of 3 tons of falseload.

Heating and cooling coils occilate between modes

Devices		Entry Date	Data Range	Consequence	$ Waste	Tons Waste
Cl V	Rh V	3/13/2002	9/1/2001 - 12/30/2001	Energy Waste and Valve Life	$82.63	4

Sequenced heating and cooling control loops appear to be fluctuating between heating and cooling quicker than the load should be changing. 51 daily periods appeared to display this unecessary occilation. The average number of mode changes in these identified periods was 2.5. Of the indicated energy cost waste, $25 was for unnecassary cooling and $58 was for unnecessary heating.

Indication of sensors out of calibration

Devices		Entry Date	Data Range	Consequence	$ Waste	Tons Waste
OA T	PH T	3/13/2002	9/1/2001 - 12/30/2001	Poor Control	$0.00	0

OA T and PH T appear uncoordinated/uncalibrated as when OAPH V is closed and the unit is running there is an average of -2.6°F temperature difference

Note by: *Brightbill, L* Date: *3/13/2002*

Again this is due to the PH temp sensing MA Temp

Lack of Economizer

Devices		Entry Date	Data Range	Consequence	$ Waste	Tons Waste
OA D		3/13/2002	9/1/2001 - 12/30/2001	Energy Waste and IAQ	$1,042.06	29

Airside economizer oppurtunities are being missed due to either component failure, manual defeat, out of

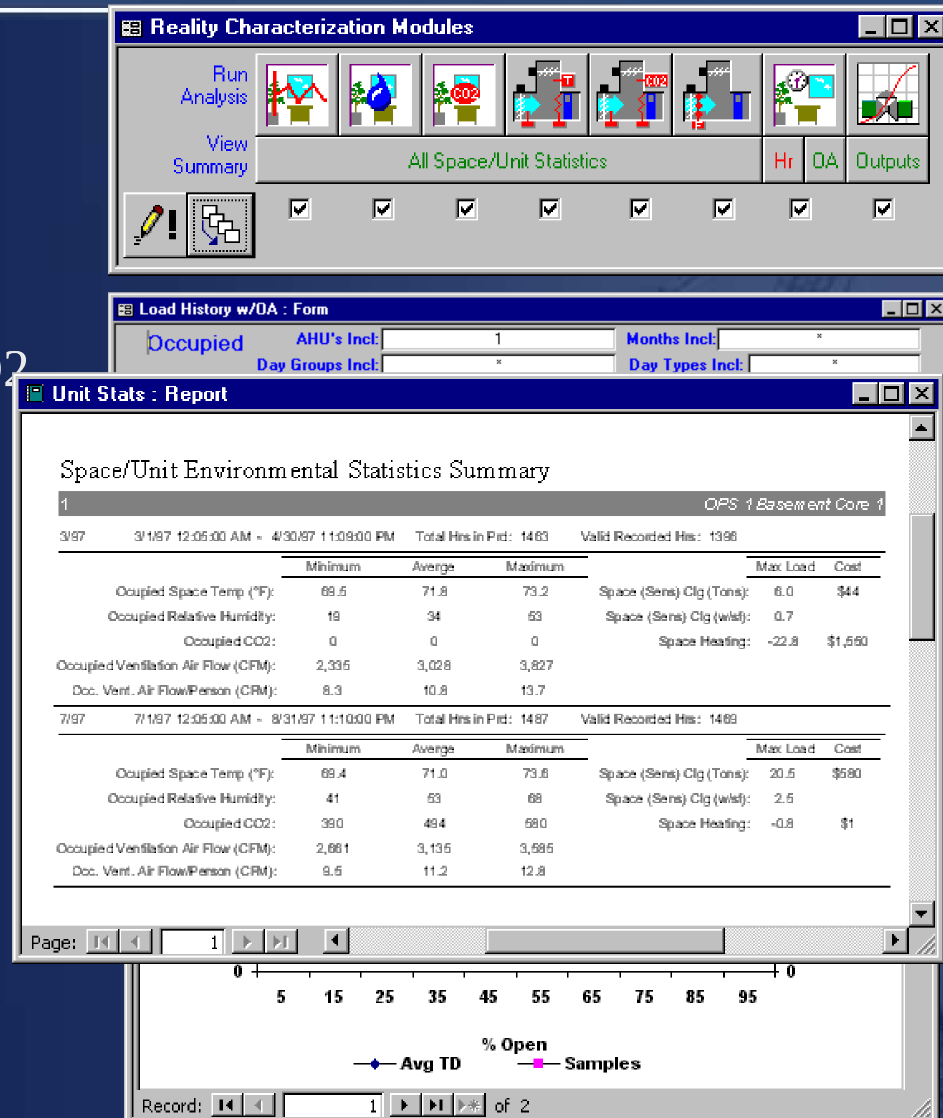
Page: 1

Record: 1 of 4

Record: 11 of 74 (Filtered)

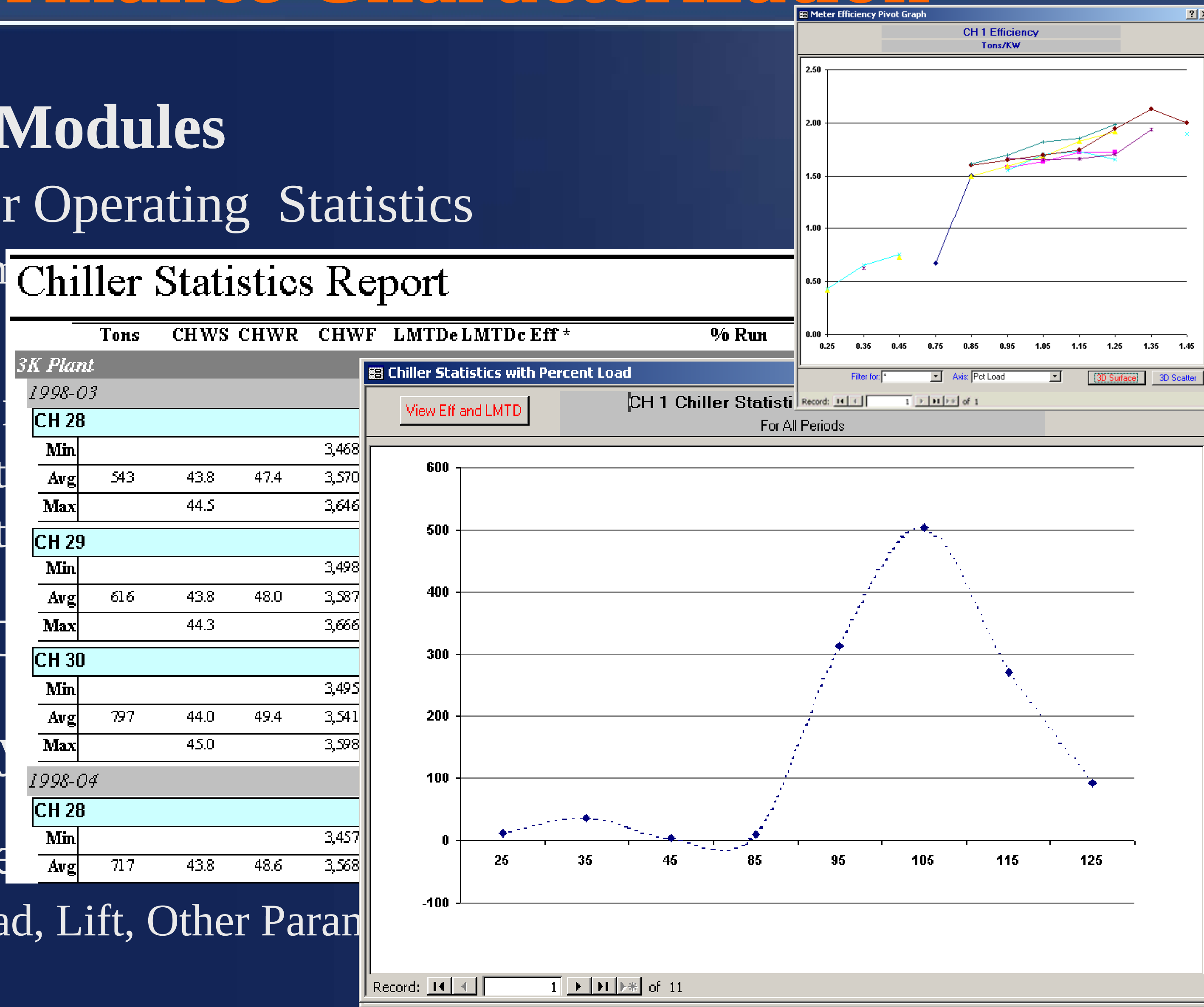
Performance Characterization

- **AH Modules**
  - Indoor Environment Statistics
    - Temperature, Humidity, CO2
  - Ventilation Statistics
  - Load Profiles and Ranges
    - With hour of day
    - With OA temp
  - Output Characteristics
  - Energy Costs



Performance Characterization

- Chiller Modules
  - Chiller Operating Statistics
    - Ten
  - Chille
    - Wit
    - Wit
  - Peak I
  - Energy
  - Efficie
    - Load, Lift, Other Paran



Chiller Statistics Report

		Tons	CHWS	CHWR	CHWF	LMTDe	LMTDc	Eff *	% Run
3K Plant									
1998-03									
CH 28									
	Min				3,468				
	Avg	543	43.8	47.4	3,570				
	Max		44.5		3,646				
CH 29									
	Min				3,498				
	Avg	616	43.8	48.0	3,587				
	Max		44.3		3,666				
CH 30									
	Min				3,495				
	Avg	797	44.0	49.4	3,541				
	Max		45.0		3,598				
1998-04									
CH 28									
	Min				3,457				
	Avg	717	43.8	48.6	3,568				

Measurement and Verification

- Micro vs. Macro approach (Bottom Up and Top Down)
  - Uses Detailed Data not Monthly Totals
  - Allows High resolution on trouble shooting and analysis
- Hierarchical Meter Organization for cost & savings calcs
- Create Multi-dimensional Baseline Histories
  - Use Day Types, Hour of Day, and other parameters such as OA Temp to index base patterns
  - Fill baseline data gaps with three dimensional interpolation
  - Expand baseline range with curve fit extrapolations
- Reporting for Performance Contracts
  - Automatically Recreate Baseline Use from Current Data
  - Calculate savings
    - Print Periodic Summaries
    - Graph Savings

Measurement and Verification

- Use Virtual Meters to Save Meter Costs and Provide More Extensive Meter Accounting
  - If you are recording the output to a device for which the energy use correlates to the output, enter equations and/or polynomials to create the energy use
- Characterize, Summarize, and Analyze Meter and Utility Data
  - Analytical tools for generating load shapes for rate negotiation purchasing
  - Directly import utility data downloaded from the internet
- Visualize the Meter Data in Aggregate and Penetrate Into the Details of Subordinate Meters
- Fabricated Meters
  - Automatically recreate base meter data from "calculated" or prescribed base patterns