An Energy-Efficiency Workshop and Exposition

Orlando, Florida

Building and Equipment Controls

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Outline

- Part I – A Snapshot of Building Controls Today
- Part II – Common Control Problems … And How to Attack and Solve Them
- Part III – Resources That Can Help

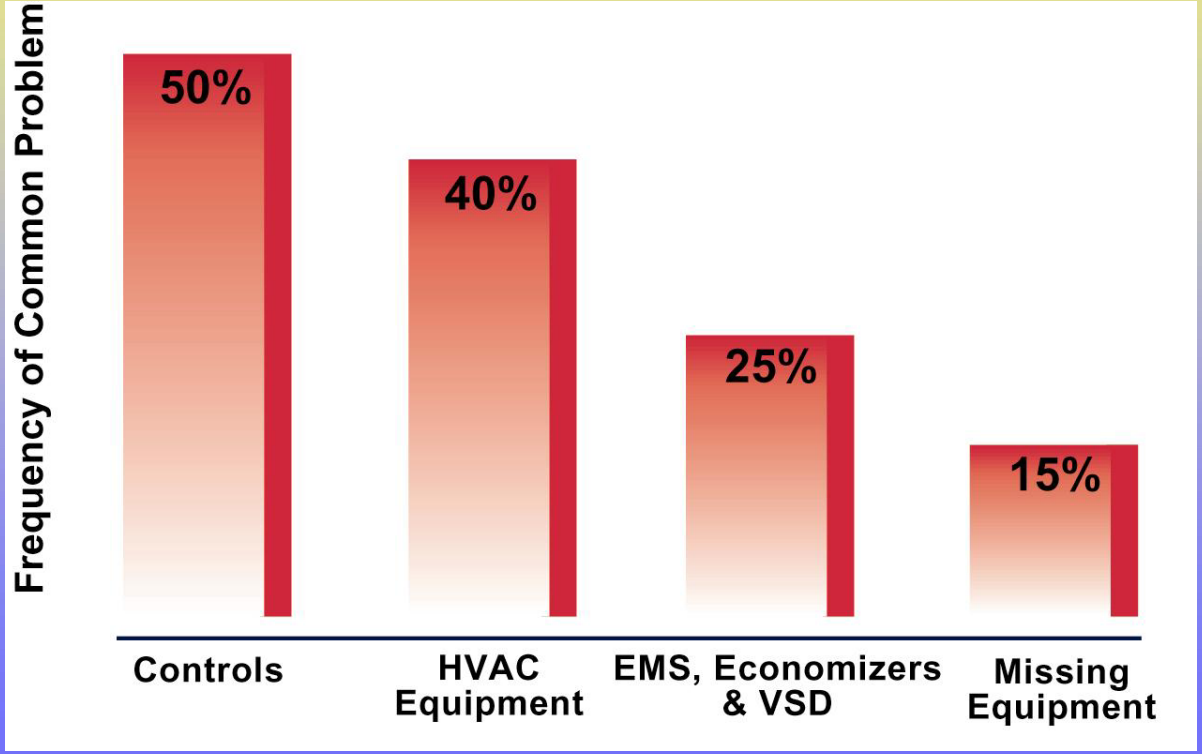
Part I – A Snapshot of Building Controls Today

- Did You Know? …
  - Energy Management and Control Systems (EMCS) are found in 7% of all commercial buildings and serve ~30% of the floorspace (House, 2003)
  - On average the normalized heating and cooling EUI of buildings with EMCS is ~14% lower than those without (House, 2003)
  - BUILDING CONTROLS FREQUENTLY DO NOT WORK

House, J. M. 2003. *NBCIP Summary Report: Characterization of Building Controls and Economizers Using the Commercial Buildings Energy Consumption Survey.* NBCIP Report NBCIP/03/01. National Building Controls Information Program.

Frequency of Control Problems

- LBNL Study of 60 Buildings

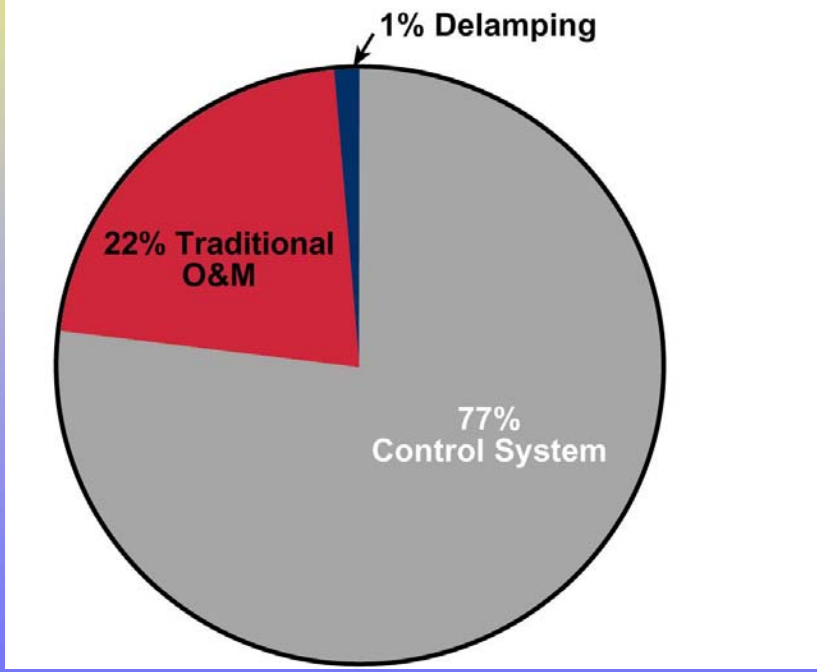


Top 10 Performance Issues in Commissioning

- From Portland Energy Conservation, Inc.
  - **Control System Issues**
  - **Economizer Issues**
  - **Loop Tuning Issues**
  - Minimum Outdoor Air Regulation
  - Scheduling Issues
  - Terminal Unit Issues
  - Variable Speed Drive Issues
  - …

What Does it Cost?

Texas A&M Study of 132 Buildings



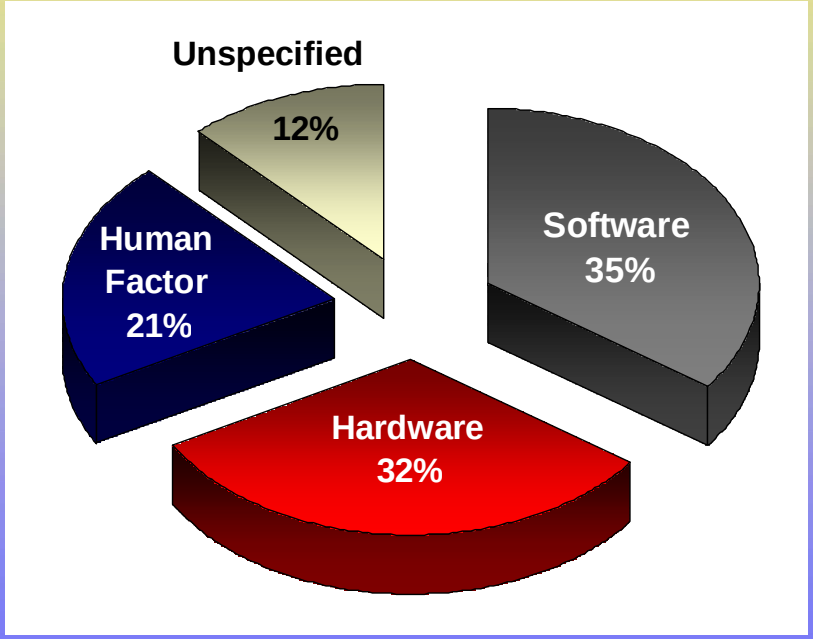
Identified O&M savings among major types of O&M measures

Potential Savings estimated to be $4,000,000 per year

77% of $ savings in the Control System

What's Wrong With Building Controls?

National Building Controls Information Program



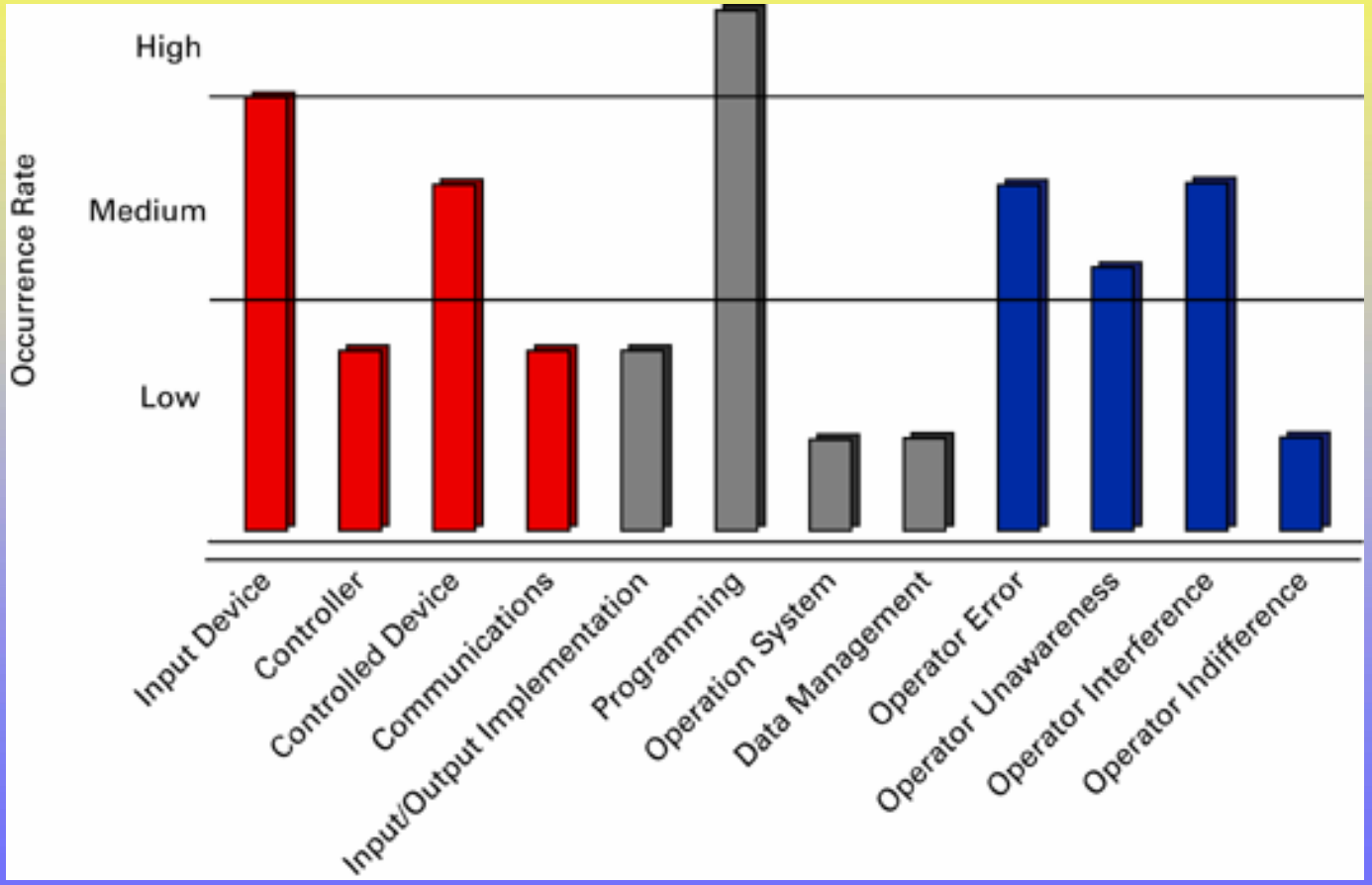
Literature review aimed at defining the connection between control problems and building energy use (Ardehali et al., 2003).

67 Case Studies involving 118 Buildings.

"Unspecified" problems typically involve economizers.

Ardehali, M.M., Smith, T.F., House, J.M., and Klaassen, C.J. 2003. "Building Energy Use and Control Problems: An Assessment of Case Studies." *ASHRAE Transactions*, Vol. 109, Pt. 2.

A Closer Look at the Case Studies



A Closer Look … Continued

Subcategory	Problem Description	# of Case Studies
Programming	Improper set point or schedule	22
	Improper control logic	11
Input Device	Malfunctioning/faulty/broken sensor/thermostat	12
	Improperly located sensor/thermostat	6
Controlled Device	Malfunctioning/inoperable damper/valve/VFD	11
Operator Interference	Manual override	3
	Disconnected devices	2
Operator Error	Sensor/thermostat calibration problem	6

Ask An Expert

- Roundtable discussions held with controls experts
  - Two roundtable sessions
  - Total of 18 controls experts participated
- Experts with extensive experience in design, installation, and commissioning of control systems selected

Ask An Expert

- Experts supported the findings from the case studies and emphasized the need for …
  - Better training of designers, specifiers, installers, and operators in the near term
  - Improved control components and systems for the long term

Control Issues

Statistics show that there are significant problems with control devices and programming.

- How can we improve the operation of building and equipment controls?
- How do we keep the controls operating correctly?
- How can we fully utilize our control systems?

Fake Thermostats

- Installing fake thermostats is not the answer.
- Wall Street Journal *"Cold, Hot, Cold, Hot: Employees Only Think They Have Control,"* January 15, 2003.

CUBICLE CULTURE

By Jared Sandberg

Cold, Hot, Cold, Hot: Employees Only Think They Have Control

LOOKING FOR an office thermostat that actually works? Good luck and Godspeed.

You may never find it. The controls for your company's heating, ventilation and air conditioning (HVAC) are likely hidden in the office ducts. If you do spy a thermostat, it's probably locked, or encased behind shatterproof glass.

Even worse, HVAC experts acknowledge what millions of office workers have suspected all along: A lot of office thermostats are completely fake—meant to dupe you into thinking you've altered the office weather conditions.

The specialists are unrepentant. Fed up with of complaints from sweaty men and shivering women, HVAC technicians install dummy thermostats to give workers the illusion of control. In some leased buildings, even the corporate tenants don't know the thermostats are useless. Other times, it's the companies themselves, barraged with calls from workers, who ask the landlord's HVAC technicians to "fix" things.

Georgia Thompson

Richard Dawson, an HVAC specialist from Homer, Ill., who has several landlord clients, says too many office workers feel their environment is "anything but what they want it to be." Better to install a dummy when they're out to lunch, he figures. He estimates that 90% of office thermostats are dummies (others say it's below 2%).

DOES HE FEEL BAD? "I did what my employer told me to do," Mr. Dawson says. The complainers in the cubicles wore him out.

Controls Operations & Maintenance (O & M)

Basic Steps to Manage Controls O & M

- Assess your overall control situation (technical & operational).
- Get your controls back operating correctly.
- Keep the controls operating correctly.
- Utilize your control system capability to the maximum extent.
- Train your staff on controls.

Assess Your Overall Control Situation

- Don't assume that just because you haven't received a zillion complaint calls, your controls are running at perfect condition.
- Chances are excellent that if the controls weren't commissioned in the first place, you've had hardware and software issues from Day One.
- And, if the operators and maintenance staff are not controls gurus, the problems got worse, not better.
- Something as simple as equipment on/off schedules probably have been disabled – why?

How Can I Get My Controls Back in Good Working Order?

Retro-commission your controls back to working order (hardware & software).

- Assess the condition of control devices and mechanical systems.
- Check point-to-point of your building automation.
- Calibrate your analog points against a verifiable standard.
- Check every control sequence.
- Tune the loops.

Hardware Issues

Correct the problems, replace broken parts, and determine if there are improvements that need to be made, and who will correct them (in-house or contractor)

- If you have broken damper actuators or valves, replace them.
- You can save significant energy from valves that leak or don't work at all.

- **Example:** If the preheat valve leaks through on a large built-up AHU, causing a one-degree rise in return temperature to the cooling coil, for a 10,000 cfm AHU, with 4,000 hours of excess heating per year, $100 per year cooling losses and $250 per year heating losses – total $350 savings.

Hardware Issues

- If your damper sections are rusted and the seals are bad, replace them.
- Leakage on dampers can cause significant energy loss.
- Even the best new damper with good seals has leakage.
- **Example:**
  - Commissioning general exhaust damper in a lab
  - With dampers fully closed, EMC measured leakage as high as 450 cfm (12-inch diameter exhaust damper).
  - This caused the system to add additional conditioned supply air to the lab room to keep it at the correct room pressure.

Hardware Issues

- Checking point-to-point on the controls will verify if the system is correctly controlling and measuring.
- If systems are in “manual,” determine why and correct so they can return to “automated” control.
- If points or actuators are “disconnected,” evaluated problem, and correct.

Hardware Issues

- Make sure sensors are located in a good location to measure appropriately. (Do you have a space temperature sensor next to the coffee pot?)
- Calibrate analog values. (Require “Pete’s Plugs” or extra thermal wells on water lines to field calibrate water temperature sensors.)
- Verify the safeties are working properly and connected to proper circuits.

Hardware Issues

- **Examples of problems:**
  - Valves and dampers disconnected
  - Calibrated 2”x 4” in OA dampers.
  - Valves stroking backwards (i.e., opening when it should be closing)
  - System reading mixed air temp was actually reading return air temp
  - Chilled water sensors not in water stream
  - OA temperature sensor in poor locations getting daily solar effects
  - HWS temperature sensor readings were swapped on 2 steam-HW exchangers
  - Static pressure sensors located in poor duct locations
  - VFDs set in manual
  - Freeze-stat tripping

Software Issues

Functional Test Your Control Sequences

- Determine how you “think” the system should be operating – design or documented changes.
- Create a functional test plan for the system.
- Test each part of the system to see its reaction to the changing of variables to see how it actually is operating (i.e., change the discharge temp setpoint on a VAV cooling coil and see if it opens/closes as expected).
- See if the system has resets and optimizations changing setpoints (example: fan static pressure resets).

Software Issues

Functional Test Your Control Sequences

- Get equipment operating on correct on/off schedule .
- Trend control loops and setpoints for 24 hours to see if system is controlling as expected & to see how well control loops are tuned.
- You may need to trend equipment at different times of the year (winter-summer-shoulder months).
- Note and correct minor software problems as you go.
- Tune controls loops that are bad, trend, and retest.
- Compare current setpoints with original design setpoints; correct as necessary.
- Check the systems network integrity
- Check the software failure modes – “What if?”

Look What I Found

Things to Look Out For:

- PIUs where minimums cfms have high limits, and fans/reheats will come on exactly at minimum cfm (no deadband) causing excess heating
- Reheat valves that won't close all the way
- Cold corridor air being sucked into laboratory, through temperature sensor, causing the space to reheat
- Secondary pumping systems on chilled water loops operating at too high a flow for tonnage
- Tri-state VAV terminal actuators with "auto-calibration"

Deferred Maintenance List

- Compile an automated controls deferred maintenance list to have an accurate accounting of system components that must be replaced and as a basis for securing the resources needed to regain lost control function and reliability.
- Create a priorities for automation items needing repair.
- Individual projects can then be initiated to address the priorities as resources become available.

Ongoing Controls Maintenance

- The owner now has a benchmark to operate the system.
- The following provides examples of the type of tasking required for effective ongoing maintenance of the automated controls to ensure stability and reliability according to the manufacturer.

Ongoing Controls Maintenance

- The energy management system (EMS) can be broken down into smaller components for the purpose of establishing maintenance routines.
- The specific individual maintenance actions should be established within the overall facilities maintenance program.
- The owners computerized maintenance management system (CMMS) program will be a major component of establishing the automated controls maintenance program.
- Information about the individual automated controls equipment such as actuators, controllers, panels, workstations, and databases should be updated and input into the CMMS.

Ongoing Network Maintenance

<u>Network Management Tasks</u>

On a Daily Basis:

- Identify offline controllers

On a Scheduled Basis:

- Reset the network diagnostic counters
- Allow data to tabulate in the diagnostic registers
- For each operator workstation and network control unit (NCU):
  - List network Diagnostic Statistics.
  - Analyze the number of reconfigurations for impact on network performance.
  - Analyze the error rate for each network node.
  - Analyze the transmission rate for each network node.
  - Determine network performance ratio.
- For each NCU or companion trunk
  - List network Diagnostic Statistics.
  - Analyze the error rate for each network node.
  - Analyze the transmission rate for each network node.
  - Determine the network performance ratios.
  - Provide a report summarizing network analysis results.
  - Perform the network analysis tasks as appropriate to verify or discount suspected communications or network throughput problems (data loss from problems arising in network devices).

Every Five Years:

- Replace memory retention back-up lithium battery.

Ongoing Controls Maintenance

<u>AHU Application Specific Controller</u>

Daily:

- Check for alarms; evaluate condition.

On a Regular Basis:

- Verify that AHU is being controlled at the appropriate values.
- Change one setpoint value; verify smooth transition and stable control at the new setpoint.
- Return set point to original value.
- Repeat for each additional control loop, if any.
- Verify that controlled valves and dampers will stroke fully in both directions, sealing tightly where appropriate.
- Verify the proper operation of critical control processes and points associated with this unit. Make adjustments if necessary.

On an Annual Basis:

- Verify on/off schedules.
- Verify setpoints.

Every Two Years:

- Verify/calibrate analog points associated with this unit.

Ongoing Controls Maintenance

<u>VAV Box Application Specific Controller</u>

On a Regular Basis:

- Verify that ASC is in stable control at the desired value(s).

Where controller performance is in doubt:

- Change setpoint value. Verify smooth, stable control at the new value.
- Return setpoint to original value.
- Verify the proper operation of critical control processes and points associated with this unit. Make adjustments if necessary.
- Verify/calibrate other points associated with these units where the need for possible "Corrective Maintenance" is indicated.

On an Annual Basis:

- Verify setpoints.

Ongoing Controls Maintenance

<u>Major AHU and Central Plant Controller</u>

Daily:

- Check for alarm indication on the LCP display panel..
- Evaluate any alarm condition(s), which may be indicated.

On a Scheduled Basis:

- Verify that equipment is being controlled at the appropriate values.
- Change one setpoint value; verify smooth transition and stable control at the new setpoint.
- Return setpoint to original value.
- Repeat for each additional control loop, if any.
- Verify that controlled valves and dampers will stroke fully in both directions, sealing tightly where appropriate.
- Verify the proper operation of critical control processes and points associated with this unit, and make adjustments, if necessary.

On an Annual Basis:

- Verify on/off schedules and setpoints.

Every Two Years:

- Verify/calibrate analog points associated with this unit.

Every Five Years:

- Replace memory retention back-up lithium battery .

Controls Mentality

- Develop a mentality to figure out what's wrong.
- "Don't just change the setpoint or the schedule or manually isolate/disconnect – figure out what the problem is."
- Example, "I increased the fan static pressure setpoint because they weren't getting enough cooling."

Controls Training

- Owners should establish a formal training program for all controls stakeholders.
- The complex nature of modern HVAC controls, energy management practices, and the EMS technology itself requires that all personnel associated with EMS be trained to a level appropriate for their job duties.
- Each stakeholder group will require a training program targeted at level of functionality required by their section leadership or job duties. Assess what the staff knows and prepare a training program.
  - Emergency Console Personnel
  - EMS operators, (Setpoints, Schedules, Graphics)
  - Central Power Plant Operators
  - Facility Management, Engineers, and Planners
  - Energy Management Engineer
  - Plant Engineers (Trending, Alarms, Scheduling)
  - Shop Maintenance Personnel

Controls Training

A formal training program should consist of the following elements:

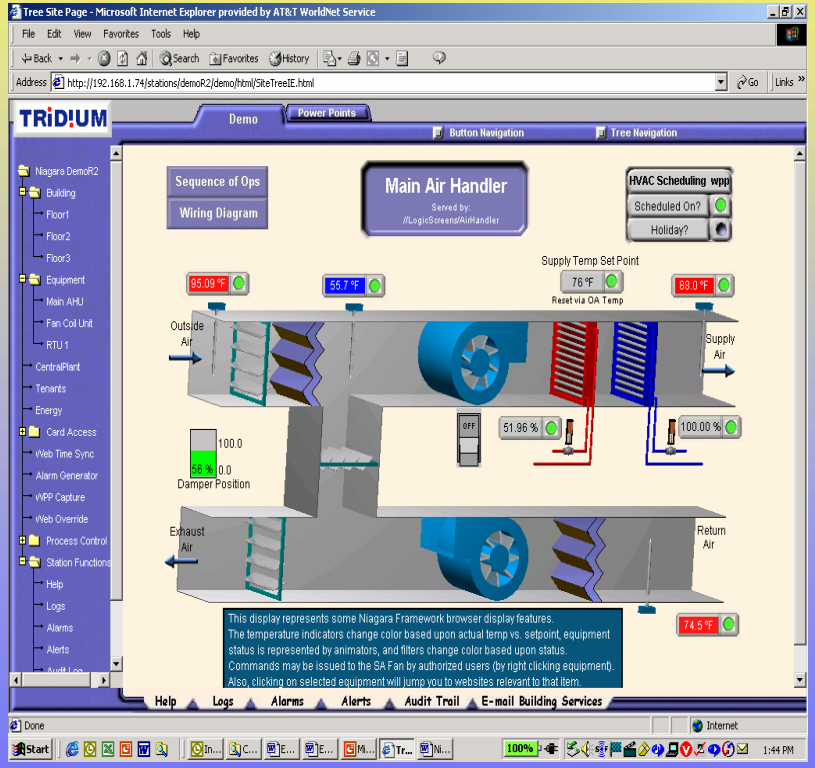
- A syllabus of required training tasks and record of hours performing them.
- An annual training calendar specifying periodic required training cycles
- A training plan for each UCS operator or user.

Fully Utilize Your Control System Capabilities

- Keep track of software issues to improve and optimize the system (i.e., get rid of screwed up sequences).
- Unfortunately, many sequences were based on a duplication of old local loop pneumatic sequences, and did not try to take advantage of improved building automation capabilities.

Examples to Improve Control System Capabilities

- Improve operator workstation graphics.
- Add trending and alarming of utility usage.
- Provide technicians with laptops and PDAs for local service.



Examples to Improve Control System Capabilities

Sometimes it's as easy as changing a setpoint.

- Example: Let the condenser water setpoint for cooling tower control float up/down as a function of OA wet-bulb temperature.
- Example: Changeover point on an OA economizer, dry-bulb or enthalpy.

Summary
Controls O & M

- Improving your controls O & M will provide a significant return on your investment.
- Basic steps to improve controls O & M
  - Assess
  - Get them operating
  - Keep them operating
  - Improve the capability
  - Train the employees

Thank You!

- Contact Information for Carl Lundstrom
  - Telephone 678-254-1221
  - Email clundstrom@emcengineers.com
  - Internet www.emcengineers.com

Part III – Resources That Can Help

- DDC Online
- National Building Controls Information Program
- Training Opportunities

DDC Online

- Online Technical Information Manual on Direct Digital Controls
  - Elements of a DDC System
  - Input/Output Devices
  - Controlled Devices
  - Controllers

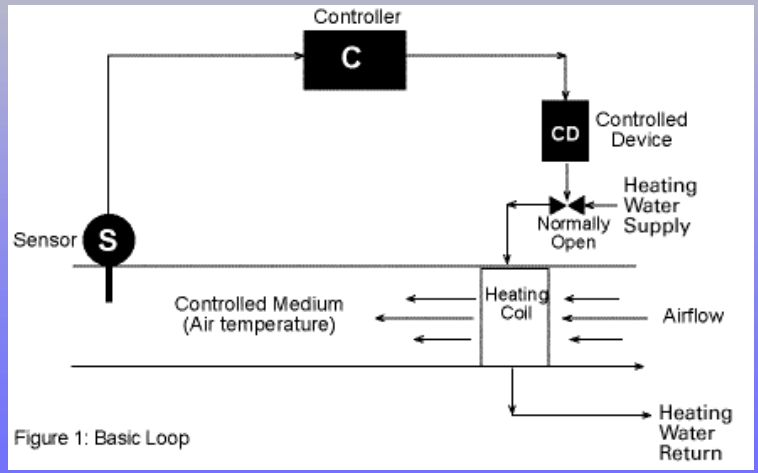
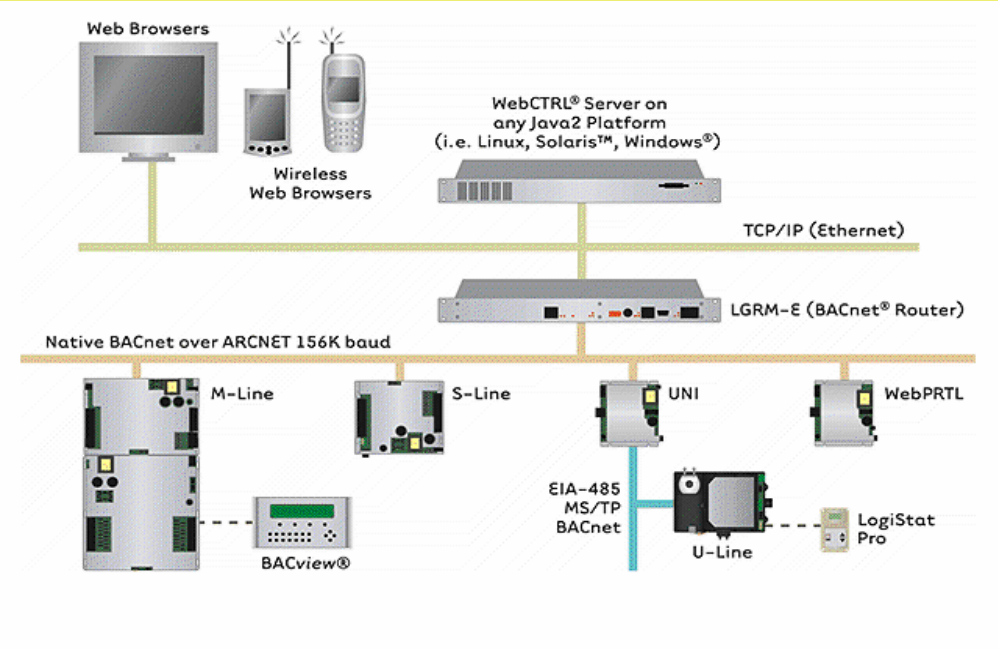


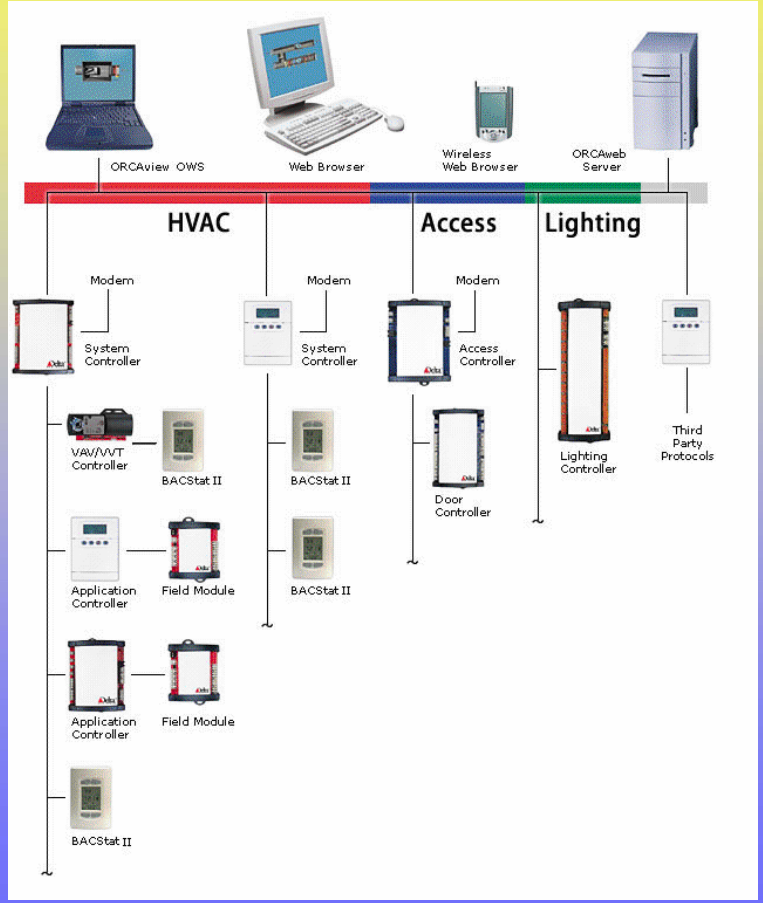
Figure 1: Basic Loop

DDC Online

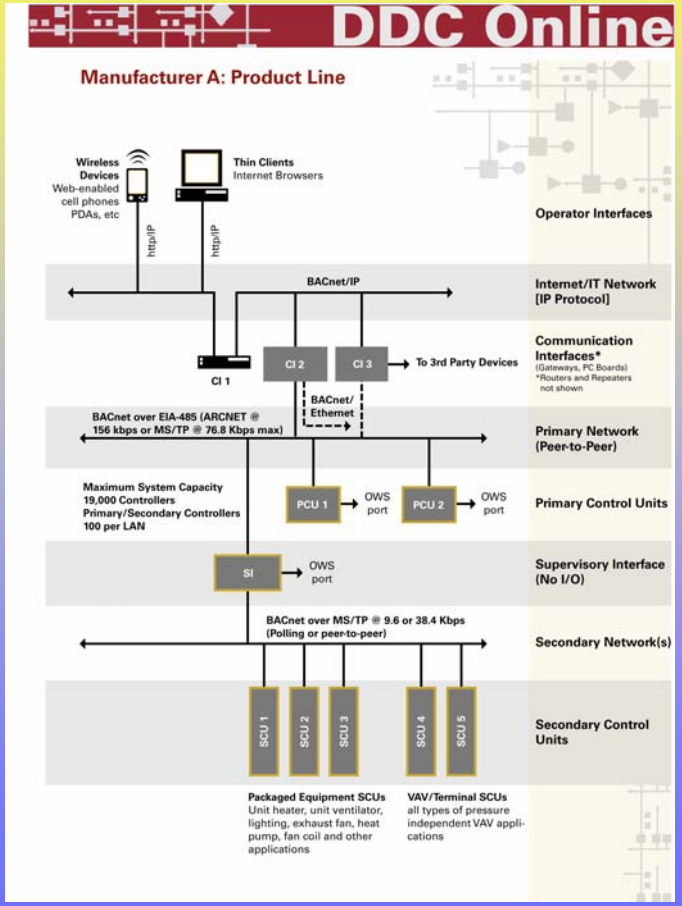
- Online Comparison of Products from Major Direct Digital Control Manufacturers
  - Products presented using a generic framework and common terminology
  - Site includes product lines from 17 manufacturers

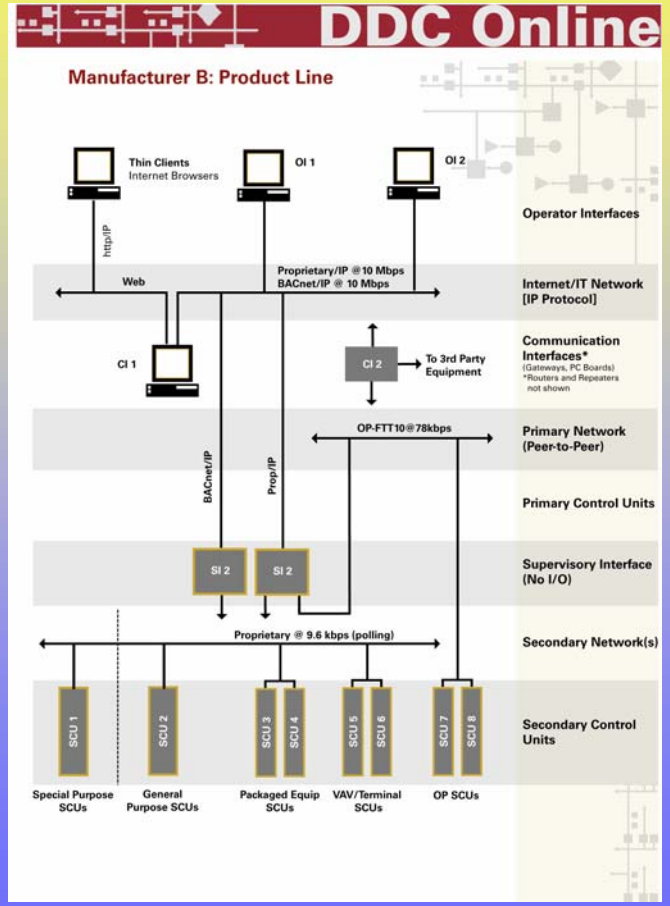
Comparing Products: The Old Way





Comparing Products: DDC Online - A New Way





Architecture Layers

- Identify Main Features of a Product Line
  - Operator Interfaces
  - Iternet/IT Network
  - Communication Interfaces
  - Primary Network
  - Primary Control Units
  - Supervisory Interfaces
  - Secondary Network
  - Secondary Control Units

Controllers – What's the Difference?

Primary Control Units

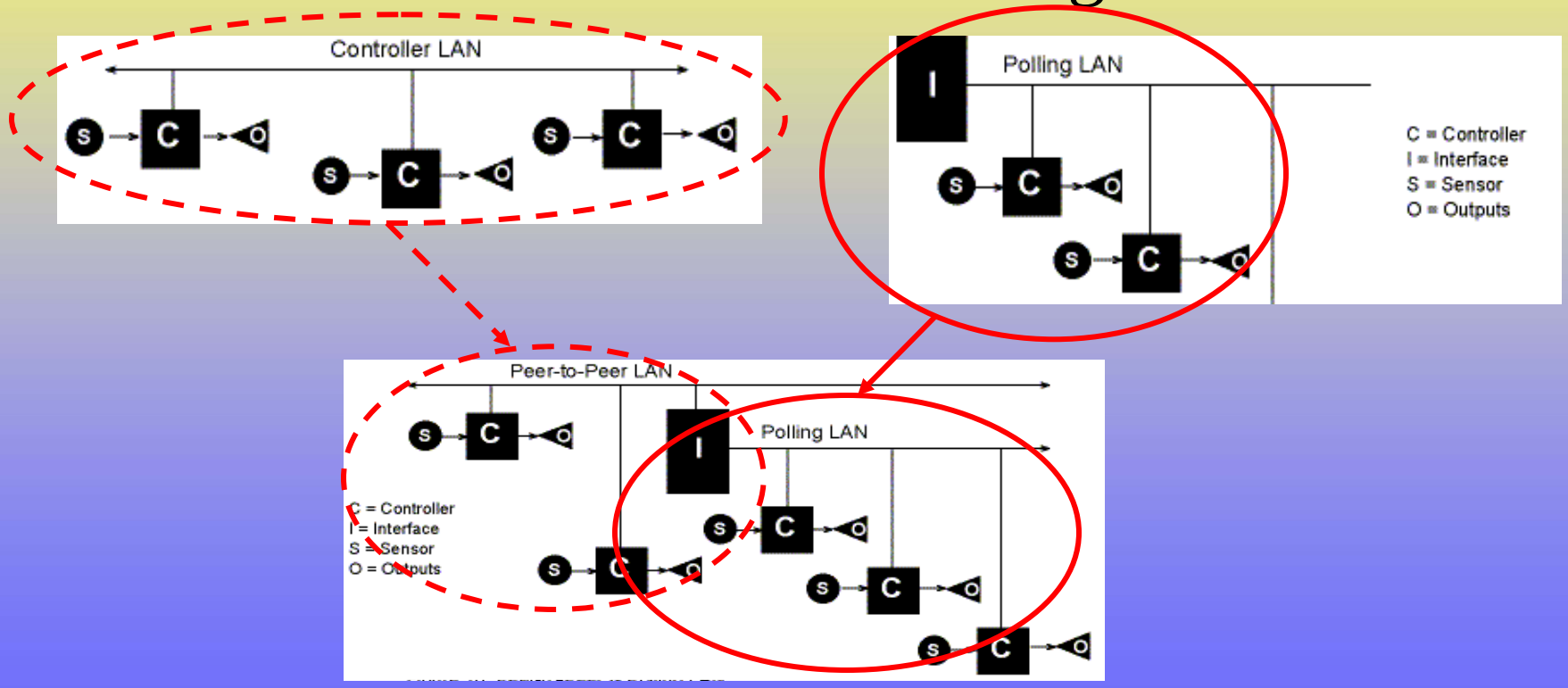
- Peer-to-peer communications
- Larger total point capacity
- Real-time accurate clock function
- Higher A/D resolution
- Custom programming
- Large buffer for alarms/messages/trend data

Secondary Control Units

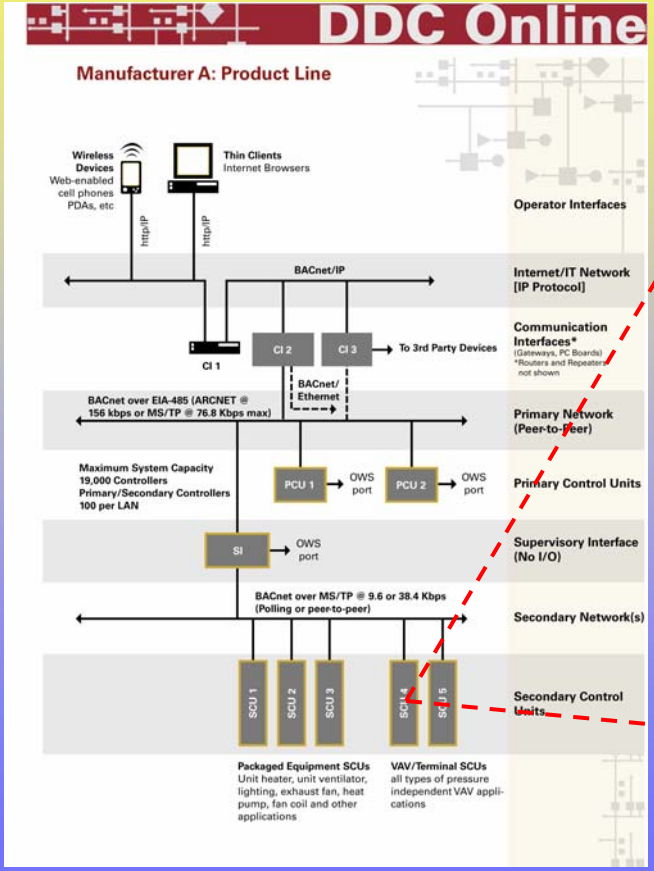
- Often have polling communications
- Typically configurable using application-specific software
- Little or no capability to store trend data

LAN Communications

- Peer-to-Peer
- Polling



DDC Online Product Details



Manufacturer Name Secondary Control Unit (Application-Specific)

SCU3 and SCU4

Quick Links

Description	Processor
IO Processing	Trend Data
VAV Controllers	Programming
I/O Expansion	Controller
Comm Ports	Power
Interfaces	Compliance

Input/Output Processing

	Point Quantity	Characteristics
Analog Input (AI)	6	• 0 - 10 Vdc • 1000 ohm RTD
Digital Input (DI)	4	• Dry contact • 24 VAC
Universal Input (AI or (DI)	X	None
Analog Output (AO)	See below	• 0-10 Vdc (@ 10 mA)
Digital Output (DO)	See below	• Triac switch (24Vac, 0.5A) • 120/240Vac SPDT relays

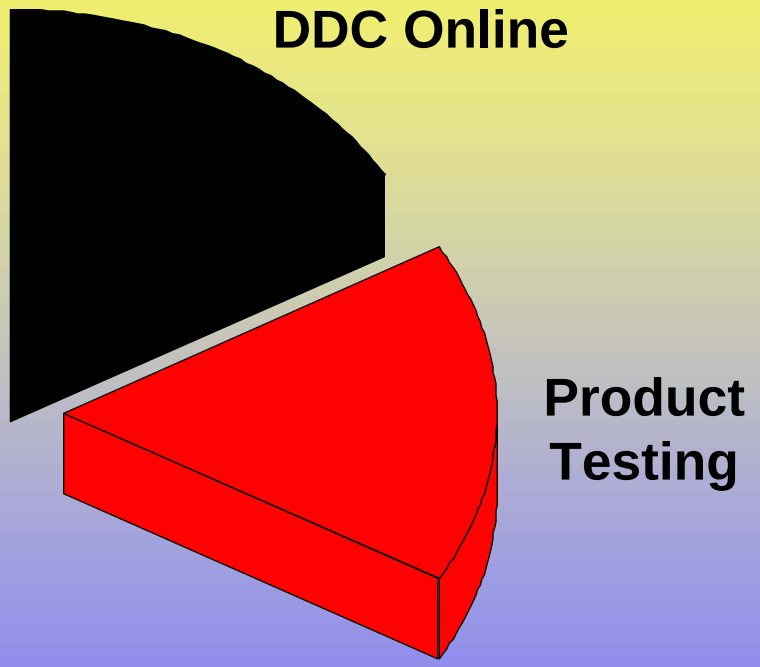
Control Unit Model #:	Point Quantity					
	AI	DI	UI	DO	AO	Other
SCU3	6	4		8		
SCU4	6	4		6	2	

A/D Converter Resolution	- 8 bit x 10 bit - 12 bit - Other
D/A Converter Resolution	- 6 bit x 8 bit - 10 bit - No Analog Output - Other

National Building Controls Information Program

- Objectives
  - Facilitate the adoption of energy-efficient control products and strategies through testing, demonstration, education and information dissemination
  - Reduce the cost to commission, operate and maintain buildings
  - Long-term goal: change the market for commercial and institutional building controls

NBCIP Program Elements



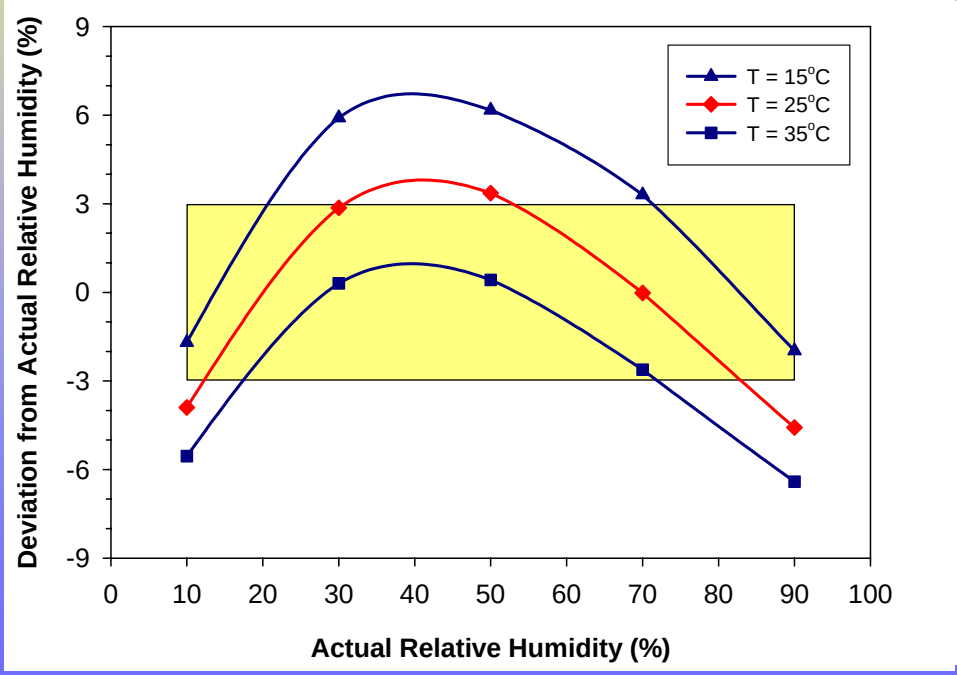
Product Testing

- Duct Mounted Relative Humidity Sensors
  - Sensors from six manufacturers under test
  - HVAC grade (±3 % accuracy)
  - Performance testing at
    - 10, 30, 50, 70 and 90% RH
    - 15, 25 and 35°C
  - Testing for:
    - Accuracy, repeatability, hysteresis, linearity, response time and drift

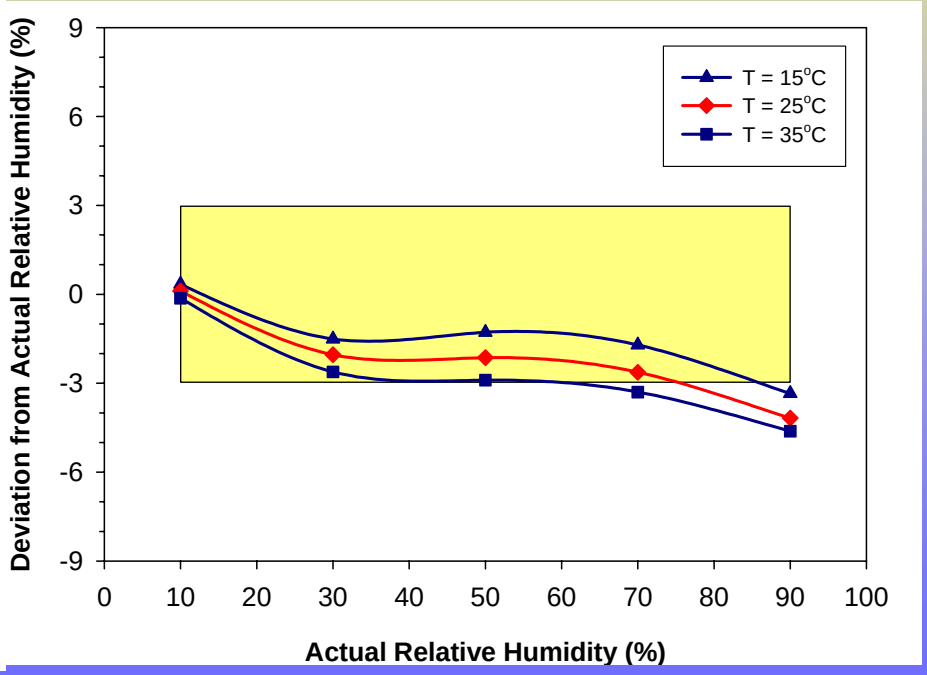
Product Testing

- Duct Mounted Relative Humidity Sensors

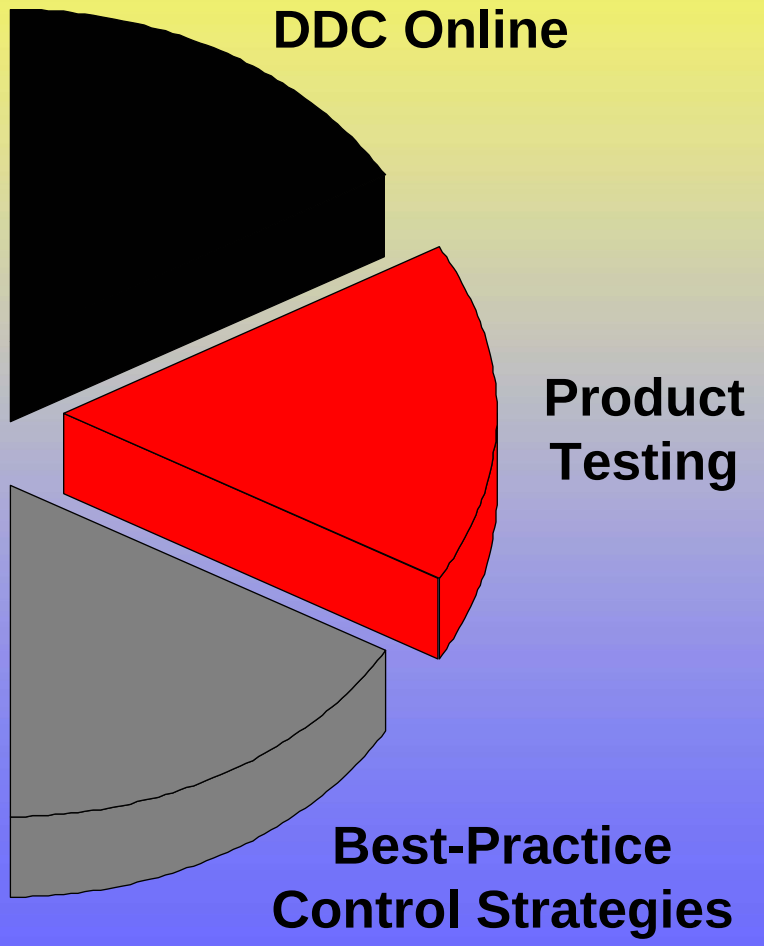
Sensor A



Sensor B



NBCIP Program Elements



Best Practice Control Strategies

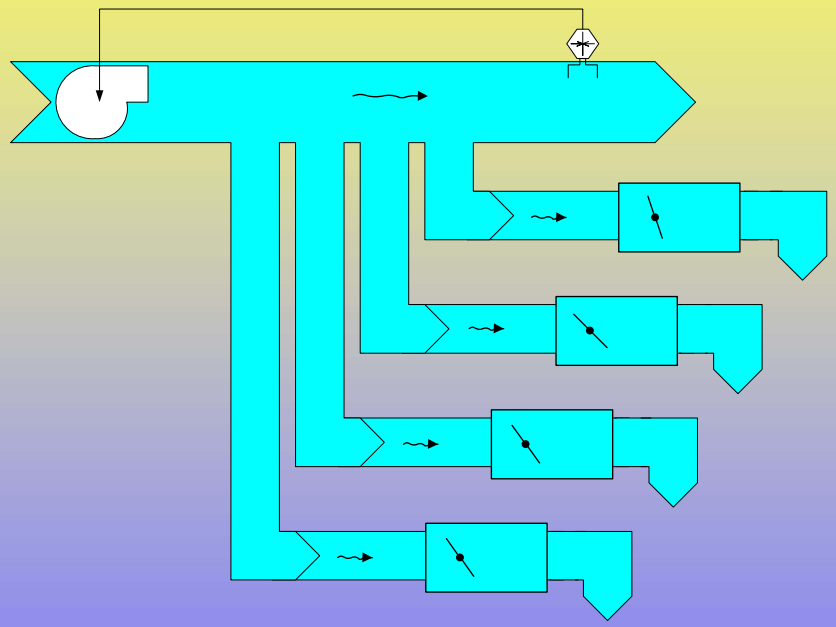
4 Matched Pairs of fully instrumented Test Rooms

Allow for Side by Side testing of Control Strategies

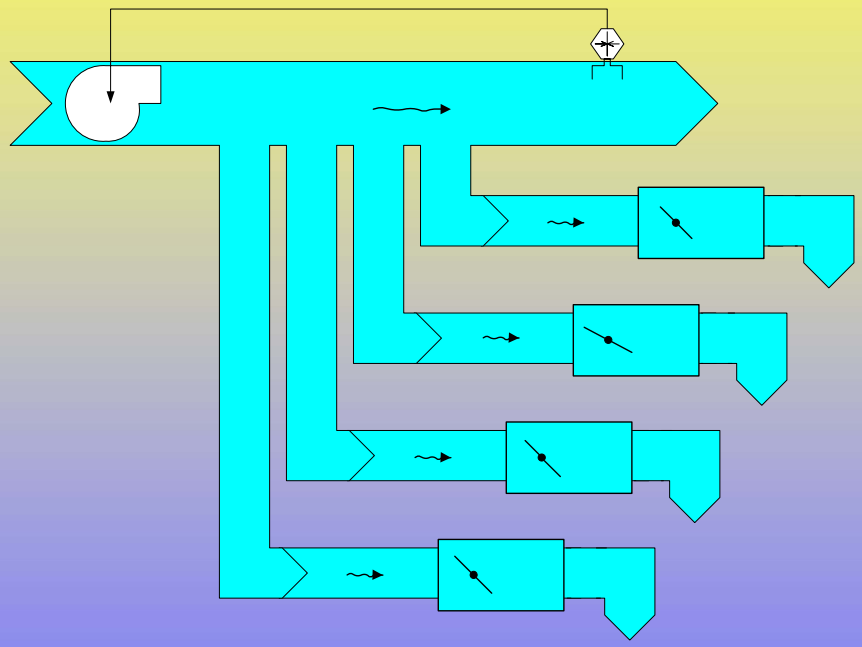
Best Practice Supply Fan Control Strategy

- Static Pressure Reset
  - Fans routinely run at unnecessarily high speeds, resulting in energy waste
  - Static pressure reset strategy automatically adjusts fan speed to minimize energy waste

Best Practice Supply Fan Control Strategy



Conventional Strategy



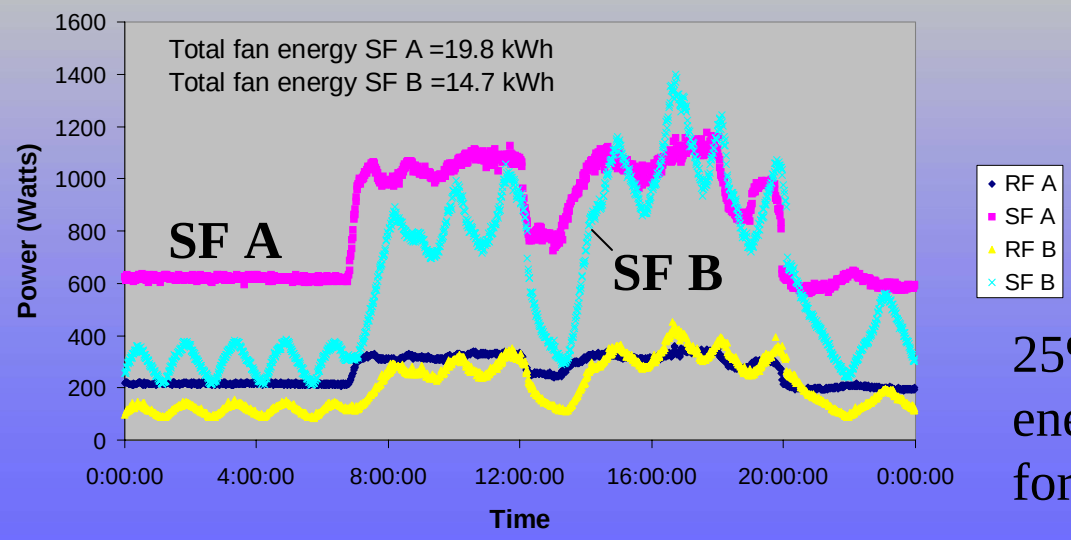
Static Pressure Reset Strategy

Power $\propto \omega^3$

P = P

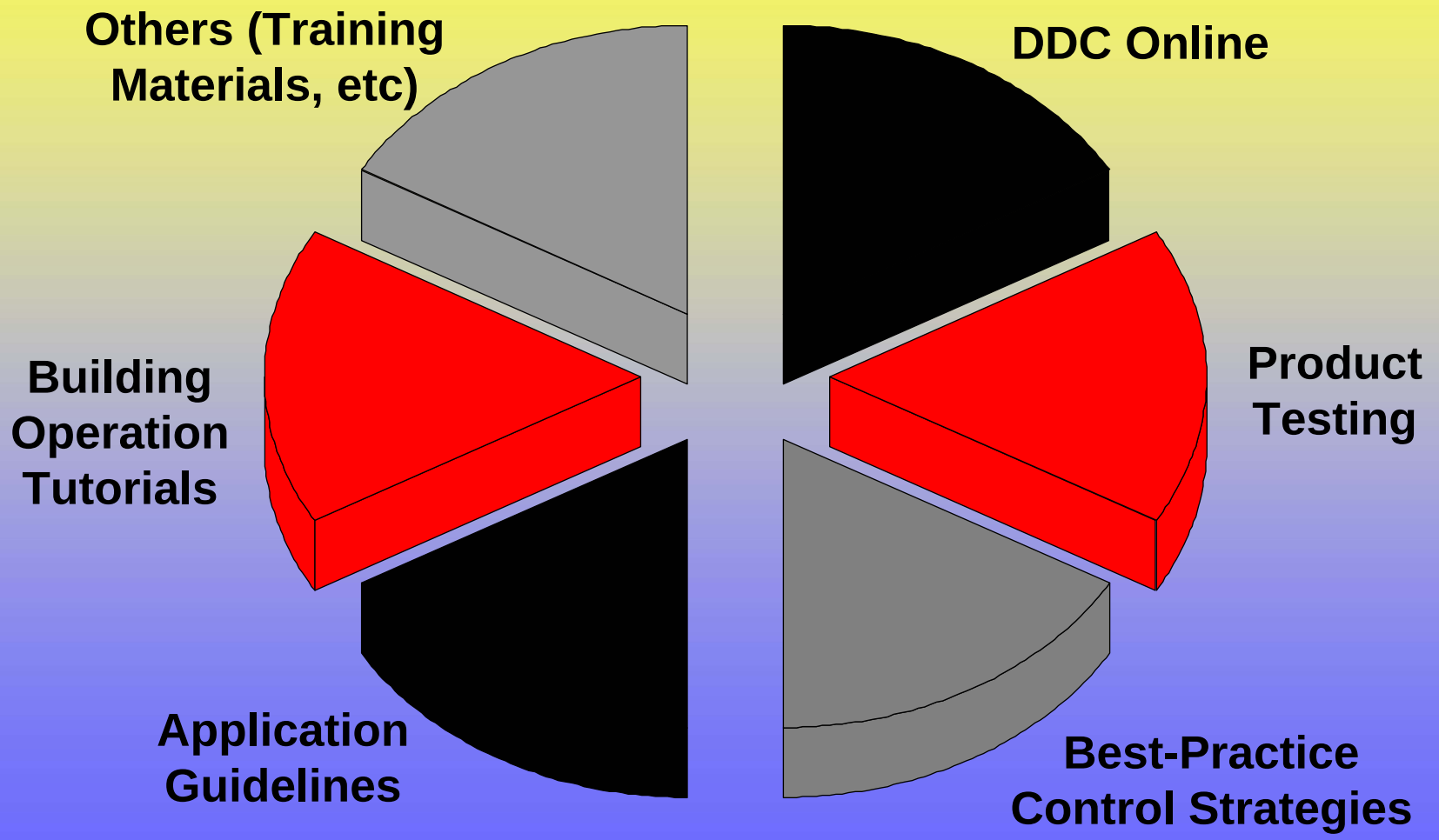
Best Practice Supply Fan Control Strategy

- Comparison Testing
  - AHU A: Conventional Fixed Static Pressure
  - AHU B: Static Pressure Reset



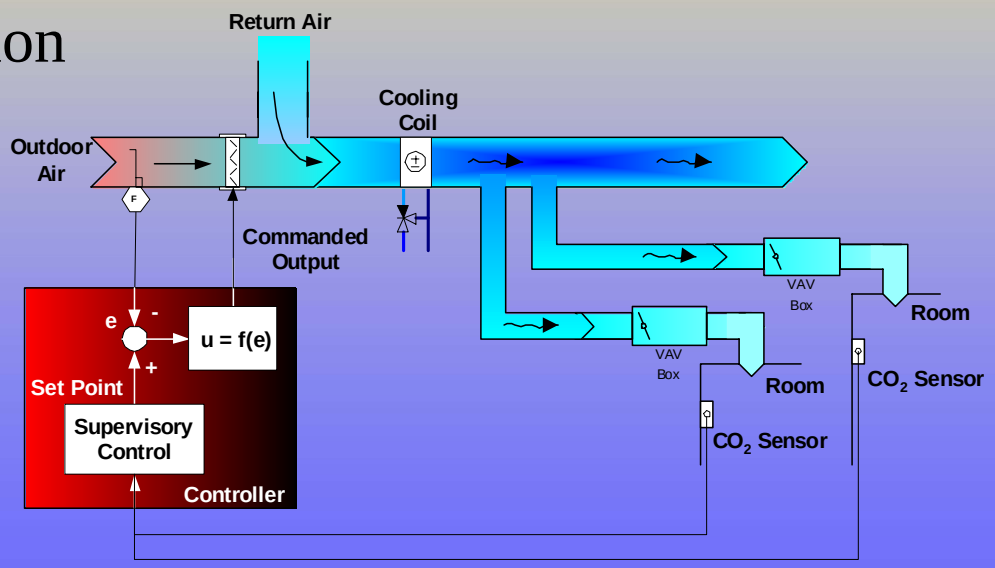
25% supply fan energy savings for AHU B

NBCIP Program Elements



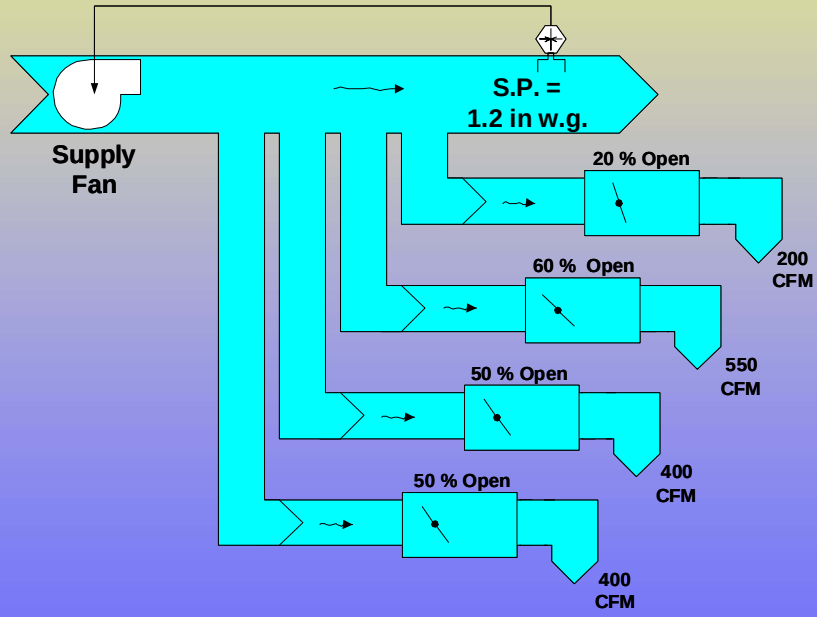
Planned Projects

- Product Testing of CO_2 sensors
  - Critical component of demand-controlled ventilation strategies
  - Sensor drift is common problem



Planned Projects

- Product Testing of Tri-State Actuators
  - Target application is VAV box damper control
  - Actual position of damper often unknown
    - Limits capability to use damper position to troubleshoot problems
    - Critical component of supply fan control strategies such as static pressure reset



Training Opportunities

- Utilities
- University Extension
- Professional Associations
- Manufacturer based

Training Opportunities

- ASHRAE SSPC 135 – BACnet Committee Website
  - http://www.bacnet.org : click on Short Courses
    - An Introduction to BACnet
    - Understanding and Specifying BACnet Systems
- The Association of Energy Engineers
  - http://www.aeecenter.org/seminars/
    - DDC Open Systems: A Consumer's Guide to BACnet, LonWorks & Networking Standards

Training Opportunities

- Online DDC Courses from UCSD
  - http://www.extension.ucsd.edu/Courses/index.cfm
  - Look for "HVAC Systems Design and Control"
- University of Wisconsin Engineering Professional Development
  - http://epdweb.engr.wisc.edu/courses
  - Click on HVAC Building Systems and look for DDC Controls

Training Opportunities

- ASHRAE
  - http://www.ashrae.org : select “Training” from Shortcuts
    - Fundamentals of HVAC Control Systems
- Pacific Energy Center
  - http://www.pge.com/003_save_energy/003c_edu_train/pec/programs/index.shtml : click on HVAC
    - Introduction to LonWorks
    - Digital Controls 101
    - DDC 201 and 202: Specifying and Commissioning Controls
    - BACnet: The Nuts and Bolts
    - DDC 203: Maximizing the Cost Benefits of Direct Digital Controls

Thank You!

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