Recommissioning Workshop

September 30, 2013

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Senior Engineer

PECI

Today's Agenda

Topic	Start time
EBCx Overview	8:30
Planning Phase	
Develop current facility requirements	
Analyze energy data	
Develop EBCx Plan	
Break	10:00
Investigation Phase	10:15
Common findings	
Review documents, conduct interviews	
Evaluate facility performance	
Lunch	12:00
Investigation Phase, cont'd.	12:45
Evaluate facility performance	
Formulate measures	
Estimate energy savings	
Break	2:30
Implementation Phase	2:45
Hand-Off Phase	
Resources	
Class dismissed!	4:30

Learning Objectives

After this class, you'll be able to:

1. List activities included in each phase of the EBCx process.

2. Describe Xcel Energy's RCx program.

3. Develop current facility requirements.

4. Describe methods for testing and evaluating HVAC, lighting, and envelope systems and assemblies.

5. List common low-cost EBCx measures for commercial and institutional buildings.

Learning Objectives, cont'd.

6. **Develop functional performance test forms.**

7. **Analyze trend data.**

8. **Investigate findings to formulate measures.**

9. **Develop and review energy savings calculations for EBCx measures.**

10. **Develop methods for maintaining the persistence of benefits realized from implementing the EBCx process.**

Introductions

- **What types of buildings are you involved with?**

- **What has been your experience with commissioning?**

- **What do you hope to learn today?**

Your Turn!

Xcel Energy's Definition of Recommissioning (RCx)

■ Recommissioning is the process of **returning a building's** mechanical and lighting **systems**, along with the building controls, **to their peak performance**.

■ This is **done through the investigation** of the existing system performance, the **adjustment** of the operating parameters and the **repair** of faulty equipment.

■ Recommissioning is intended to **optimize the existing systems without having to add new components**, which typically exposes low cost measures with attractive paybacks.

RCx Program Features

- **Program available to all Xcel Energy electric and natural gas business customers in Colorado**
  - ◆ **Must be retail gas customer**
- **Study funding**
  - ◆ **Up to 75% of the cost of the study, not to exceed $25,000**
- **Implementation rebates (max rebate is 60% of cost)**
  - ◆ **$400/kW or $0.08/kWh (whichever is higher) plus $4/Dth**
    - ■ **Rebates available for measures with paybacks between 1 – 15 years**
- **Program covers both re- and retro-commissioning**

Process Overview

1. **Customer applies for study preapproval to determine funding**

2. **Study is completed and submitted to Xcel Energy for review**

3. **Study is approved**

4. **Study rebate is paid**

5. **Customer determines which measures they'd like to implement**

6. **Implementation is completed**

7. **Implementation rebate is paid and Xcel Energy claims the savings**

Phase I: Preapproval

- Customer submits study preapproval application and recommissioning proposal
  - **Proposal should contain:**
    - **Addendum A** – Required List of RCx Measures
    - **Building and equipment description**
      - Is there a control system? If so, provide information
    - **What you will analyze**
    - **Preliminary observations for RCx opportunities**
      - Identify what you already know is wrong with the building
    - **Customer concerns**
    - **Proposed cost for the study**
- If approved, we'll notify the customer, the provider and the account manager via email

Commonly Identified Findings

- AHU Air leak reduction

- AHU Coil cleaning

- AHU optimize economizer

- AHU outside air reduction

- AHU run time reduction

- AHU supply air static pressure adjustment / reset

- AHU supply air temperature reset

- AHU VAV minimum flow reduction

- Lighting and equipment run time reduction

- Unoccupied setback

- Exhaust system operation

Phase II: Investigation

- Complete study and send draft version to Xcel Energy engineer

- Once approved, notification will be sent to both customer and provider

- Present approved study to customer, invite Xcel Energy Account Manager to meeting

- Customer pays for study and submits rebate form and paid invoice to Xcel Energy Account Manager

- Xcel Energy issues study rebate

Calculation Tool

- **Created RCx energy savings calculator tool for use with RCx studies in our territory**

- **Streamlines saving calculations for provider**

- **Contains 19 Energy Conservation Opportunities (ECOs)**

- **Reduces internal review time by engineer**

Phase III: Implementation

- Customer determines which recommissioning measures to implement

- Customer signs rebate form and submits to Xcel Energy
  - ◆ For all recommissioning measures implemented
    - Need each line signed and dated
    - Provide costs for each individual recommissioning measure
    - Submit project invoice

- Rebate is processed and is sent to customer

Study Provider Approval Process

- **Investigator Application**
  - **One lead investigator required per firm – not a requirement to perform a study**
  - **We need a point of contact for study clarification**
- **Study Provider Training**
  - **Two hour training conducted by Xcel Energy's RCx team**
  - **Required for anyone who will be working on study and seeking access to our calculator tool**
  - **Complete our license agreement and return to us**
- **Study Provider List**
  - **Once you have a study approved in the Recommissioning program you will be added to our provider list on XcelEnergy.com. You do not need to be on the provider list to do a study.**

EBCx Process

Planning Phase
- Select a building
- Define RCx objectives
- Assemble a team
- Develop a *Retrocommissioning Plan*

Investigation Phase
- Review facility documentation
- Perform diagnostic monitoring & testing
- Develop *Master List of Findings*
- Prioritize and select RCx improvements

Implementation Phase
- Develop *Implementation Plan*
- Implement selected operational improvements
- Verify results
- Develop *Final Report*

Hand-Off Phase
- Develop *Recommissioning Plan* & recommend persistence strategies
- Conduct staff training
- Hold close-out meeting

Post Retrocommissioning
- Implement persistence strategies

Source: EPA

Planning
Investigation
Implementation
Hand-Off
Post-RCx

Planning Phase Summary

- **Define EBCx goals**

- **Select building**

- **Form the EBCx team**

- **Analyze historic energy data**

- **Gather facility documentation**

- **Conduct building walk-through**

- **Develop current facility requirements**

- **Develop *EBCx Plan***

Planning Phase Summary

■ **Define EBCx goals**

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■ **Develop current facility requirements**

■ **Develop *EBCx Plan***

Analyze Monthly Utility Data

Average Daily Electricity Use for ABC Tower
Account XXX-XXX-XXX
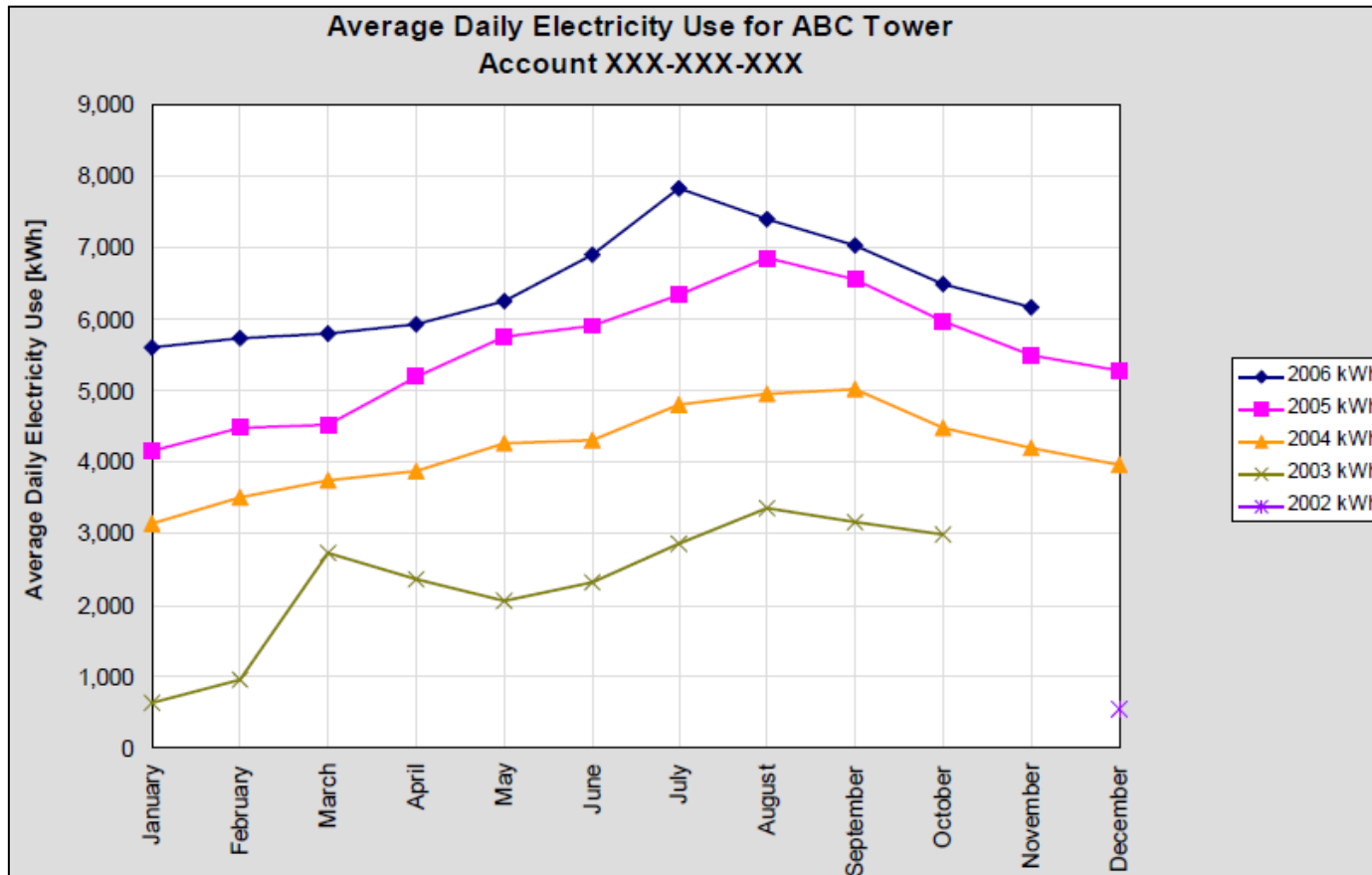
More Useful Utility Data

■ **Interval utility data**

◆ **Identify base load during unoccupied periods**

◆ **Identify operational problems**

'Good' office profile:
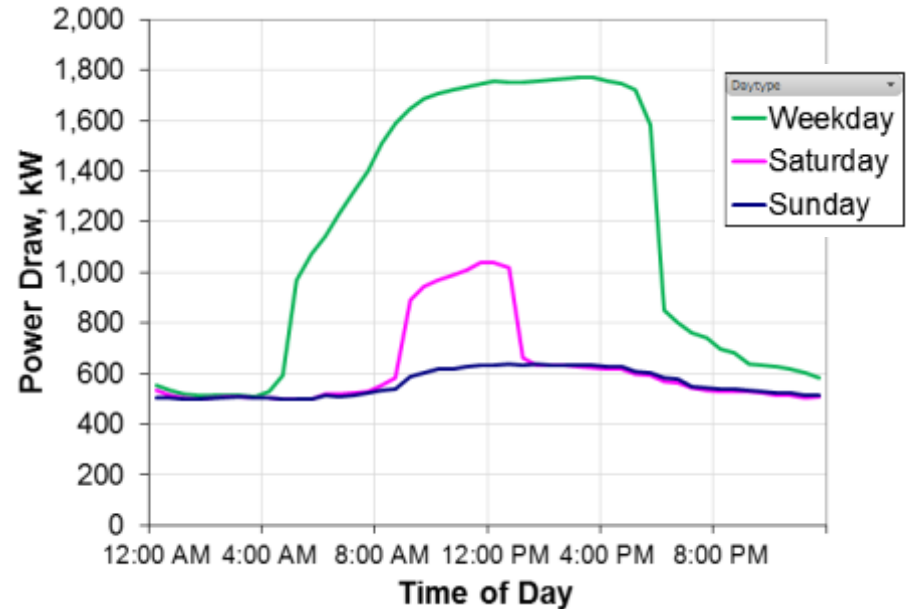
What does this chart tell us?

Office building, M-F 8a-5p occupancy
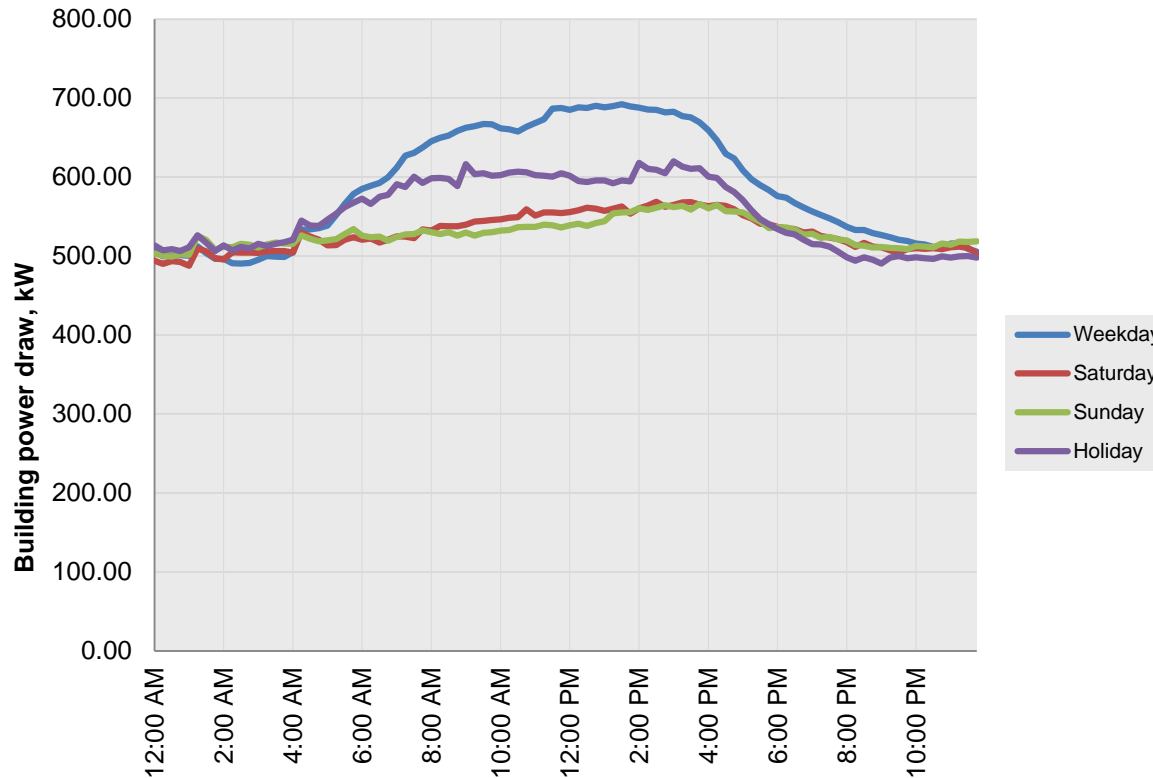
Your Turn!

Gather Facility Documentation

Purpose:

- **Increase understanding of building**

- **Determine what documentation is available**

Useful Documentation

- **Building plans and specifications**

- **O&M manuals**

- **Testing, adjusting and balancing reports**

- **Controls drawings**

- **Controls sequences of operations**

- **Maintenance documentation records**

- **Historical energy consumption and cost data**

- **Recent energy studies**

Conduct Building Walk-Through

Purpose:

- **Learn space types and occupancy levels**

- **Observe operation and condition of equipment**

- **Identify indicators of opportunity**

Conduct Building Walk-Through

Conduct it with a knowledgeable building staff member.

Conduct Building Walk-Through

Observe:

- **Occupied and unoccupied areas**

- **HVAC, lighting, plug load, envelope, control systems**

- **Quality of maintenance**

Look for optimization opportunities.

Keep the EBCx goals in mind!

Building Walk-Through: HVAC

Your Turn!

Building Walk-Through: BAS
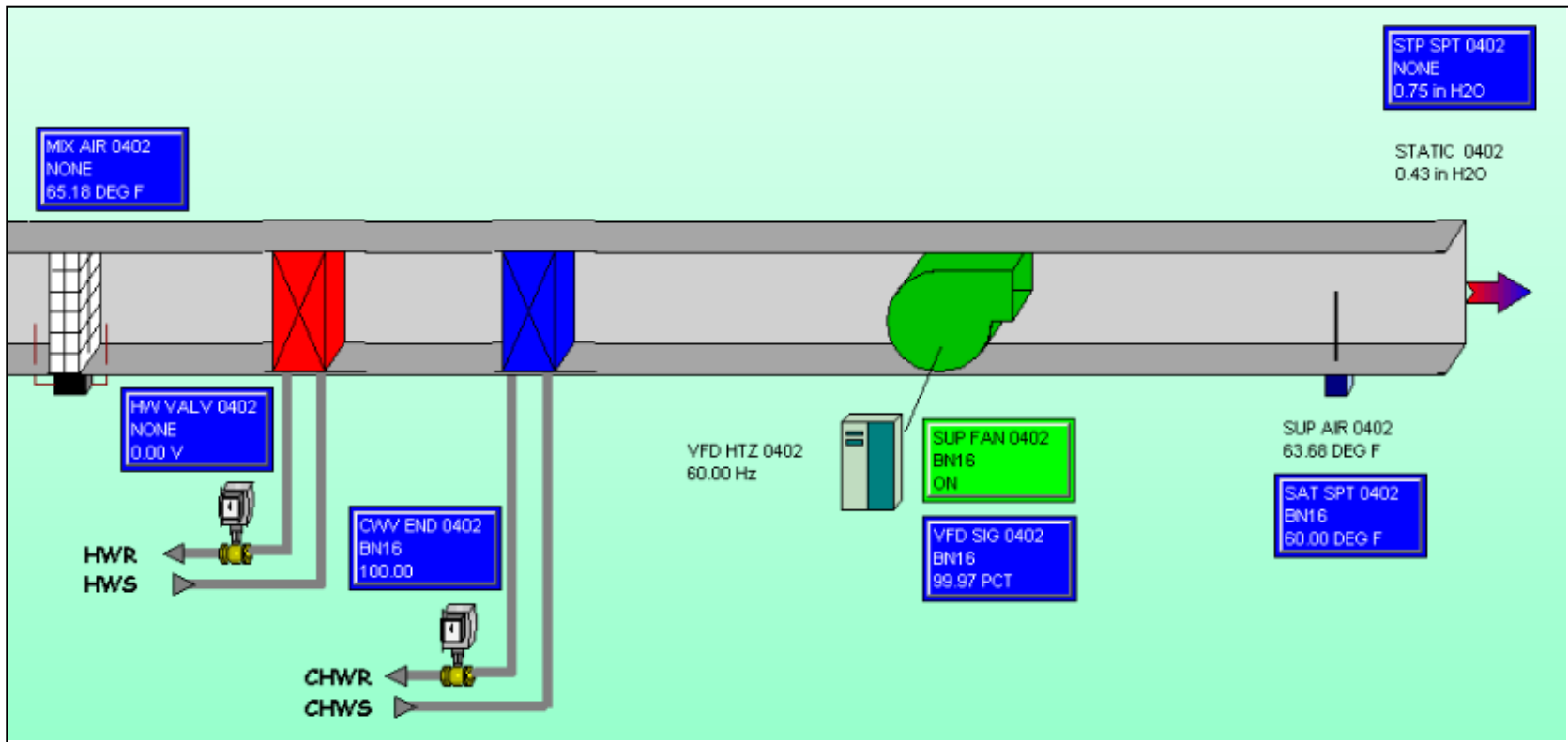
Building Walk-Through: Lighting

Your Turn!

Building Walk-Through: Plug Loads
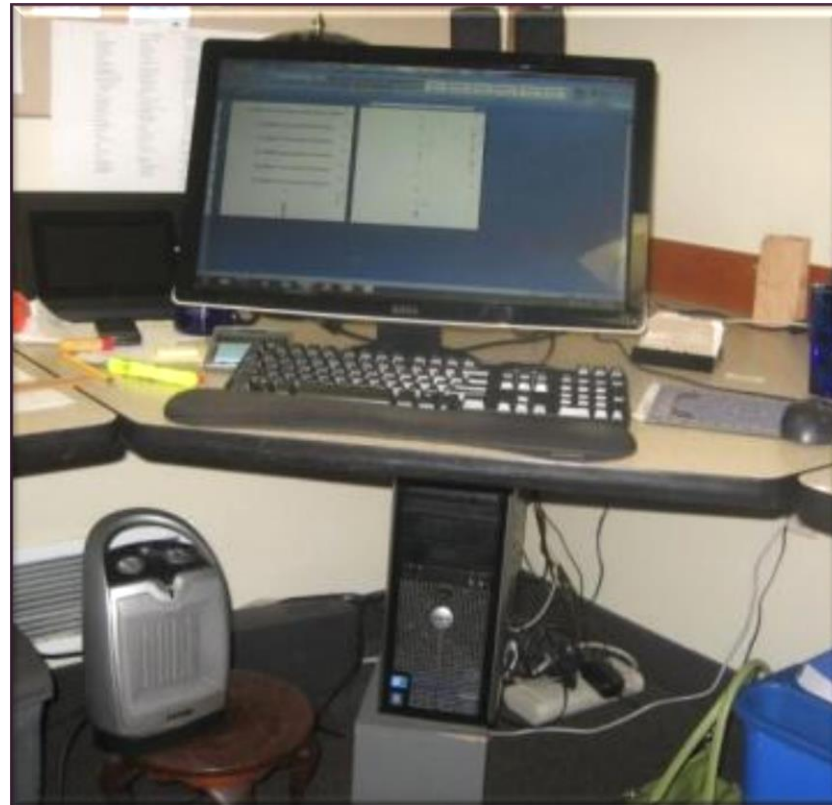
Your Turn!

Building Walk-Through: Envelope

Your Turn!

Findings to Look For

Resources / lists:

- **Xcel Energy's Addendum A (handout)**
- **Listed in "Resources" table:**
  - ◆ **ASHRAE's *Procedures for Commercial Building Energy Audits***
  - ◆ **Doty's *Commercial Energy Auditing Reference Handbook***
  - ◆ **BetterBricks**

Develop the CFR

CFR = <u>C</u>urrent <u>F</u>acility <u>R</u>equirements

- **Defines the operational needs and requirements for the building**

- **Meeting the CFR is an inherent goal of EBCx**

Develop the CFR

■ **CFR typically includes:**

- ▪ **Temperature and humidity setpoints**
- ▪ **Equipment operating schedules**
- ▪ **Lighting levels**
- ▪ **Facility staff training**
- ▪ **Sustainability**
- ▪ **Other**

Develop the CFR

Requirement	General Office	Conference Rooms	Customer Service	Data Center & LAN Rooms	Mail & Printing	Art Gallery	Shower Locker Rest Rooms	Parking Garage	Tenant Retail Space
Square Footage	316,056	Included in General Office	6,548	2,052	10,743	6,467	609	183,140	10,127
Temperature requirements for heating season	70-74 °F	70-74 °F	70-74 °F	68-77°F	68-72°F	70 °F +/- 4 °F	68-72°F	NA	NA
Temperature requirements for cooling season	74-78 °F	74-78 °F	74-78 °F	68-77°F	74-78 °F	70 °F +/- 4 °F	74-78 °F	NA	NA
Humidification requirements % RH	None	None	None	40-55 % RH	None	45 % RH +/- 8%	None	None	None
Dehumidification requirements	Less than 65% RH	Less than 65% RH	Less than 65% RH	40-55 % RH	Less than 65% RH	45 % RH +/- 8%	Less than 65% RH	None	Less than 65% RH
Pressure relationship requirements	Positive to Outside	Positive to Outside	Positive to Outside	Positive to Adjacent Spaces	Negative to Adjacent Spaces	Positive to Adjacent Spaces	Negative to Adjacent Spaces	Negative to Adjacent Spaces	Positive to Outside
Filtration Requirements	MERV 9 40 to 45%	MERV 9 40 to 45%	MERV 9 40 to 45%	MERV 13 80 to 90%	MERV 9 40 to 45%	MERV 13 80 to 90%	MERV 9 40 to 45%	NA	MERV 9 40 to 45%

Develop the CFR

What might be some CFR items for these:

System / Aspect	CFR Items
Lighting	
Occupant comfort	
Sustainability	

Your Turn!

Planning Phase Main Tasks

- _____

- _____

- _____

- _____

- _____

- _____

- _____

- _____

Your Turn!

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Planning
Investigation
Implementation
Hand-Off
Post-RCx

Investigation Phase Summary

- ■ **Conduct detailed document review**

- ■ **Interview occupants and operating staff**

- ■ **Evaluate facility performance**

- ■ **Identify findings**

- ■ **Formulate measures**

- ■ **Analyze measures**

EBCx Results from the Field

Frequency of Implementation (n=371)
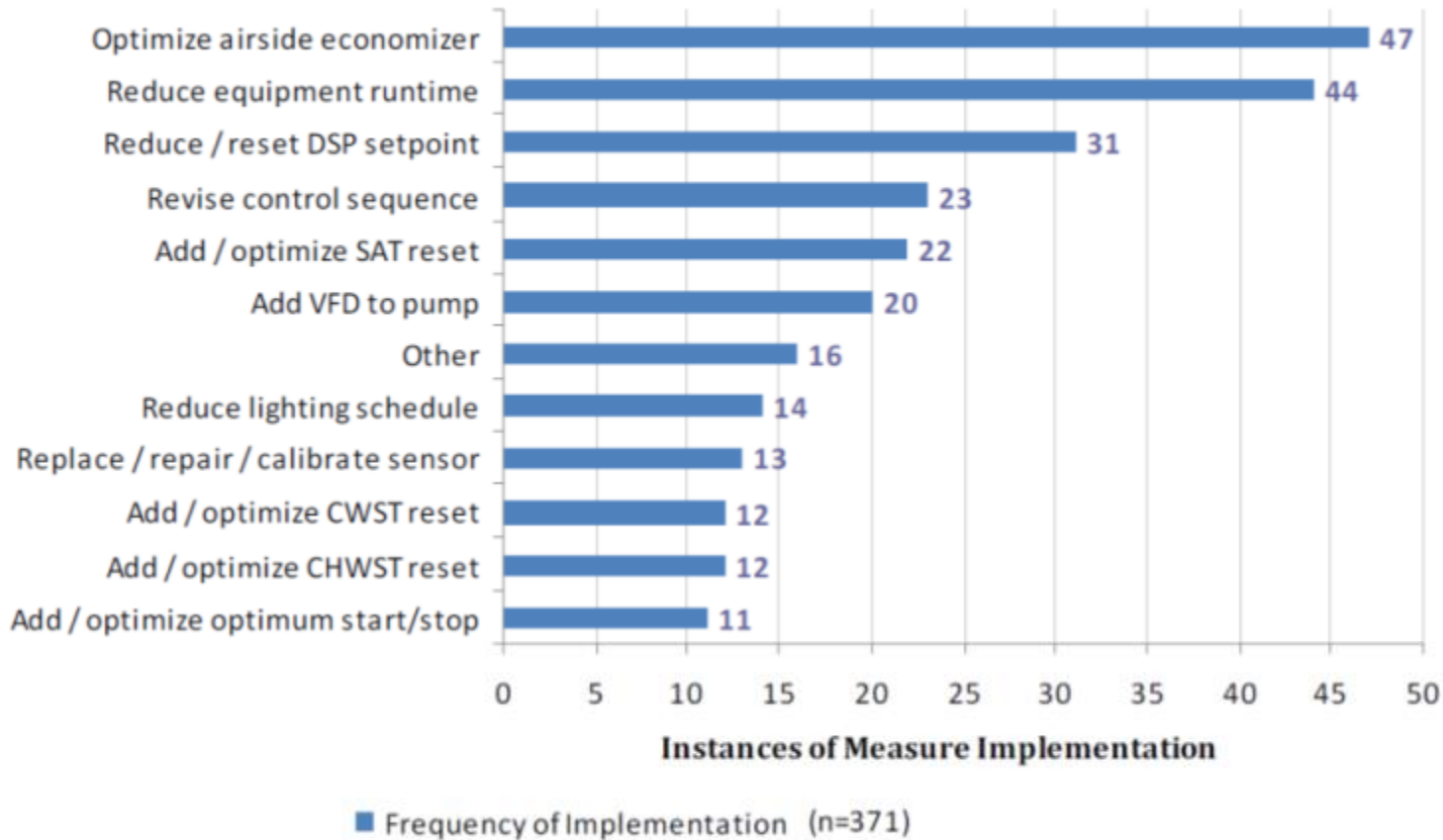
122 EBCx projects, most in CA.

EBCx Results – Denver, CO

■ **Prevalent measures (five projects):**

◆ **Revise control sequence**

◆ **Add / optimize SAT reset**

◆ **Reduce equipment runtime**

Xcel Energy RCx Data

Measures in past Xcel RCx projects:

- AHU Air leak reduction
- AHU Coil cleaning
- AHU optimize economizer
- AHU outside air reduction
- AHU run time reduction
- AHU supply air static pressure adjustment / reset

- AHU supply air temperature reset
- AHU VAV minimum flow reduction
- Lighting and equipment run time reduction
- Unoccupied setback
- Exhaust system operation

Detailed Document Review

Review the documents gathered during the Planning Phase.

■ **Space types, configurations and layout**

■ **System design concepts**

■ **Equipment types, quantities, sizes, etc.**

■ **Zoning configurations**

■ **Maintenance procedures**

■ **Operating schedules and sequences**

Detailed Document Review - Example

Written sequences of operations.

SEQUENCE OF OPERATIONS:

Heating Ventilating Unit HV-1 Associated Exhaust Fans E-1

Location: 3rd Floor MER
Serving Area: Sub-cellar

Updated: 04.15.08

Unit Off

When the unit is off, the outside air damper, two discharged air dampers, two return air dampers, and the exhaust fan's discharge damper will be closed. The HV-1 supply fan remains off. The exhaust fans E-1 will be interlocked with the supply fan and remain off

Unit On

The unit can be started locally, manually from the BMS, or from the smoke control panel.

Assessing System Configuration

■ **System diagrams**

 ◆ **See how it all fits together**

 ◆ **Identify optimization opportunities**
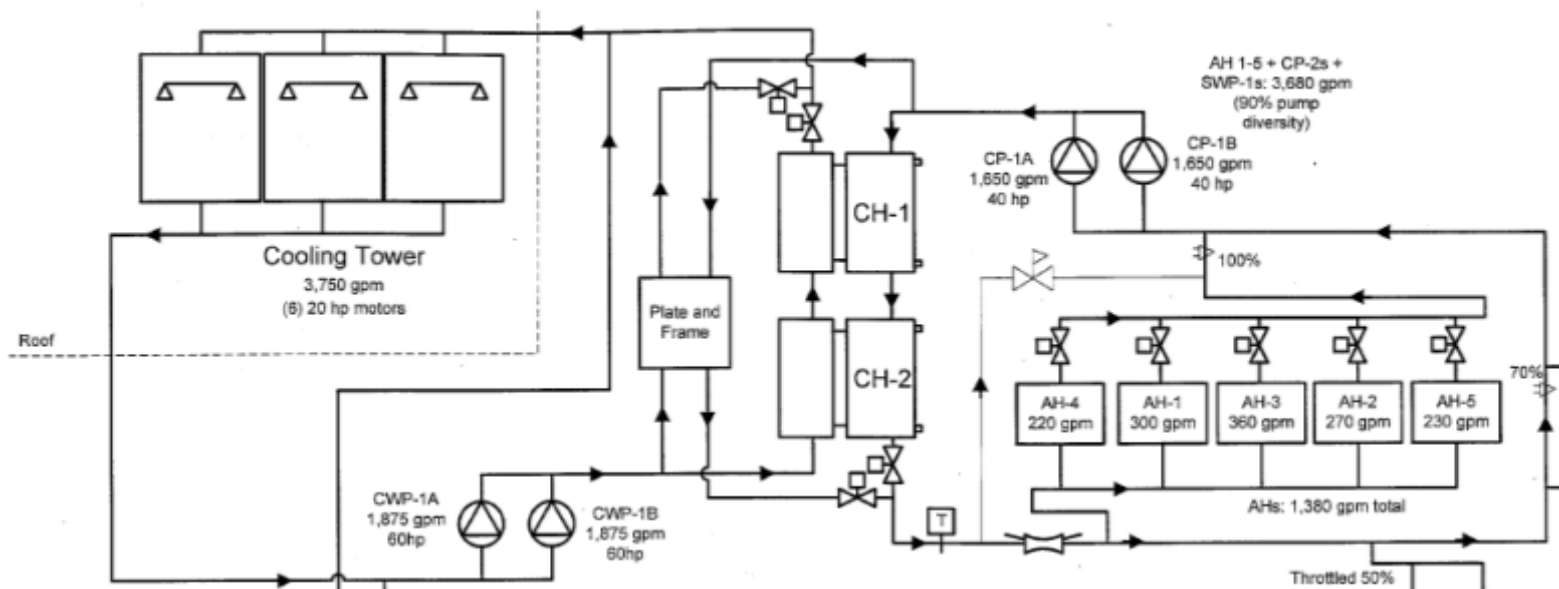
System Diagrams

- **Keep it simple (untangled)**

- **Include all components that can affect flow rate or path**

- **Pay attention to the order of connection**

What appears complex …

… may be schematically simple
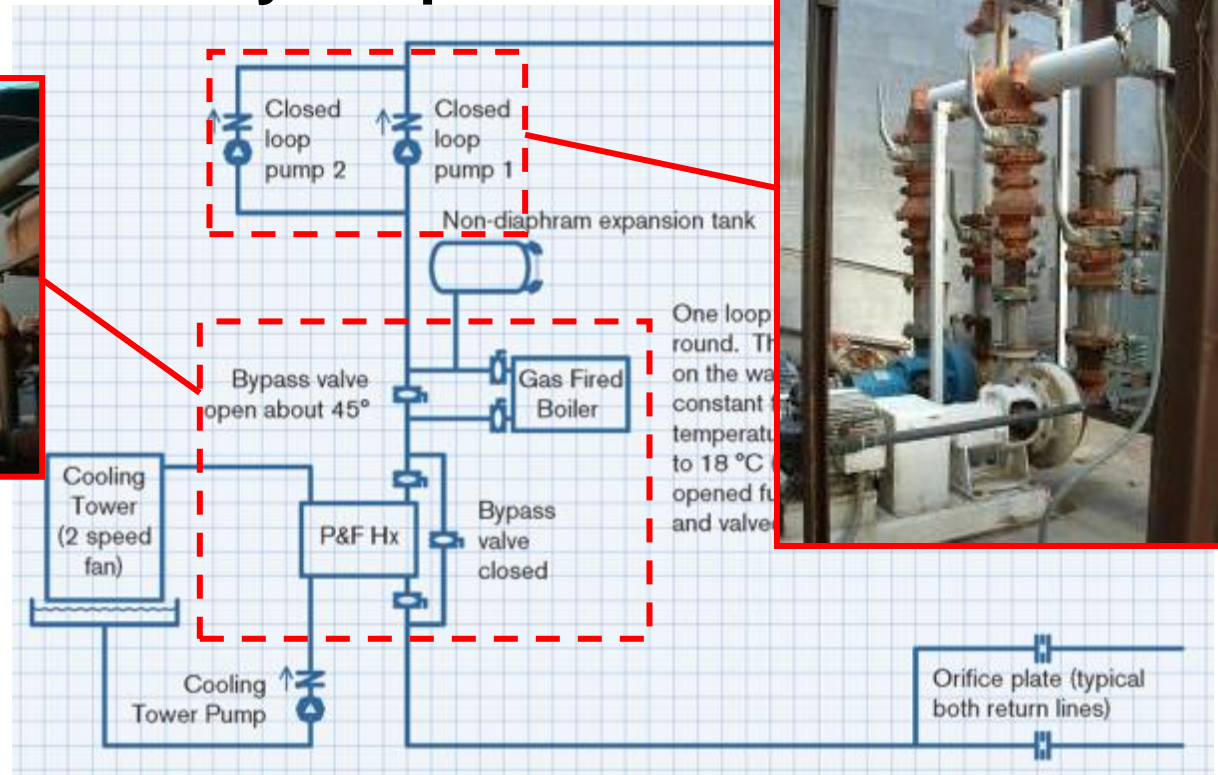
Tangled Vs. Untangled
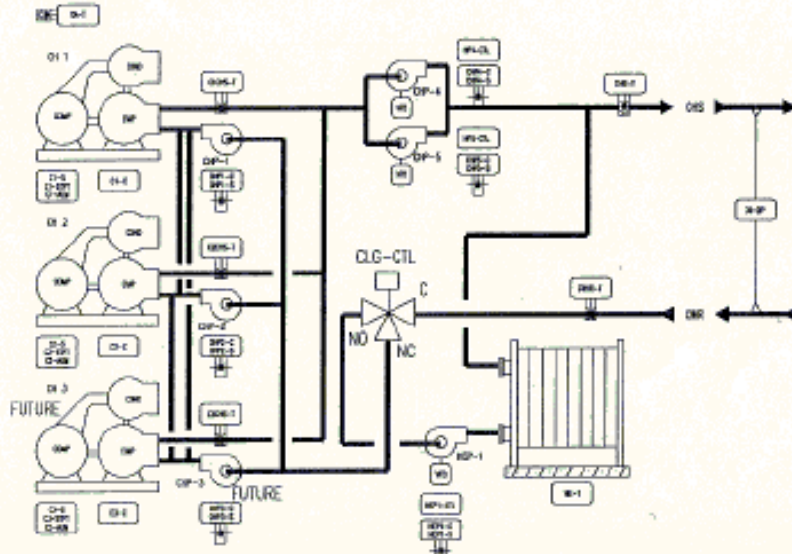
CHILLED WATER SUPPLY CONTROL DIAGRAM

- **Minimize line crossings**

- **Elbows don't matter**

- **Looks like ladder on its side**

Order of Connection Matters

From the Construction Drawings

All loads receive the same supply water temperature

Order of Connection Matters

Based on "as piped" field conditions

Some loads could receive warmer water.
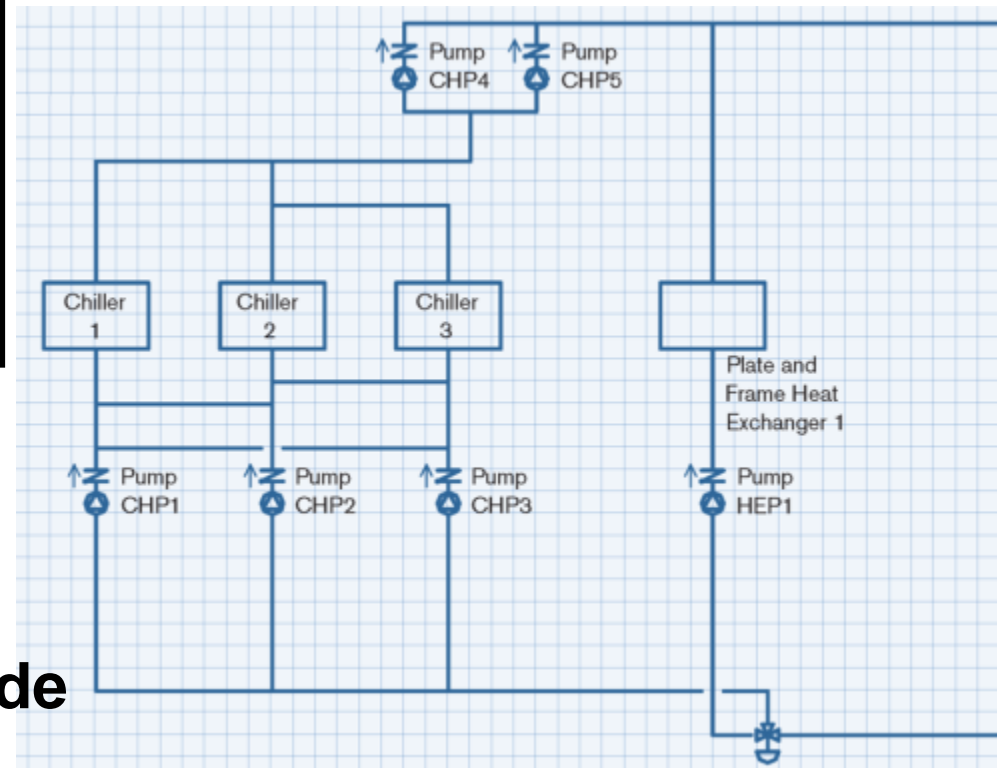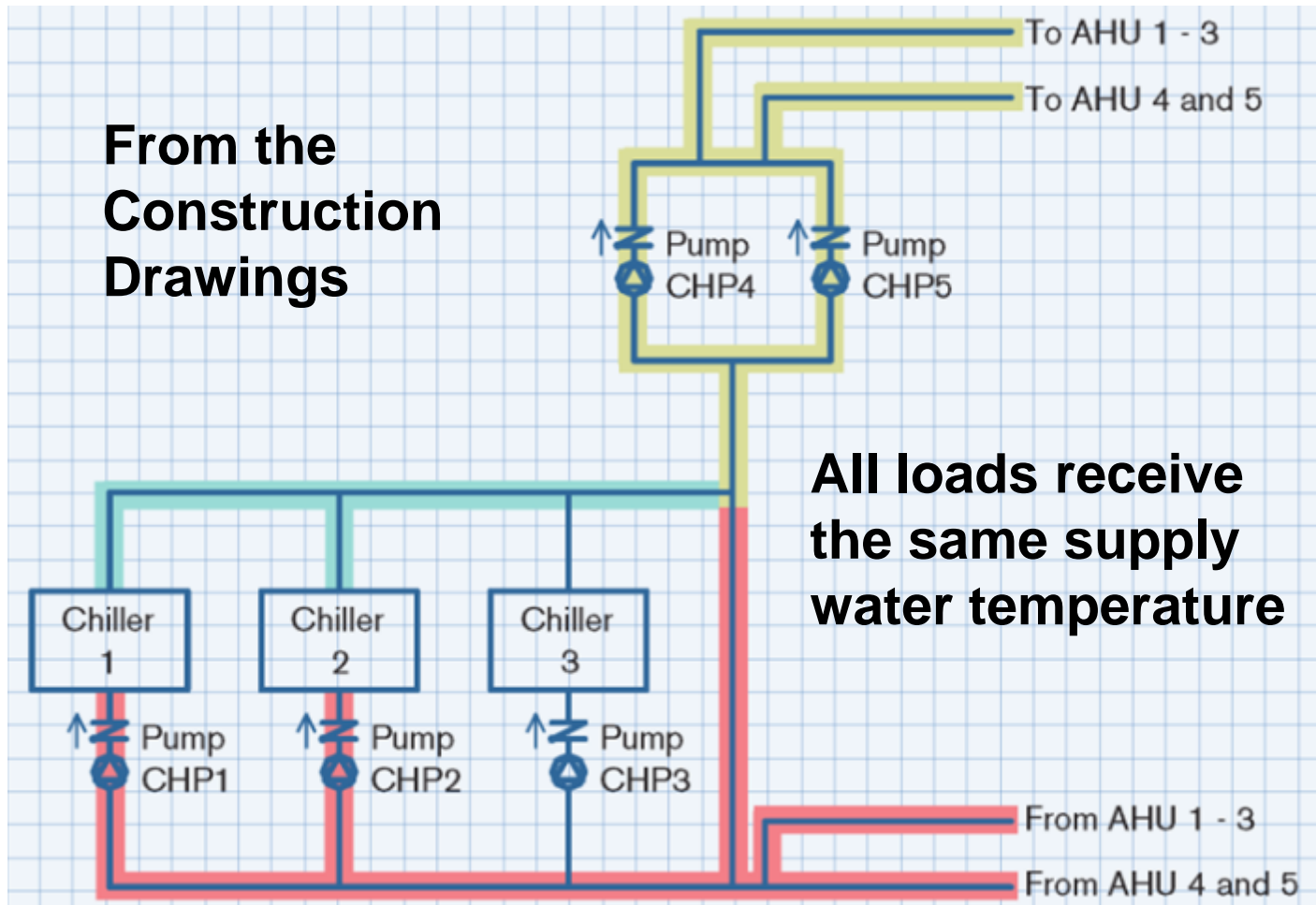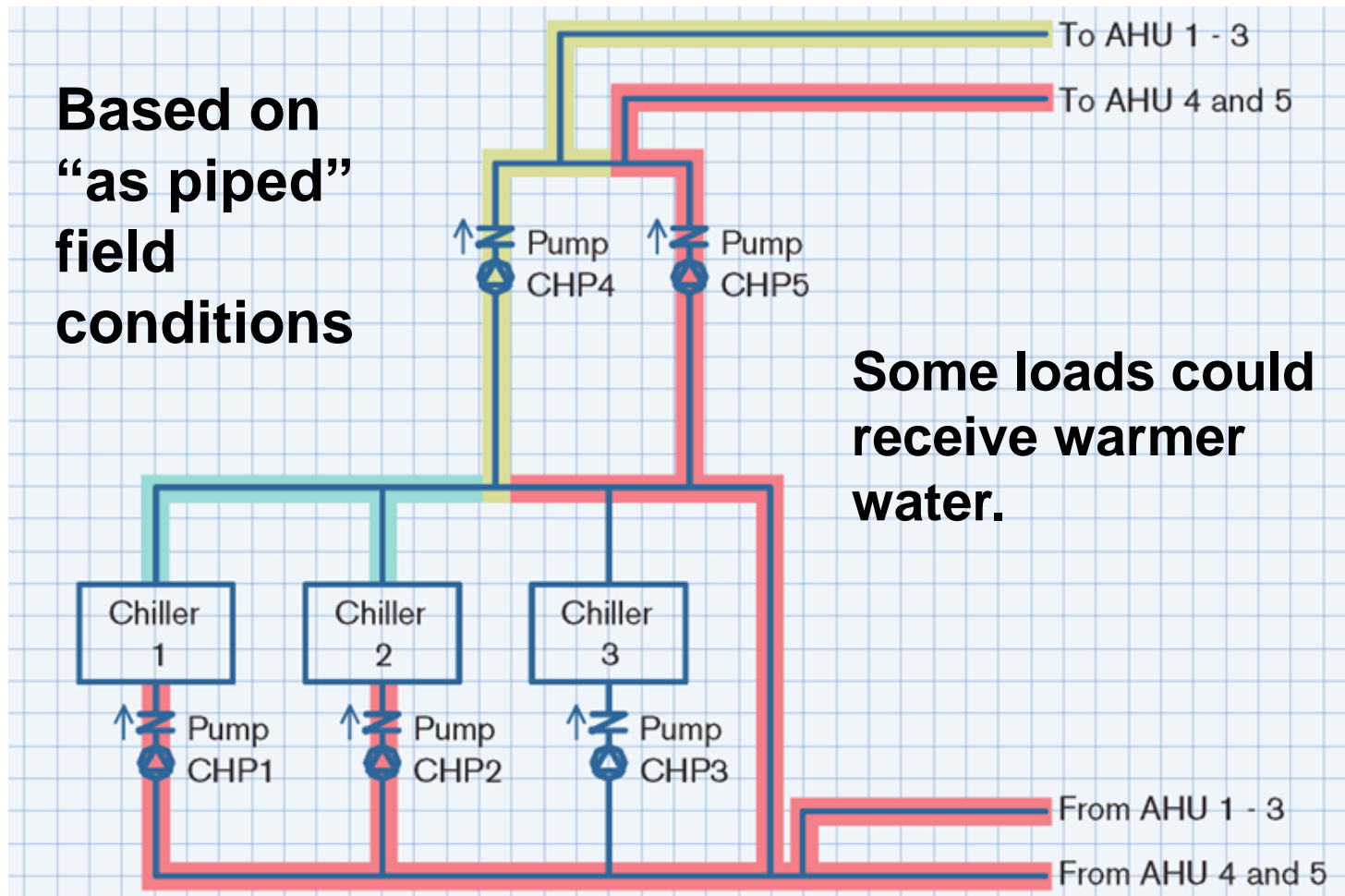
Same Project, Same System, Three Different Diagrams
Which one represents what was actually installed?

Based on control system screen

Based on drawing piping plan

Based on drawing schematic
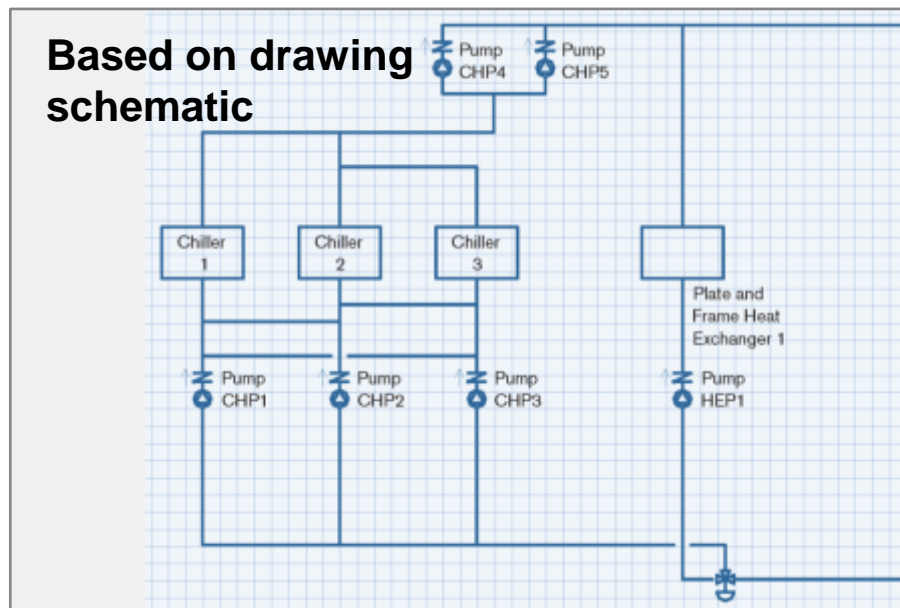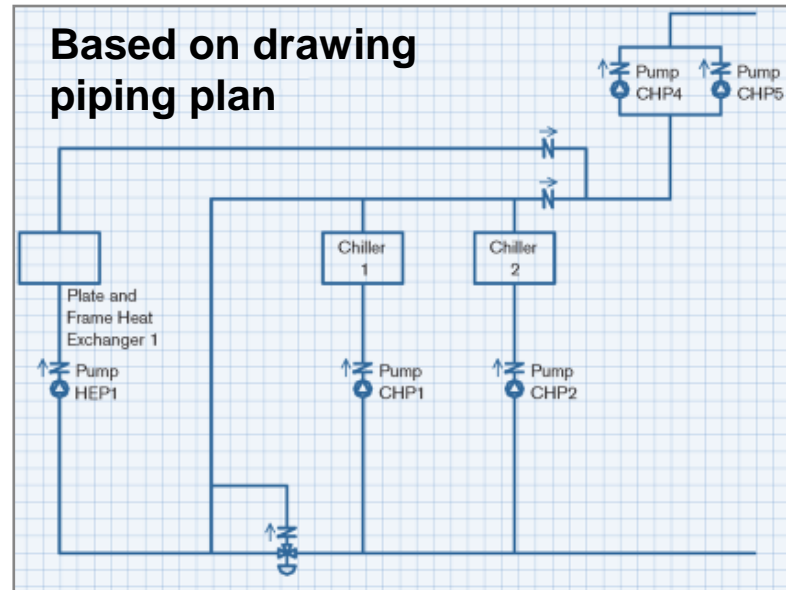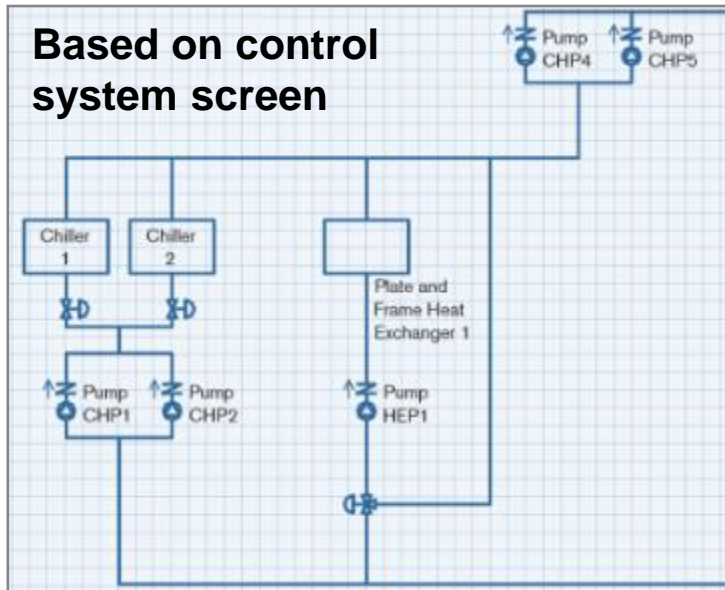
None of Them! What are the findings?
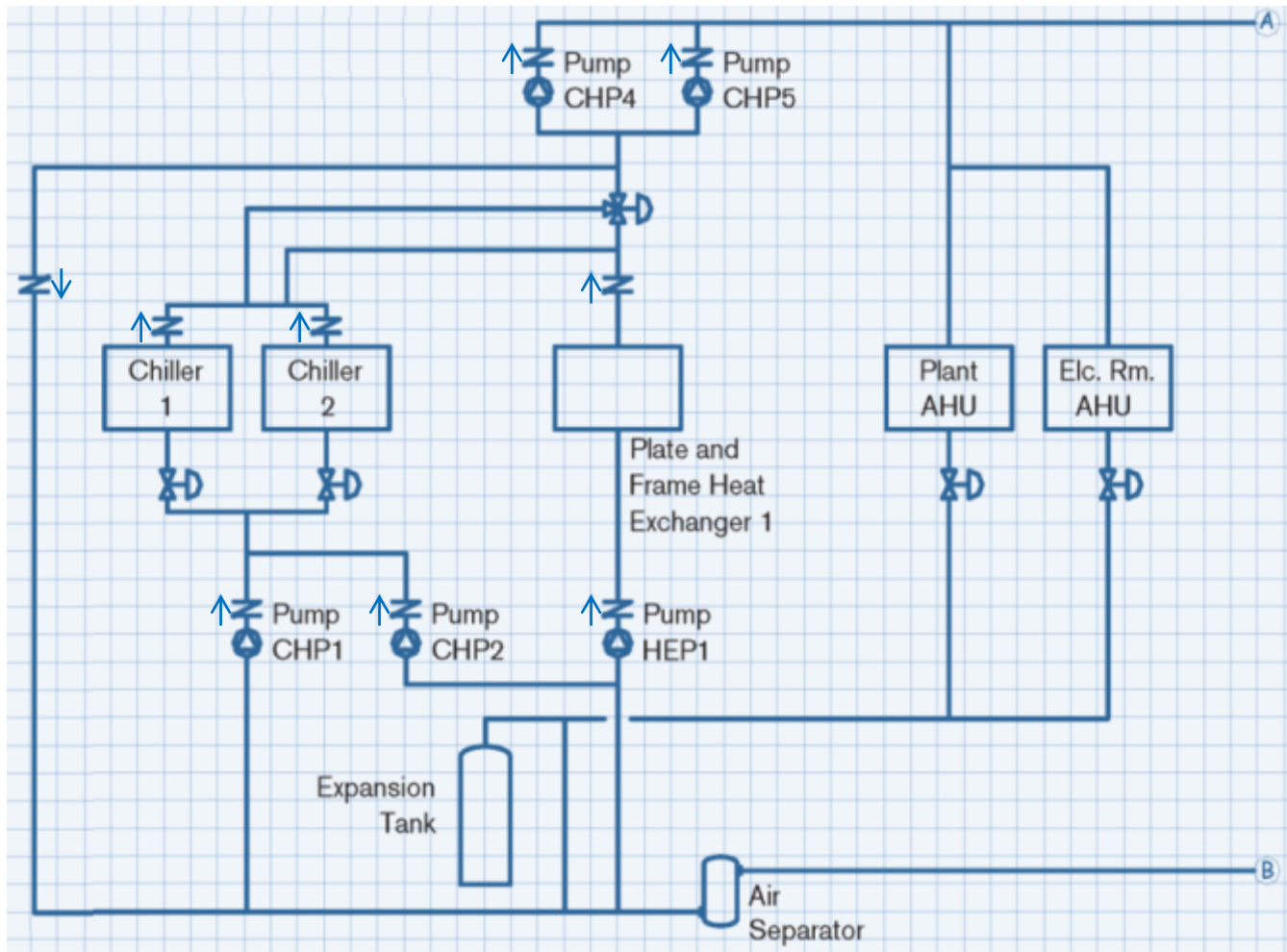
Your Turn!

Findings:
The three way valve does basically nothing
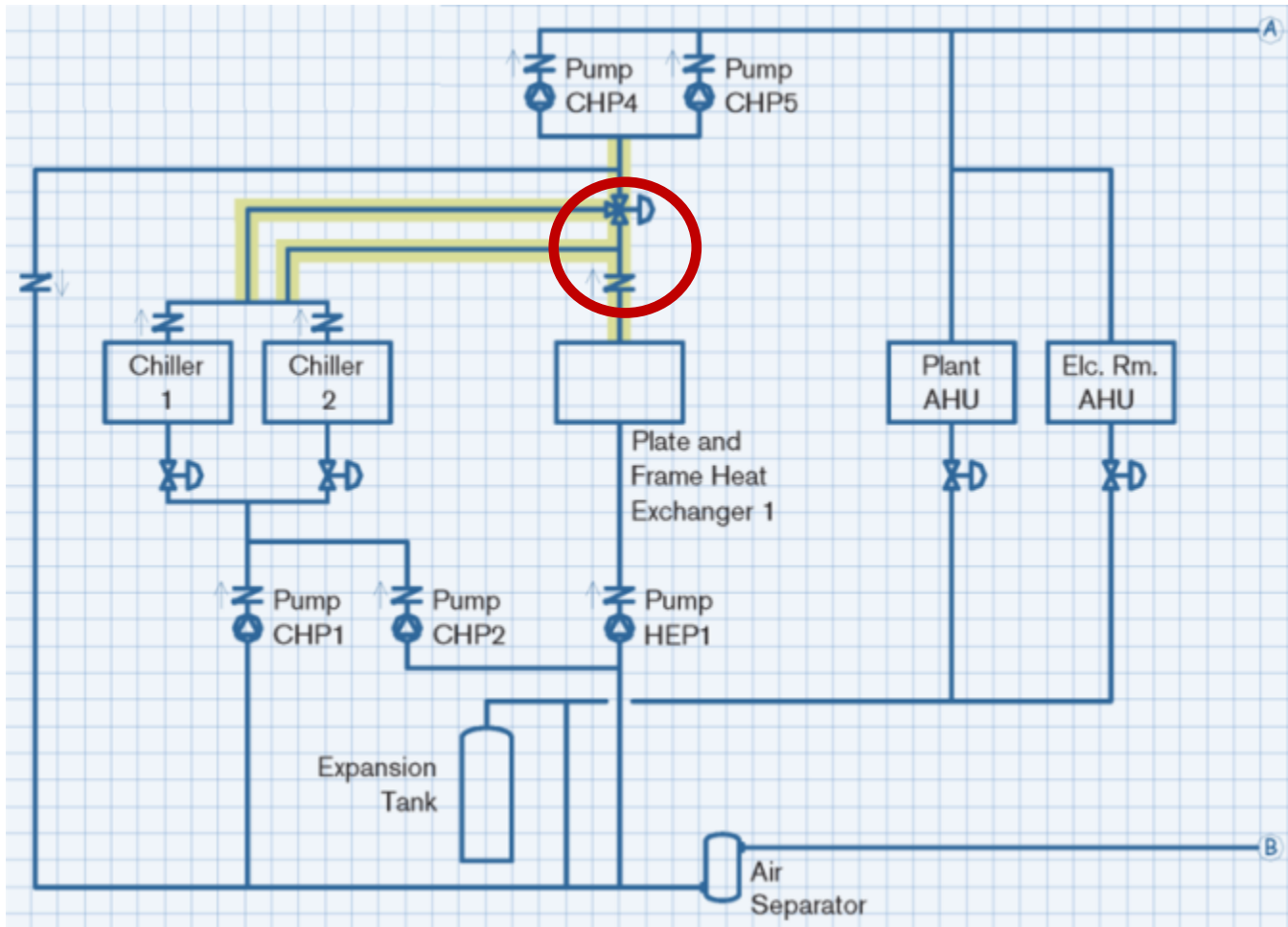
A check valve eliminates decoupling under some conditions.
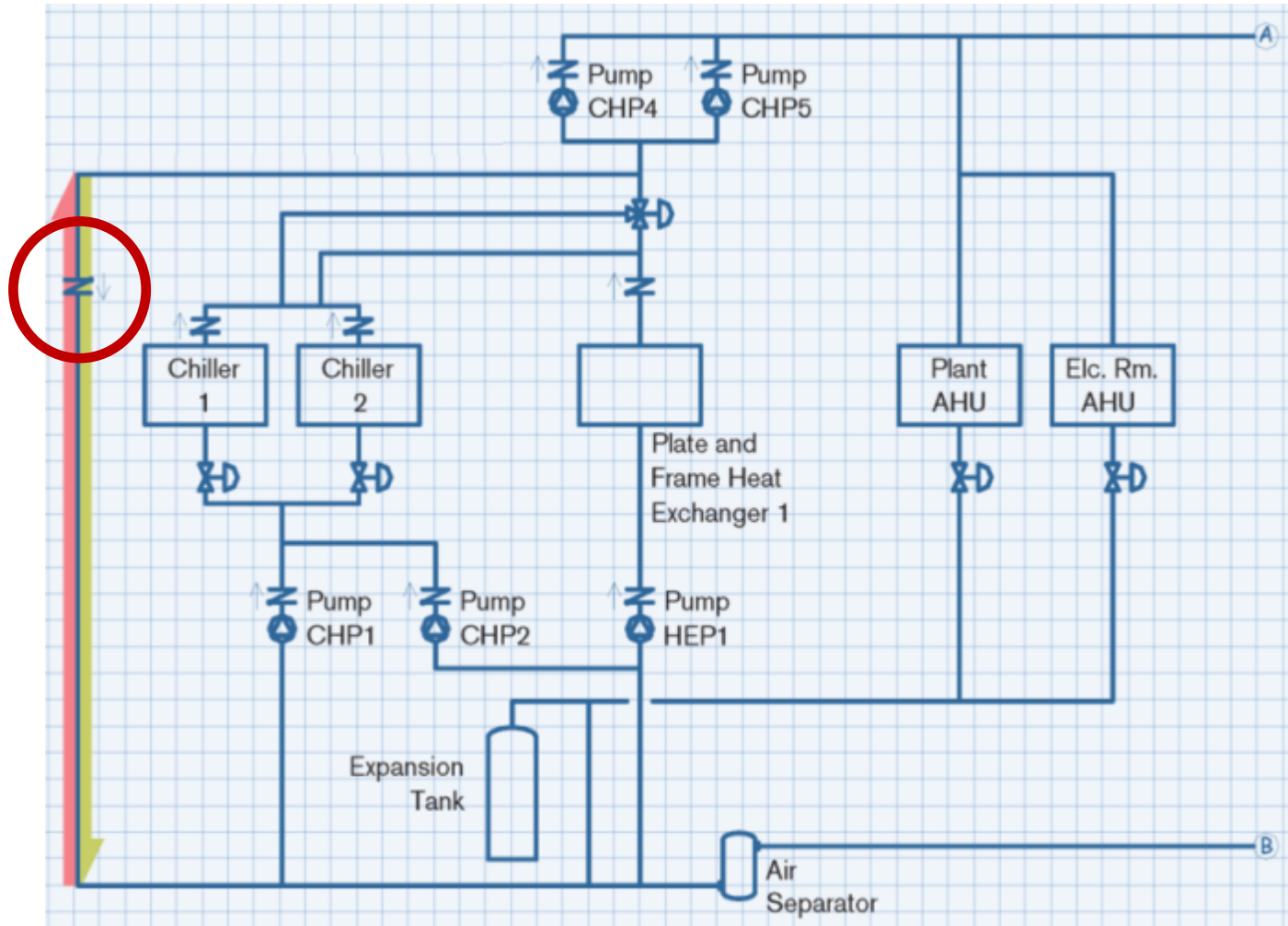
Conduct Operator Interviews

Speak with operators

- **Allow adequate time**

- **Be respectful – they're the experts**

- **Ask open-ended questions**

- **Use a structured format**

- **Document the interview**

Conduct Operator Interviews

Example operator interview form available at cacx.org

How is both the interior and exterior lighting controlled for your building (manual switches, lighting control system, time clocks etc.)? Interior: Exterior:	
Do you have any problems with the lighting controls? If yes, explain:	☐ Yes ☐ No
Do you feel there are any areas in the building that are over-lit? If yes, explain	☐ Yes ☐ No
Do you have a maintenance contract for your control system?	☐ Yes ☐ No
If yes, generally, how often is the control system contractor consulted, and for what reason(s)?	

Evaluate Facility Performance

Purpose:

- **Determine if CFR are met**

- **Identify findings and determine measures**

Methods:

- **Analyze energy usage**

- **Review interview results**

- **Review service requests and complaints**

- **Compare actual conditions to CFR**

- **Perform diagnostic monitoring**

- **Conduct site investigation and testing**

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Compare Conditions to CFR

Summer Conditions Sample Building	Acceptible Levels			Spot Measurements			Acceptible? Y/N		
	CO2 Levels (PPM)	Temperature (ºF)	Humidity (% Relative Humidity)	CO2 Levels (PPM)	Temperature (ºF)	Humidity (% Relative Humidity)	CO2 Levels (PPM)	Temperature (ºF)	Humidity (% Relative
Open Office 1	< 1100	72-78	20-60	670	68.0	50.5%	Y	N	Y
Open Office 2	< 1100	72-78	20-60	440	67.0	45.5%	Y	N	Y
Private Office 1	< 1100	72-78	20-60	540	68.0	47.0%	Y	N	Y
Private Office 2	< 1100	72-78	20-60	470	67.6	51.0%	Y	N	Y
Conference Room 1	< 1100	72-78	20-60	450	66.7	44.0%	Y	N	Y
Conference Room 2	< 1100	72-78	20-60	500	67.4	42.5%	Y	N	Y
Lobby	< 1100	72-78	20-60	610	69.0	48.2%	Y	N	Y

OVER COOLING

Activity

- **Review the Sample CFR and Mechanical schedule.**
- **What are the findings?**

Your Turn!

Activity

- **Findings**
  - **Overventilation (1,500 cfm > 1,000 cfm)**
  - **RTU-1 does not have an economizer section**
  - **Economizer high limit is lower than required**
  - **Thermostat h/c setpoints are swapped**
  - **Thermostats only have one stage of cooling**

BAS GUI Review

Before Digging In …

Verify the accuracy of the GUI

■ **Conduct point-to-point check**

■ **Verify accuracy of system diagrams, equipment arrangements, and sensor locations on GUI**

■ **Verify calibration of sensors**
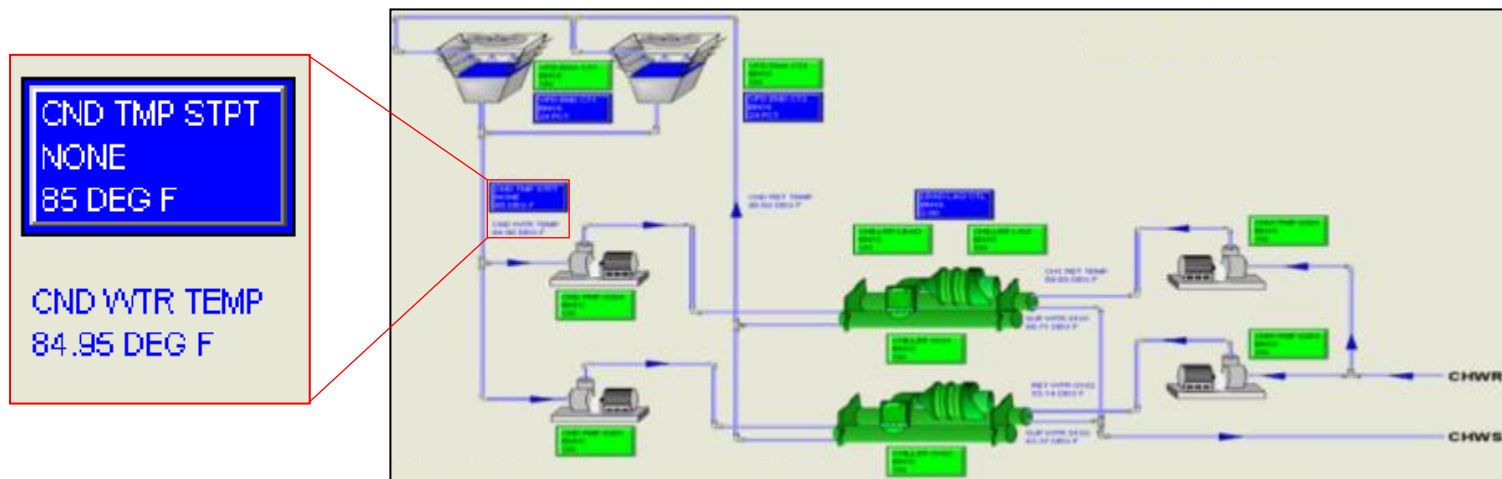
BAS GUI Review

■ **Spot check TUs, especially those with the greatest deviation from setpoint.**

Photo: PECI

64
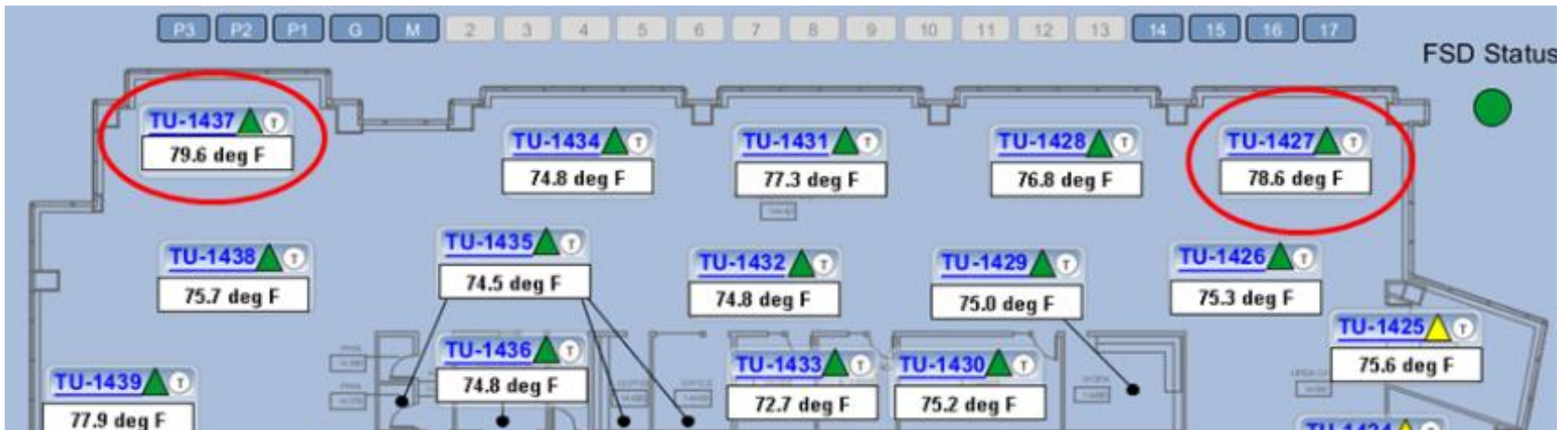
BAS GUI Review

- **Is the system operating as expected?**

Investigate where operation doesn't make sense

4 pm, west facing, gobs of daylight coming in:

What is wrong with this picture?

95%

95%

95%

P6

P7

P8

Mild spring day in Portland, OR.

**Hot water reset
140°F above 60°F OA
180°F below 48°F OA**

P3   **P4**   **P5**

B3   B4   B5

**Hot deck DAT reset:
150°F above 60°F OA
180°F below 48°F OA**

Heating AHUs

**design:
180 EWT
105 LAT**

3-5ºF ΔT

B1   **P1**

B2   **P2**
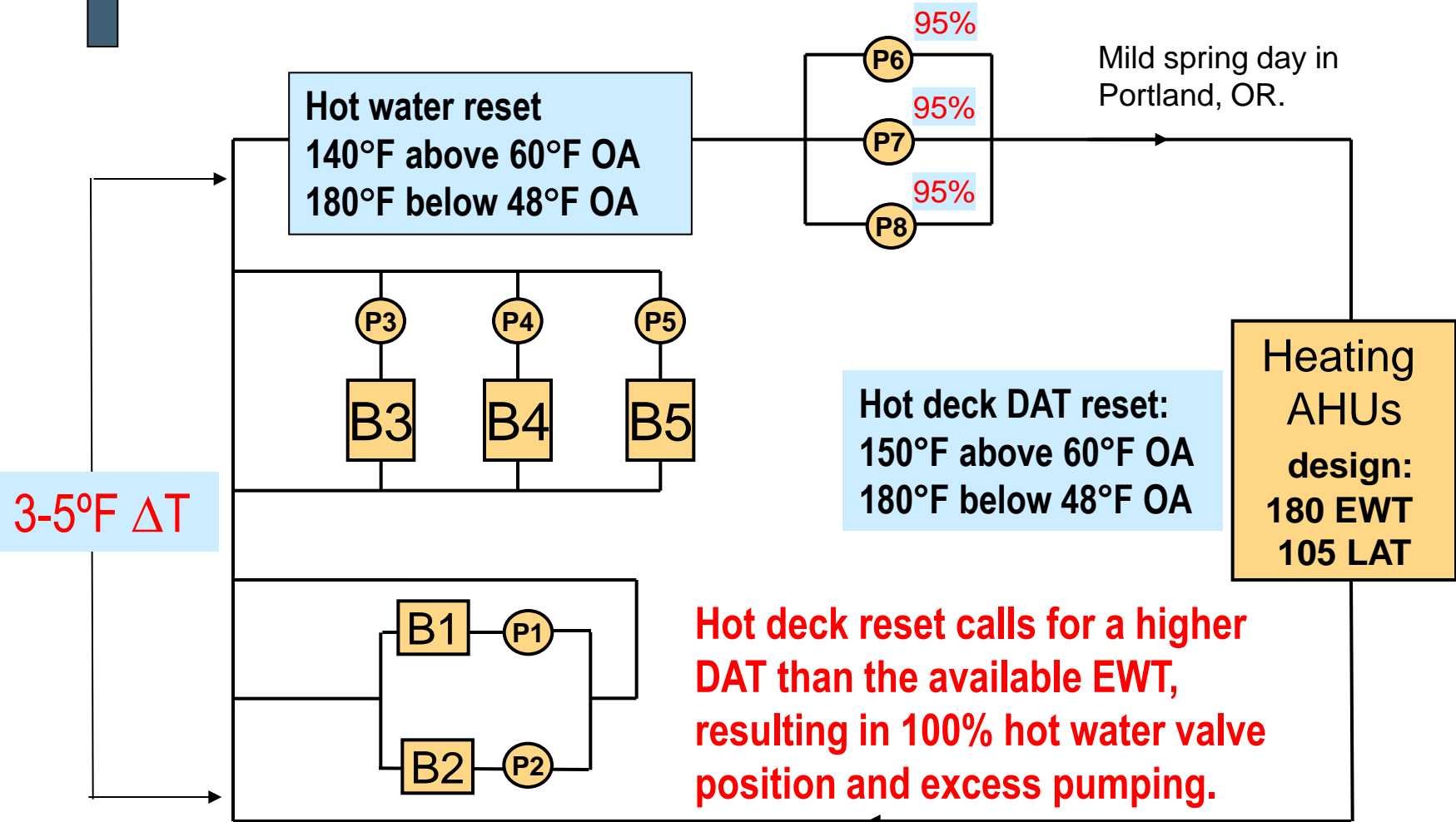
Hot deck reset calls for a higher DAT than the available EWT, resulting in 100% hot water valve position and excess pumping.

Your Turn!

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Proper Operation

Hot water reset
140°F above 60°F OA
180°F below 48°F OA

P6 — 0%
P7 — 50%
P8 — 50%

P3 P4 P5

B3 B4 B5

30°F ∆T

Was 150°F
Was 180°F

Hot deck DAT reset:
70°F above 60°F OA
110°F below 48°F OA

Heating AHUs
**design:
180 EWT
105 LAT**

B1 — P1
B2 — P2

One pump is OFF and the other two operate between 0-50% speed to meet load. Delta-T across the loop is about 30F.

68
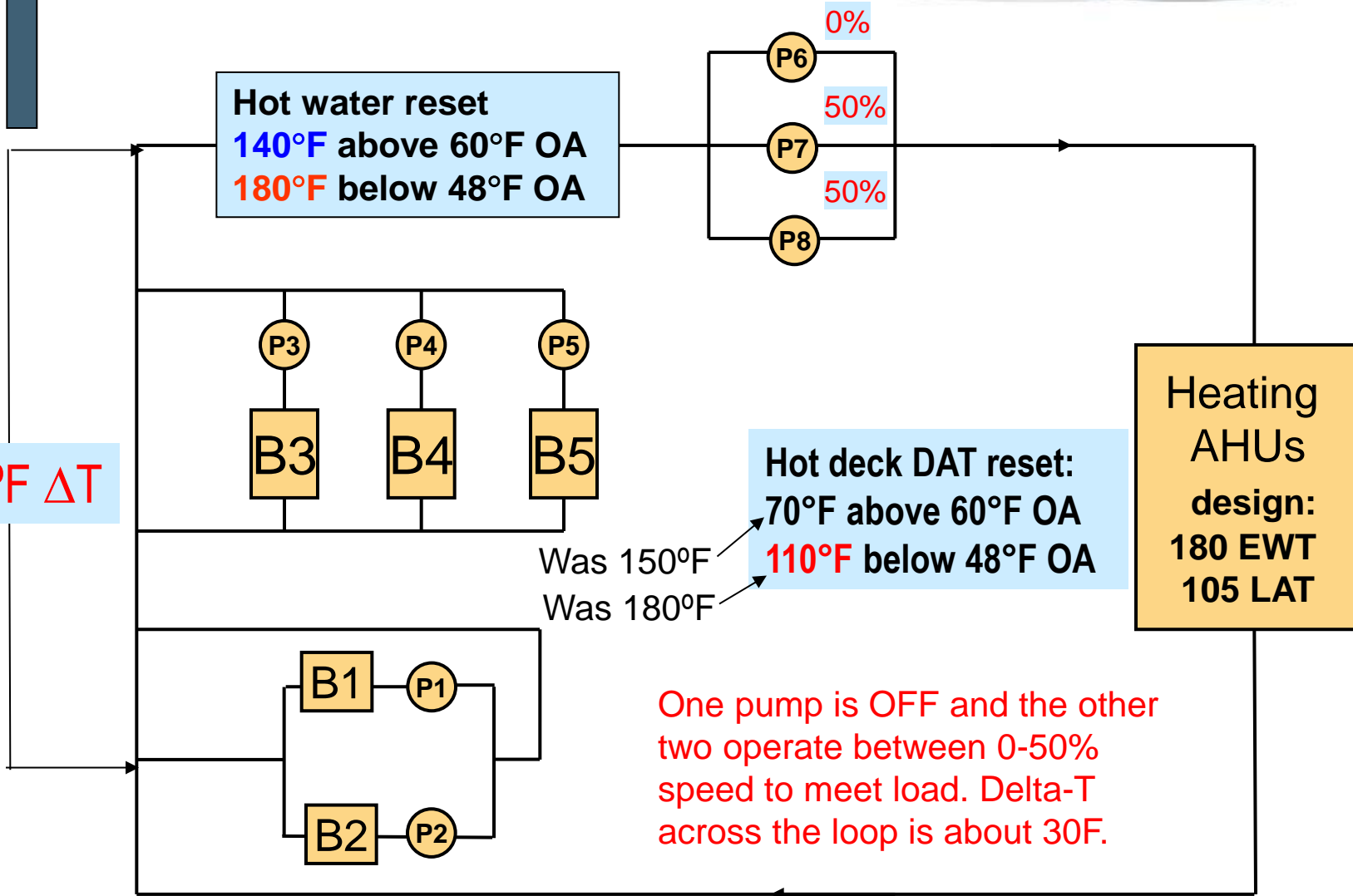
Controls Reset Findings

- **Multiple reset strategies counteracting each other**
  - ◆ **E.g., DSP reset and SAT reset**
- **Setpoints are manually reset in response to comfort complaints**
- **Variable volume systems acting more like constant volume systems**
- **Control instability present**
- **Things just don't make sense**

Diagnostic Monitoring

Process:

- **Collect relevant data**
  - ◆ **BAS trends**
  - ◆ **Portable data logger trends**
  - ◆ **Spot measurements**
  - ◆ **Energy data**
  - ◆ **Weather data**
- **Compile the data**
- **Analyze the data**

VAV Box Performance
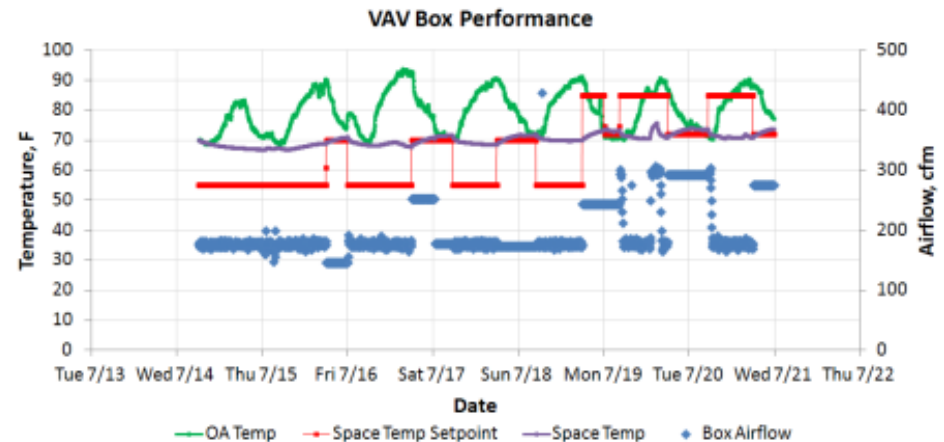
Diagnostic Monitoring
Using BAS trends to identify issues

SAT setpoint is constant

Temperature, °F — Outside Air — Supply Air Setpoint
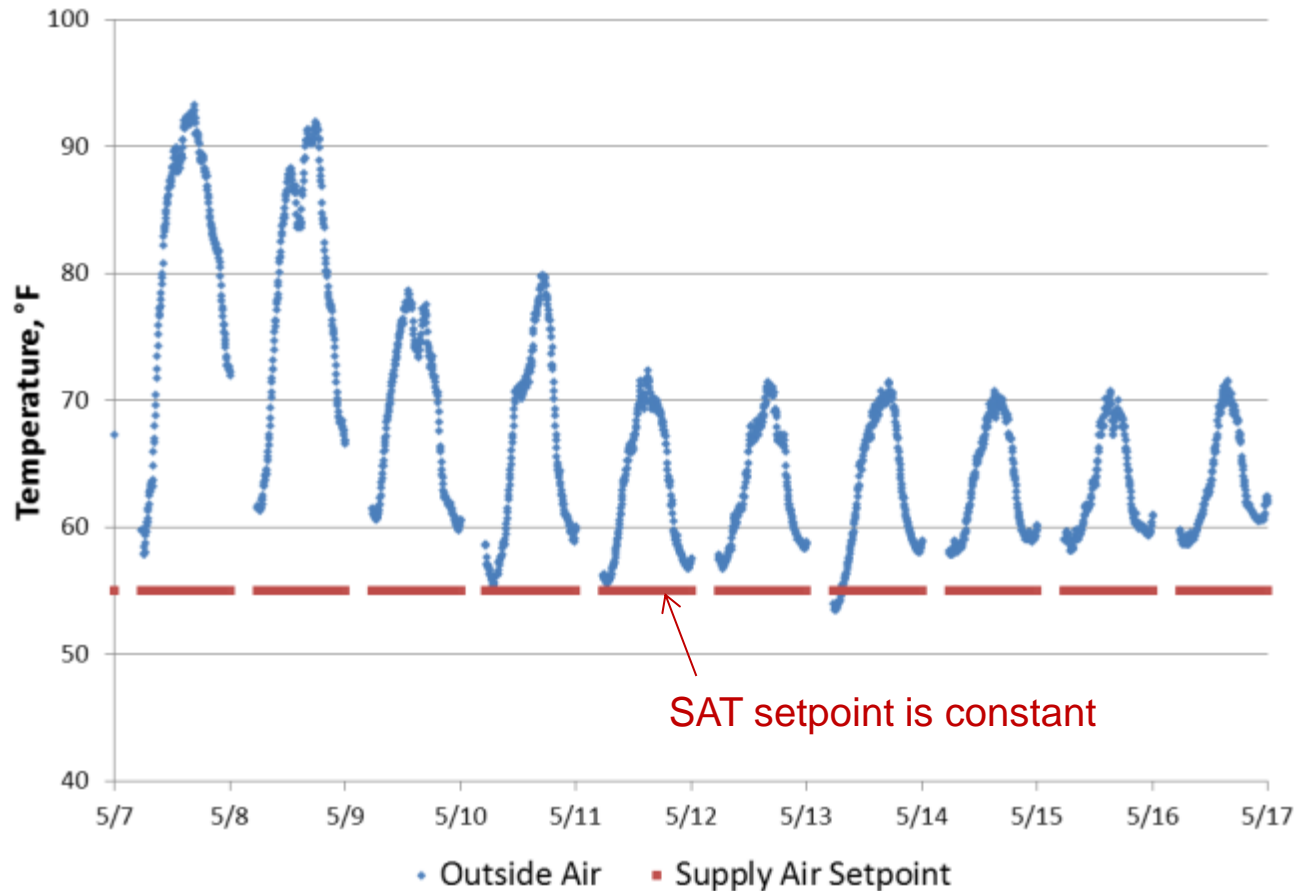
Diagnostic Monitoring
Using data loggers to identify issues
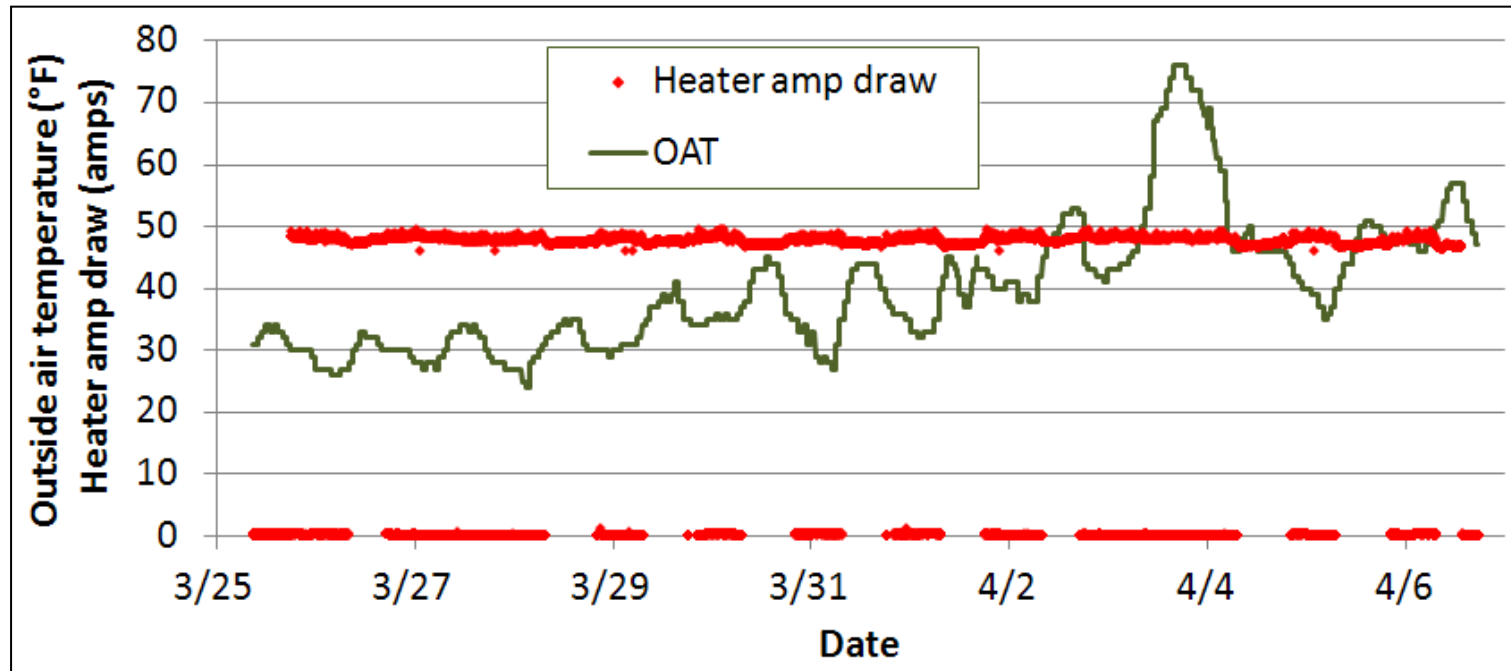
Heaters should be off at OATs above 40°F.

How's that working?

Your Turn!

Diagnostic Monitoring
Portable data logging equipment

Temperature

Amp draw

On/off w/ readout

Light on/off, occupancy

Carbon monoxide

Carbon dioxide

Light on/off, motor on/off

Diagnostic Monitoring

Choose an appropriate sampling rate

Data sampled every 15 minutes makes every thing look like its just fine!

Data sampled every 5 minutes shows a distorted wave form as compared to real time.

Data sampled every 3 minutes appears to be stable but off-set from set point about 1°F.

Data sampled at 1/minute appears to have a slightly lower peak and lower frequency than real time

A sampling rate of 1/second reflects the real time data fairly accurately.

Real time control system response shows a 2°F sinasoidal occillation with a 3 minute cycle time.

Legend:
— Real time data
— 1 Second data sample rate
— 1 Minute data sample rate
— 3 Minute data sample rate
— 5 Minute data sample rate
— 15 Minute data sample rate

Time in Minutes

74
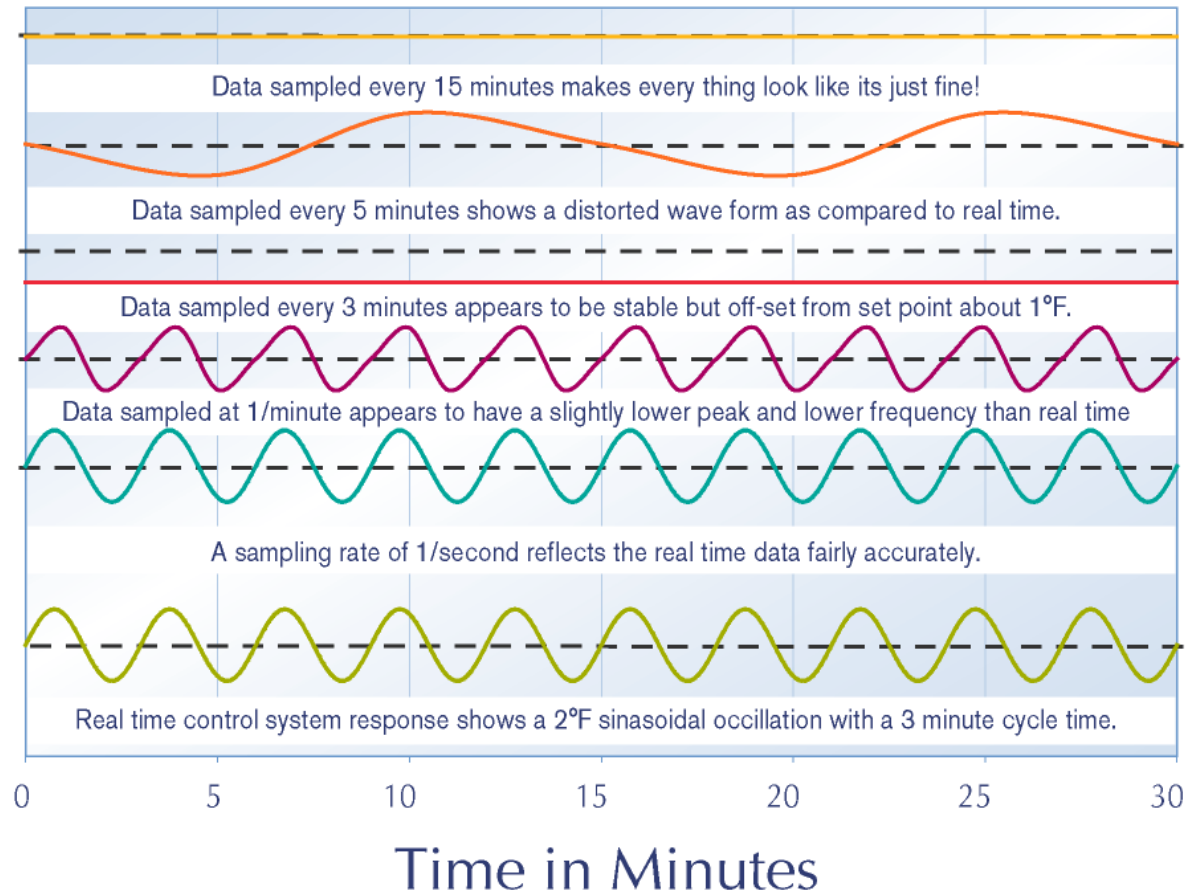
Diagnostic Monitoring

Supply fan should be tracking return fan.
How's that working?

Hours, 12/19/04 - 12/19/04
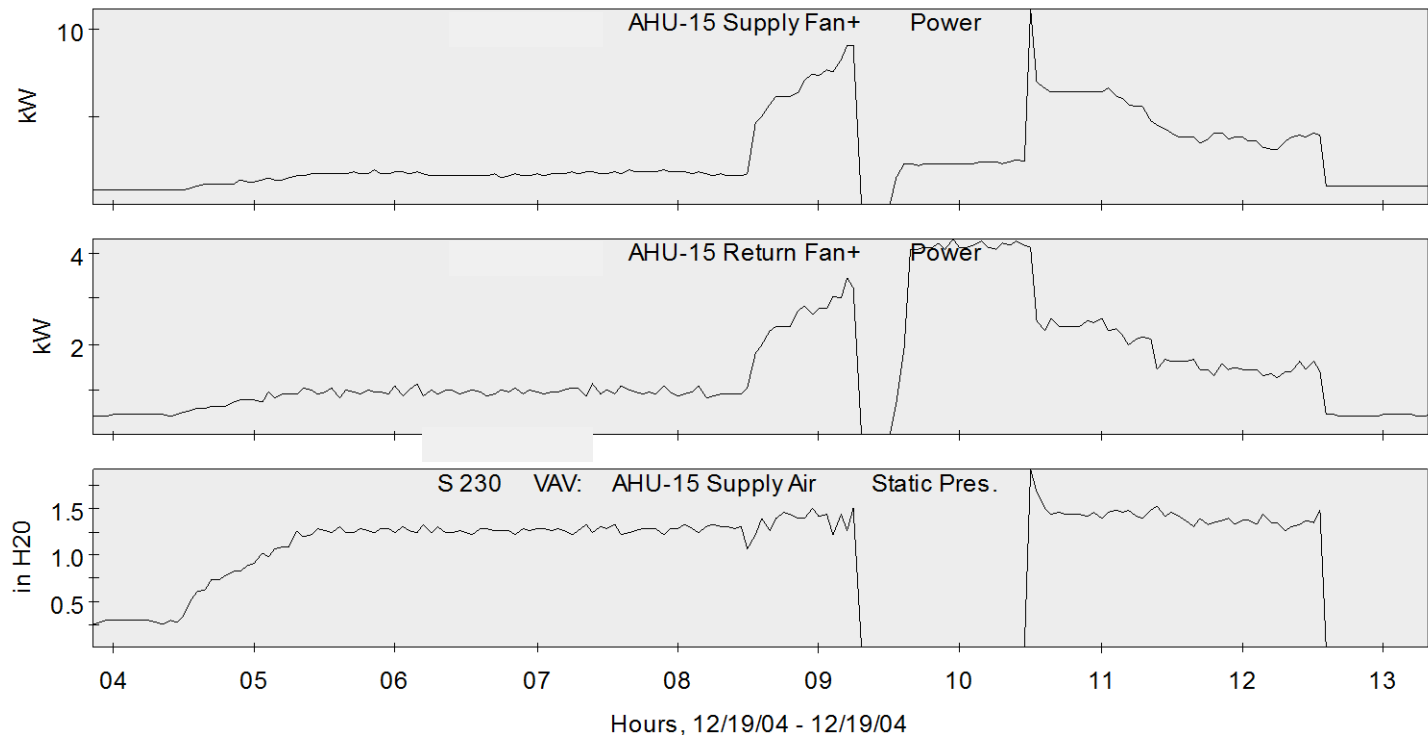
Your Turn!

Diagnostic Monitoring

VAV box damper should be closed when unoccupied.
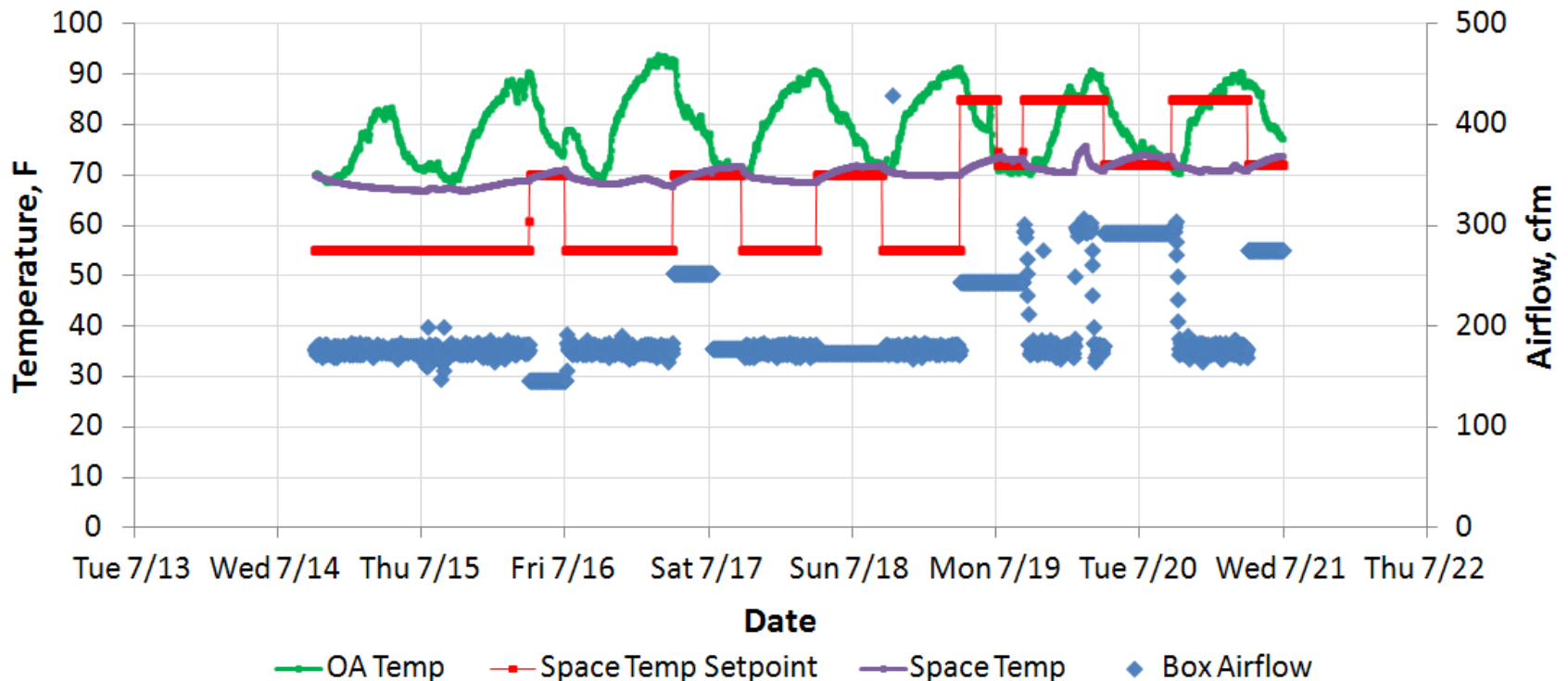
Your Turn!

Universal Translator

Trend data management and analysis

- **Combines different data sets**
- **Filters data**
- **Creates regressions and charts**
- **Analyzes data for certain systems:**

Category	Result Score	Percent Of Time Over Sp	Percent Of Time Under Sp	Ave Temp Over Sp	Ave Temp Under Sp	Max Value	Min Value	Errors
5127	5.7	78.60%	17.50%	4.4	1.3	81.8	0	
5327	5.8	95.10%	3.90%	5.3	0.6	81.3	0	
5329	5.9	93.20%	5.80%	3.4	2.6	78.6	72	
5133	6.1	100.00%	0.00%	6.1	0	80.0	0	
5324	6.3	77.70%	21.40%	5.4	0.9	83.4	0	
5320	6.5	92.20%	2.90%	6.3	0.2	83.5	0	
5334	8.3	88.30%	10.70%	6.6	1.7	85.9	0	
5332	8.7	92.20%	4.90%	7.5	1.2	85.3	0	
5333	8.7	88.30%	8.70%	7.6	1.1	86.3	0	

VAV boxes

Airside economizers

77
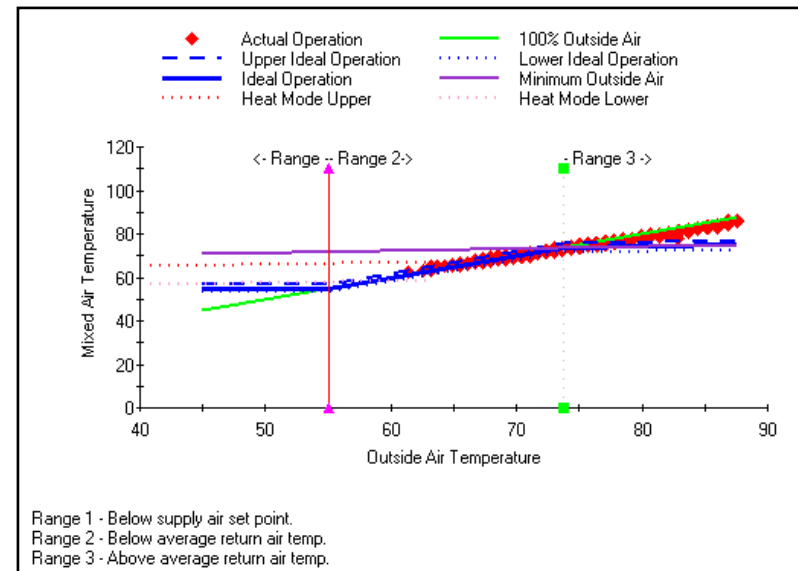
Functional Performance Testing

Process:

- **Change parameters to simulate a condition** O&M staff

- **Observe and record results** CxA

- **Determine pass/fail** CxA

- **Identify findings** CxA

FPT forms CxA

- **Method**

- **Steps**

- **Prerequisites**

- **Acceptance**

> *FPT forms and more information on FPT at www.ftguide.org*

Functional Testing and Design Guides

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Functional Performance Testing

Specific process:

- **Record pretest values**

- **Identify sensors, verify sensor calibration**

- **Check device calibration**

- **Implement FPT**

Functional Performance Testing

Usually involves two people:

One to work with the BAS

One to observe and document the system response

Proced. No. & Spec. Seq. ID[1]	Req ID No.[2]	Test Procedure[3] (including special conditions)	Expected and Actual Response[4] [Write ACTUAL response in brackets or circle]	Pass Y/N	Note #
CHILLER SYSTEM STARTUP AND STAGING					
1 Seq 1-4, 16, 20-23, 32	Spec s 1568 2 3.3.; 1568 3 3.2	Startup Sequence. Lead = CH-____. (This is not the initial startup by factory reps). With chiller system off, with schedule allowing chillers ON and OSAT >56F, turn chillers and pumps to auto. Turn on AHUs and cause a call for cooling sufficient to call for chillers (see manually open preheat coil valve, lower space temperature SPt, etc. A call for the chillers will be made when any AHU fan is ON and its CCV is => 15% open for 10minutes.	Observe that the lead primary CHW pump does not turn ON until a CCV on an ON AHU is => 15% [_____%] open for 10 min. [_____]. Observe lead secondary CHW pump start when a CCV is 15% [_____] open for 10 [_____] minutes. Observe CHW primary and secondary pumps turning on, then the oil pump; then the CD pump (30-60s delay ea.) Observe that secondary pumps start at minimum RPM and slowly ramp up. Starting RPM = [_____]. Observe the lead chiller starting. Observe that the vanes start closed and begin to open. (max spd = 0-full open in ~3 min. and closed in ~1 minute)		

FPT Activity

On page 3 of the Daylight Harvesting System FPT Form, fill in the No Daylight Simulation and Full Daylight Simulation procedures.

Shades

Lights

Light level sensor
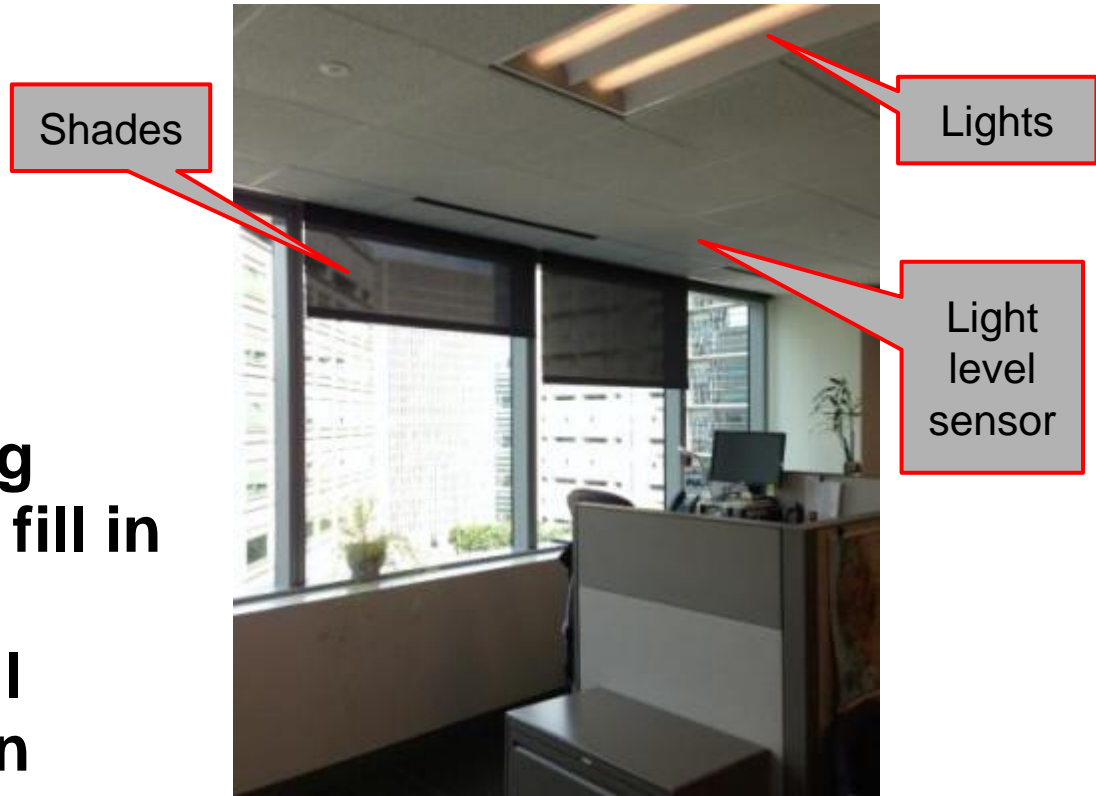
Your Turn!

Diagnostic Monitoring and FPT

Diagnostic Monitoring

- **A passive process (once logging equipment has been launched)**

- **Analyze system performance by trending normal operation over time**

Functional Performance Testing

- **An active, hands-on process**

- **Adjust inputs to see if systems respond as expected**

Diagnostic monitoring, FPT, or both?

- **The space temperature for a lab needs to be maintained between 72 and 74 degrees continuously (24/7).**

  —————————————————

- **Lights in storage room should turn off five minutes after occupants leave room.**

  —————————————————

- **Emergency generator should turn on when utility power drops.**

  —————————————————

Your Turn!

Evaluate HVAC Performance

Served By: AC-05-1		Status:	
VAV	Room Temp	Setpoint	Damper	Airflow
00	73.75 DEG F	74.00 DEG F	50.40 PCT	27.25 PCT
01	76.00 DEG F	74.00 DEG F	26.00 PCT	127.25 PCT
02	75.75 DEG F	76.00 DEG F	33.20 PCT	0.00 PCT
03	75.00 DEG F	76.00 DEG F	29.20 PCT	20.00 PCT
04	73.50 DEG F	74.00 DEG F	51.60 PCT	63.25 PCT
05	74.25 DEG F	74.00 DEG F	28.00 PCT	53.50 PCT
06	74.00 DEG F	74.00 DEG F	27.60 PCT	32.00 PCT
07	74.50 DEG F	74.00 DEG F	34.80 PCT	78.50 PCT
08	75.50 DEG F	74.00 DEG F	18.80 PCT	46.75 PCT
09	76.25 DEG F	76.00 DEG F	18.00 PCT	32.50 PCT
10	73.25 DEG F	74.00 DEG F	24.00 PCT	20.50 PCT
11	74.00 DEG F	74.00 DEG F	40.80 PCT	96.50 PCT
12	73.25 DEG F	71.00 DEG F	37.20 PCT	107.00 PCT
13	73.75 DEG F	74.00 DEG F	31.60 PCT	25.00 PCT
14	73.25 DEG F	74.00 DEG F	27.20 PCT	34.50 PCT
15	72.25 DEG F	74.00 DEG F	27.20 PCT	34.50 PCT
16	74.25 DEG F	74.00 DEG F	37.20 PCT	31.00 PCT

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Evaluate HVAC Setpoints

Setpoint issues

- **Constant setpoint values**
- **Setpoints changed to address complaints**
- **Setpoints not right since construction**

How to identify:

- **Variable flow systems acting like constant flow systems**
- **Trend data analysis**

Evaluate HVAC Setpoints

Potential Setpoint Resets

- **Chilled water supply temperature**

- **Condenser water supply temperature**

- **Heating water supply temperature**

- **Supply air temperature**

- **Duct static pressure**

- **Water loop differential pressure**

  - ◆ **Chilled water**

  - ◆ **Heating water**

Evaluate Reset Strategies

Heating Water Supply Temperature vs. Outside Air

(Time Series)
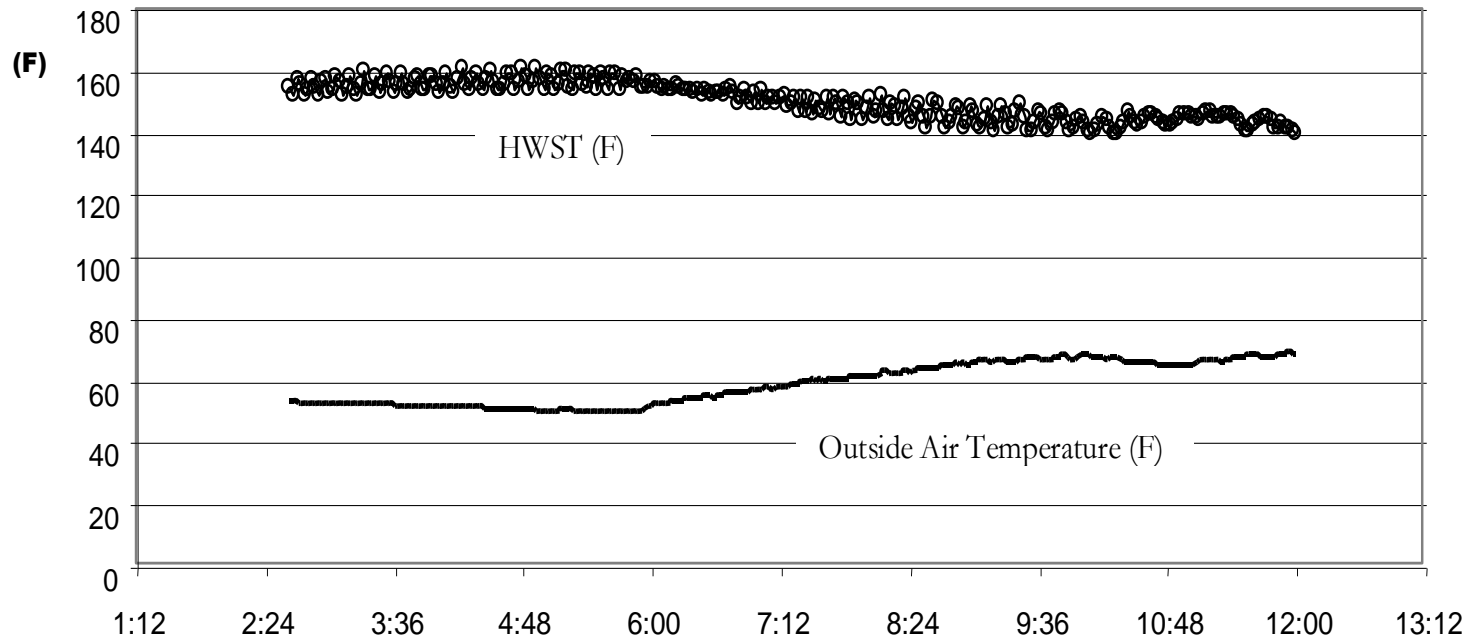
OAT-based HWST reset. How's it working?

Your Turn!

Evaluate Reset Strategies

Heating Water Supply Temperature vs. Outside Air (HWST vs OSAT)
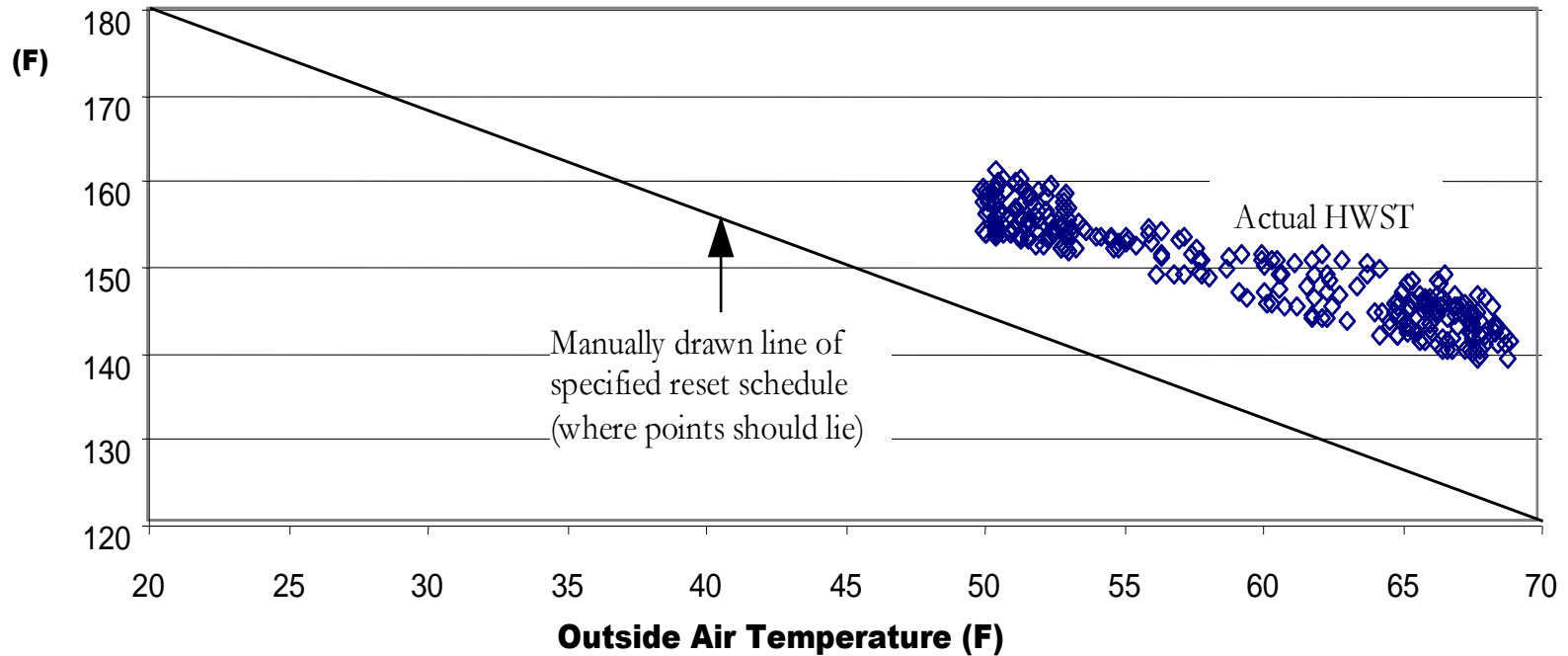
OAT-based HWST reset. How's it working?

Your Turn!

Evaluate Airside Economizers

Airside economizers

- **64%-75% of RTUs have inoperable economizers**
- **Economizer failure is the most common EBCx finding**

Common issues

- **Damper system design**
- **Controls sequences**
- **Maintenance**

Evaluate Airside Economizers

Inspect economizer maintenance

- **Blade and jamb seals installed, in good condition?**

- **Actuators adjusted for full closure?**

- **Actuators connected to dampers?**

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Evaluate Airside Economizers

Time-series charts can be tough to read:
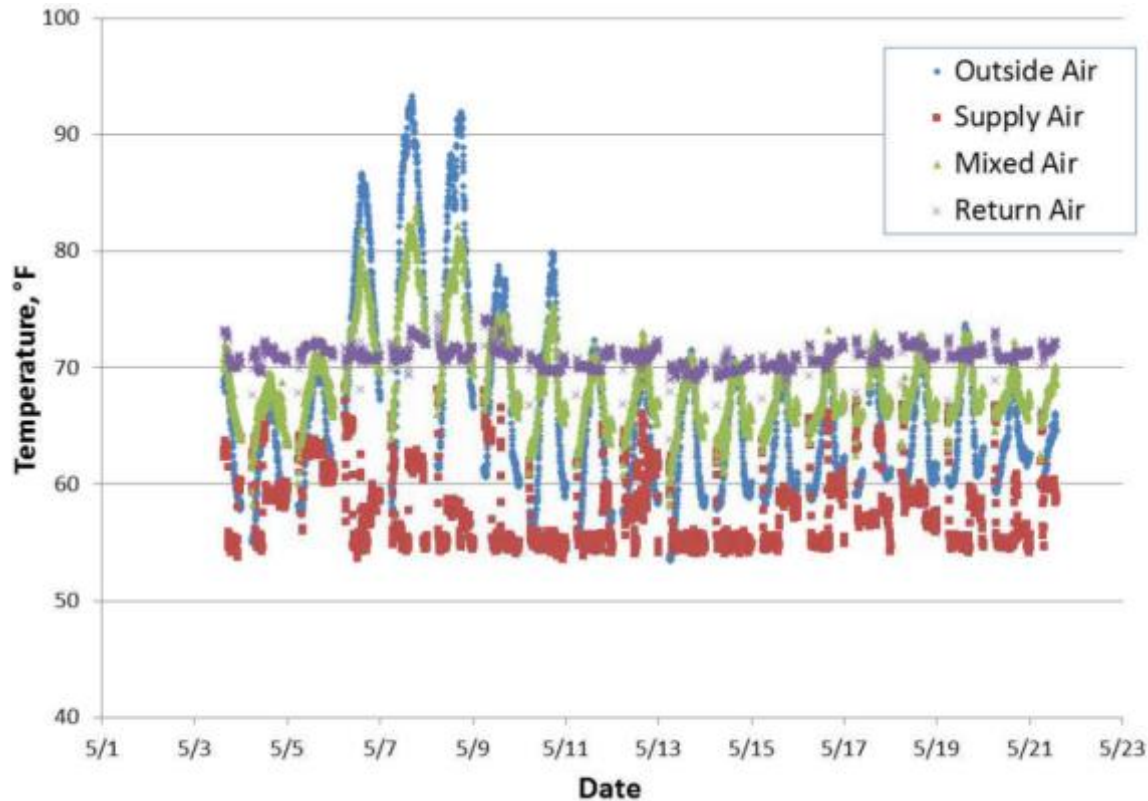
Evaluate Airside Economizers

X-Y scatter charts can be more useful. Plot expected and actual.
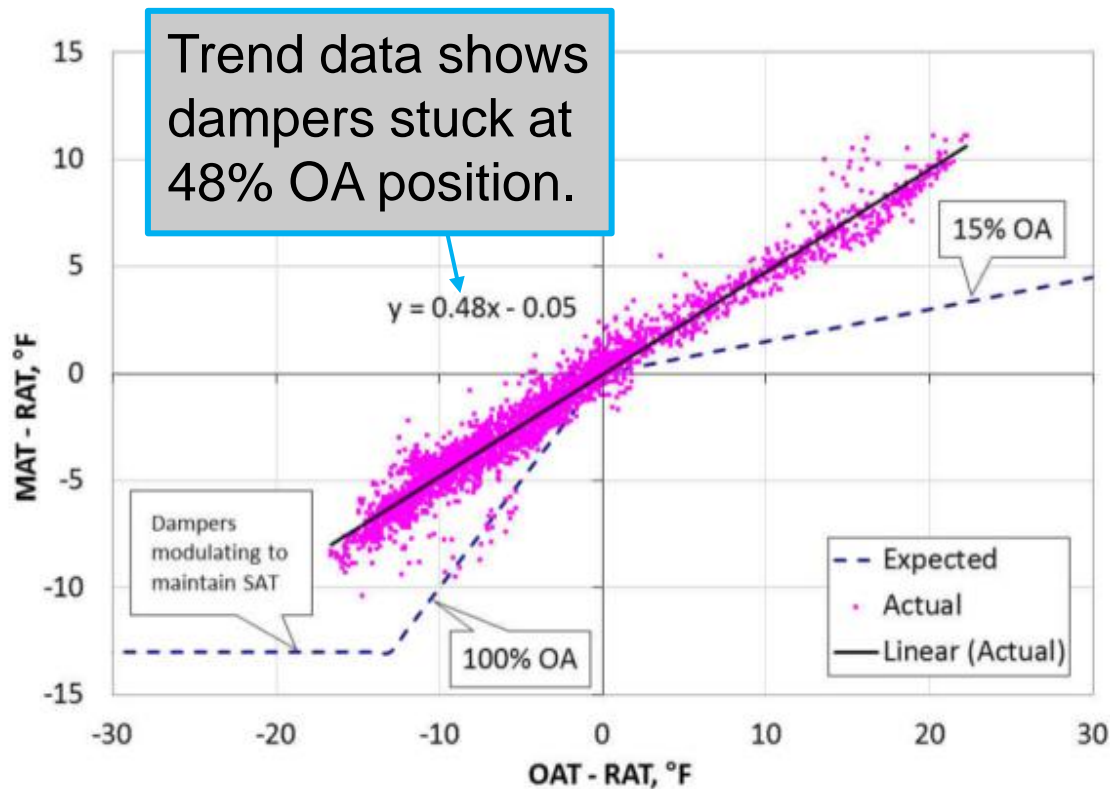
Good Economizer Damper Design

■ **OA & RA dampers sized and arranged to promote linearity**

 ◆ **Sized for proper authority**

  ■ **Rule of thumb: >=1,500 fpm velocity across open damper**

 ◆ **Lower velocity = lower ΔP and lower fan energy, but poor control**

■ **Damper rotation promotes mixing**

■ **Sufficient distance to mix**

Damper Characteristics

Dependent on damper type and damper authority (damper ΔP divided by section ΔP)
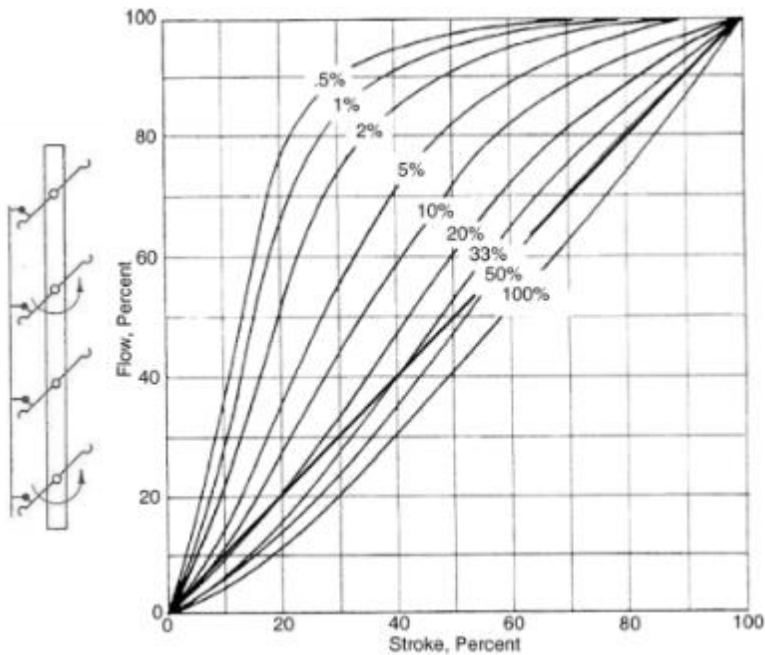
Parallel blade   Opposed blade

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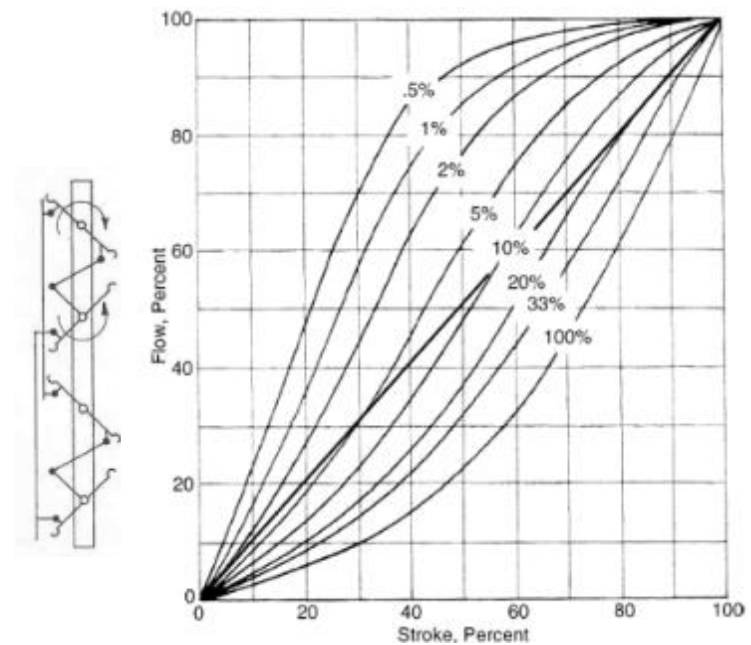
Return or Relief Fan?

Damper sizes depend on system arrangement and design pressures
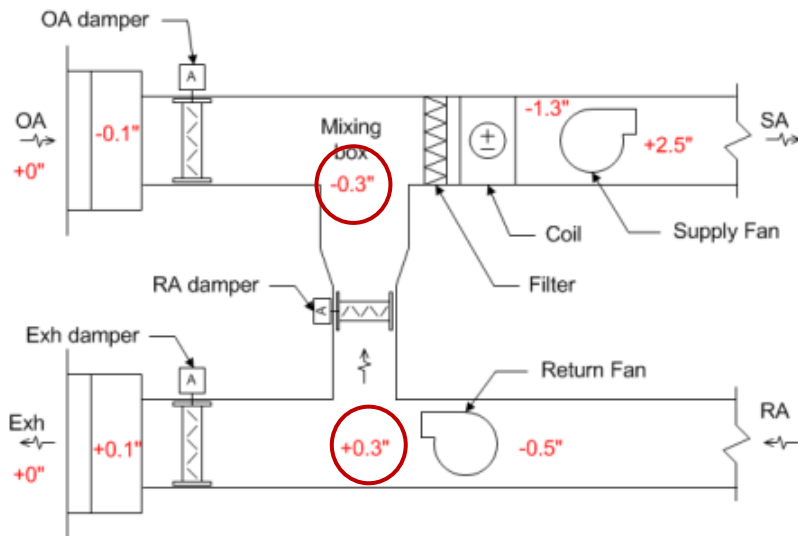
Return air system
RA damper ΔP = 0.6"
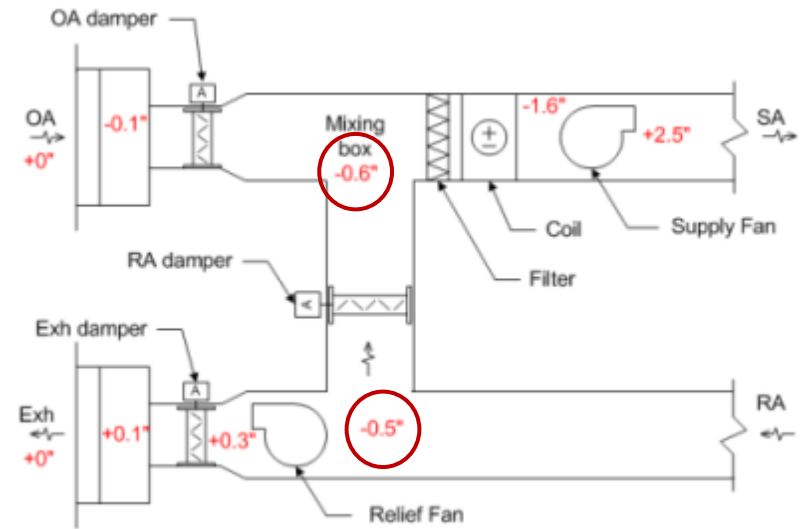
Relief air system
RA damper ΔP = 0.1"

Über non-linear

Return fan system, oversized parallel blade return dampers:
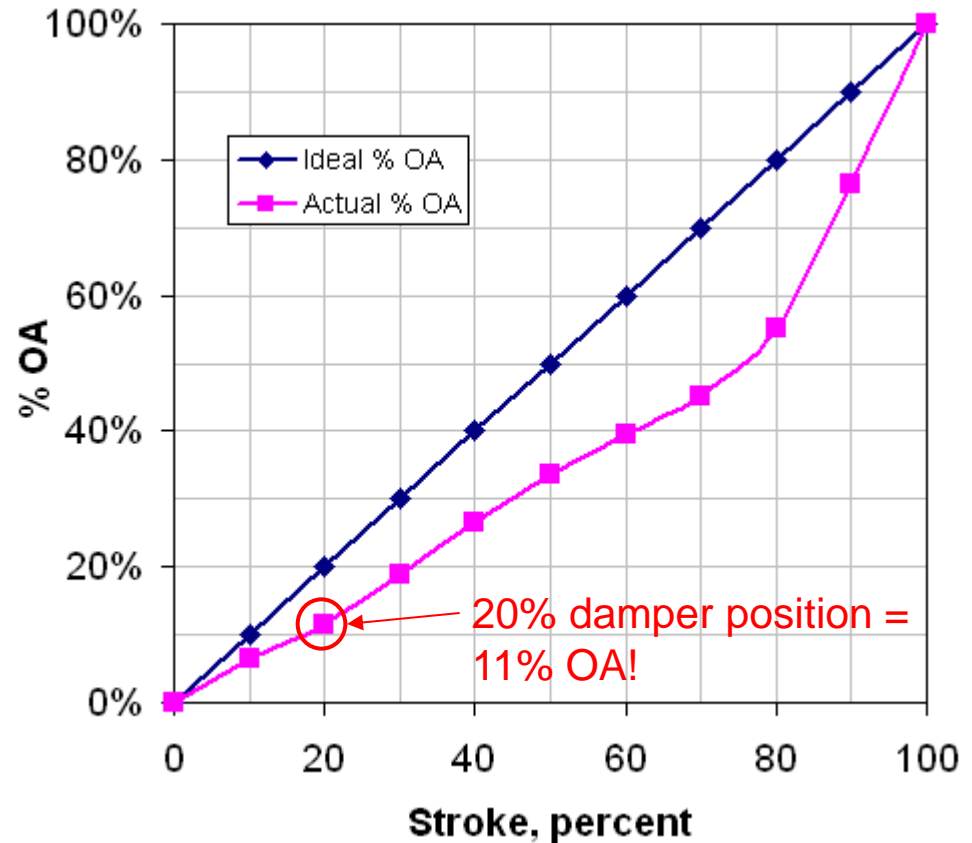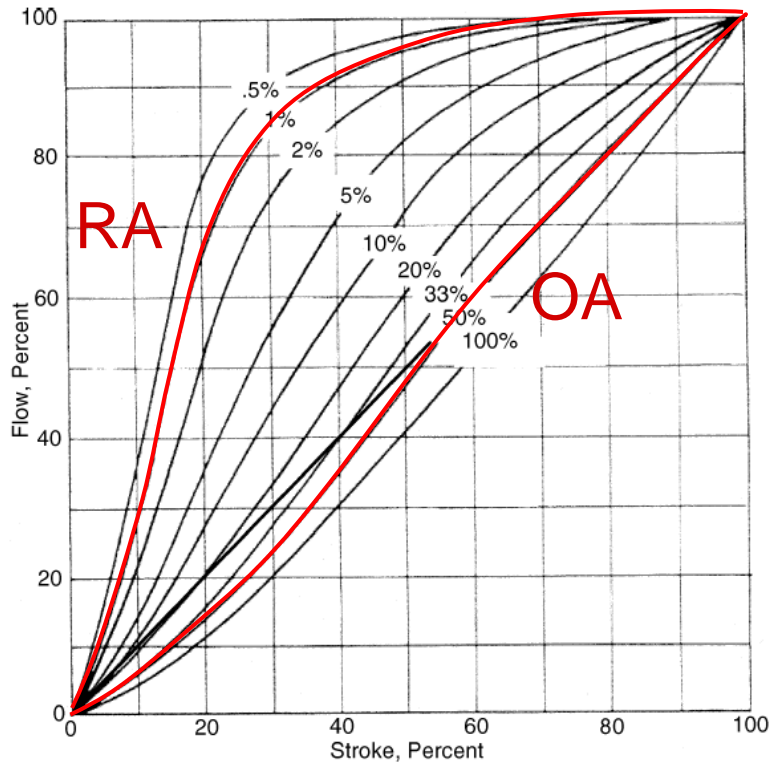
Another non-linear example

Oversized OA dampers can mean too much OA
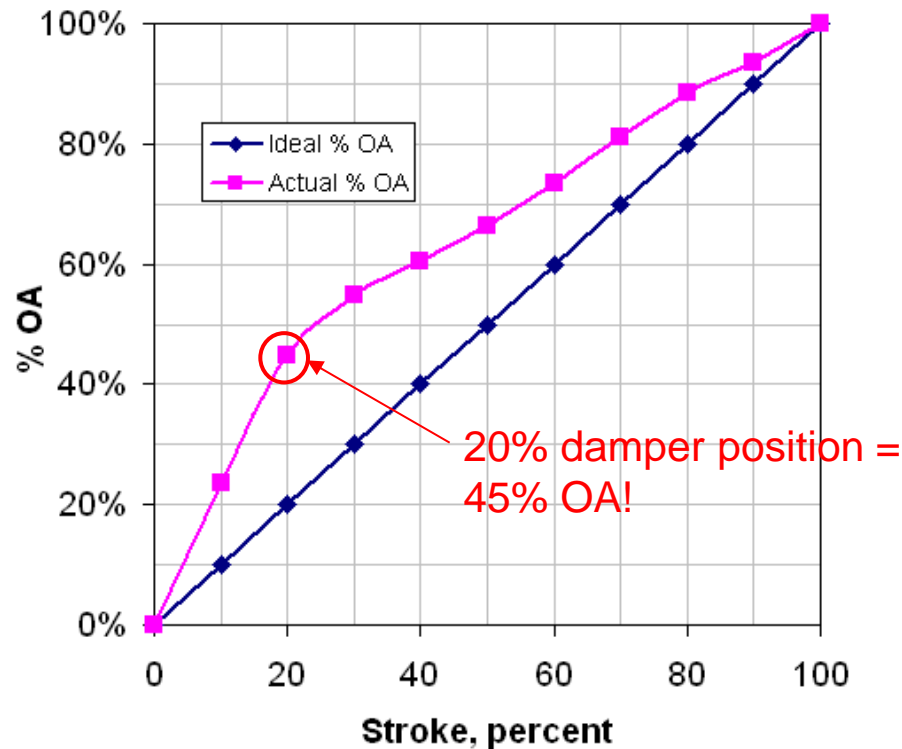
Damper Sizing and VAV System Economizer Performance

- **Systems can perform poorly at low flow rates**
  - ◆ **Turn-down creates the same effects as poorly sized damper sections**
  - ◆ **Turn-down can aggravate sensing problems**
- **Flow variations can change the mixed air plenum pressure relative to ambient**
  - ◆ **Plenum to OA pressure drives outdoor air flow**
  - ◆ **System flow variations may produce minimum outdoor air flow variations**

Dark, Windy, *and* Variable
What are the implications?

52°F OAT, 65-70°F RAT

8% OA (ave. 64.3°F MAT)

20	20	20	20	20	20	20
62.5	63.8	63.1	63.3	64.2	64.5	64.5
64.0	62.3	63.5	64.2	64.7	65.3	64.9
62.2	62.4	63.8	65.1	64.9	65.0	66.0
63.3	65.7	63.3	64.0	65.3	66.8	66.2
64.7	64.5	64.2	64.4	65.6	66.3	66.3

Coldest — Hottest

31% OA (ave. 64.3°F MAT)

20	20	20	20	20	20	20
60.9	60.8	63.5	64.7	64.9	65.4	66.9
60.2	61.8	63.3	64.7	64.4	65.9	66.5
60.8	61.5	64.0	65.1	69.9	66.3	66.5
60.0	60.9	64.0	64.9	66.2	66.7	66.7
60.0	61.7	64.4	65.4	66.7	67.1	67.1

Minimum — Maximum

83% OA (ave. 55.1°F MAT)

20	20	20	20	20	20	20
57.5	57.3	57.0	55.4	53.9	52.7	52.5
57.5	57.9	57.0	55.9	53.9	52.7	52.1
58.4	58.1	57.0	57.9	54.1	52.5	52.5
58.8	57.9	58.1	55.4	53.7	52.5	51.8
59.3	57.3	55.7	54.3	52.7	52.3	52.8

8% OA

20	20	20	20	20	20	20
526	506	604	564	623	604	447
604	681	604	663	663	506	526
721	447	272	252	447	409	429
584	487	546	526	447	623	526
429	389	405	405	546	350	447

Slowest — Fastest

31% OA

20	20	20	20	20	20	20
584	409	584	584	623	526	506
623	567	604	564	584	650	526
604	584	506	389	506	584	701
564	564	564	564	370	584	564
429	350	467	487	584	564	487

Minimum — Maximum

83% OA

20	20	20	20	20	20	20
331	350	272	643	779	643	632
350	292	370	741	945	799	653
800	604	429	760	858	643	701
681	487	604	663	741	663	604
467	487	623	389	447	487	623

Data courtesy of David Sellers

Your Turn!

Economizers and Building Pressure

■ **Make sure the relief air system operates correctly at 100% OA.**

◆ **E.g., no exterior doors standing open.**
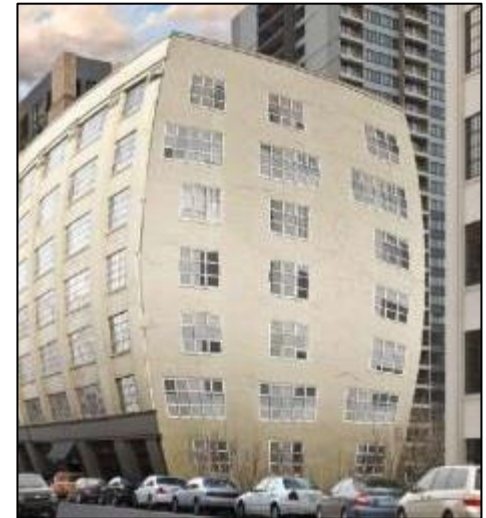
Courtesy of BetterBricks

Evaluate HVAC Pumps

Pumping Opportunities

■ **Many pumps are oversized**

■ **How to identify:**

◆ **Throttled discharge valve**

◆ **Both parallel pumps running**

◆ **Low temperature differential across loop**

Evaluate HVAC Pumps
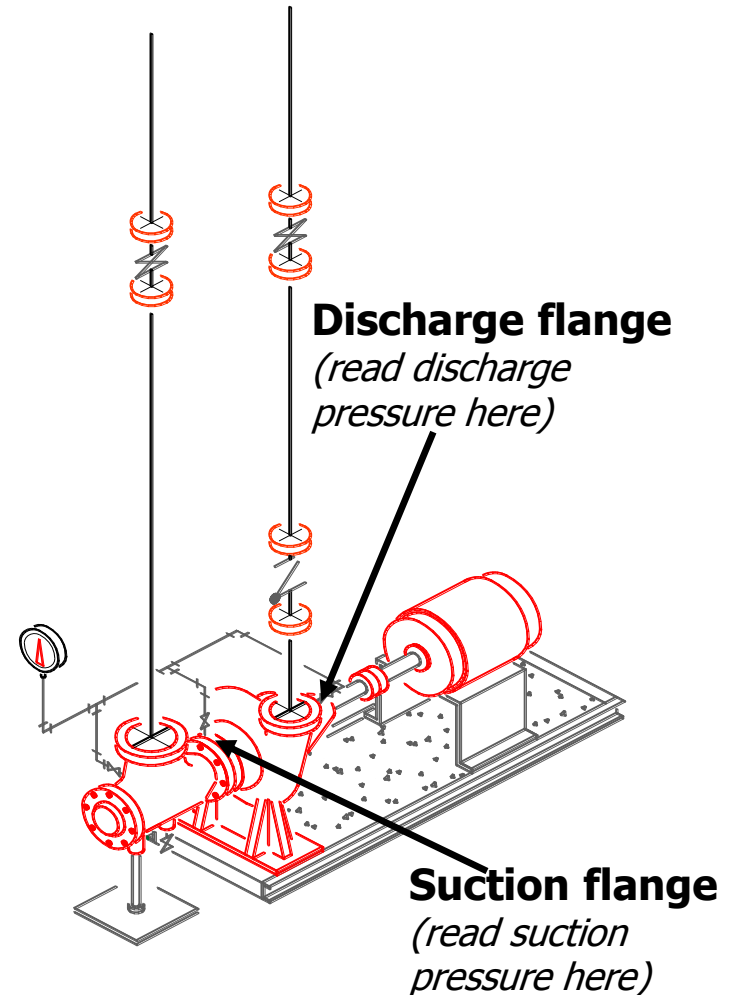
Sometimes it's easy to spot a throttled discharge valve …

Open

Closed
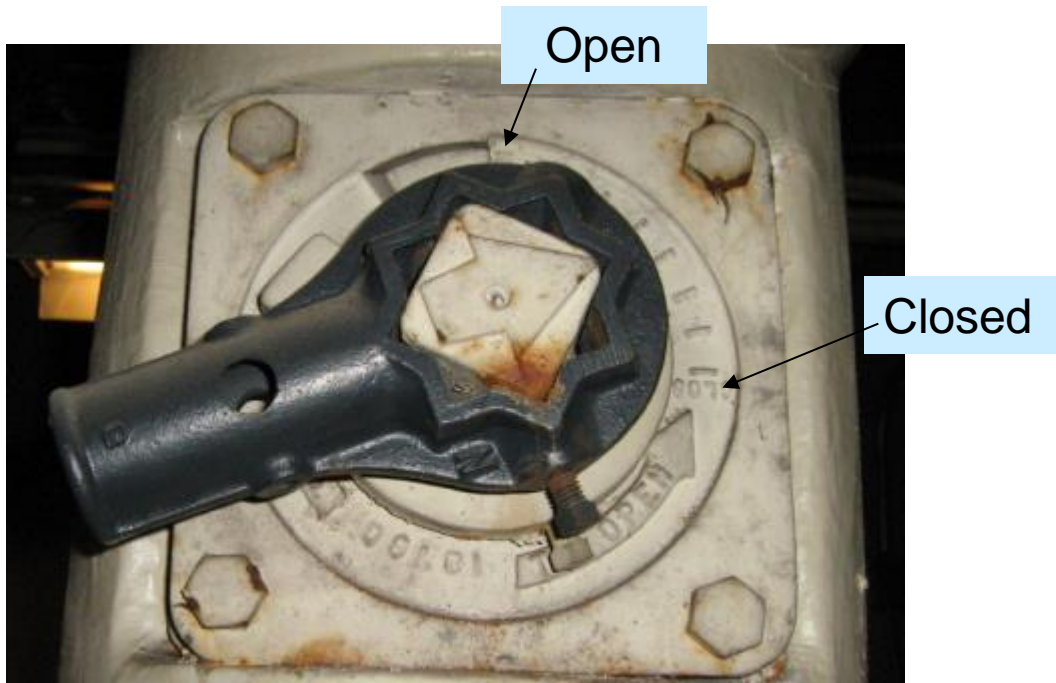
Evaluate HVAC Pumps

… other times, not so much.

Performing a Pump Test

- **Pump curves are certified performance**

  - ◆ **Flow vs. head for various impeller sizes**

- **Measure pressures at flanges**

Discharge flange
(read discharge pressure here)

Suction flange
(read suction pressure here)

As Found Conditions

■ **Record the current operating conditions**

◆ **Record suction and discharge pressures**

◆ **Mark current position of throttling valve so that the system can be returned to the as-found state once the test is complete**

No Flow Test

■ **Verify impeller size**

◆ **Turn off the pump.**

◆ **Close the throttling valve completely and turn the motor back on.**

◆ **Record suction and discharge pressure.**

◆ **Plot the point on the pump curve, determine impeller size.**

No Flow Test Results

Credit: Bell and Gossett catalog.
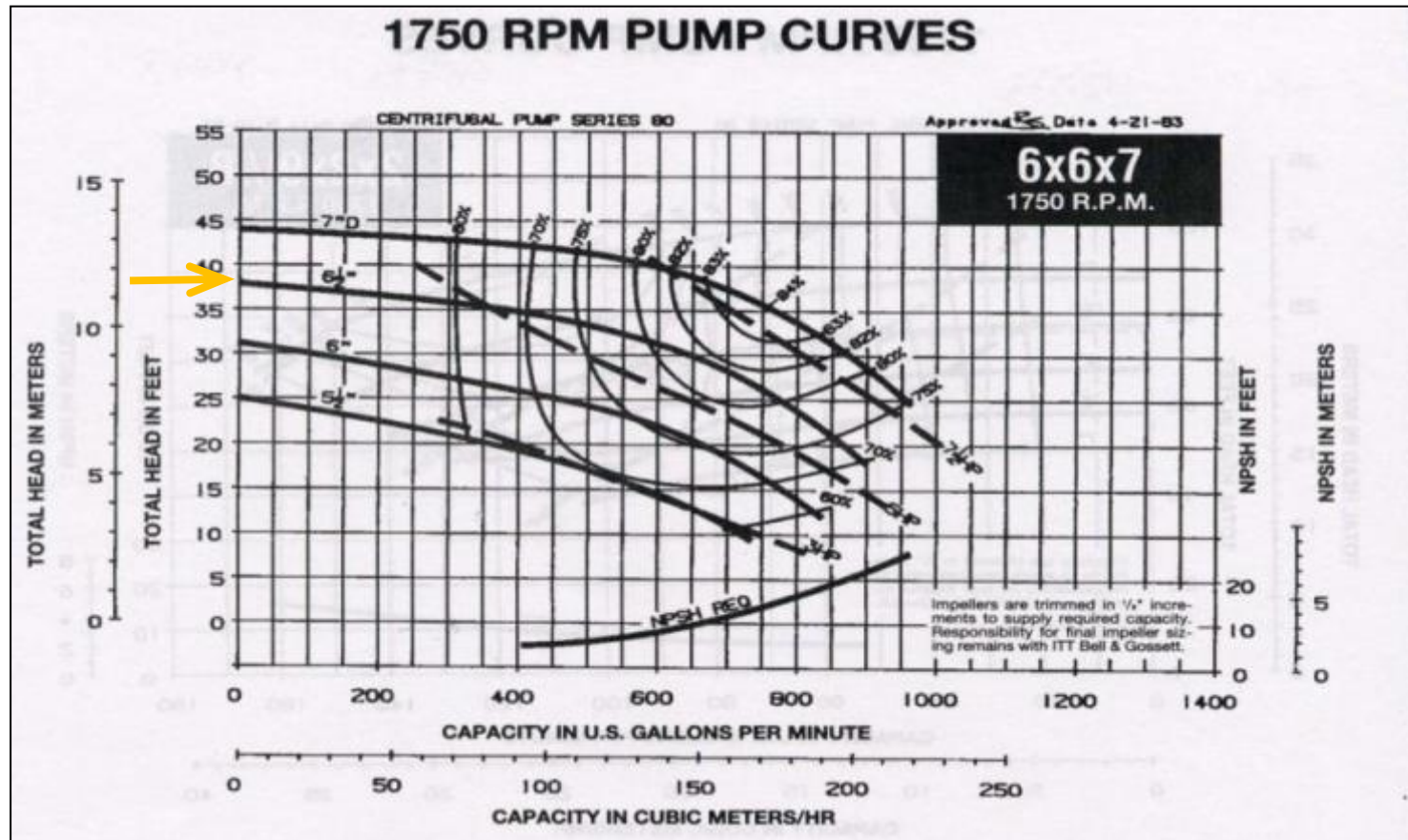
Wide Open Test

■ **Throttling valve completely open.**

◆ **Open the throttling valve completely.**

◆ **Ensure that all control valves in the loop are open.**

◆ **Record suction and discharge pressure.**

◆ **Plot the point on the pump curve.**

Wide Open Test Results

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Plotting the Results

1750 RPM PUMP CURVES

CENTRIFUGAL PUMP SERIES 80   Approved Date 4-21-83

6x6x7
1750 R.P.M.

Design Point
550 gpm @ 32 ft
w.c.

As Found

Wide Open

Ideal point on system curve. Trim to 5.5 in impeller and throttle to design flow.

Impellers are trimmed in ⅛" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.

TOTAL HEAD IN METERS

TOTAL HEAD IN FEET

NPSH IN FEET

NPSH IN METERS

NPSH REQ

CAPACITY IN U.S. GALLONS PER MINUTE

CAPACITY IN CUBIC METERS/HR

Credit: Bell and Gossett catalog.

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Pump Affinity Laws

- **Predict performance on the system curve**
- **Generate new impeller curves**

Useful derived relationships :

$$Q_2 = Q_1\left(\frac{D_2}{D_1}\right),\ H_2 = H_1\left(\frac{Q_2}{Q_1}\right)^2,\ \text{and}\ BHP_2 = BHP_1\left(\frac{Q_2}{Q_1}\right)^3$$

Where :

Q = Flow

D = Impeller diameter

H = Head

BHP = Shaft horsepower

Use the Laws With Care

Affinity laws do not account for leakage and hydraulic losses. Predicted performance may not match actual.
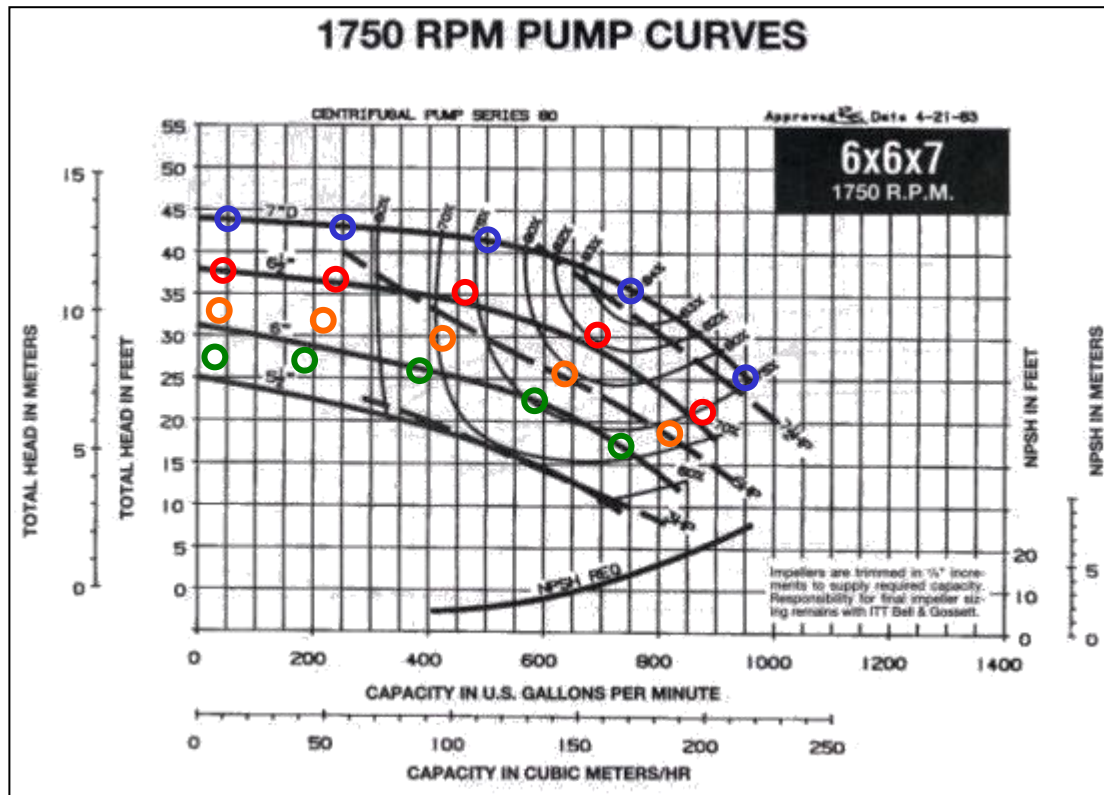
Impeller Diameter	Flow	Head
7.0	950	26
	750	36
	500	42
	250	43
	50	44
6.5	882	22
	696	31
	464	36
	232	37
	46	38
6.0	814	19
	643	27
	429	31
	214	32
	43	33
5.5	746	17
	589	23
	393	27
	196	28
	39	28
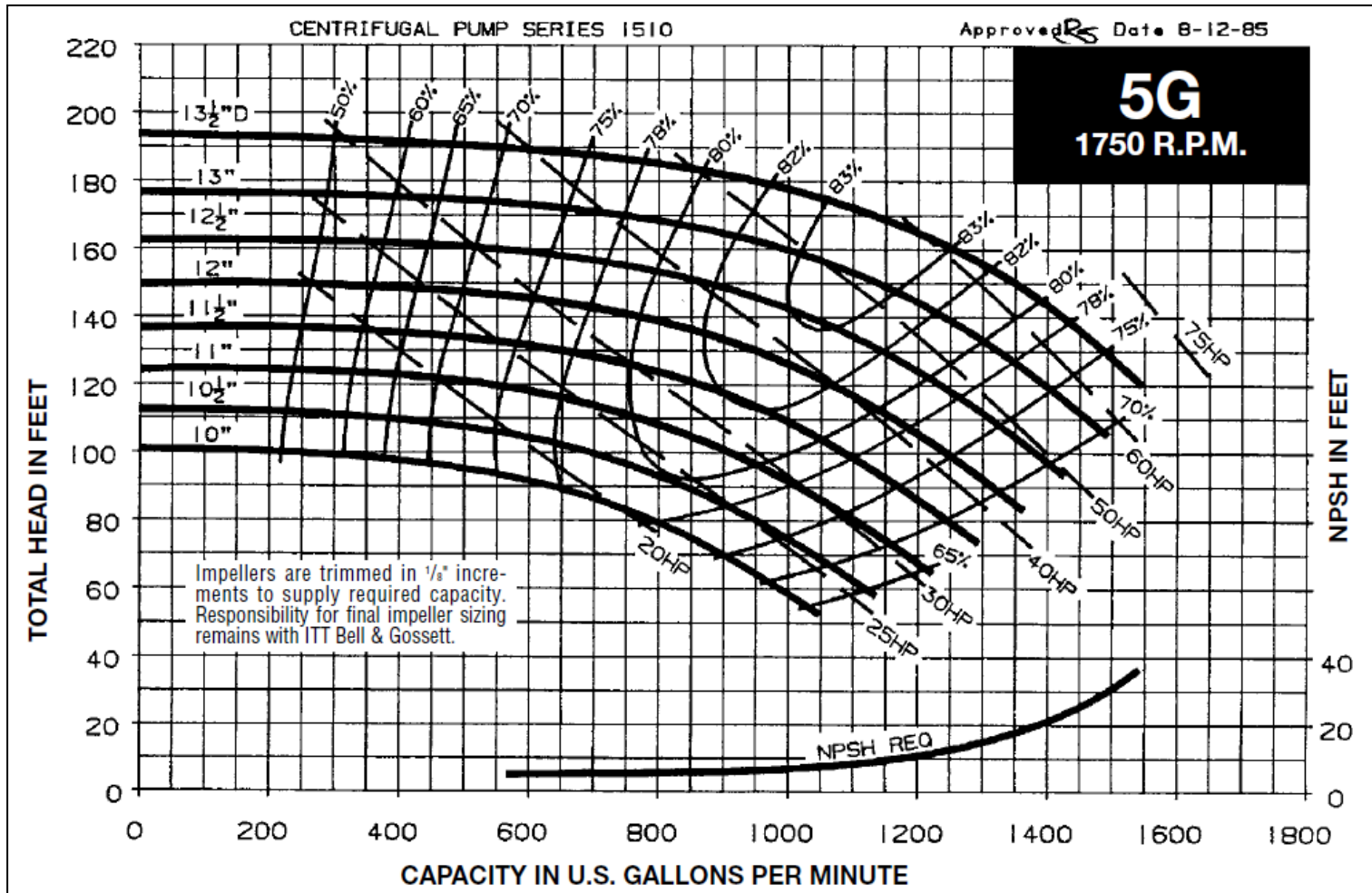
Credit: Bell and Gossett catalog.

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Pump Analysis Activity

Credit: Bell and Gossett catalog.

Your Turn!

Pump Analysis Activity
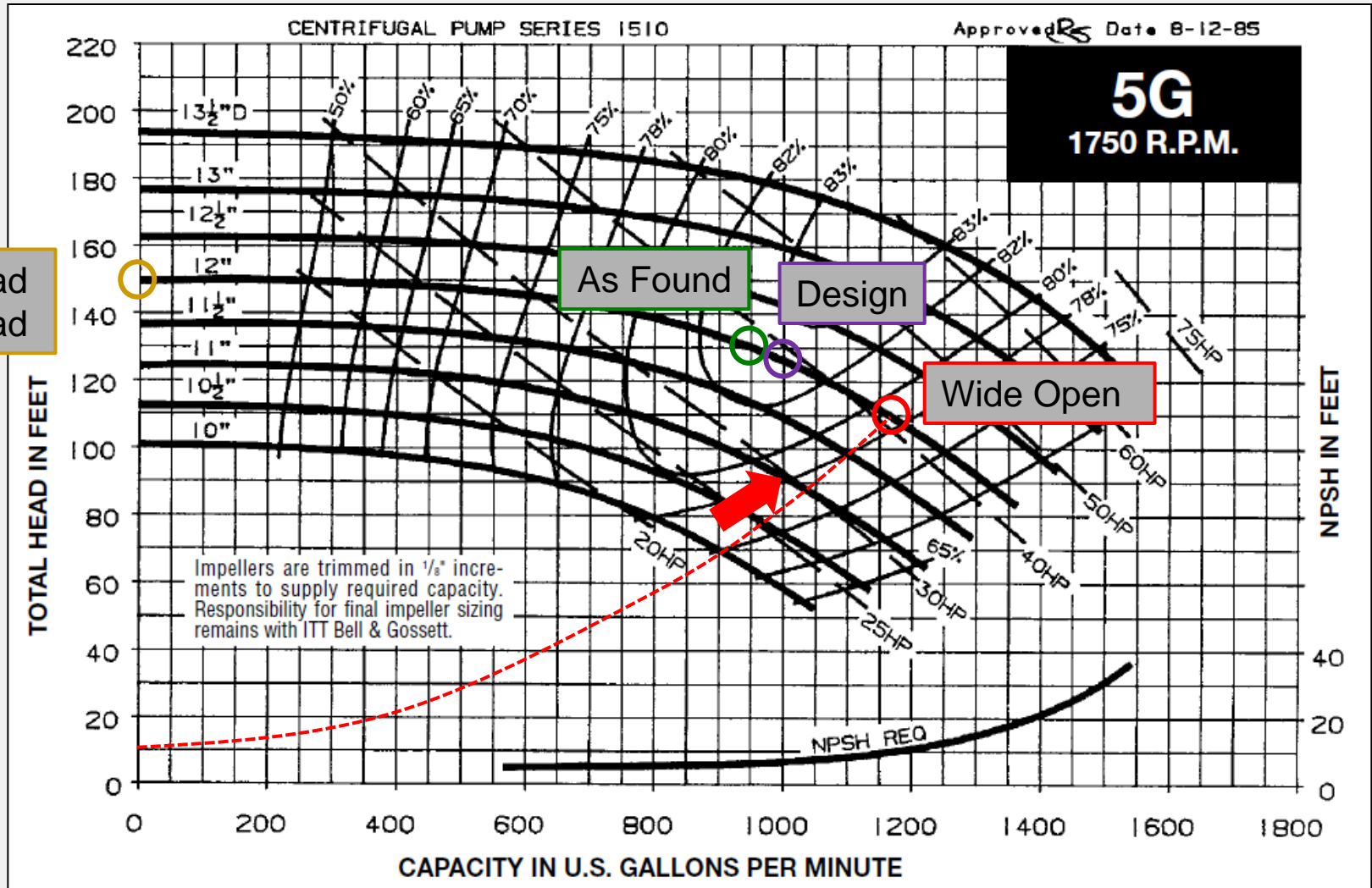
Evaluate HVAC Pumps

■ **Parallel pumps – shut one off?**

■ **Level of savings depends on pump curve.**
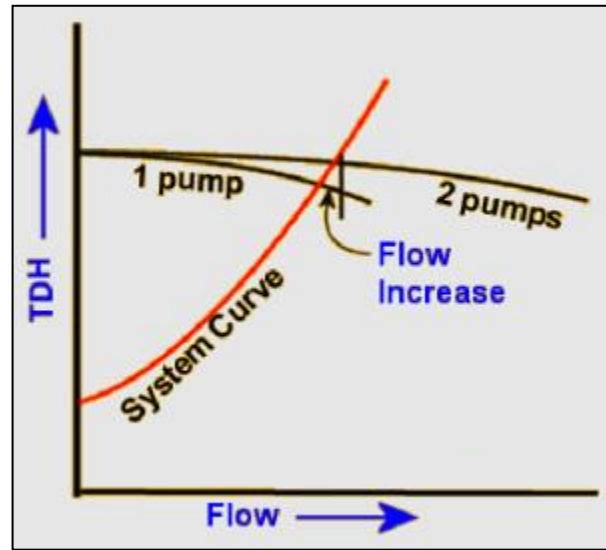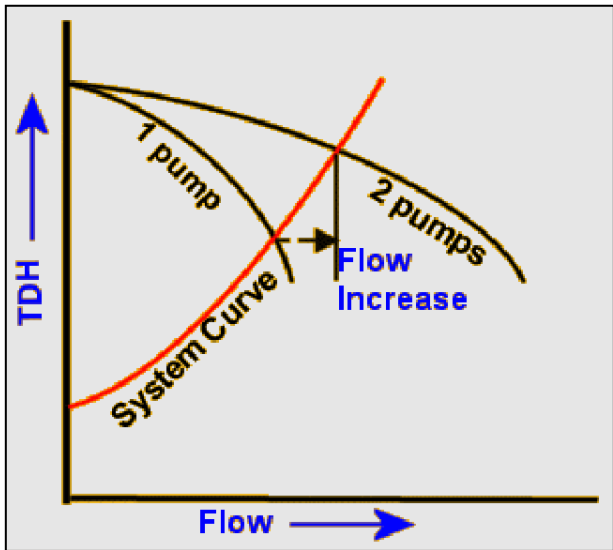
Shallow curve – less flow increase

Evaluate Ventilation

Ventilation control – typical issues:

- **Actual occupant load less than design**
- **Space usage changed**

Common opportunities:

- **Add demand-controlled ventilation (DCV)**
- **Reduce minimum OA flow rate**
- **Reduce VAV box min flow rates**
- **Reset VAV box min flow rates**

Evaluate Ventilation

Clues to identify ventilation issues:

- **Cold complaints in zones with no reheat**
- **Low measured CO_2 values**
- **High summertime boiler usage**

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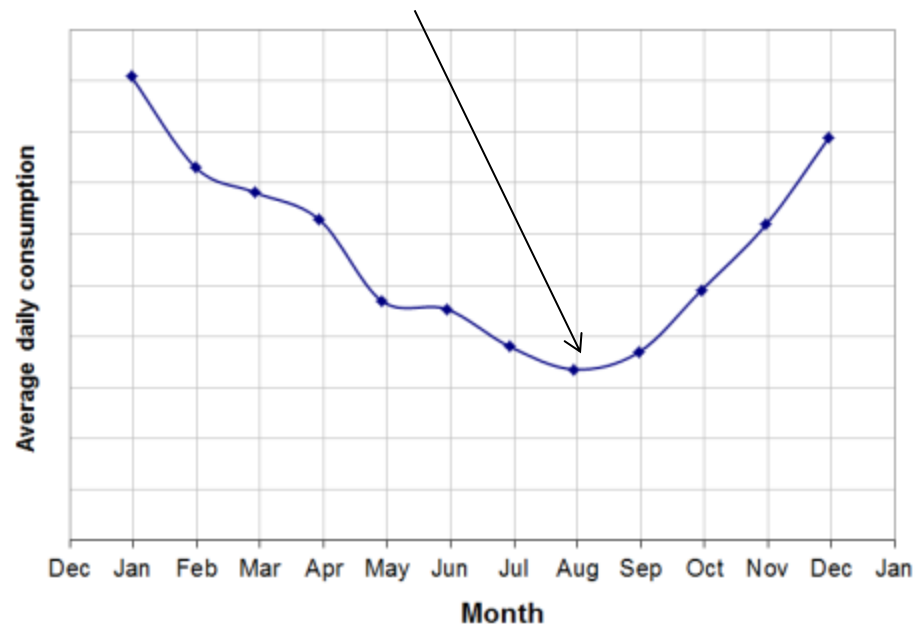
VAV? Or mostly CAV?

Typical Interior Office Cooling Loads
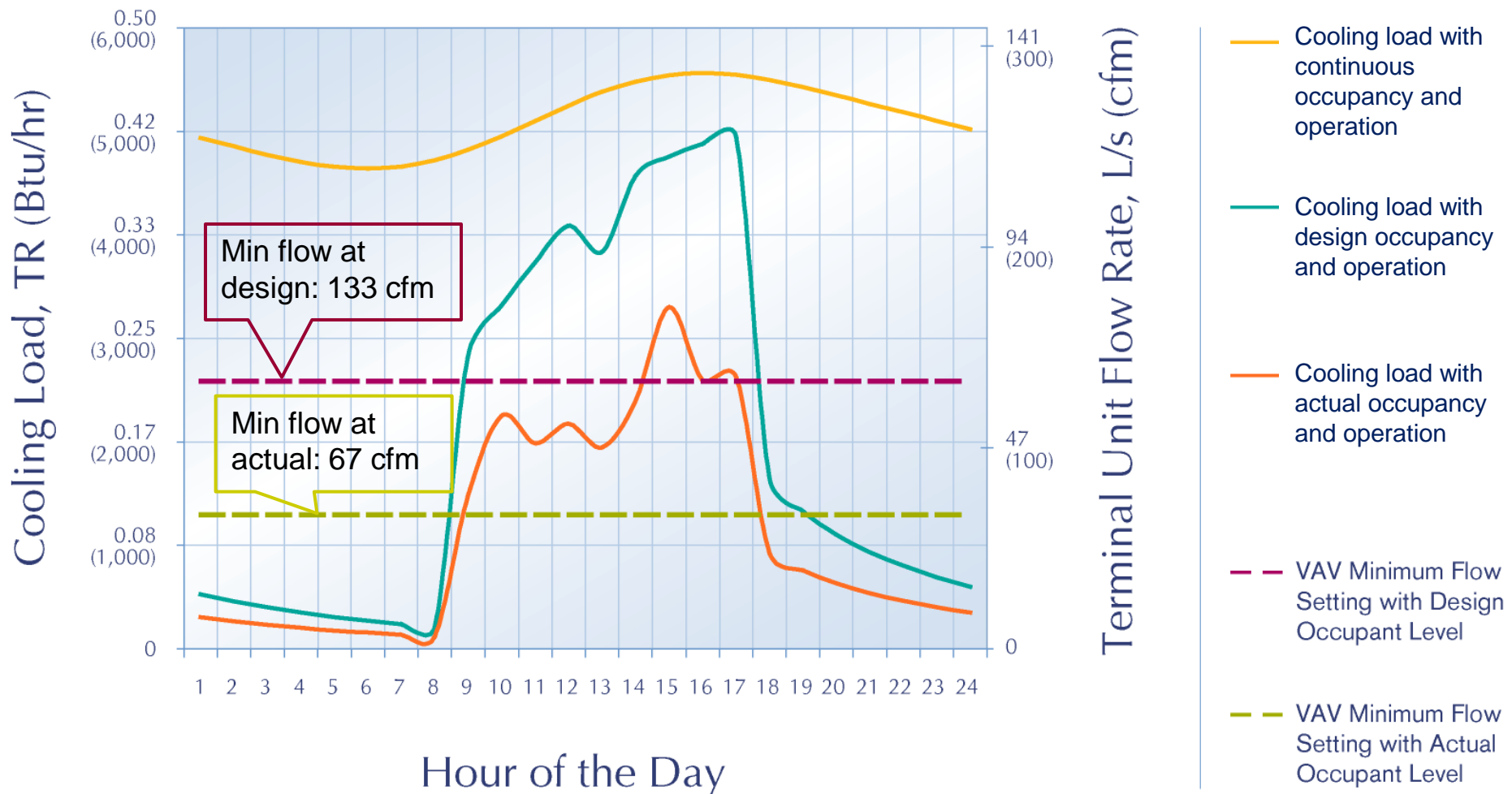
Ventilation Activity

When evaluating reduced minimum ventilation rates or reduced VAV box minimum flow setpoints, list some considerations related to:

- **Measuring CO_2**
- **Code-required ventilation rates**
- **VAV box airflow measurement rings**
- **Electric reheat at VAV boxes**
- **Supply air turn-down capability of the AHU**
- **Integration with lighting occupancy sensors**
- **Capabilities of the control system**
- **Other considerations?**

Your Turn!

Evaluate Lighting Performance

Measure lighting levels, compare to CFR

Location	Acceptable Illuminance Level Range (FC)	Measured Illuminance Level (FC)	Acceptable?
1st floor open office	20-50	107	N
1st floor conf room	20-70	54	Y
1st floor lobby	10-30	59	N
1st floor enclosed office	20-50	27	Y
1st floor corridor	10-30	12	Y
2nd floor open office	20-50	21	Y
2nd floor storage	10-30	22	Y

Evaluate Lighting Performance

Lighting controls. Example types:

- **Scheduled**
- **Photocell-controlled**
- **Daylight harvesting**
- **Occupancy sensor-controlled**
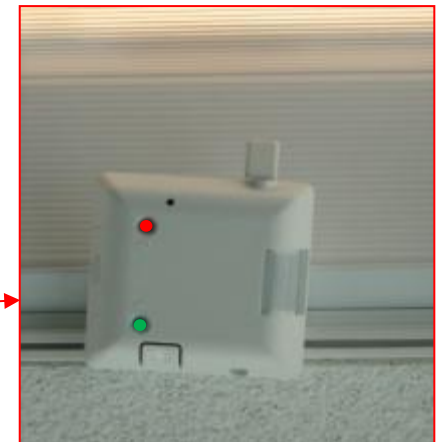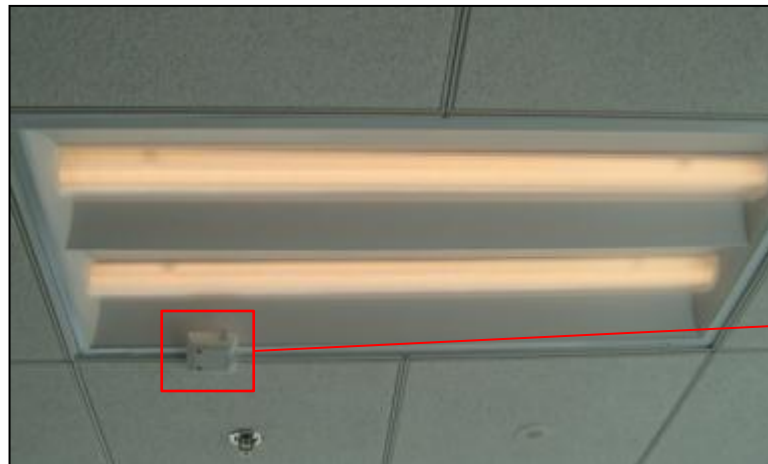
Evaluate Lighting Performance

- **Lighting controls case study**
- **Issue:**
  - ◆ **Plaza lights on during day.**
  - ◆ **Identified during walk-through**

How could this issue be investigated?

What methods could be used?

Your Turn!

Evaluate Lighting Performance

Verify suspicions

Plaza Lighting

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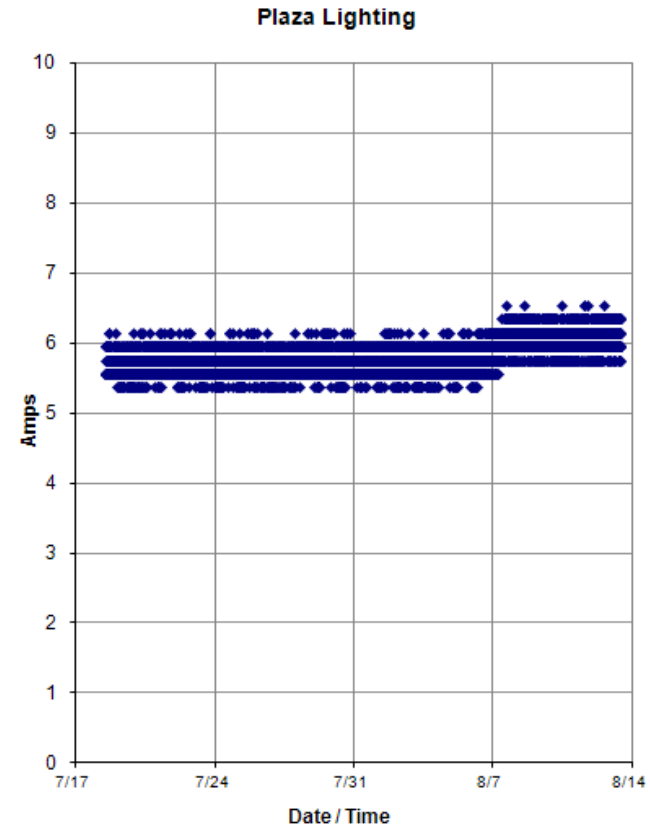
Evaluate Envelope Performance

General considerations

- **Maintenance**
- **Air sealing / infiltration**
- **Operable components**
- **Known issues**
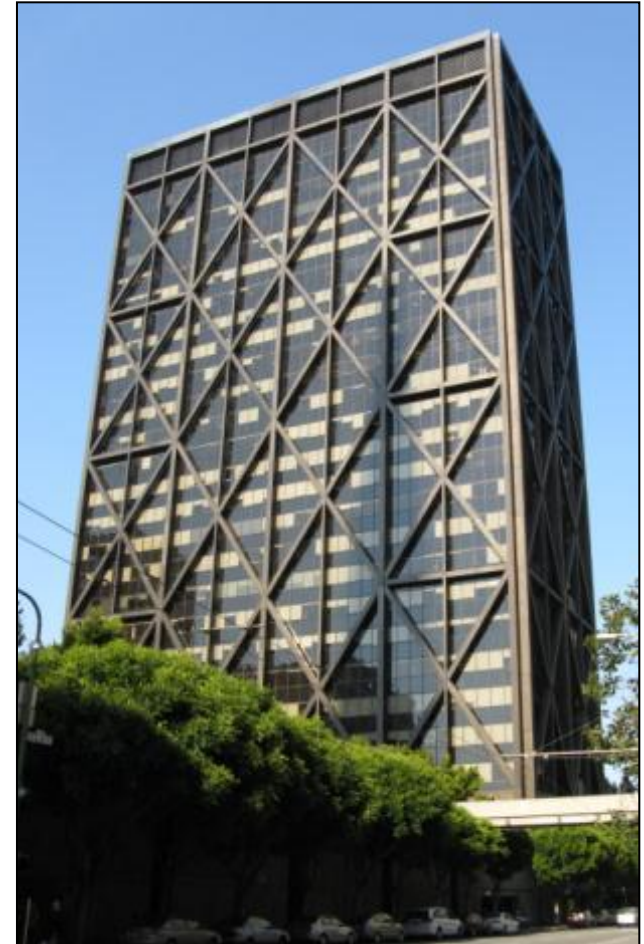
Evaluate Envelope Performance

Check air leakage

- **Gaps around windows and doors**

- **Operable windows and doors**

- **Use thermal imaging camera or smoke pen**

Evaluate Envelope Performance

Stack effect

- **Common in high rise buildings**

- **Symptoms: drafts on lower floors, overheating on upper floors**

After hours infiltration

- **Conduct a night walk**

- **BetterBricks Building Night Walk Video Series**

Your Turn!

Evaluate Plug Loads

Items and areas to investigate

- **Computer power management**

- **Space heaters**

- **Projectors**

- **Data centers**

Look for scheduling opportunities. Diagnostic monitoring can be used.

Turning Findings into Measures

Work with operating staff to develop appropriate measures to correct the identified findings.

Turning Findings into Measures

Measure types

- **Those that repair / restore operation**

- **Those that add enhancements / technology (e.g., advanced control sequences, VFDs)**

  - **With this type, consider the availability and capability of the building operating staff.**

Analyze Measures

Estimate:

- **Implementation cost**
- **Benefits (e.g., energy savings)**
- **Financial metrics**

					Bldg		Air Cooled Reciprocating Electric Chillers						Chiller Pumpin
Annual Bin Totals			Operating		Load	CHWS	Chiller (1) 360 ton			Chiller (2) 360 ton			P-1A	P-2A
BIN-DEG F		Hours	Hours	AVE WB	Tons	Temp	tons	kW/ton	kW	tons	kW/ton	kW	kW	KW
					a	b	c	d	e	f	g	h	i	i
100 TO	105	1	1	78	550	44	270	1.32	356.4	280	1.32	369.6	6.4	
95 TO	100	6	6	77	550	44	270	1.32	356.4	280	1.32	369.6	6.4	
90 TO	95	62	62	76	450	44	270	1.32	356.4	180	1.32	237.6	6.4	
85 TO	90	155	155	74	400	44	270	1.32	356.4	130	1.32	171.6	6.4	
80 TO	85	337	337	72	350	44	270	1.32	356.4	80	1.32	105.6	6.4	
75 TO	80	449	449	68	300	44	240	1.32	316.8	60	1.32	79.2	6.4	
70 TO	75	502	502	64	120	44	120	1.40	168.0	0	0.00	0.0	6.4	
65 TO	70	706	353	61	90	44	90	1.45	130.5	0	0.00	0.0	6.4	
60 TO	65	934	374	57	50	44	50	1.45	72.5	0	0.00	0.0	6.4	
55 TO	60	766	191.5	53	30	44	30	1.50	45.0	0	0.00	0.0	6.4	
	Totals	3918	2430											

Existing Chiller Plant Operation

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Analyze Measures

Implementation cost considerations

- **Contractor or in-house labor**

- **Materials and equipment**

- **Contractor markups**

- **Engineering, training and M&V fees**

- **Updating documentation**

- **Project contingency**

Analyze Measures
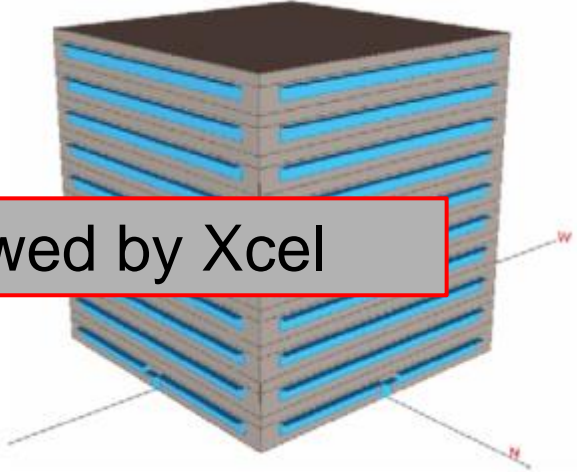
Energy and demand savings calculation methodology options

- **Whole building energy modeling software**
- **Stipulated savings from utility programs**
- **Manufacturer's software**
- **Custom spreadsheets**
- **Other calculators**
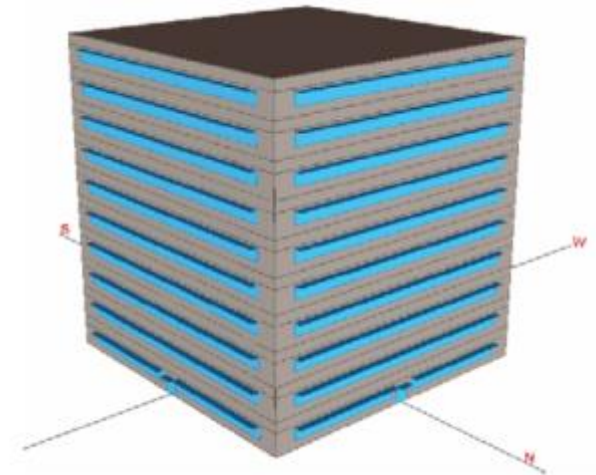
Analyze Measures

Energy and demand savings calculation methodology options

- ■ **Whole building energy modeling software**

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- ■ **Manufacturer's software**

- ■ **Custom spreadsheets**

- ■ **Other calculators**
  - ◆ **Xcel Energy RCx Tool**

Allowed by Xcel

Analyze Measures

Energy and demand savings general approach

- **Collect baseline data**

- **Develop baseline energy use estimate**

- **Develop post-implementation energy use estimate**

- **Calculate savings**

  - ◆ **Baseline minus post-implementation**

- **Review calculations**

Custom Spreadsheets

1. Collect baseline data

■ **Demonstrate the finding**

■ **Basis for savings calculations**

■ **Sources:**

   ◆ **Spot measurements**

   ◆ **Nameplate data**

   ◆ **Drawings**

   ◆ **Site observations**

   ◆ **Functional performance test data**

   ◆ **Trend data**

Custom Spreadsheets

2. Develop baseline energy use estimates

- **Document assumptions and inputs**
- **Filter bin data and trend data**
- **Show intermediate calculation steps**
- **Use equations, don't "paste values"**
- **Use appropriate calculation approach**
  - ◆ **Simple calculations**
    - **For consistent operational characteristics**
  - ◆ **Bin methods**
  - ◆ **8,760-hour methods**
    - **Better than bin for demand estimates**

Custom Spreadsheets

3. Develop post-imp energy use estimates

- **Predict the measure's impact on the affected system(s)**

- **Use engineering formulas**

4. Calculate savings

- **Baseline minus post-imp energy use**

- **Allow for future modification of the estimate based on actual post-imp data**

Custom Spreadsheet Example

Dry-bulb outside air temperature, °F	Load (kW)	Baseline operation bin hours (M-F 6a-10p, Sa 7a-5p)	Baseline Energy (kWh)	Proposed operation bin hours	Proposed energy use (kWh)	Energy savings, (kWh)
a	b	c	d	e	f	g
	See regression on 'Load' worksheet	BinMaker for Minneapolis	b * c	Lockout at OATs<50°F	b * e	d - f
97.5	40.5	1	40	1	40	0
92.5	40.0	16	639	16	639	0
87.5	39.5	56	2,209	56	2,209	0
82.5	39.0	237	9,231	237	9,231	0
77.5	38.5	356	13,688	356	13,688	0
72.5	38.0	383	14,535	383	14,535	0
67.5	37.5	324	12,134	324	12,134	0
62.5	37.0	413	15,260	413	15,260	0
57.5	36.5	305	11,117	305	11,117	0
52.5	36.0	301	10,821	301	10,821	0
47.5	35.5	249	8,827	0	0	8,827
42.5	35.0	192	6,710	0	0	6,710
37.5	34.5	295	10,163	0	0	10,163
32.5	34.0	273	9,268	0	0	9,268
27.5	33.5	259	8,664	0	0	8,664
22.5	33.0	200	6,590	0	0	6,590
17.5	32.5	319	10,352	0	0	10,352
12.5	32.0	161	5,144	0	0	5,144
7.5	31.5	110	3,460	0	0	3,460
2.5	31.0	82	2,538	0	0	2,538
-2.5	30.5	48	1,462	0	0	1,462
-7.5	30.0	68	2,037	0	0	2,037
-12.5	29.5	26	766	0	0	766
-17.5	29.0	6	174	0	0	174
		4,680	165,828		89,675	**76,153**

Line #

Source

46% reduction

More Typical Custom Spreadsheet

Custom Spreadsheets

Best practices

- **Clearly label all assumptions**

- **Quickly test all assumptions**
  - ◆ **For those that have significant effect, be accurate (e.g., use spot measured values)**

- **Include supporting documentation**

- **Only use regressions that correlate well**

- **Account for interactions**
  - ◆ **Between systems**
  - ◆ **Between measures**

- **Vary equipment efficiencies with load**

Savings Calculation Activity

What's the annual kWh savings related to adding a VFD?
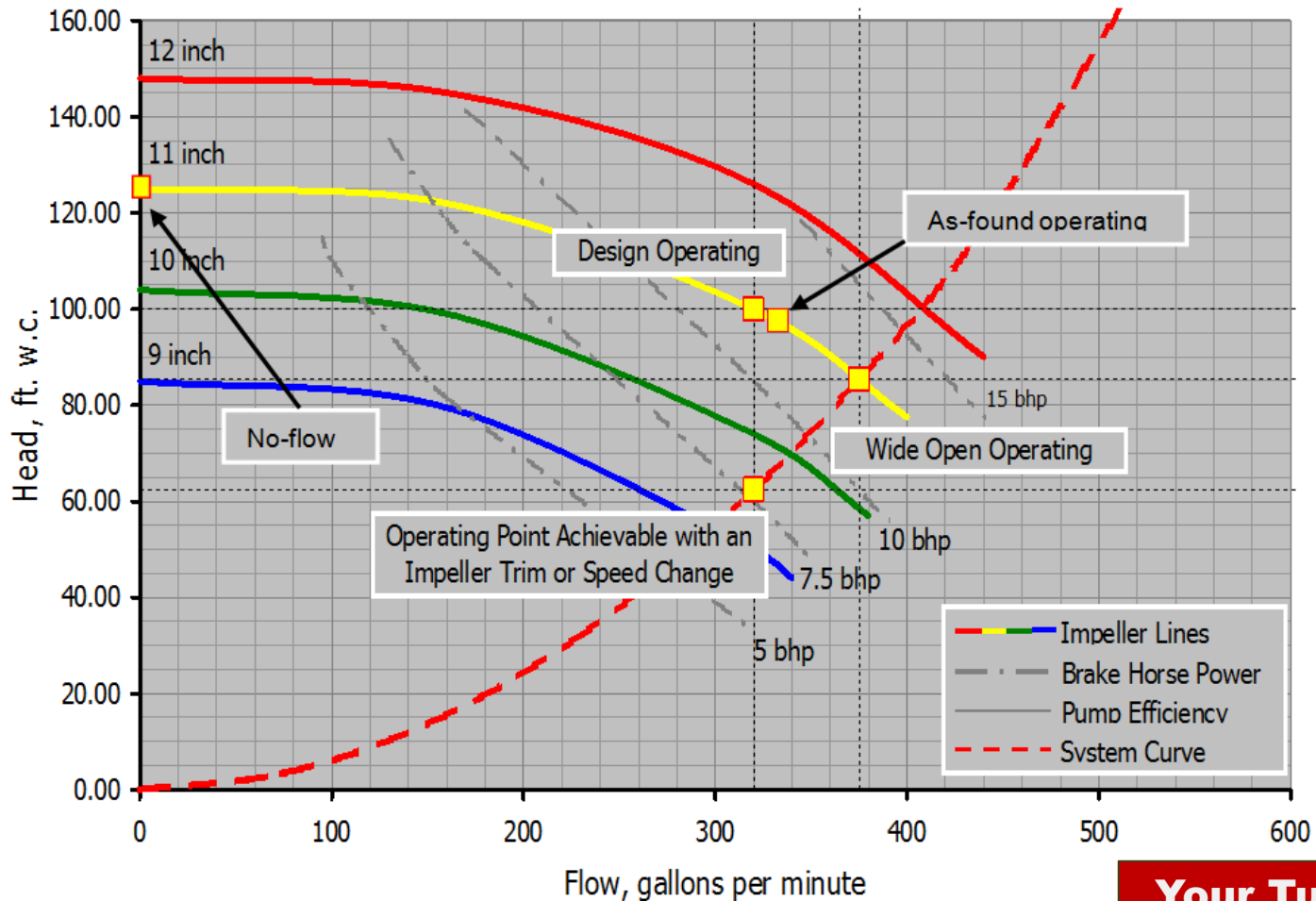
Your Turn!

Savings Calculation Activity

What's the annual kWh savings related to adding a VFD?

- **As-found kW = (12 * .746) / (.9) = 10 kW**

- **Achievable kW = (7.5 * .746) / (.9 * .95) = 6.5 kW**

- **Savings = (10-6.5) * 4000 = 14,000 kWh**

  - **At $0.10 / kWh, that's $1,400 / year.**
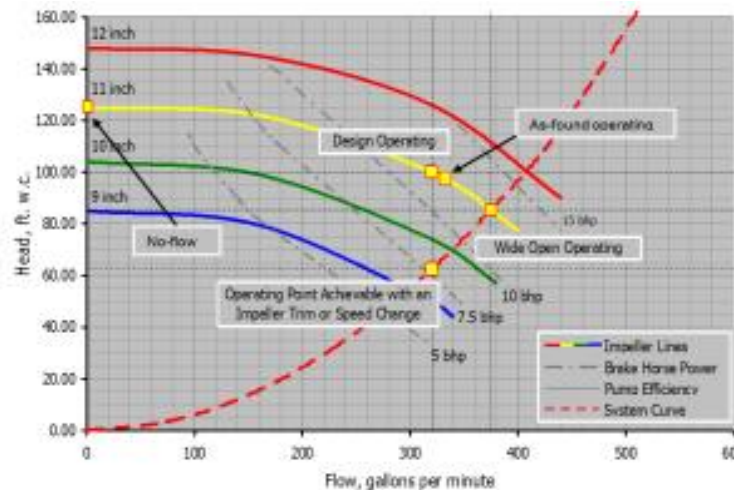
Reviewing Calculations

- **High level review (giggle / sniff test)**
    - ◆ **% reduction in equipment usage**
    - ◆ **% reduction in end-use usage**
        - ■ **Could use CBECS data for baseline end-use estimates**
    - ◆ **% reduction in whole building usage**

- **Detailed review**
    - ◆ **Adjust variables, observe effect on savings**
    - ◆ **Start at the final savings number and work backwards**
        - ■ **Review equations used**
        - ■ **Review inputs**

Planning

Investigation

Implementation

Hand-Off

Post-RCx

Implementation Phase Summary

- **Select measures for implementation**

- **Prepare implementation plan**

- **Implement measures**

- **Verify successful measure implementation**

Implementation Phase

Owner's considerations when selecting measures

- **Benefits**

- **Costs and available incentives**

- **Return on investment**

- **Work done in-house or by contractors?**

- **Timing (seasonal, budget, etc.)**

- **Drawbacks, risks**

Implementation Phase

Implementation plan topics

- **Team roles and responsibilities**
- **Schedule**
- **Key coordination points**
- **Verification plan**

Implementation Phase Schedule

	November, Year 1			December, Year 1			January, Year 2			February, Year 2			March, Year 2		
Contractor Walkthrough		■														
Contractor Bids Due			■	■												
Purchase Orders Due					■	■										
Implementation Begins							■	■	■	■	■					
Measurement and Verification											■	■				
Training and Turnover													■			
Owner's Review and Approval														■		
Provide Approved Documentation															■	

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Implementation Phase

Implementation approach options

- Turn-key installation
- Owner-led
- Owner-led with vendor assistance

Implementation Phase

Verify implementation

- **Site observations**

- **Spot measurements**

- **Diagnostic monitoring**

- **Functional performance testing**

Planning

Investigation

Implementation

Hand-Off

Post-RCx

Hand-Off Phase Summary

■ **Update documentation**

■ **Develop persistence strategies**

■ **Conduct training**

■ **Develop Final Report**

Hand-Off Phase

Update documentation

- **Drawings**

- **Controls sequences**

- **O&M manuals**

- **PM schedule**

- **CFR**

Hand-Off Phase

Develop persistence strategies

- **Track energy usage**

- **Track key system performance metrics**

- **Implement smart alarms in BAS**

- **Develop a re-commissioning plan**

- **Update PM program and service contracts**

- **Redefine responsibilities**

Hand-Off Phase

Persistence strategies do not need to be complicated

Finding	Measure	Ongoing Maintenance of Measure
Economizer control has been disabled for all four AHs.	Re-enable economizer control for all air handlers.	Check economizer operation once a month, as part of regular PMs. Economizer control should be enabled.
Both HHW pumps run 24/7 during the winter.	Shut off one of the two heating water pumps. Add HW pump enable points to the BAS.	Once a week as part of regular PMs, check to see that pumps are not operating in hand. They should be operating in 'auto', according to the sequence of operations. One pump at OATs> 52°F, two pumps at OATs<52°F.
Roof architectural lighting on 24/7	Connect rooftop lighting to BAS, implement schedule.	Once a month as part of regular PMs, check to see that rooftop lights are off during the day.

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Activity

Develop possible persistence strategies for:

- **HWST setpoint reset strategy**
  - **Baseline: Constant 180°F HWST setpoint.**
  - **Measure: Reset HWST setpoint based on OAT. 180°F at OATs<40°F, 120°F at OATs>70°F, linear in between.**

- **Lighting scheduling**
  - **Baseline: Lights are on continuously.**
  - **Measure: Lights are scheduled on at 6 am, off at 8 pm from central lighting control system.**

Your Turn!

Hand-Off Phase

Develop Systems Manual

- **Document for use by operating staff in day-to-day operations of building**

Development process:

- **Determine format**

- **Develop table of contents**

- **Compile documentation**

Hand-Off Phase

**Systems Manual
table of contents**

I.   Building Overview
     A. Building Description
     B. HVAC and lighting systems
     C. Building Automation System
II. Current Facility Requirements (CFR)
III. Mechanical Equipment Inventory
IV. Operating Instructions
       A. HVAC
       B. Lighting
       C. Building automation system
V.   Troubleshooting Instructions
VI.   Ongoing Optimization Guidance
VII. Equipment Manufacturers
VIII. Control As-Builts & Sequences of Operations
       A. Control Drawings
       B. Sequences of Operation
       C. Product literature

Hand-Off Phase

Conduct training

- **Informal**
- **Formal**

Topics to discuss:

- **Details of implemented FIMs**
- **Persistence strategies**
- **Updated documentation**
- **Hands-on training can be most effective.**
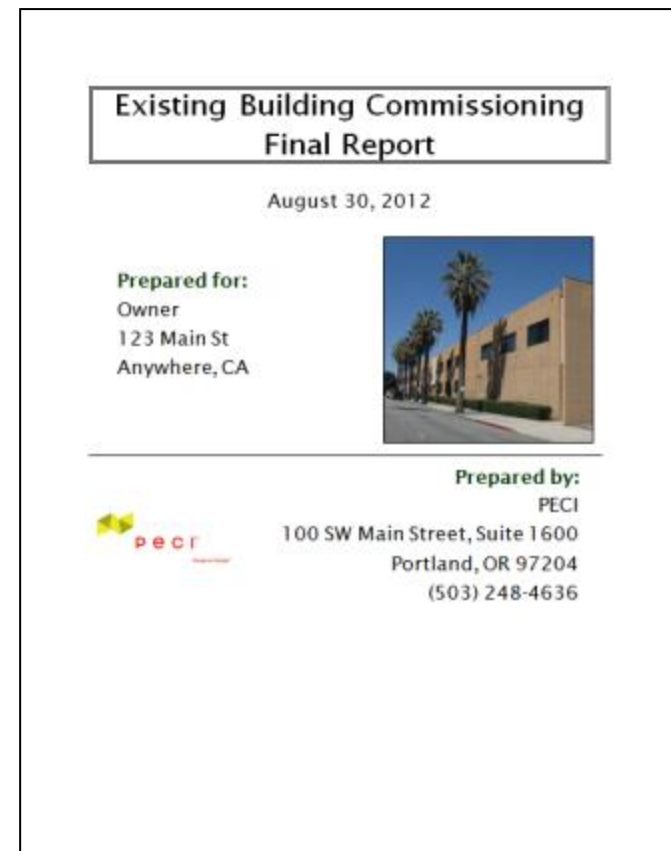
Hand-Off Phase

Document the training

- **Systems Manual**
- **Handouts**
- **Consider recording video**

Hand-Off Phase

Final Report purpose:

- **Record of EBCx activities**
- **Resource for current and future operators**

Hand-Off Phase

Final Report table of contents

I.   Executive Summary

II.   Current Facility Requirements

III.   Master List of Findings

IV.   Implemented Facility Improvement Measures

IV.   Final Savings Estimates and Implementation Costs

V.   Diagnostic Monitoring Plan and Results

VI.   Functional Test Forms and Results

VI. Updated Building Documentation

VII. Recommendations for Maintaining New Improvements

VIII. Training Summary and Training Materials

Develop In-House Resources

- **Planning phase walk-through checklist**
- **Measurement and monitoring tools**
- **Findings identified on past projects, by system type**
- **Findings to look for on future projects**
- **Common engineering formulas and conversions**

| η_{VFD} loss | η_{motor} loss | η_{belt} loss | $\eta_{fan\ or\ pump}$ loss | |

HP-INPUT — VFD — MOTOR — DRIVE — FAN/PUMP — HP-OUTPUT FLUID WORK

(kW input)

$BHP_{fan\ or\ pump}$

Electric losses in the motor.

Drive losses from belts, sheaves, transmissions, electrical or mechanical. For direct coupled motors, this factor is 1.0

Mechanical efficiency is less than 1. Loss goes to heat in the fluid.

Remaining power is for actual fluid work, but upstream energy input is higher.

Develop In-House Resources

For custom spreadsheet savings calculations:

- Spreadsheets developed for past projects
- Template spreadsheets for use on future projects
- Development checklist
- Review checklist

Network directory with useful:

- Studies, guides, handbooks, articles, presentations
- Photos and screenshots from past projects
- Functional performance test forms
- Software tools
- Screenshots

PECI Training Program 104 Online Lessons

Commissioning Authority Training

– Fundamentals of Commissioning

– Commissioning Systems & Equipment

– Systems Performance & Analysis

Commissioning Authority Training

+ Fundamentals of Commissioning

– Commissioning Systems & Equipment

  + Facility Envelope Components

  + Facility Operating Requirements

  + Facility Energy Considerations

  + Intro to MEP Systems and Equipment

  + MEP- AHU

  + Cooling Equipment

  + Combustion and Boilers

  + Chilled Water Systems

  + Hot Water & Steam Heating

  + Domestic Hot Water Systems

  – Electrical Systems and Equipment

    Electrical Drawings and Documents

    Electrical Distribution Systems 1

    Electrical Distribution Systems 2

    Lighting Systems

    Lighting Controls

    Renewable Energy Systems

  + Control Systems Fundamentals

  + Control Systems

+ Systems Performance & Analysis

http://learn.peci.org/

PECI Training Program One Week Lab

10 real-world exercises, including:

◆ Energy use analysis

◆ Design review

◆ BAS trend data analysis

◆ BAS sensor location and calibration verification

◆ Functional performance test development and observation

◆ Pump performance analysis

◆ Cx Progress Report development

http://learn.peci.org/
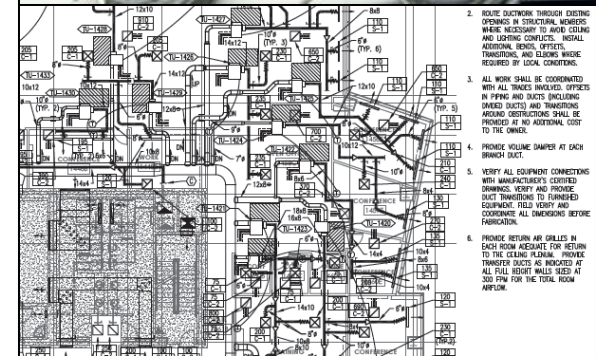
Questions / Discussion

Thank you!

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