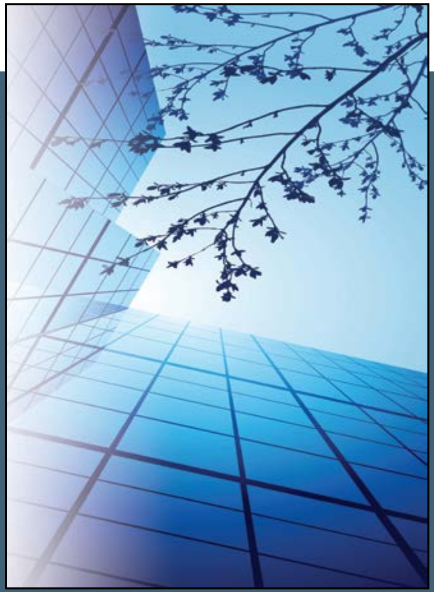


Recommissioning Workshop

September 11, 2013

Dave Moser, PE

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 Minnesota
- 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 $0.045/kWh (whichever is higher) plus $5/Dth
    - Rebates available for measures with paybacks 9 months – 15 years
- Program covers both re- and retro-commissioning

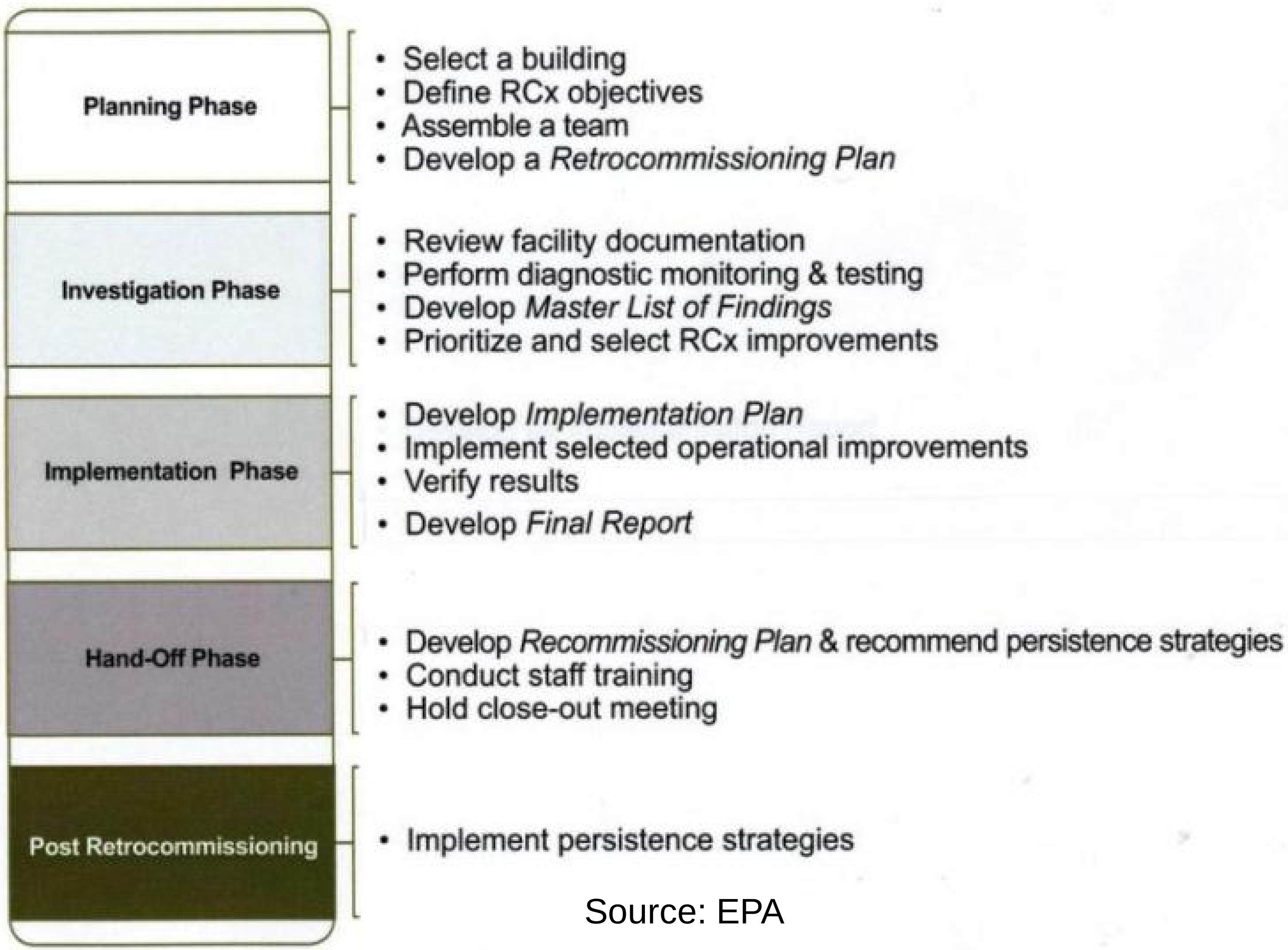
Process Overview

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 Implementation is completed**
6. **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

EBCx Process



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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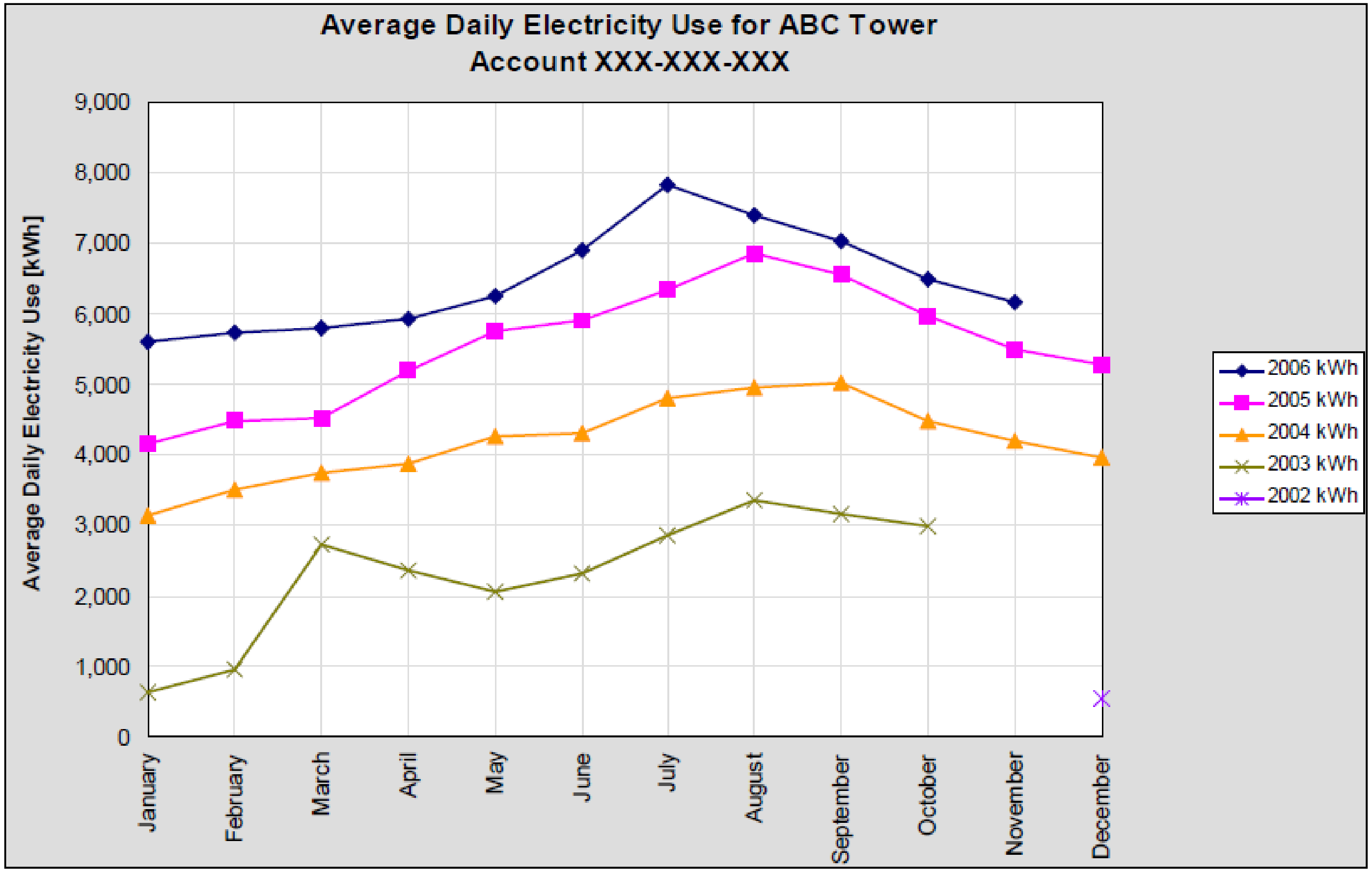
- Develop current facility requirements
- Develop *EBCx Plan*

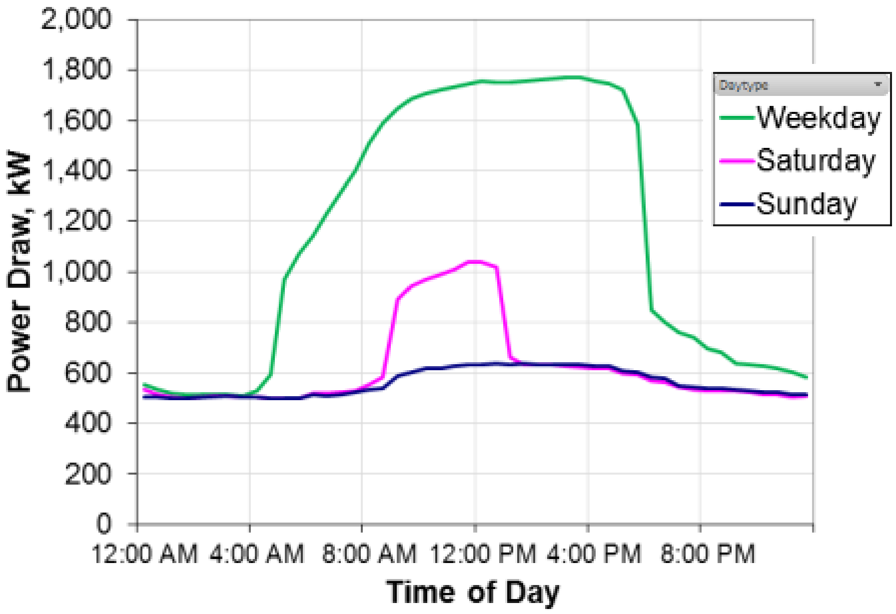
Analyze Monthly Utility Data



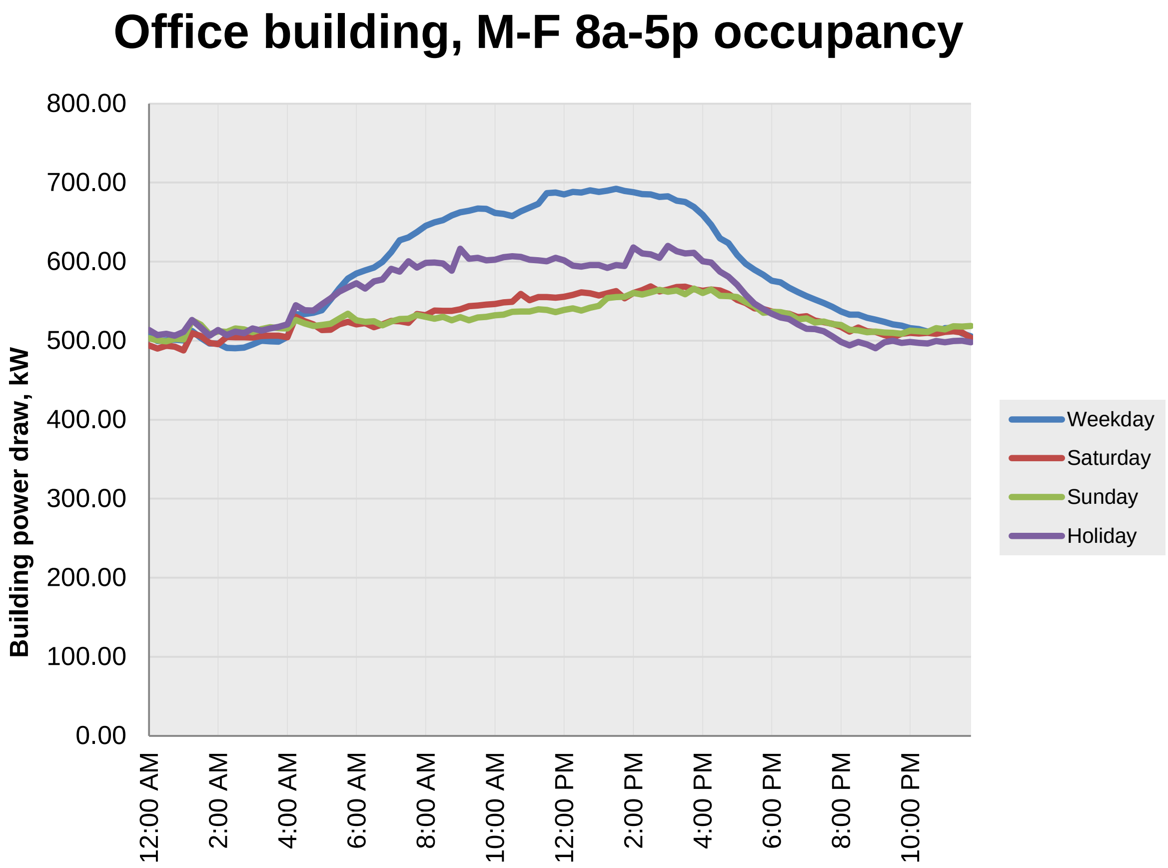
More Useful Utility Data

- Interval utility data
  - Identify base load during unoccupied periods
  - Identify operational problems

‘Good’ office profile:



What does this chart tell us?



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

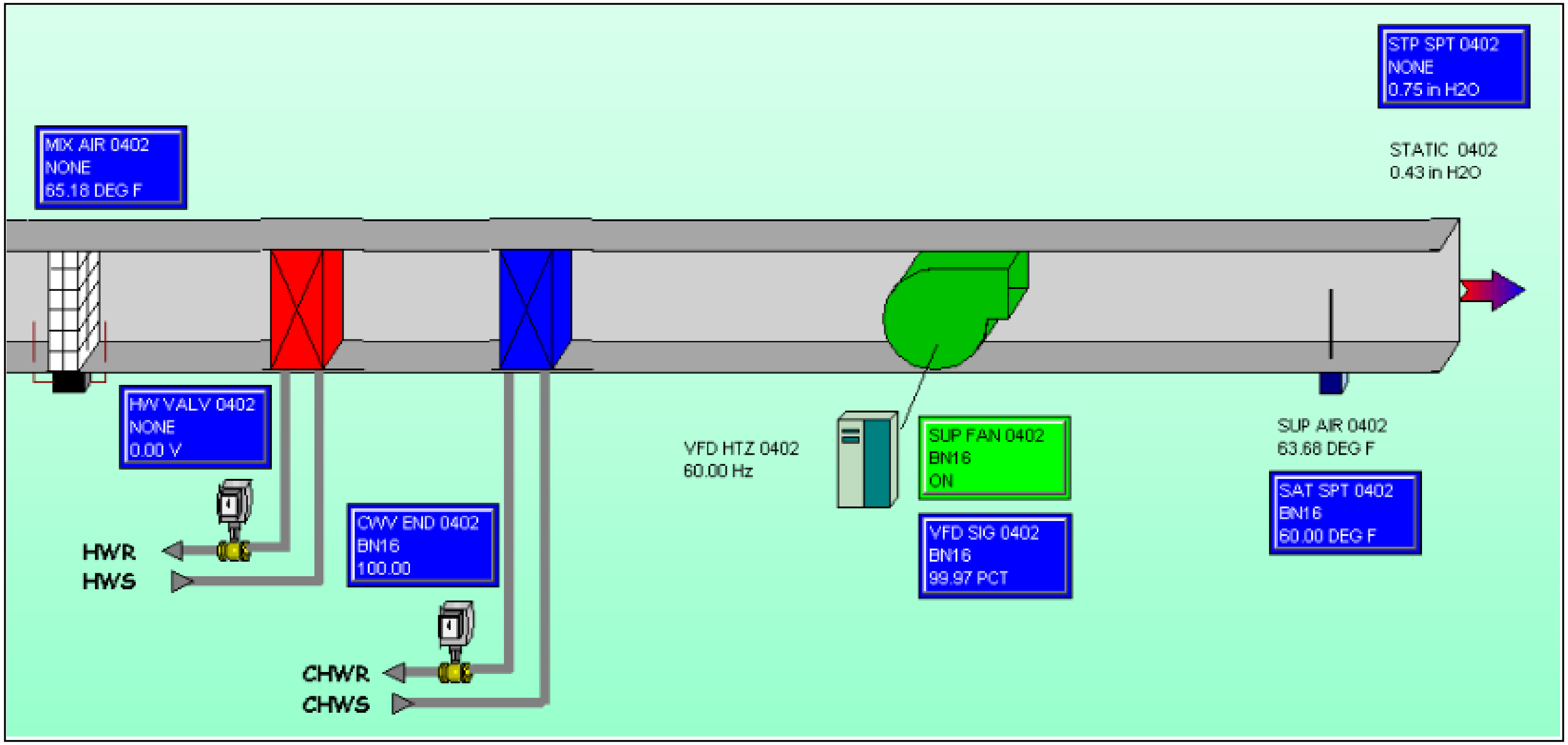
Look for optimization opportunities.

Keep the EBCx goals in mind!

Building Walk-Through: HVAC

Your Turn!

Building Walk-Through: BAS



Your Turn!

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 = Current Facility Requirements

- **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:

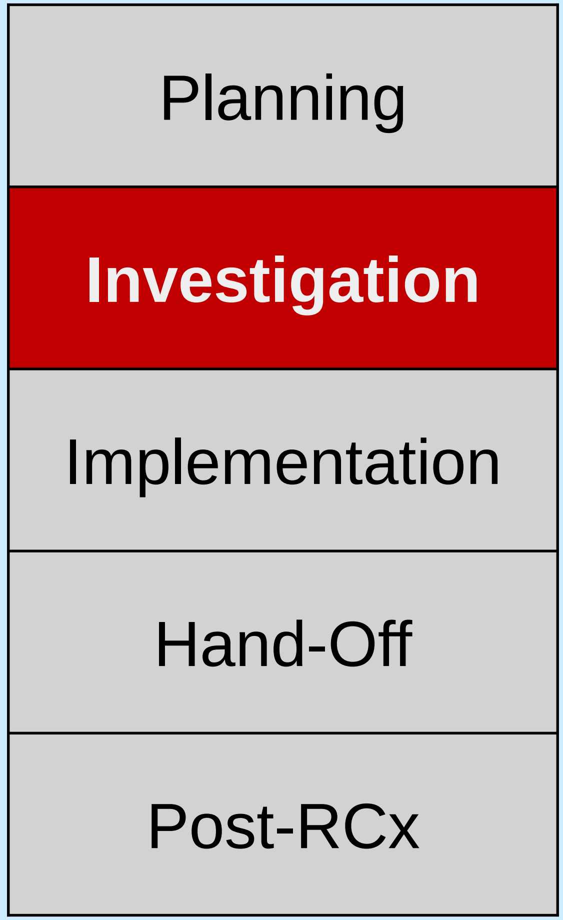
System / Aspect	CFR Items
Lighting	
Occupant comfort	
Sustainability	

Your Turn!

Planning Phase Main Tasks

- ____
- ____
- ____
- ____
- ____
- ____
- ____
- ____

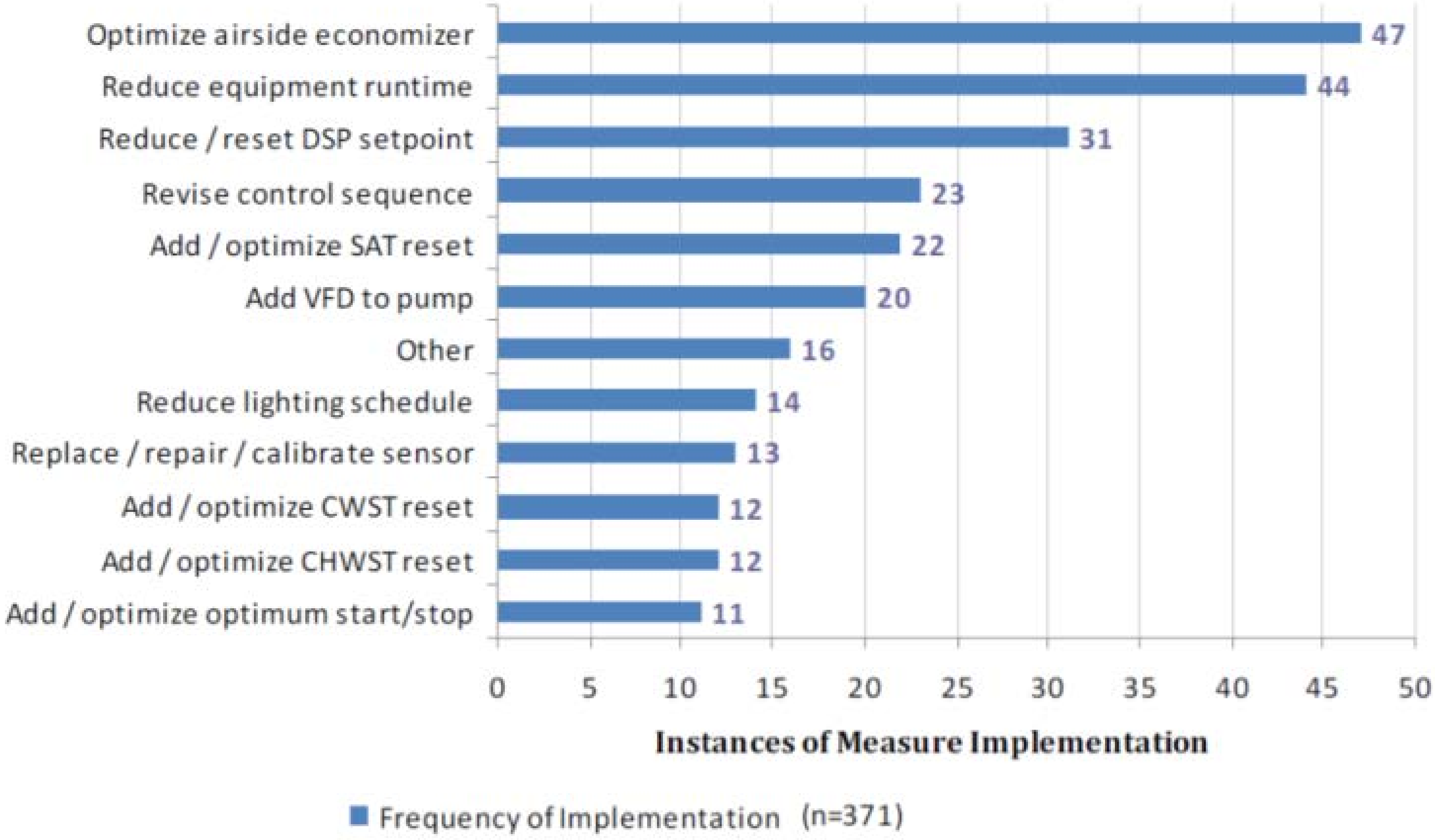
Your Turn!


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



122 EBCx projects, most in CA.

Source: PECI, 2009

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
- Chiller Optimization

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

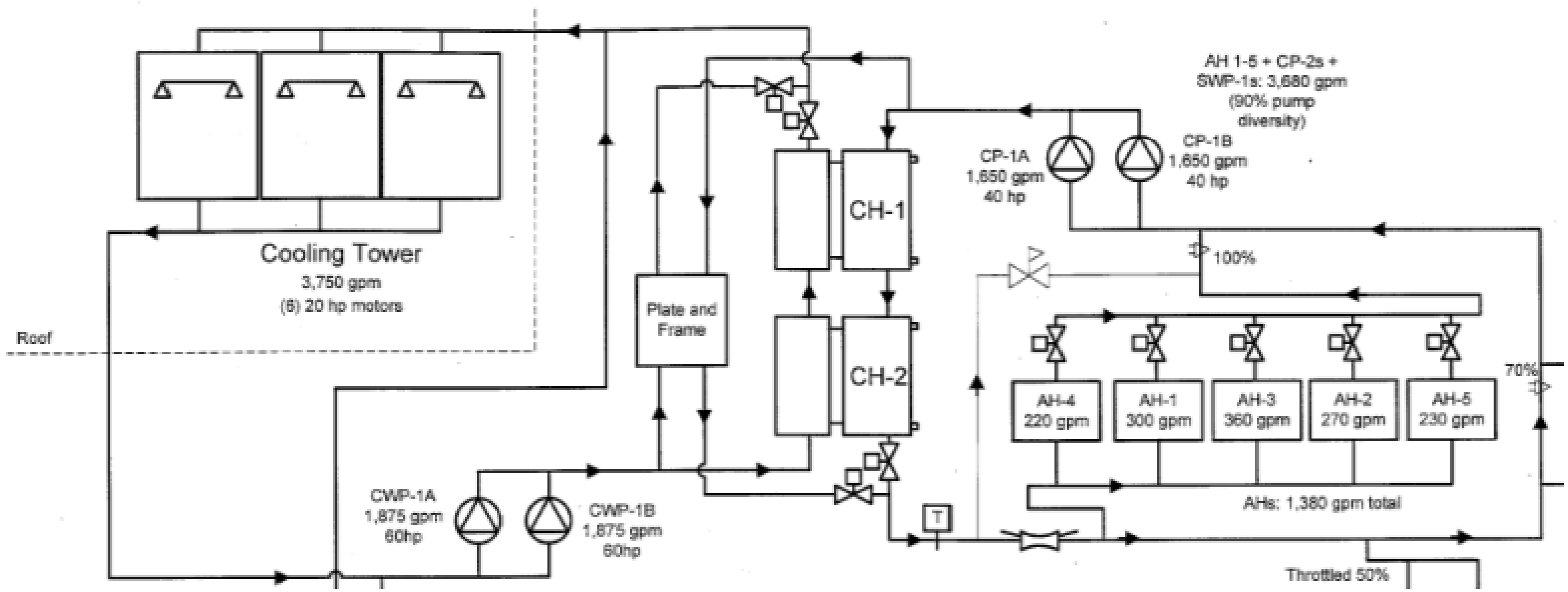
When the unit is off, the outside air damper, two discharged air dampers, two return air dampers, and the exhaust fan's discharge damper will be closed. The HV-1 supply fan remains off. The exhaust fans E-1 will be interlocked with the supply fan and remain off

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

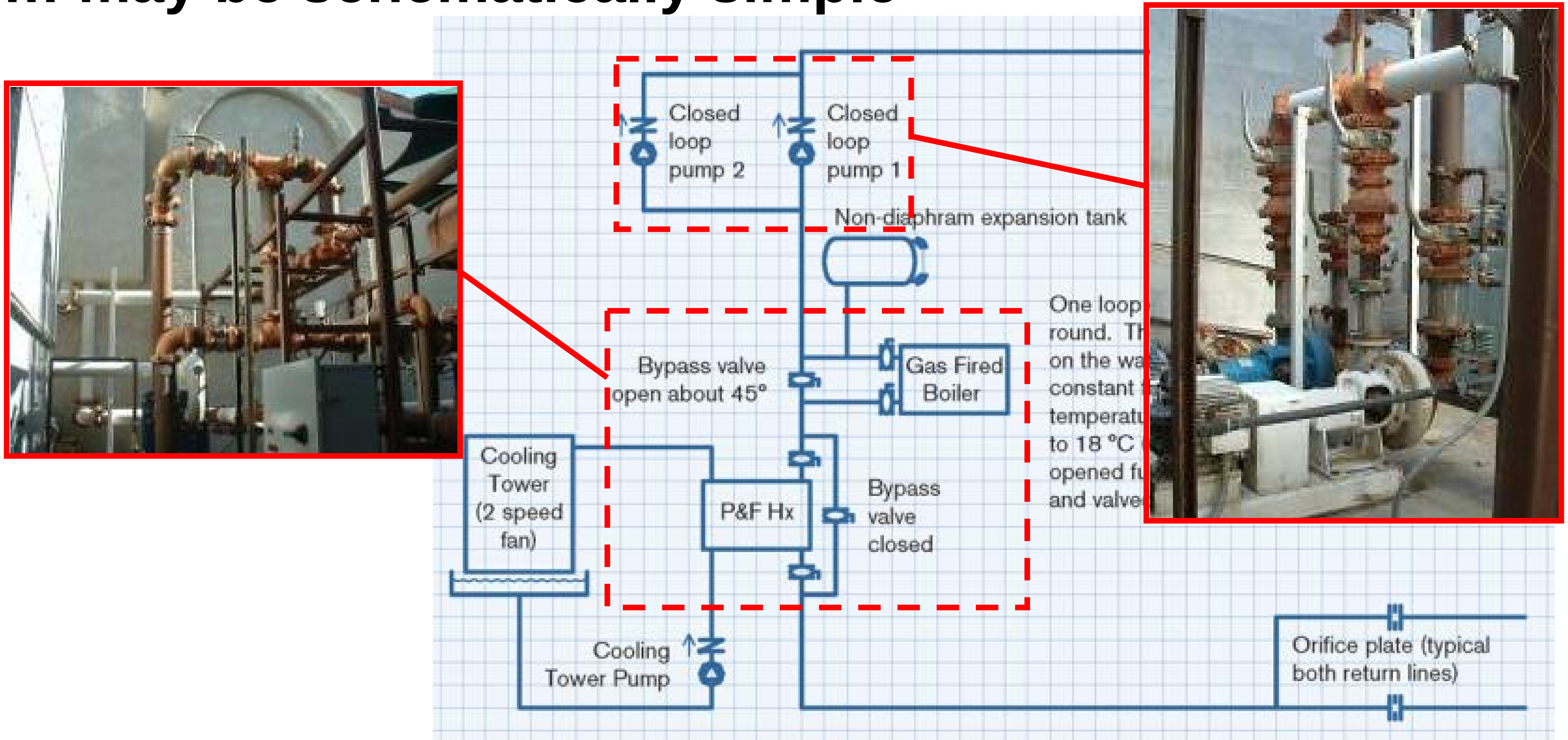


System Diagrams

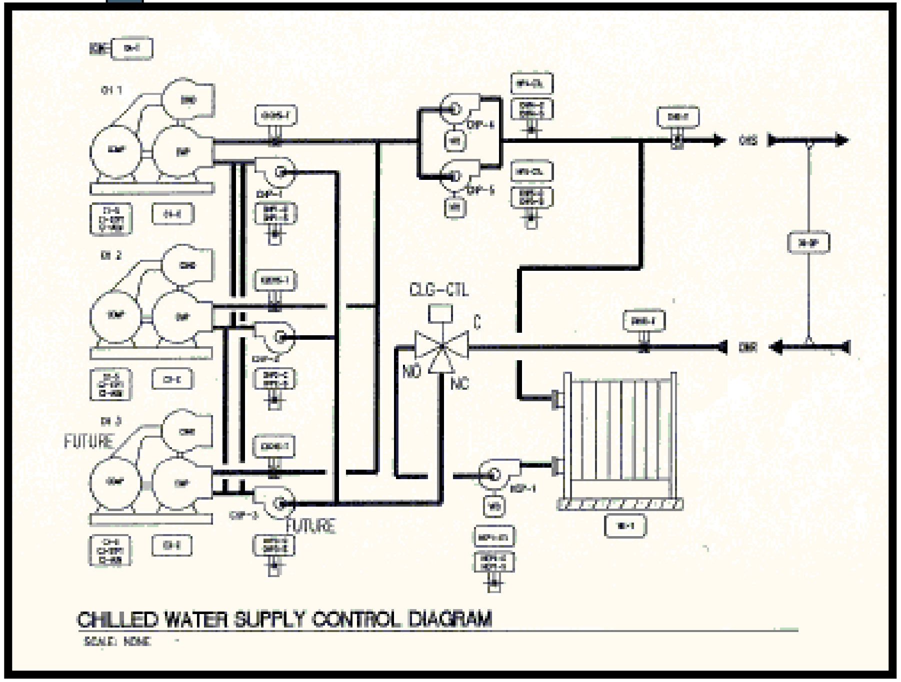
- Keep it simple (untangled)
- Include all components that can affect flow rate or path
- Pay attention to the order of connection

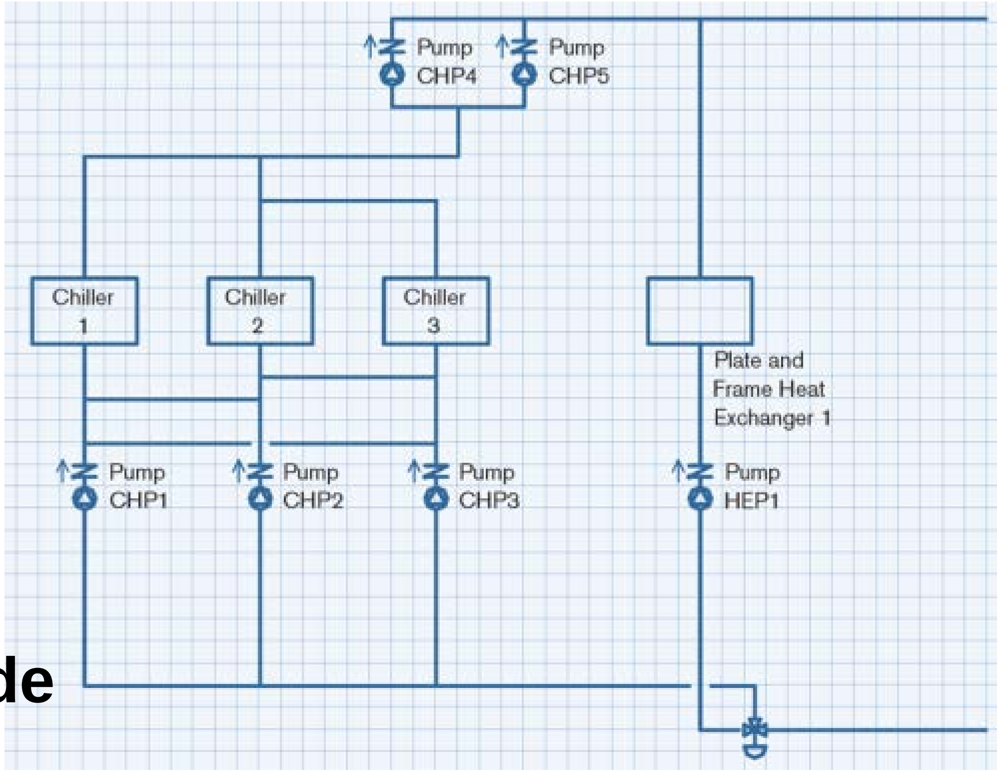
What appears complex …

… may be schematically simple



Tangled Vs. Untangled

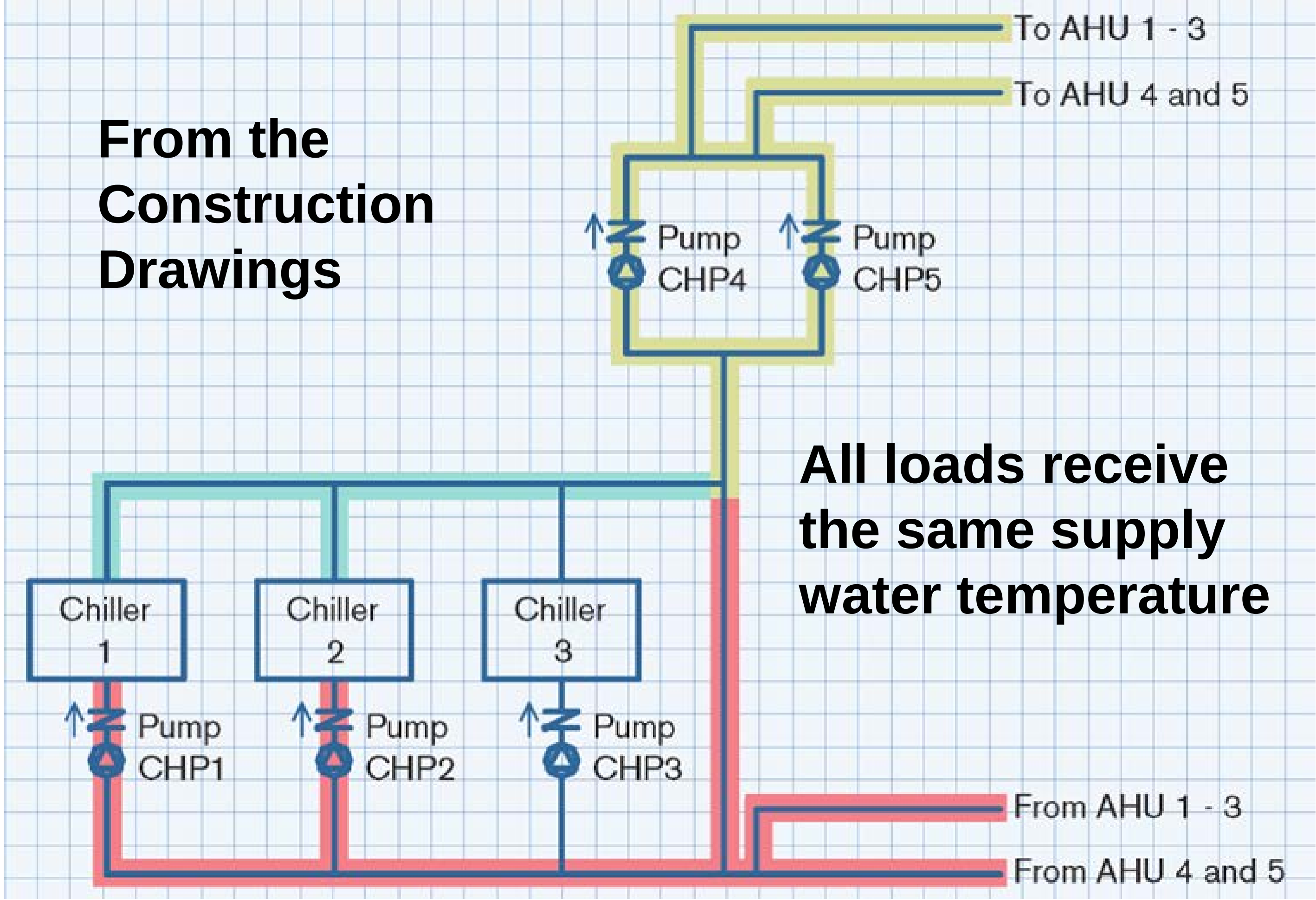




- **Minimize line crossings**
- **Elbows don't matter**
- **Looks like ladder on its side**

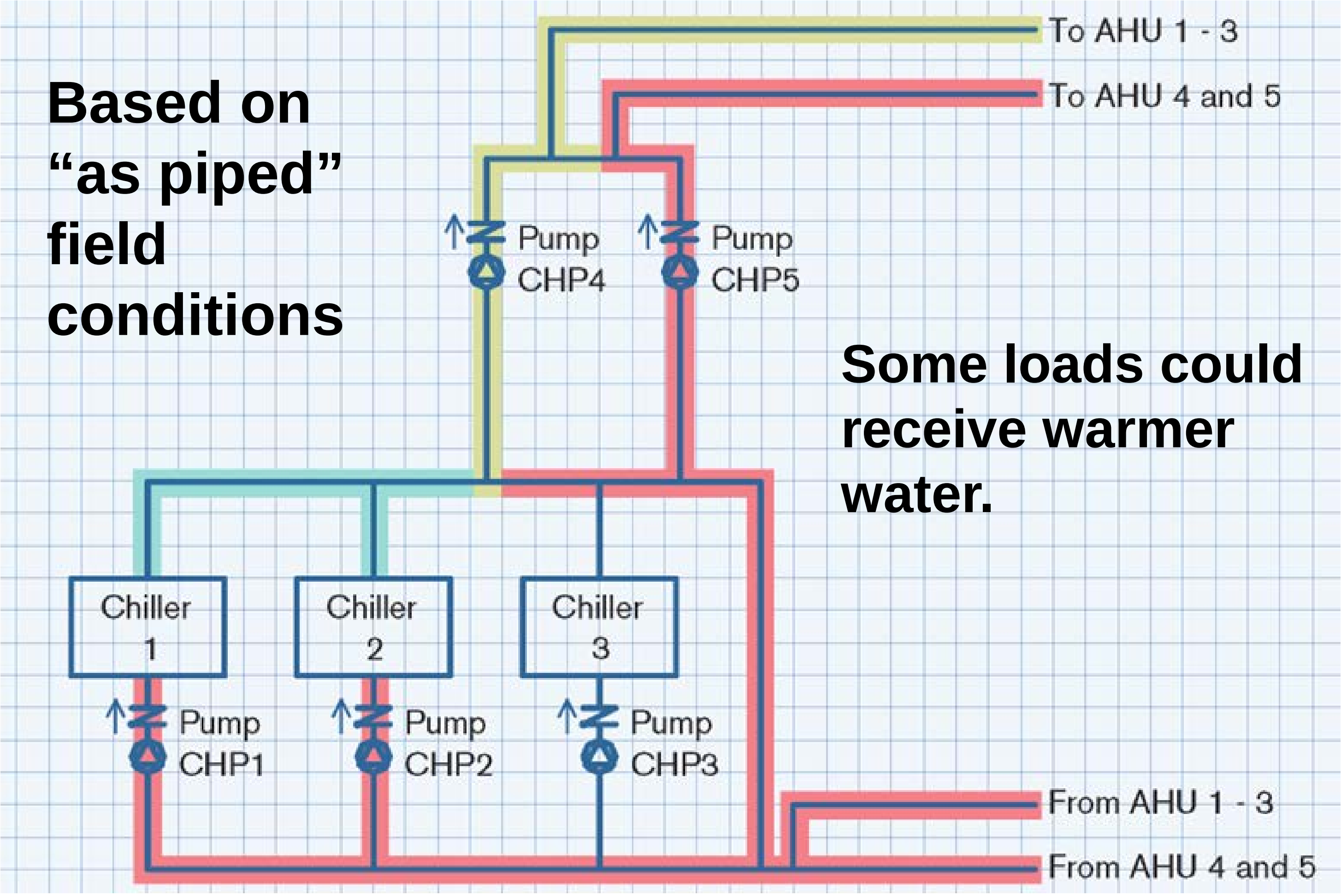
Order of Connection Matters

From the Construction Drawings



All loads receive the same supply water temperature

Order of Connection Matters

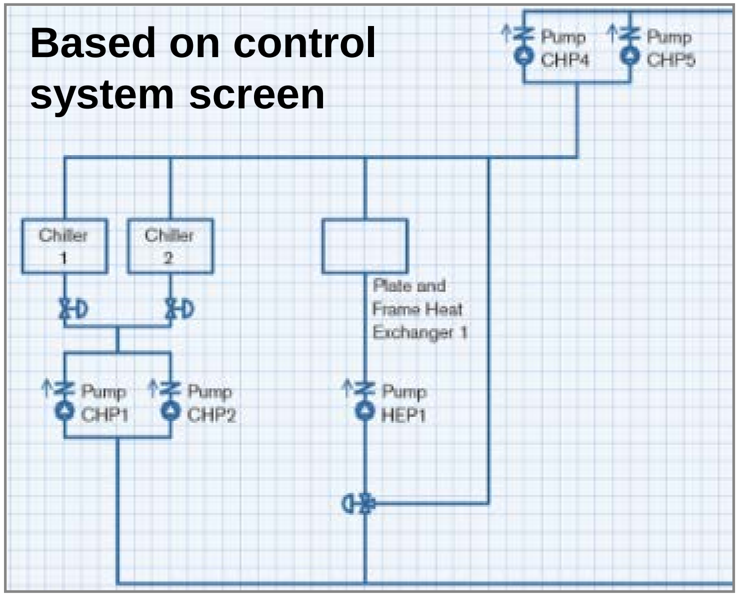


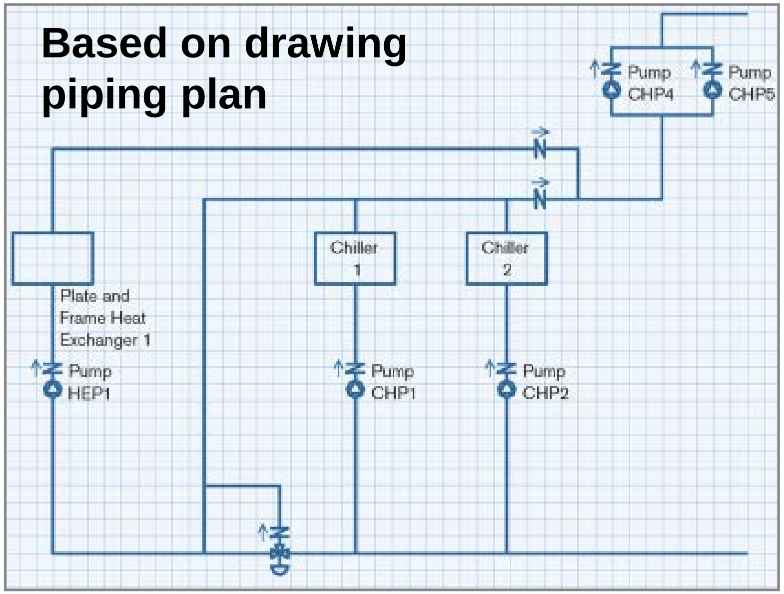
Based on "as piped" field conditions

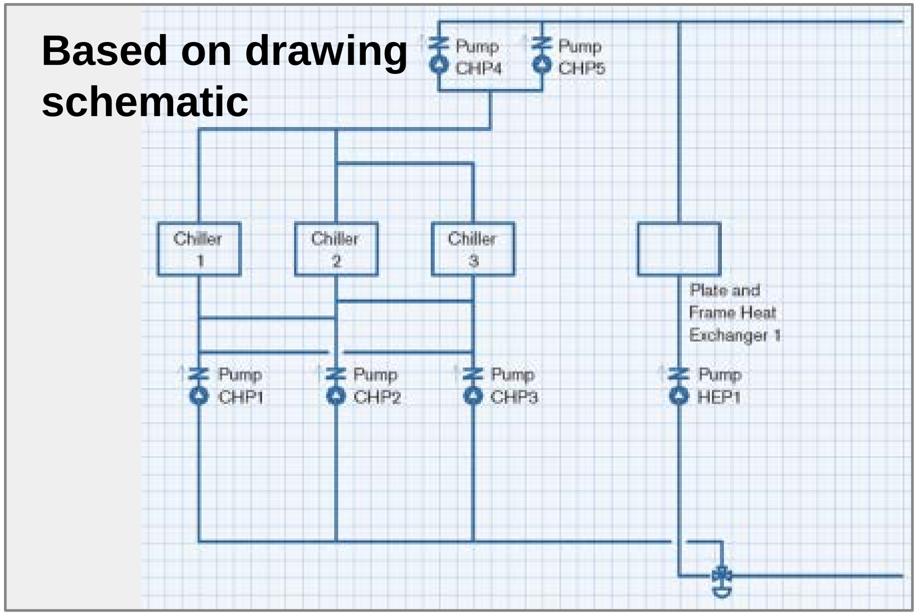
Some loads could receive warmer water.

Same Project, Same System, Three Different Diagrams

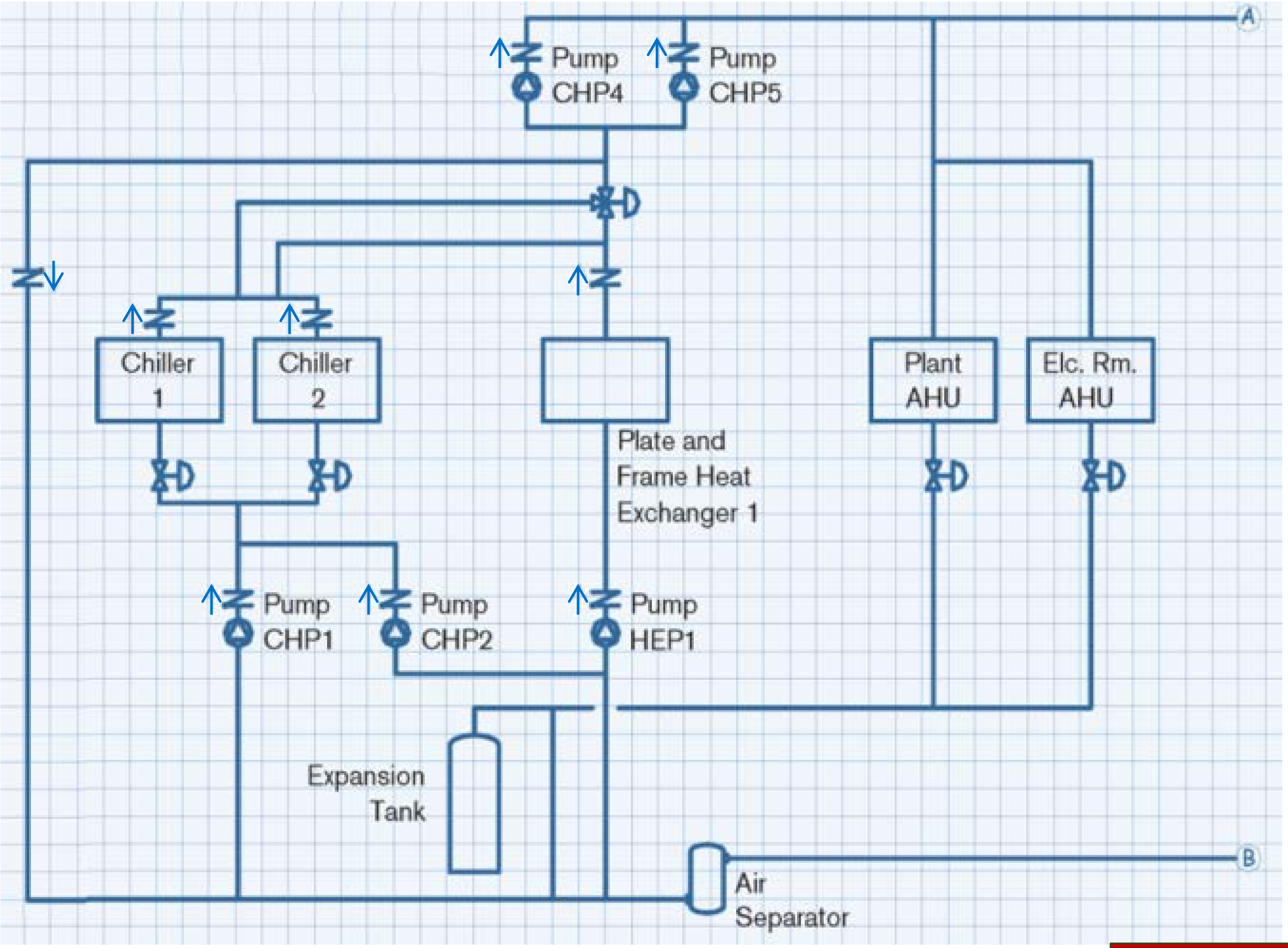
Which one represents what was actually installed?







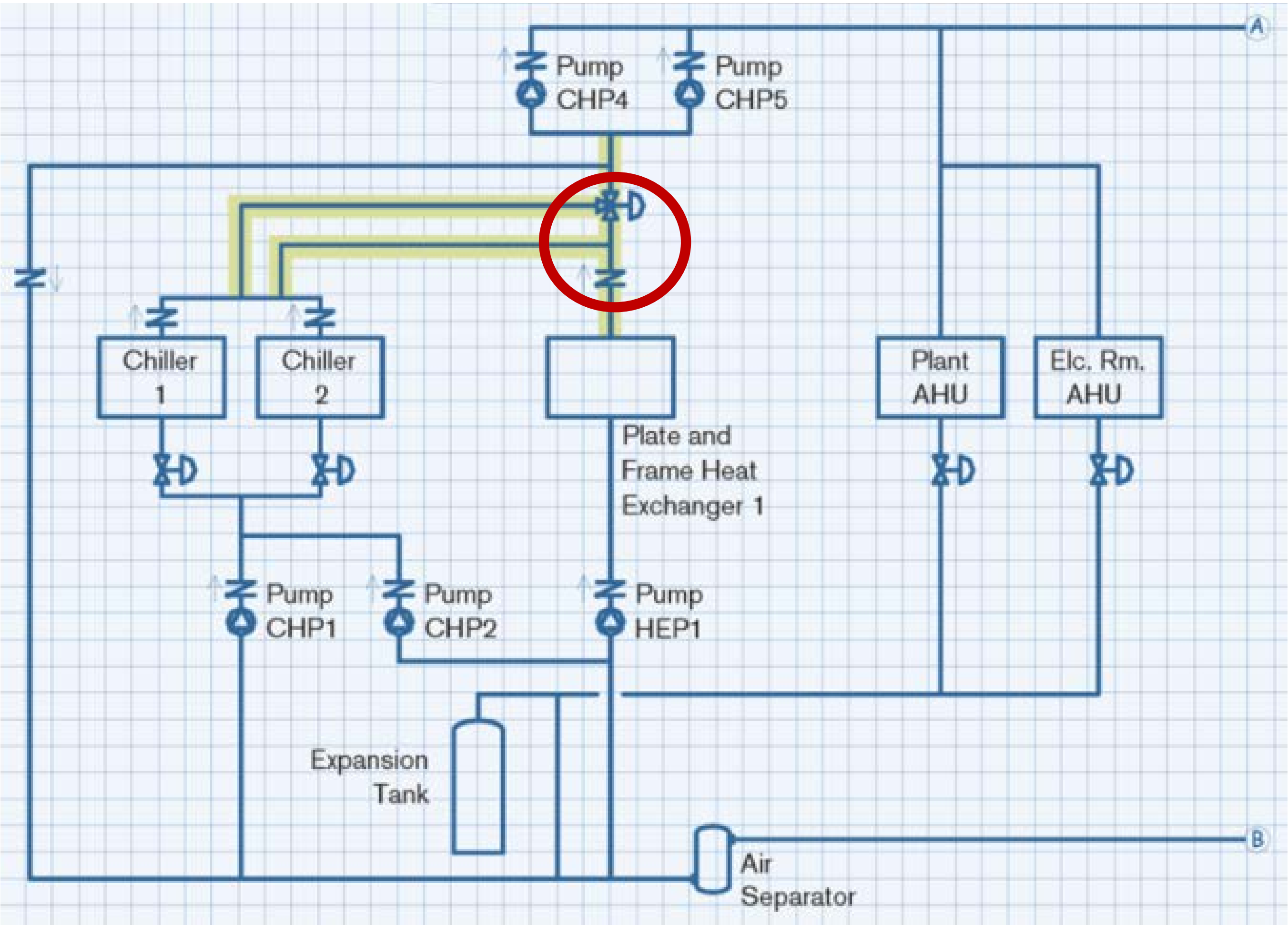
None of Them! What are the findings?



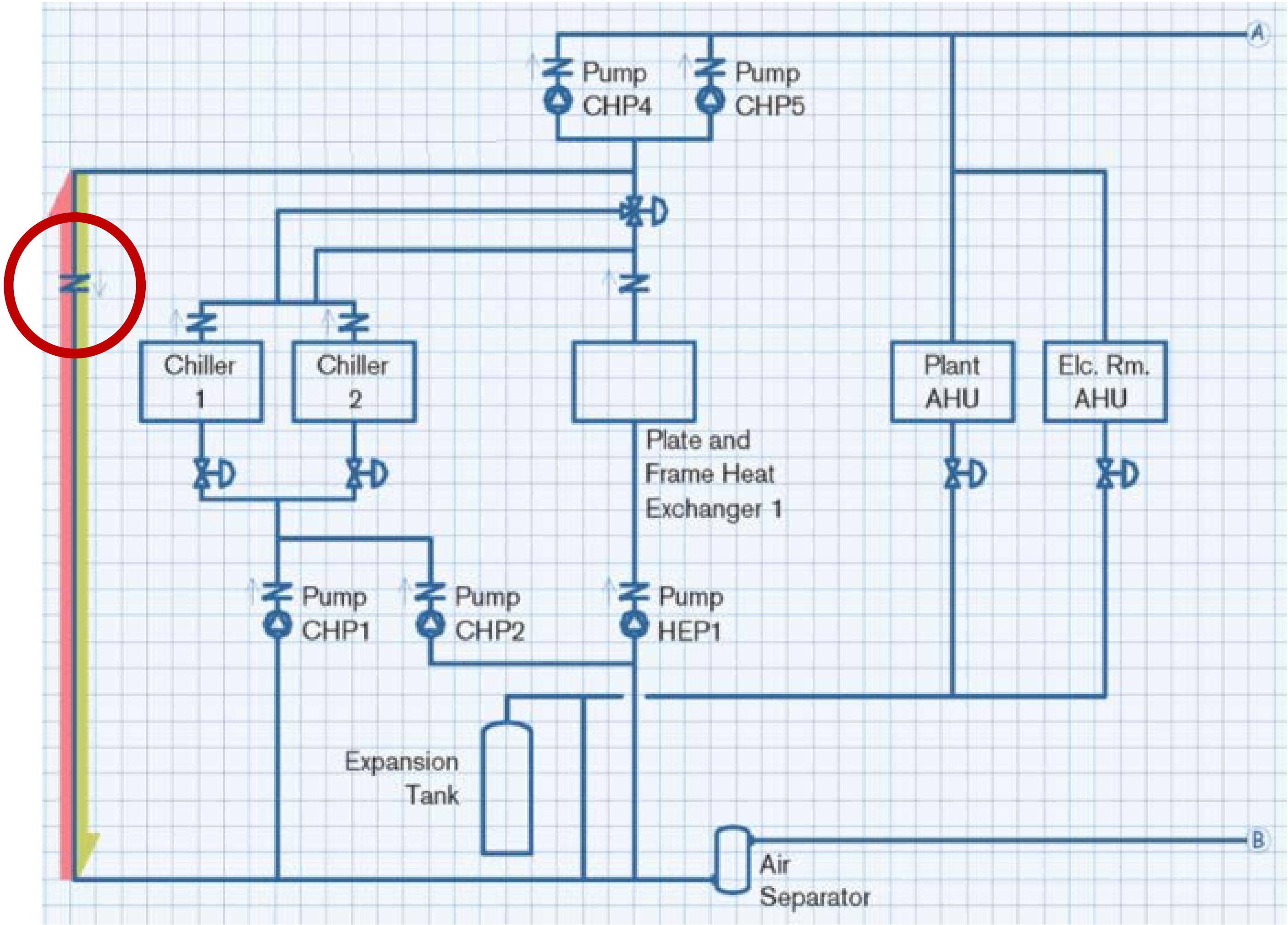
Your Turn!

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	Acceptible Levels			Spot Measurements			Acceptible? Y/N		
Sample Building	CO_2 Levels (PPM)	Temperature (ºF)	Humidity (% Relative Humidity)	CO_2 Levels (PPM)	Temperature (ºF)	Humidity (% Relative Humidity)	CO_2 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?

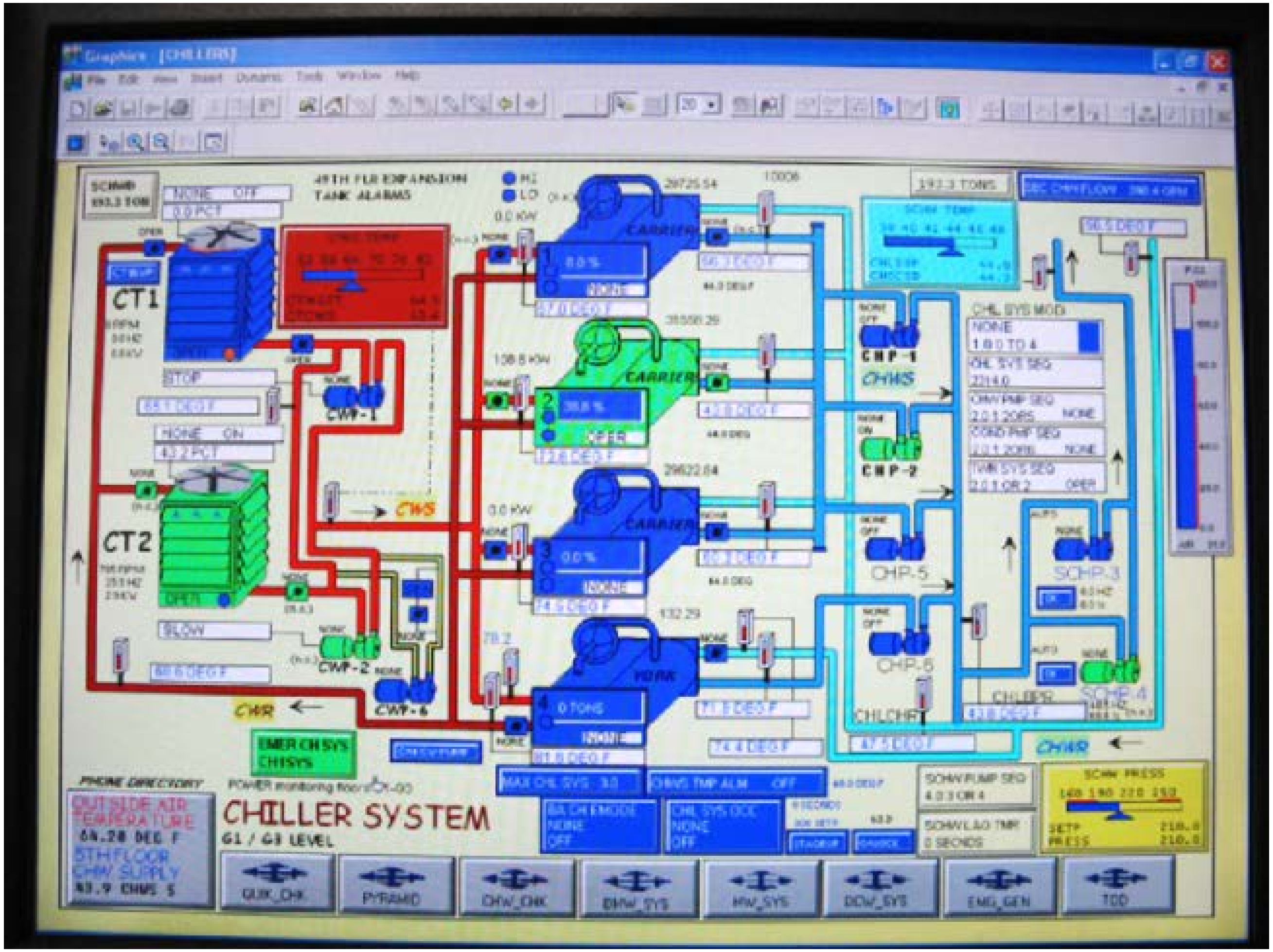
Your Turn!

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**

Investigation

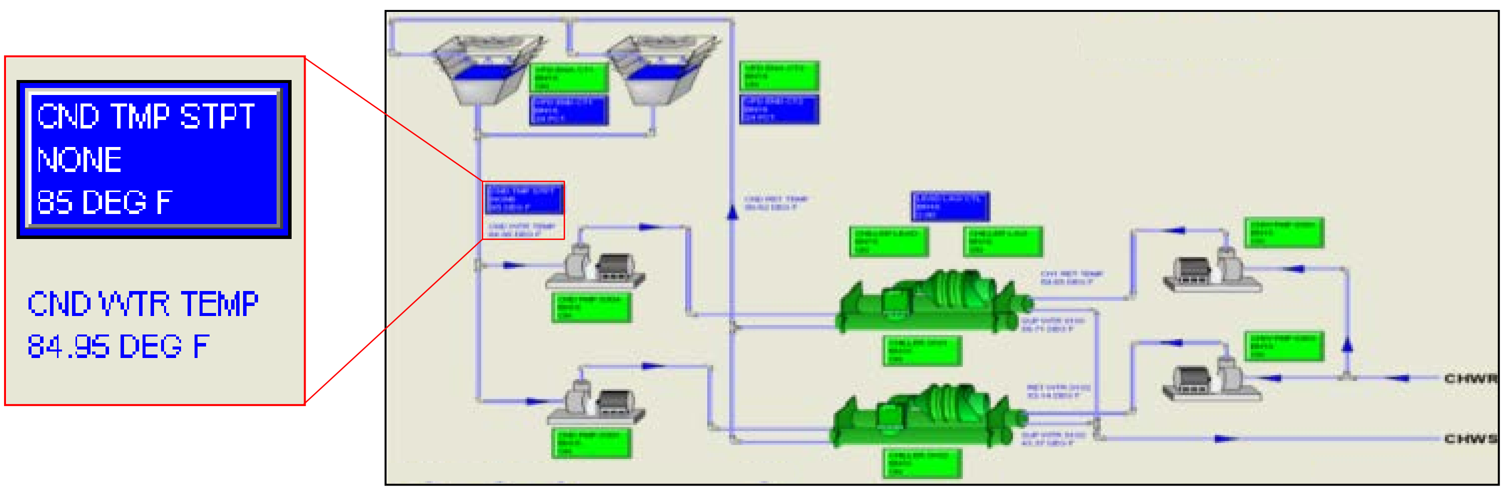
BAS GUI Review



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.**

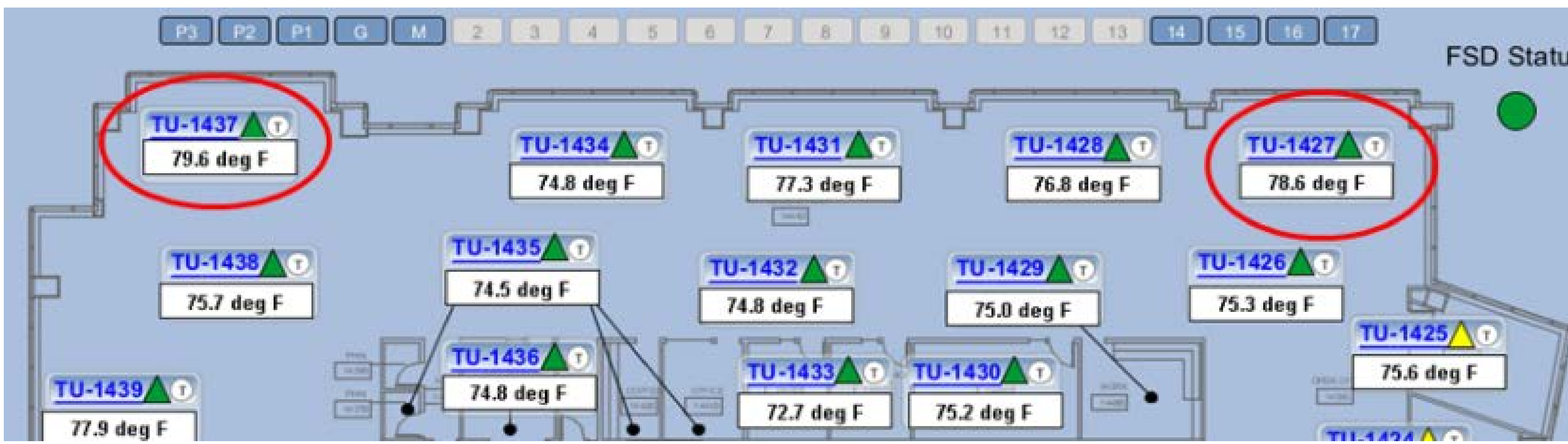
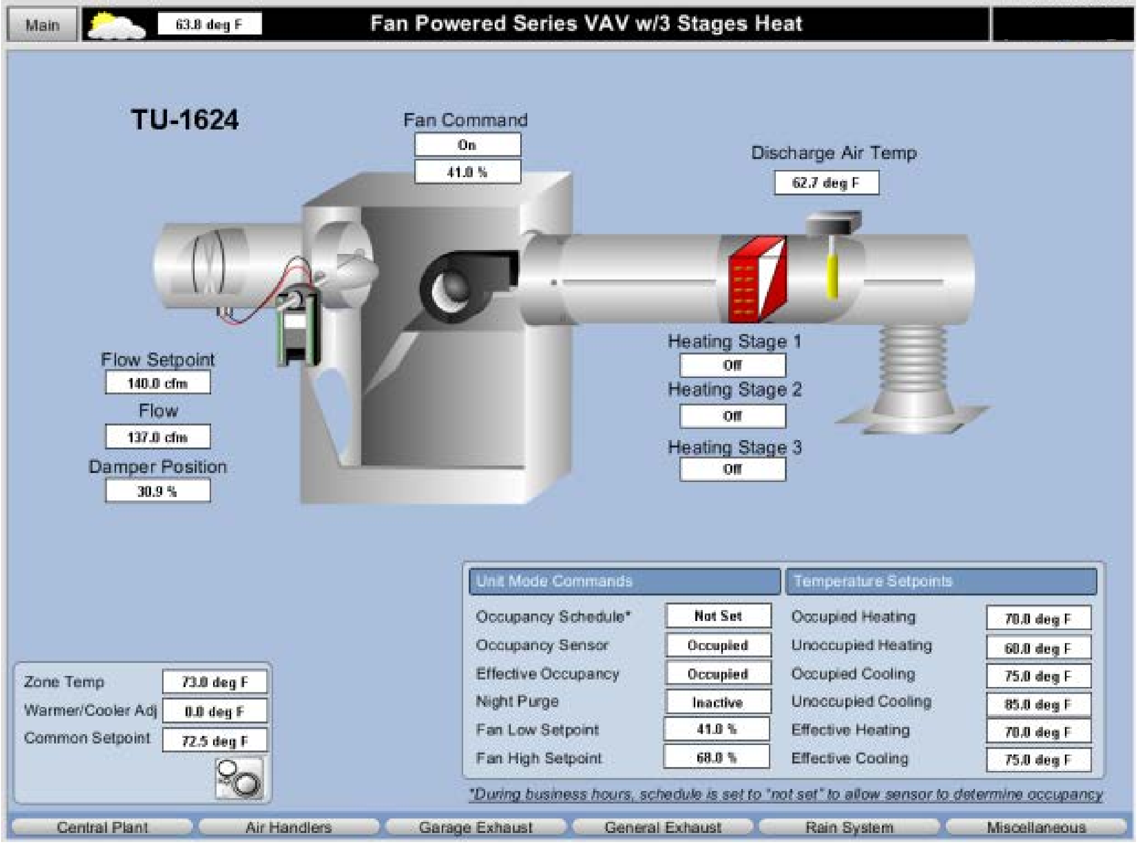


Photo: PECI

BAS GUI Review

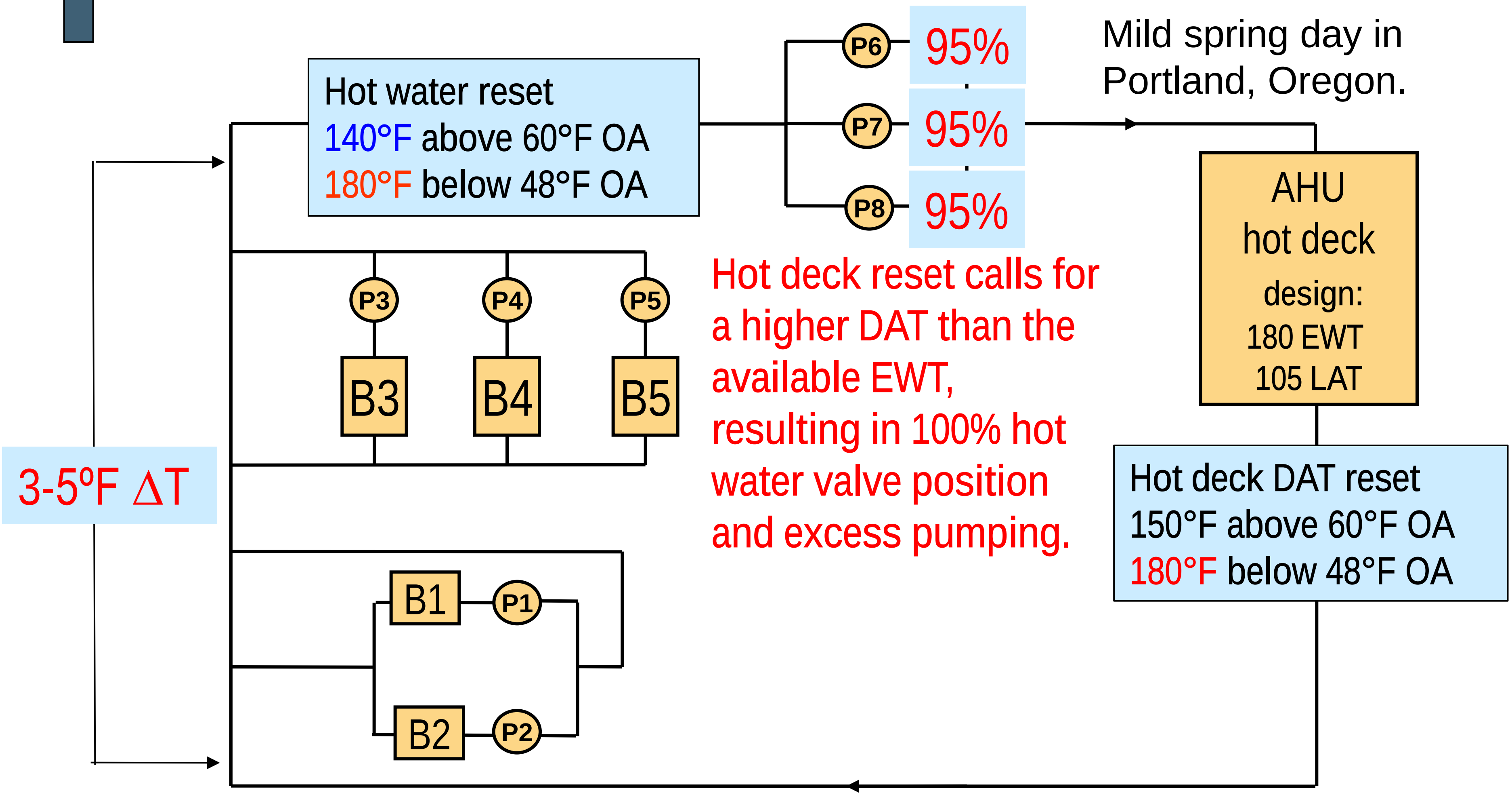
- **Is the system operating as expected?**



Investigate where operation doesn't make sense

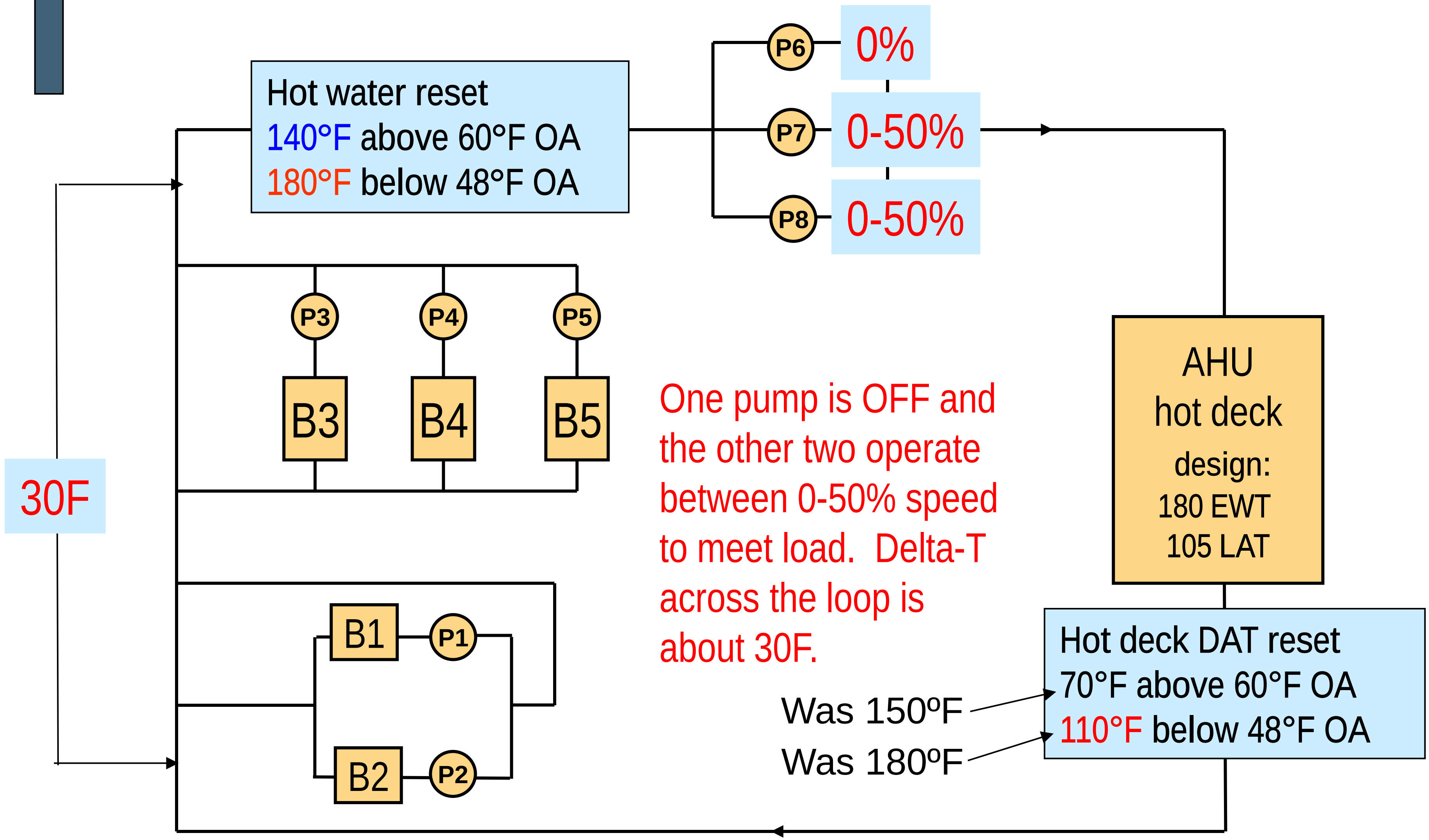
4 pm, west facing, gobs of daylight coming in:

What is wrong with this picture?



Your Turn!

Proper operation



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

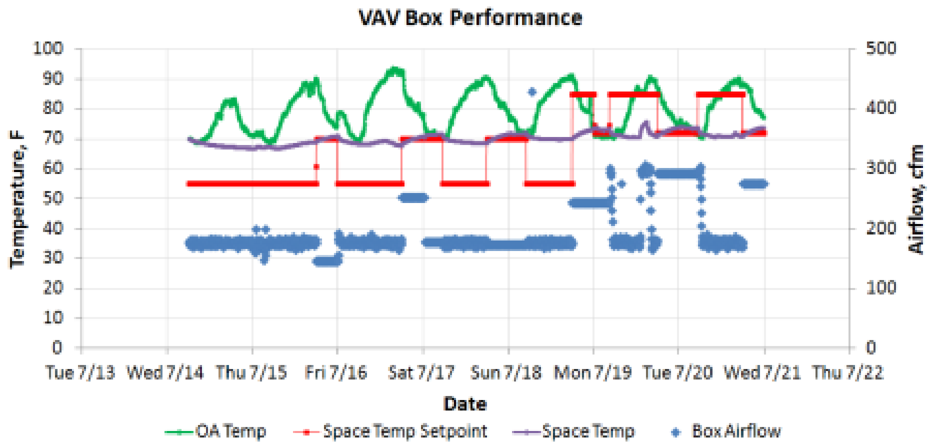
Controls Reset Findings

- 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

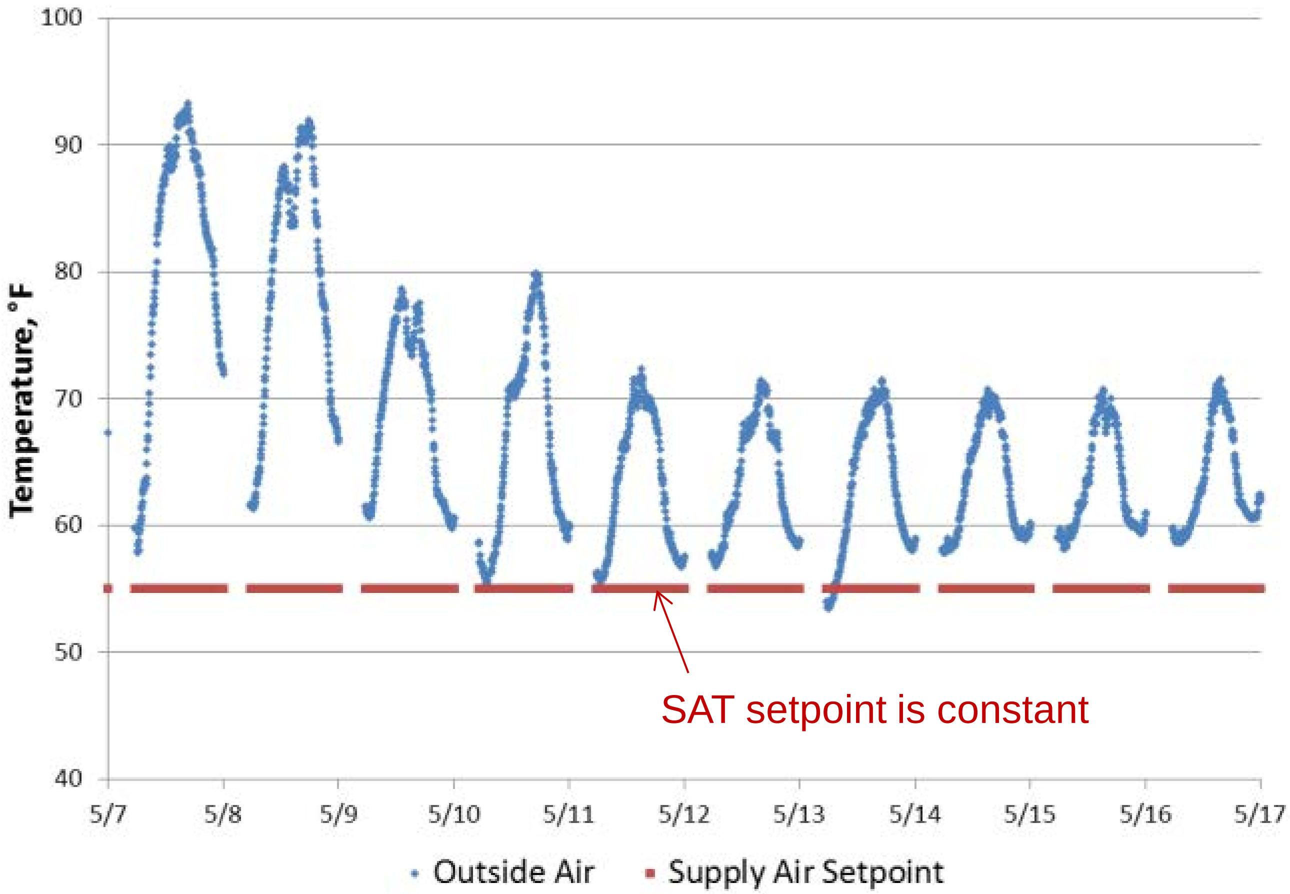
Diagnostic Monitoring

Process:

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

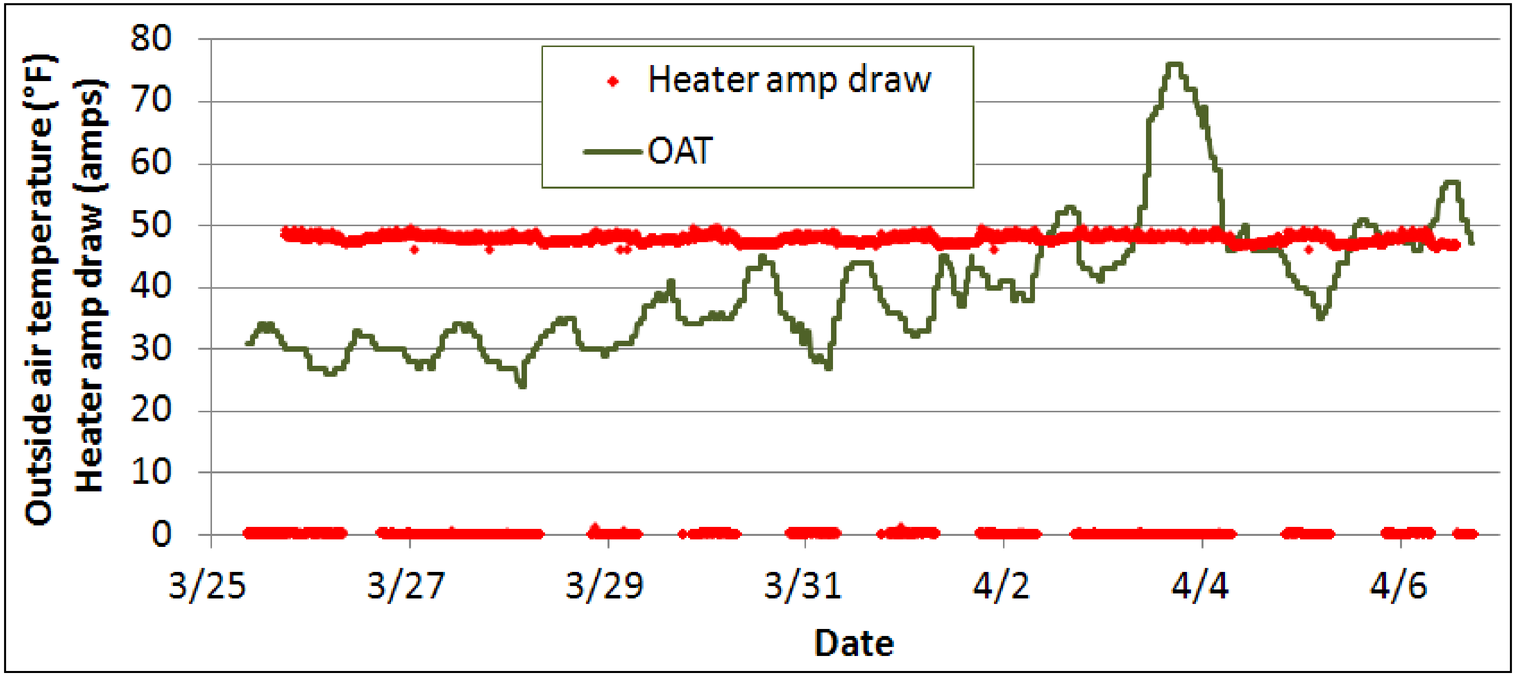


Diagnostic Monitoring
Using BAS trends to identify issues



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

Light on/off, occupancy

Amp draw

On/off w/ readout

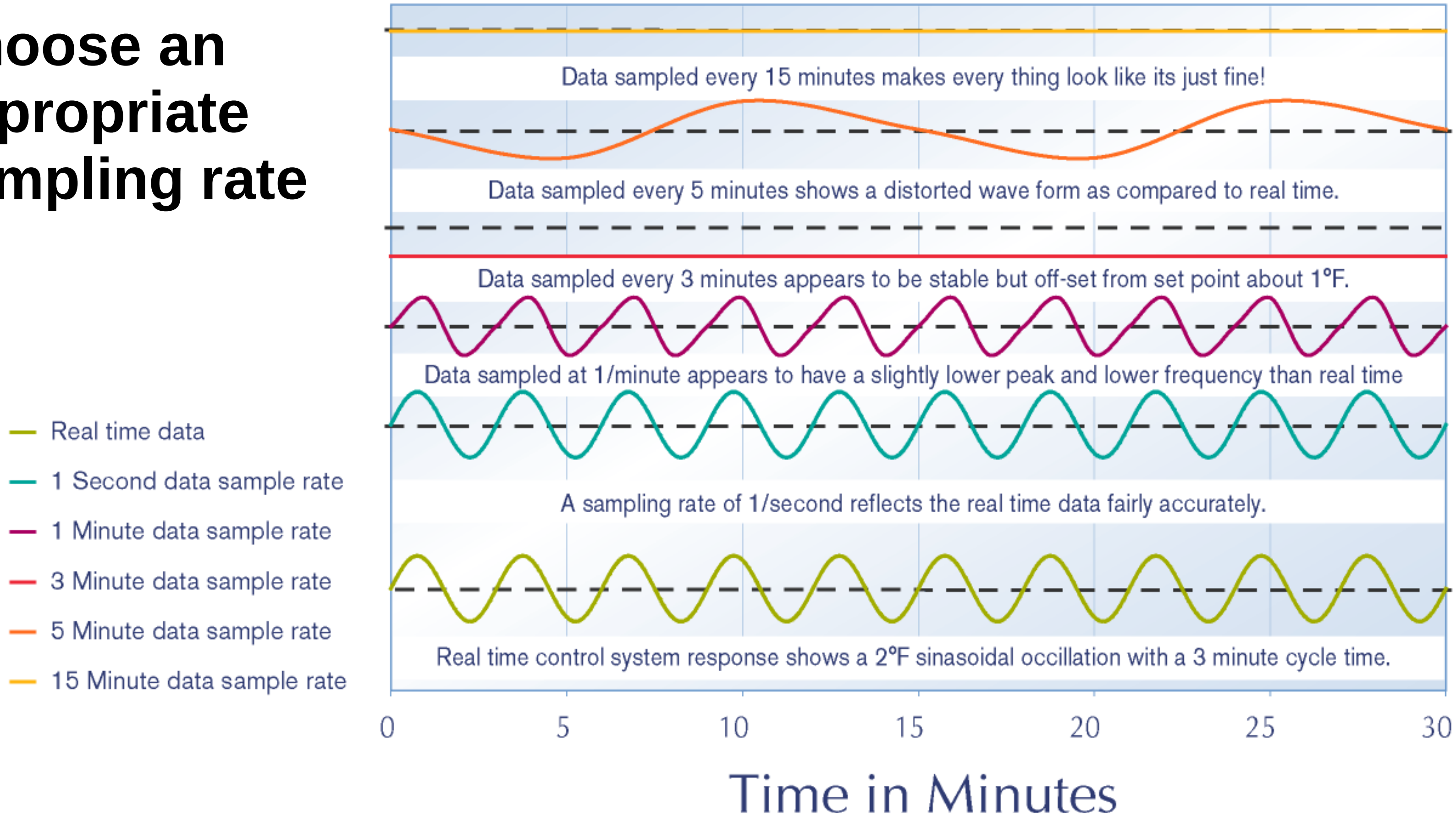
Carbon monoxide

Carbon dioxide

Light on/off, motor on/off

Diagnostic Monitoring

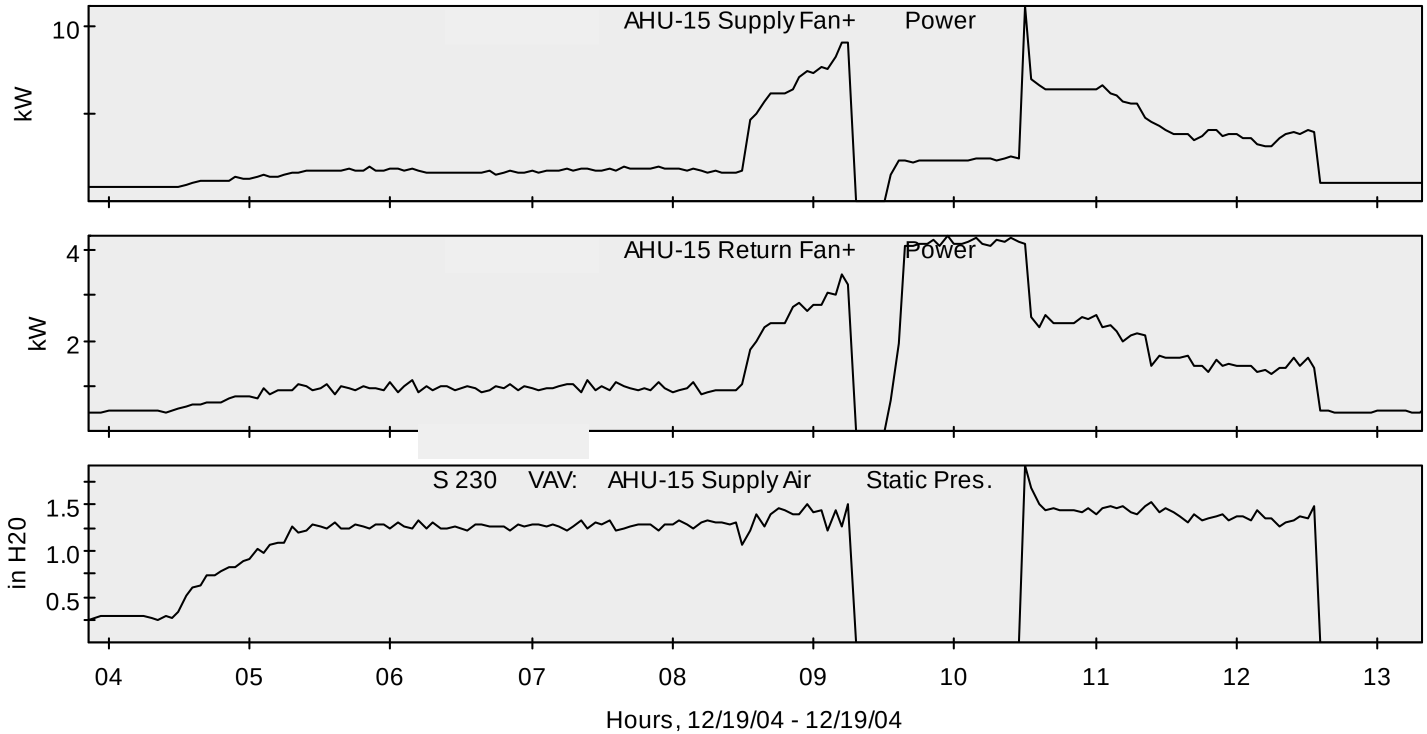
Choose an appropriate sampling rate



Diagnostic Monitoring

Supply fan should be tracking return fan.

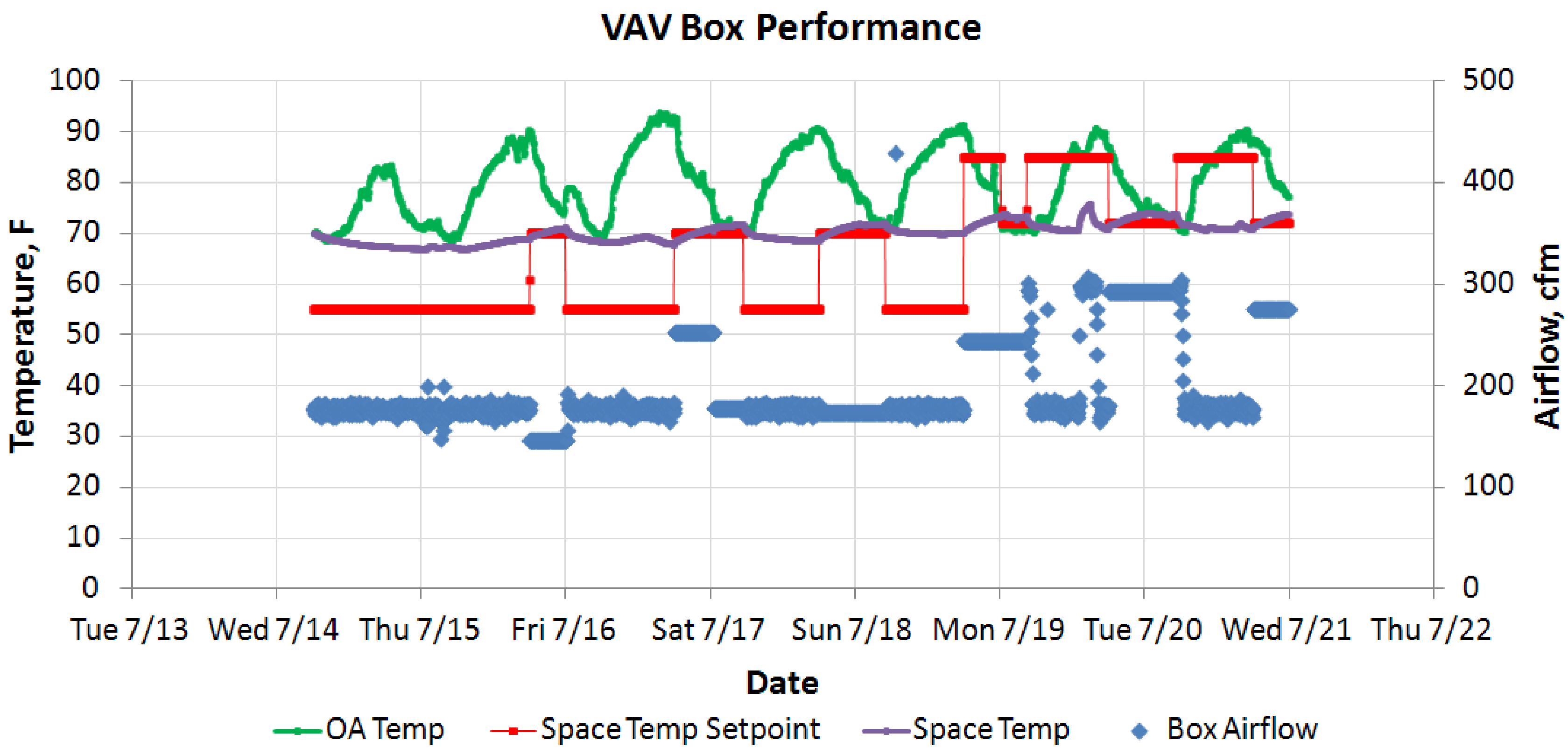
How's that working?



Your Turn!

Diagnostic Monitoring

VAV box damper should be closed when unoccupied.



Your Turn!

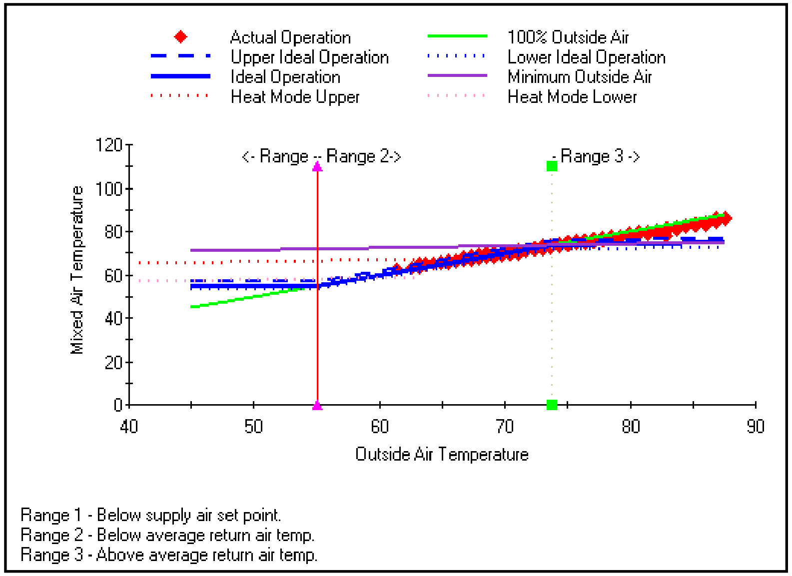
Universal Translator

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

Functional Performance Testing

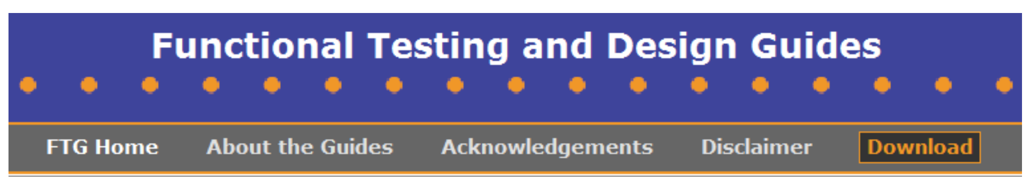
Process:

- **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 Performance Testing

Specific process:

- Record pretest values
- Identify sensors, verify sensor calibration
- Check device calibration
- Implement FPT

Functional Performance Testing

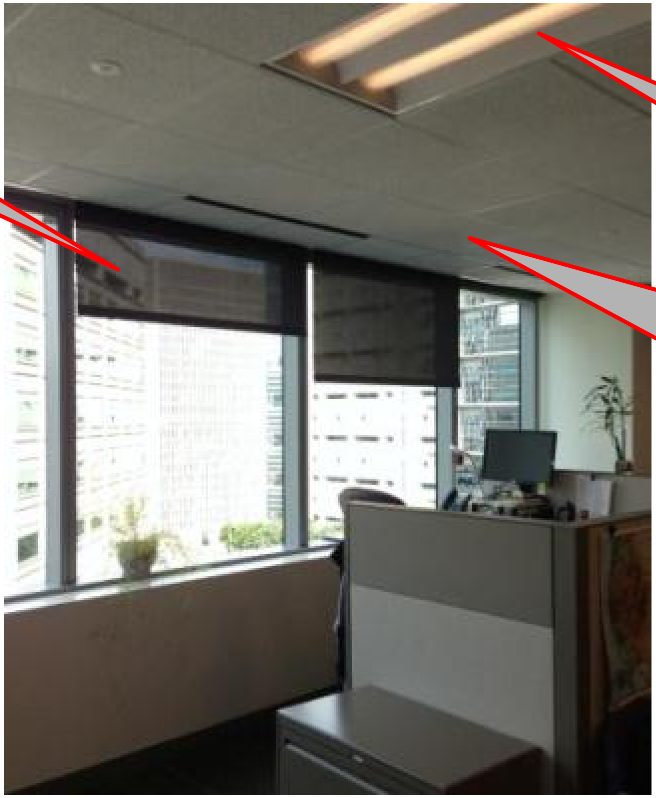
Usually involves two people:

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	Specs 15682 3.3.; 15683 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.

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

Evaluate HVAC Setpoints

Setpoint issues

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

How to identify:

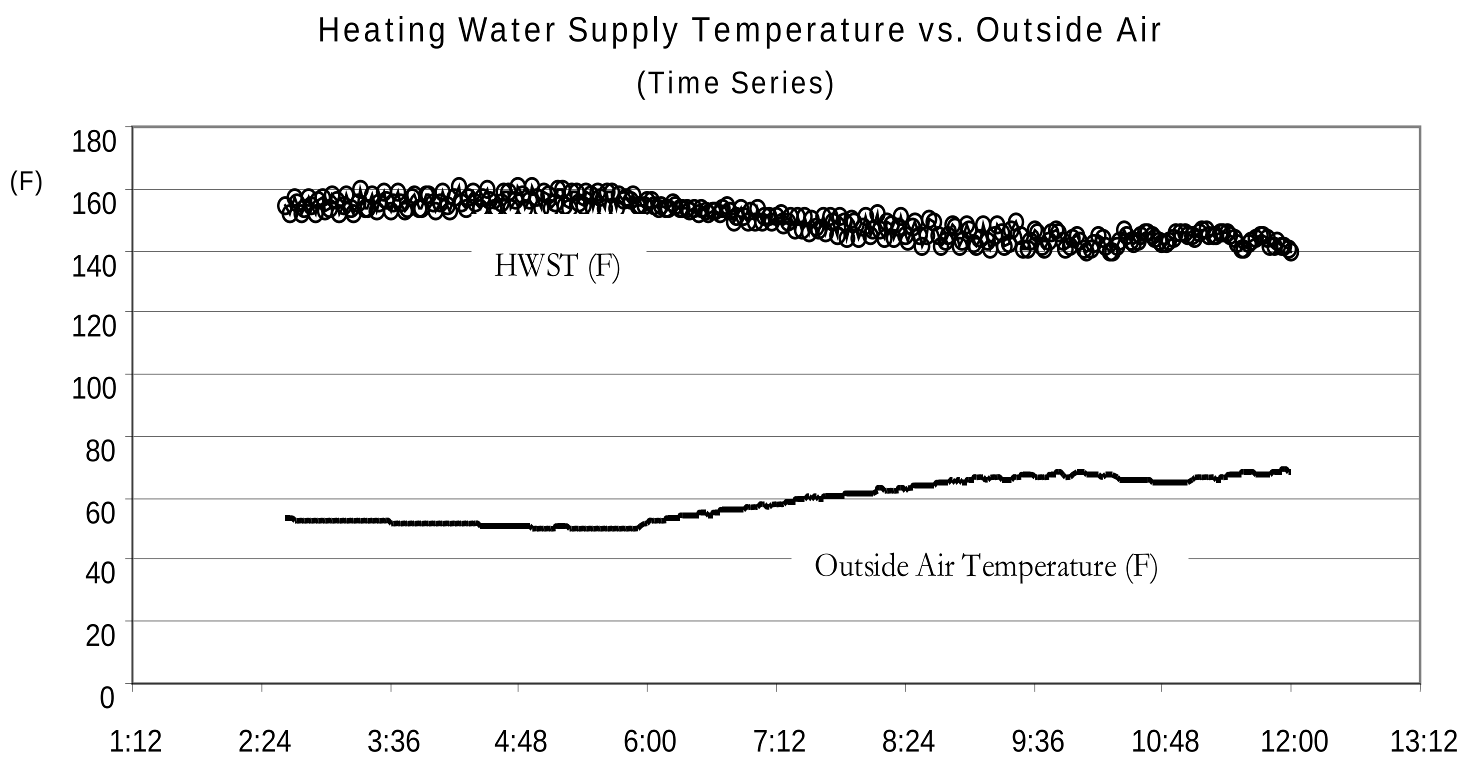
- Variable flow systems acting like constant flow systems
- Trend data analysis

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

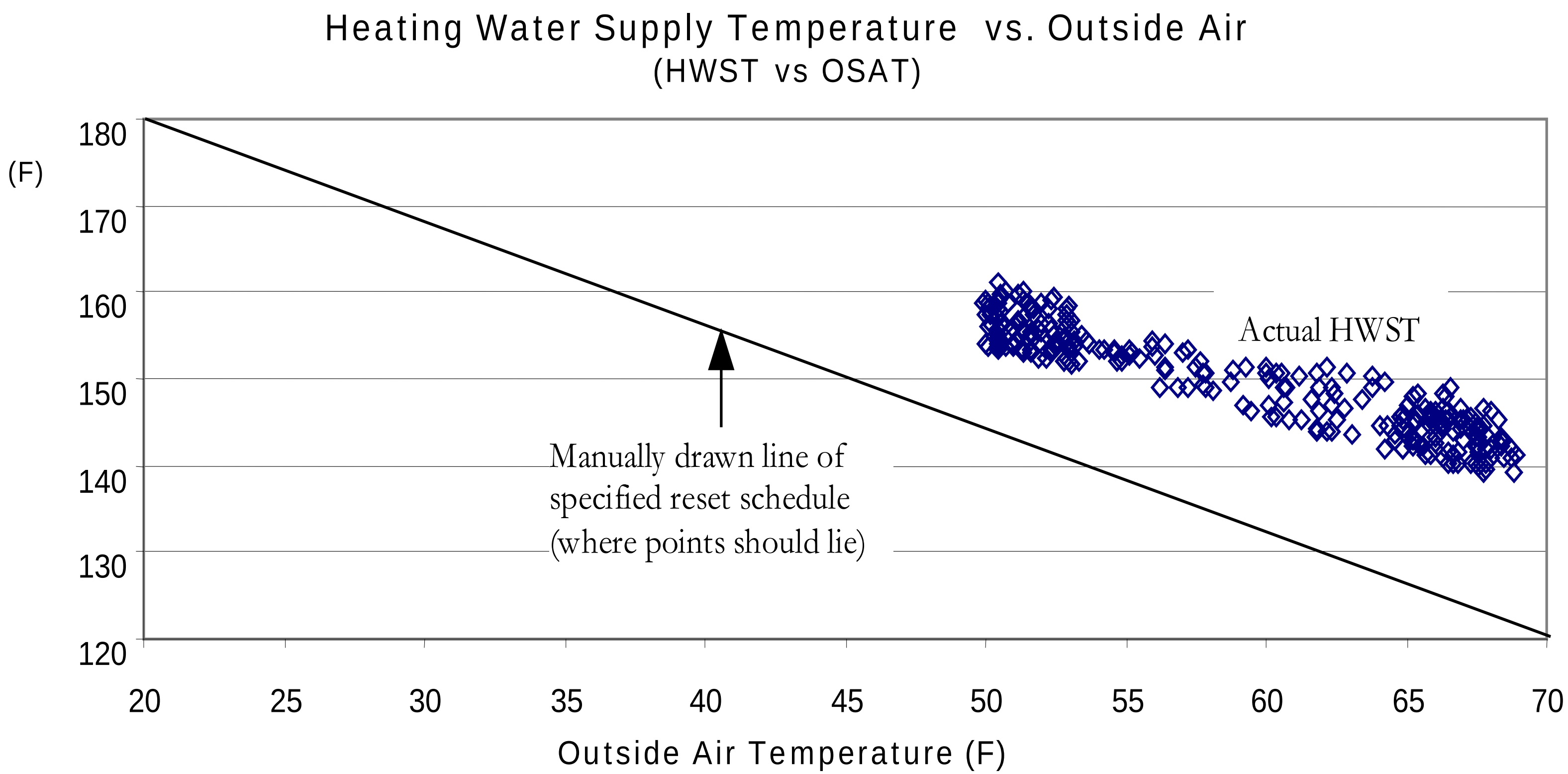
Evaluate Reset Strategies



OAT-based HWST reset. How's it working?

Your Turn!

Evaluate Reset Strategies



OAT-based HWST reset. How's it working?

Your Turn!

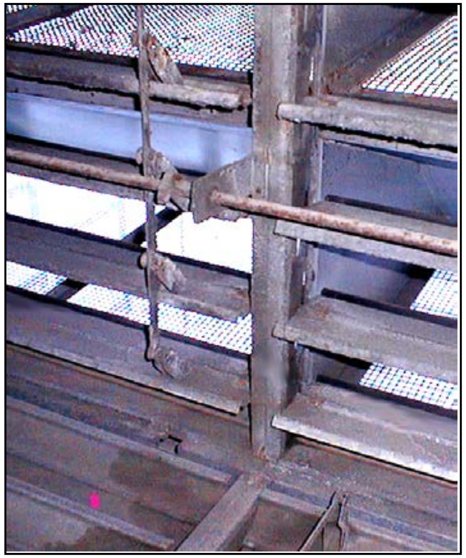
Evaluate Airside Economizers

Airside economizers

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

Common issues

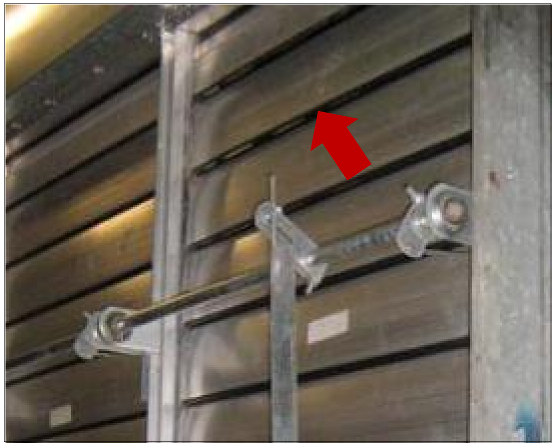
- Damper system design
- Controls sequences
- Maintenance

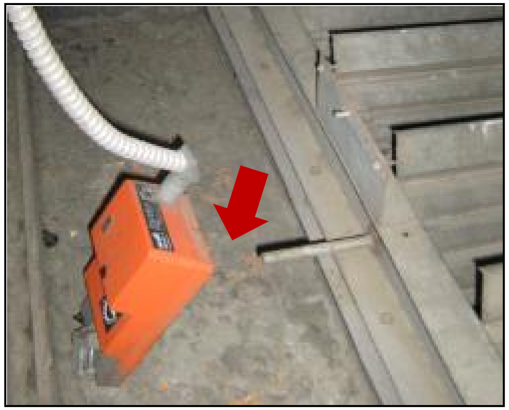


Evaluate Airside Economizers

Inspect economizer maintenance

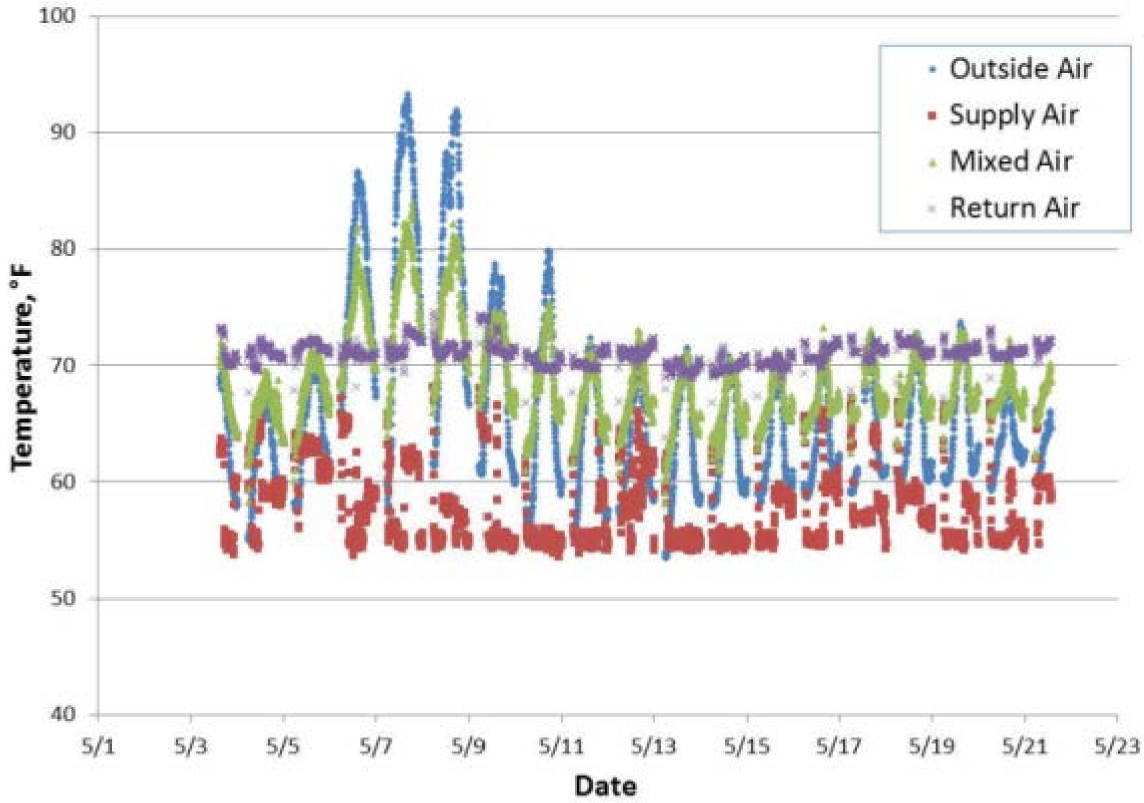
- **Blade and jamb seals installed, in good condition?**
- **Actuators adjusted for full closure?**
- **Actuators connected to dampers?**





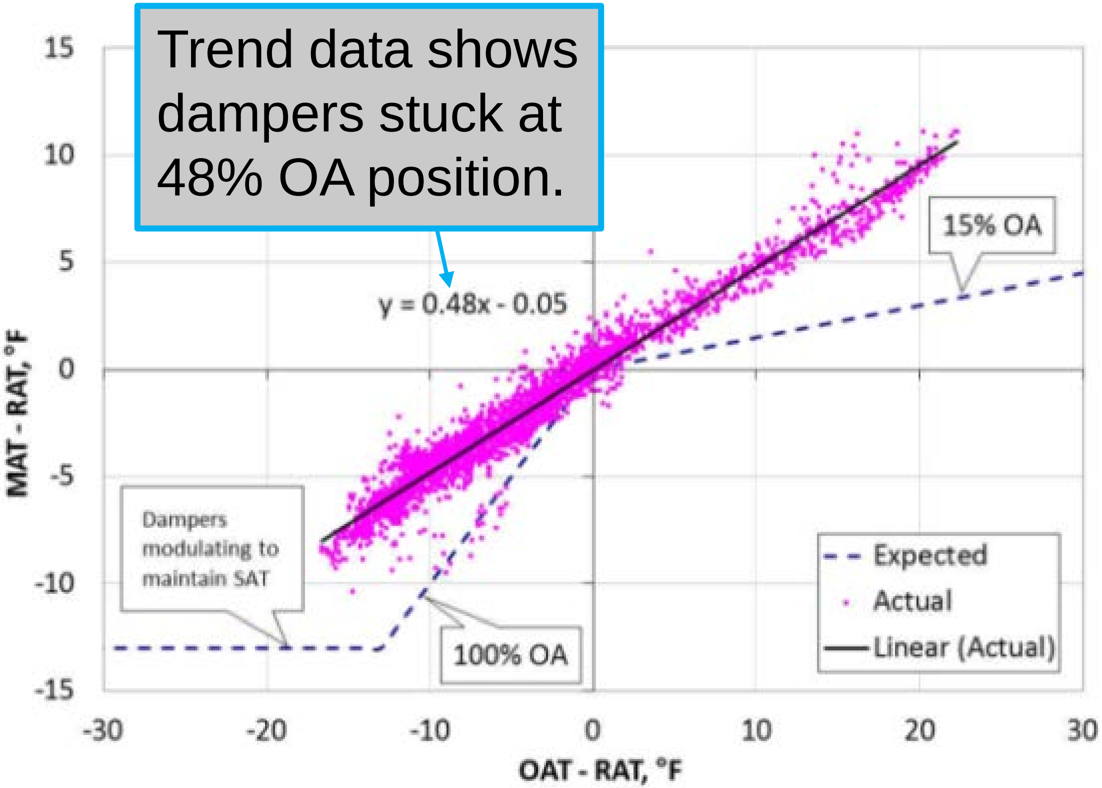
Evaluate Airside Economizers

Time-series charts can be tough to read:



Evaluate Airside Economizers

X-Y scatter charts can be more useful. Plot expected and actual.

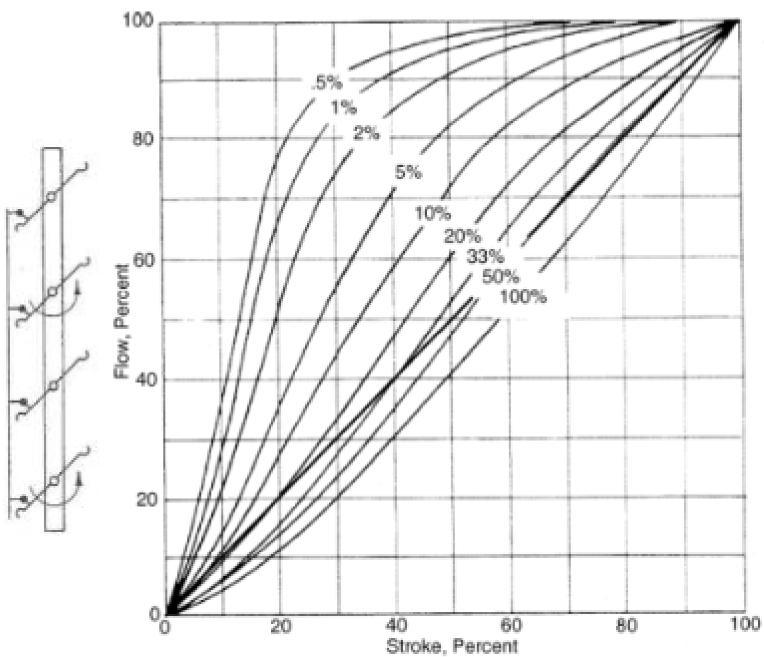


Good Economizer Damper Design

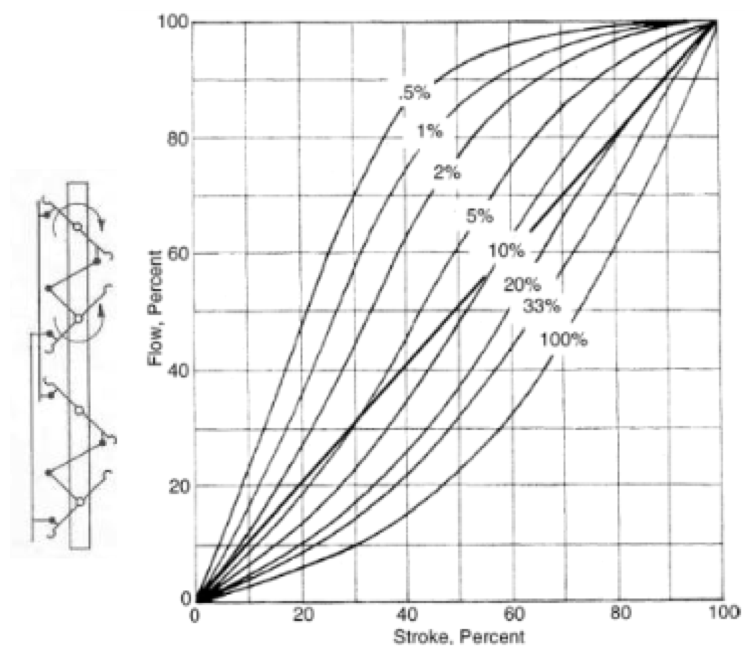
- OA & RA dampers sized and arranged to promote linearity
  - Sized for proper authority
    - Rule of thumb: >=1,500 fpm velocity across open damper
  - Lower velocity = lower ΔP and lower fan energy, but poor control
- Damper rotation promotes mixing
- Sufficient distance to mix

Damper Characteristics

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



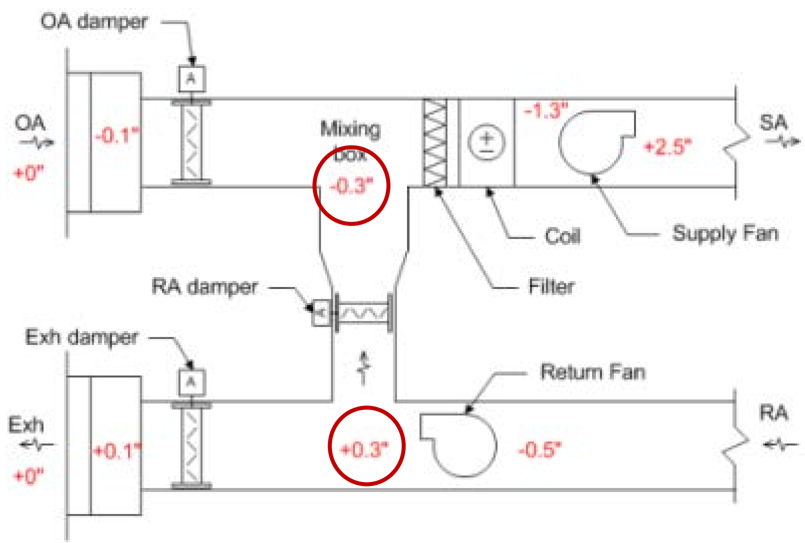
Parallel blade



Opposed blade

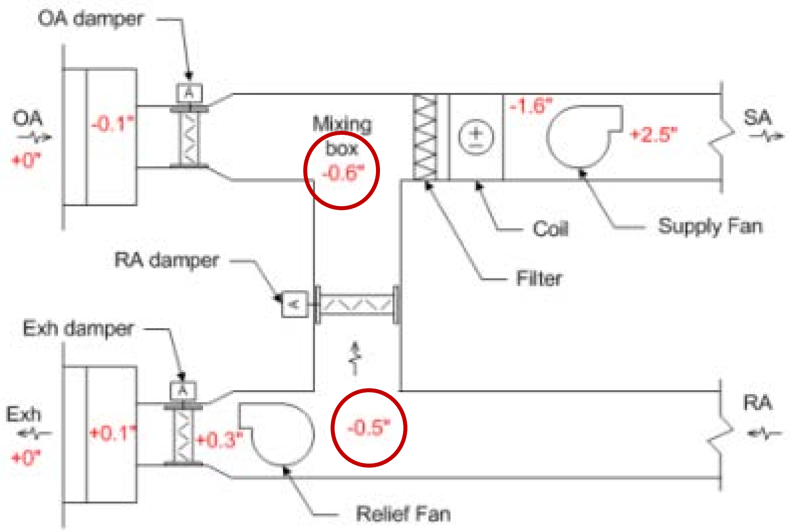
Return or Relief Fan?

Damper sizes depend on system arrangement and design pressures



Return air system

RA damper ΔP = 0.6”

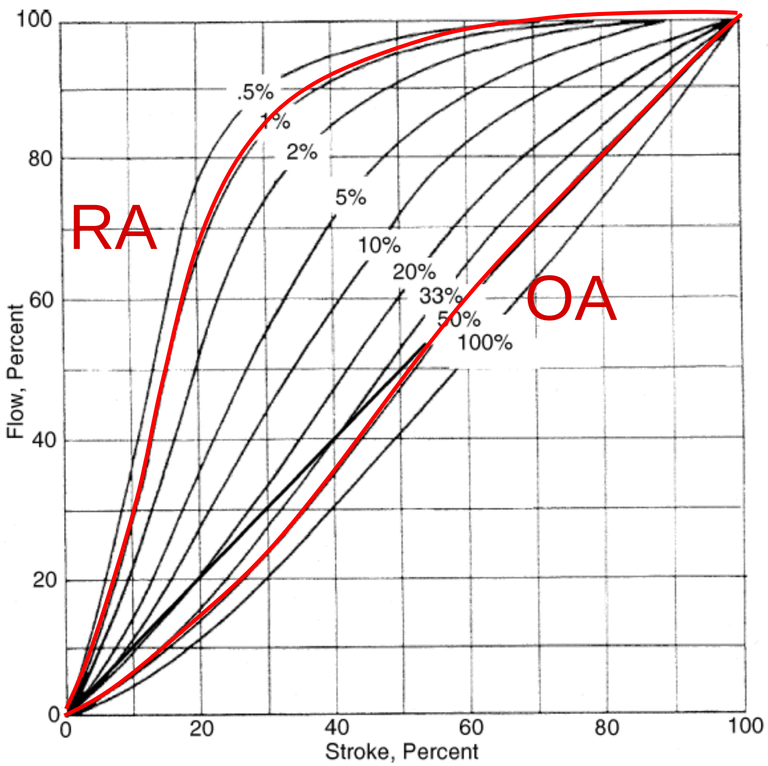


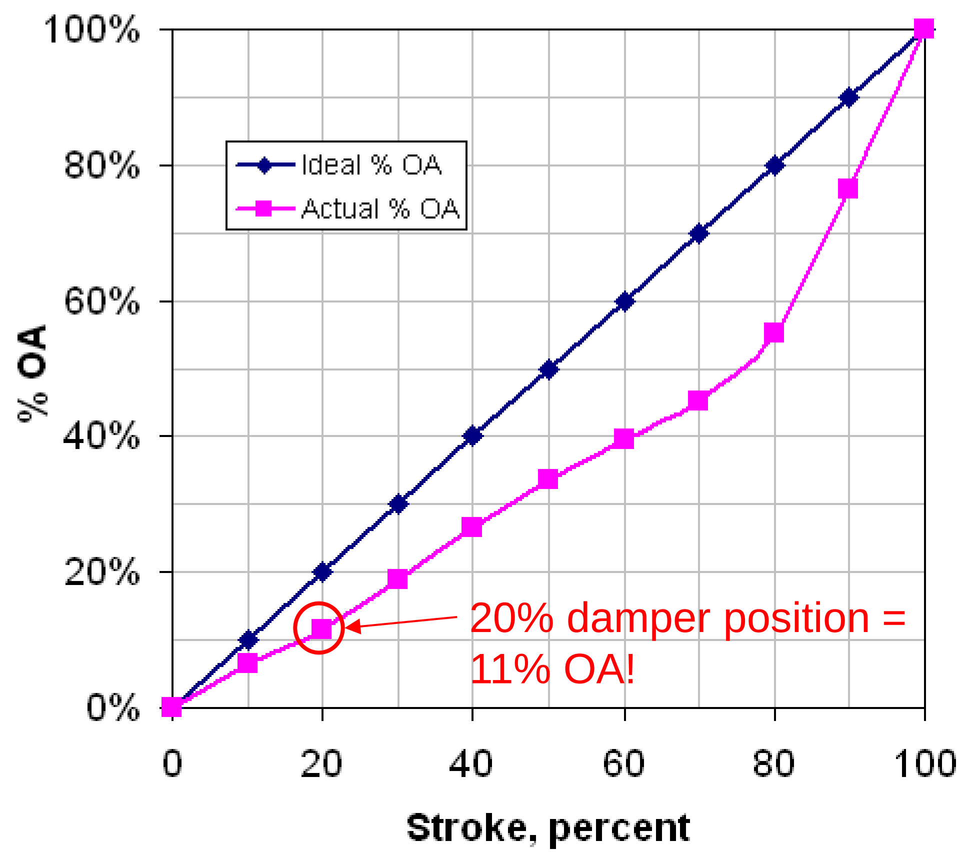
Relief air system

RA damper ΔP = 0.1”

Über non-linear

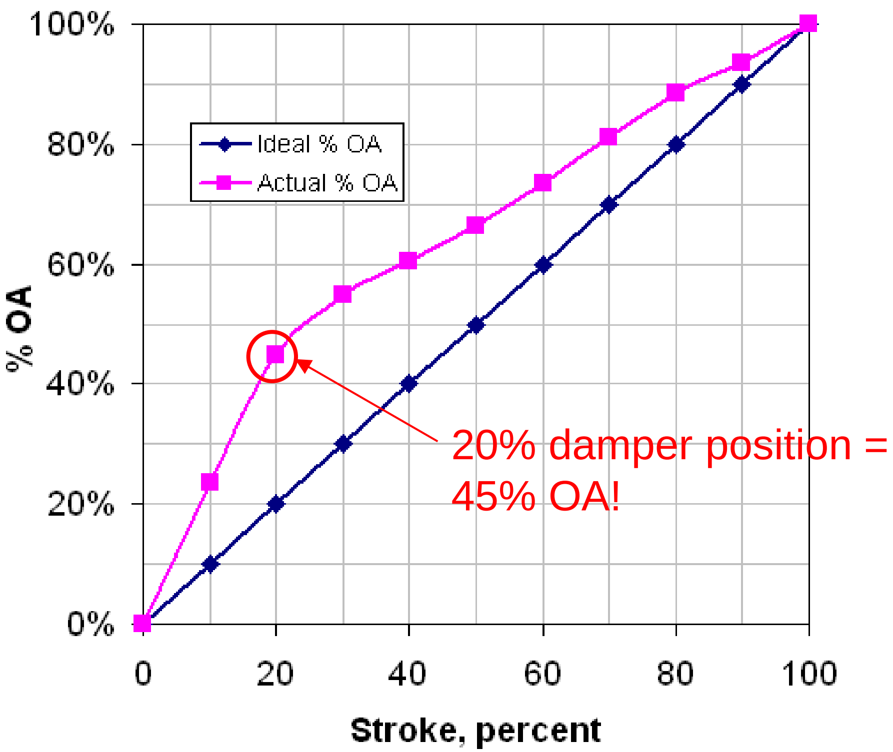
Return fan system, oversized parallel blade return dampers:





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**

Investigation

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

31% OA (ave. 64.3°F MAT)

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

83% OA (ave. 55.1°F MAT)

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

Coldest Hottest

Minimum Maximum

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

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

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

Slowest Fastest

Minimum Maximum

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

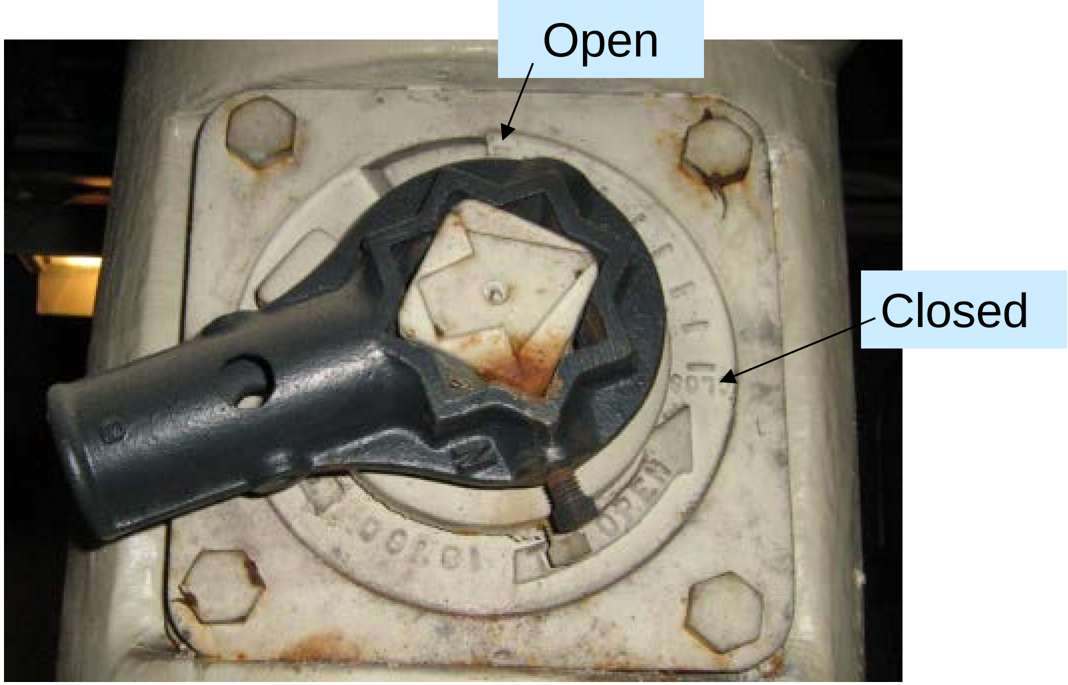
Evaluate HVAC Pumps

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 …

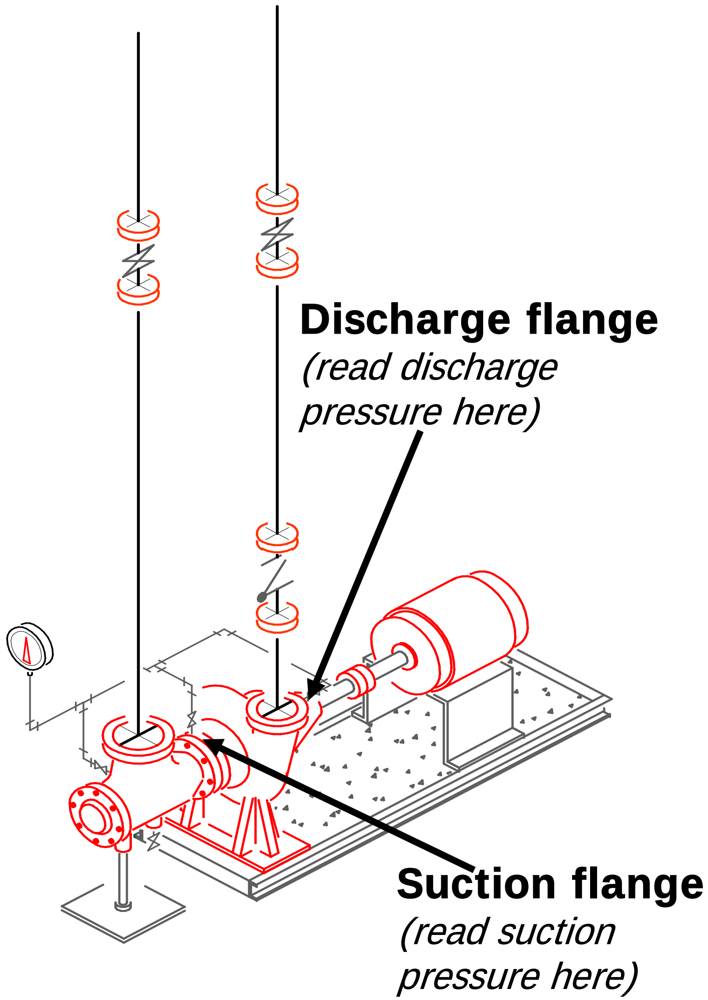


Evaluate HVAC Pumps

… 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



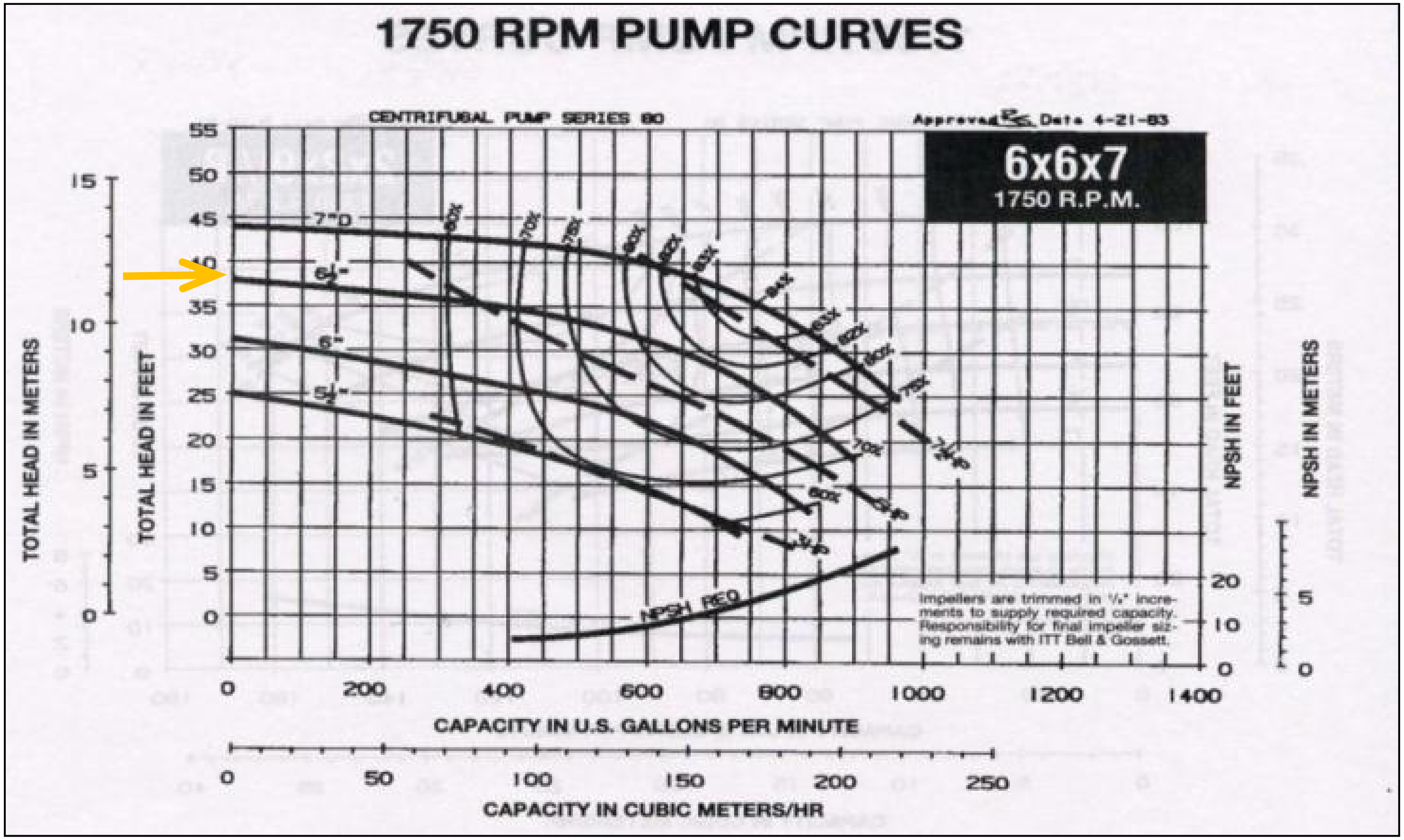
As Found Conditions

- 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

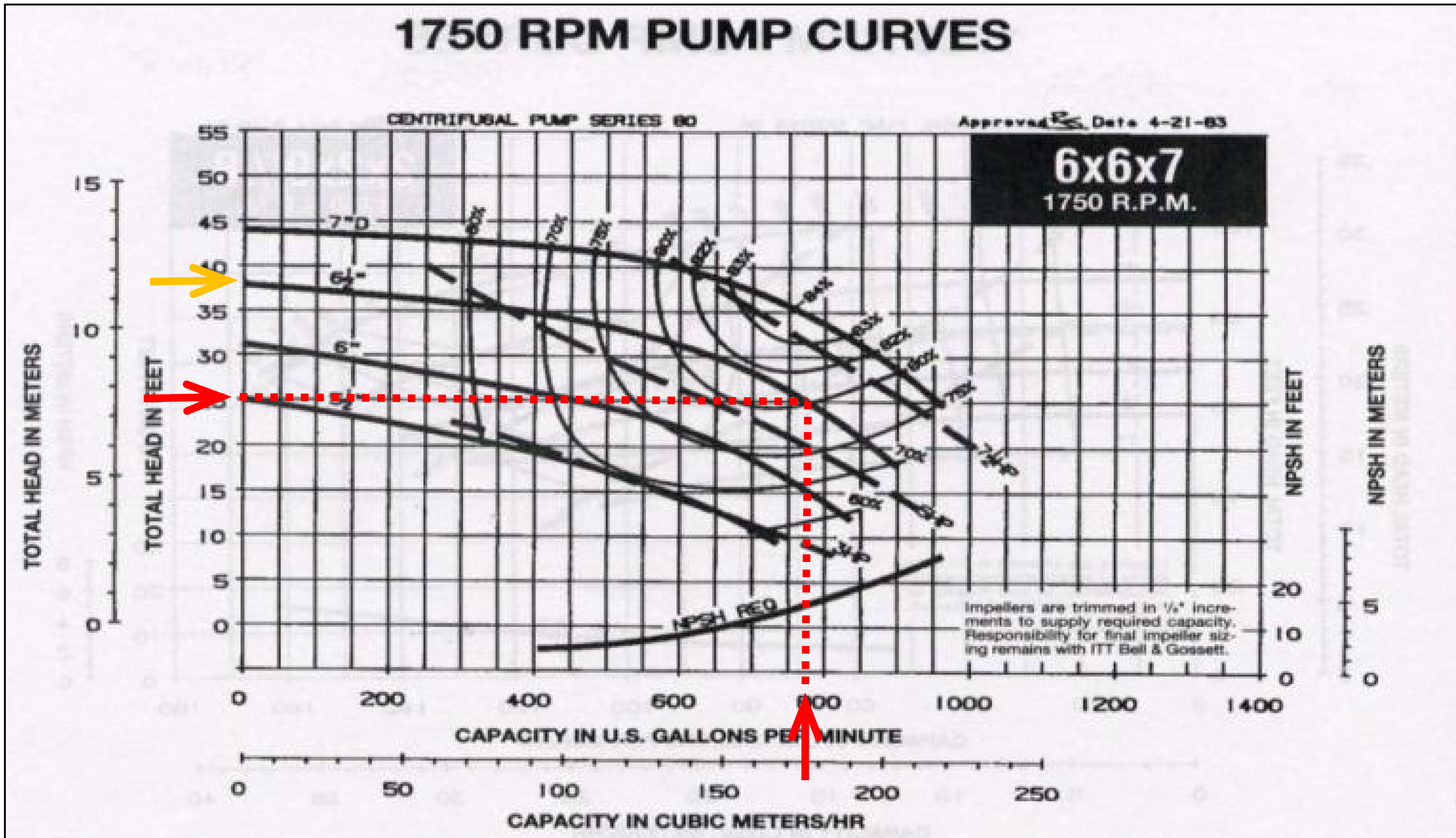


Credit: Bell and Gossett catalog.

Wide Open Test

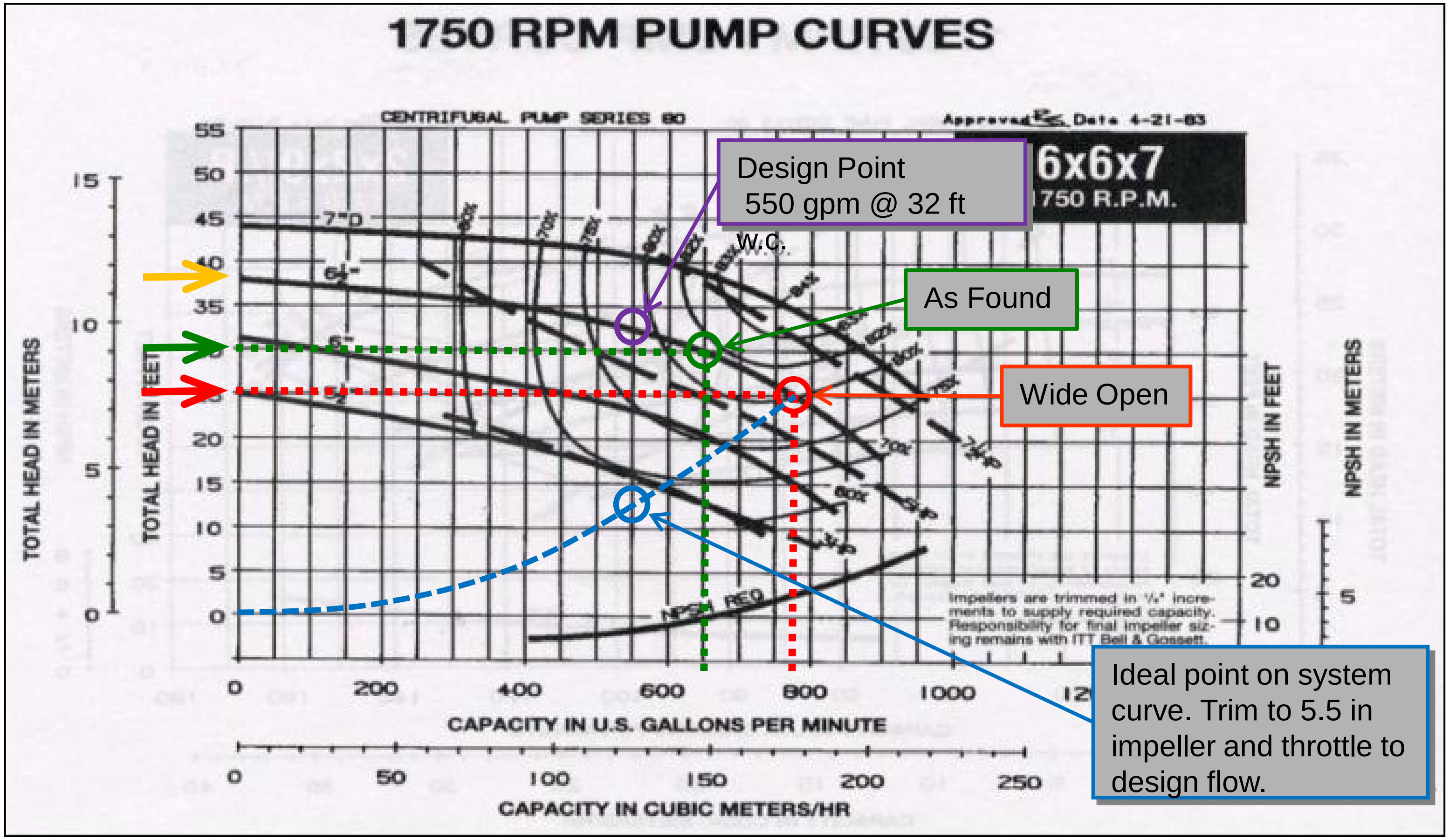
- Throttling valve completely open.
  - Open the throttling valve completely.
  - Ensure that all control valves in the loop are open.
  - Record suction and discharge pressure.
  - Plot the point on the pump curve.

Wide Open Test Results



Credit: Bell and Gossett catalog.

Plotting the Results



Credit: Bell and Gossett catalog.

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

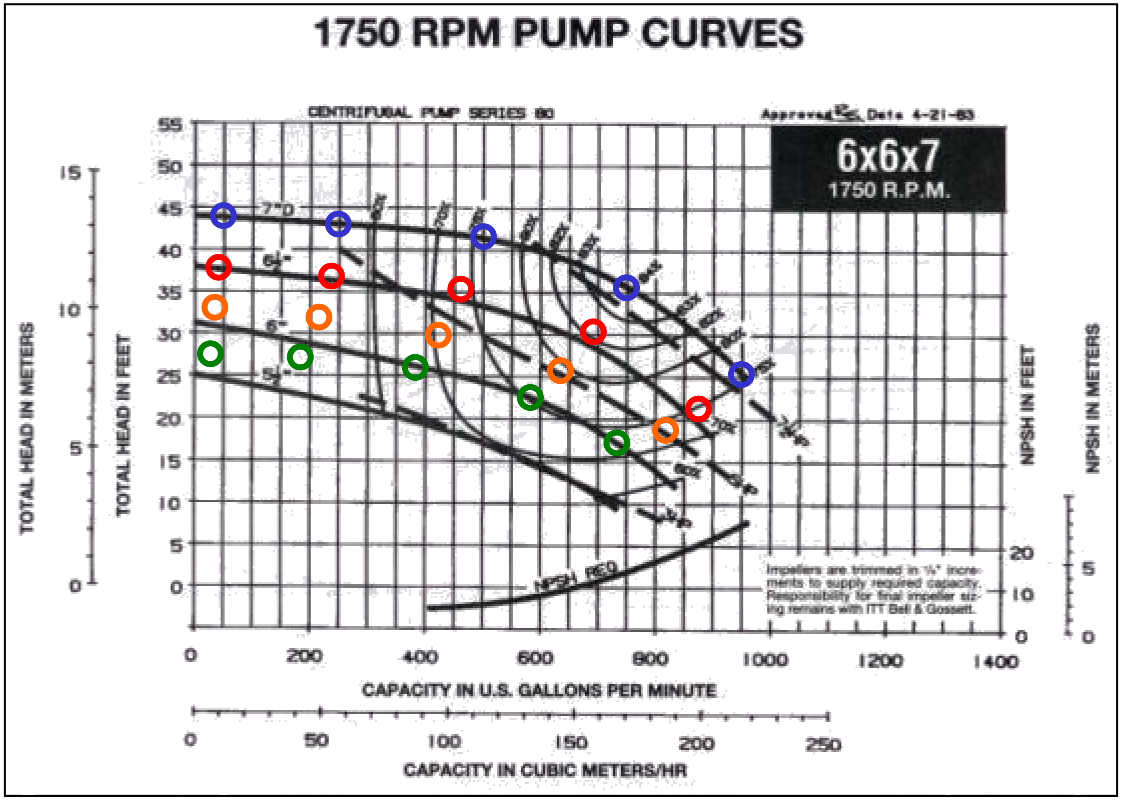
D = Impeller diameter

H = Head

BHP = Shaft horsepower

Use the Laws With Care

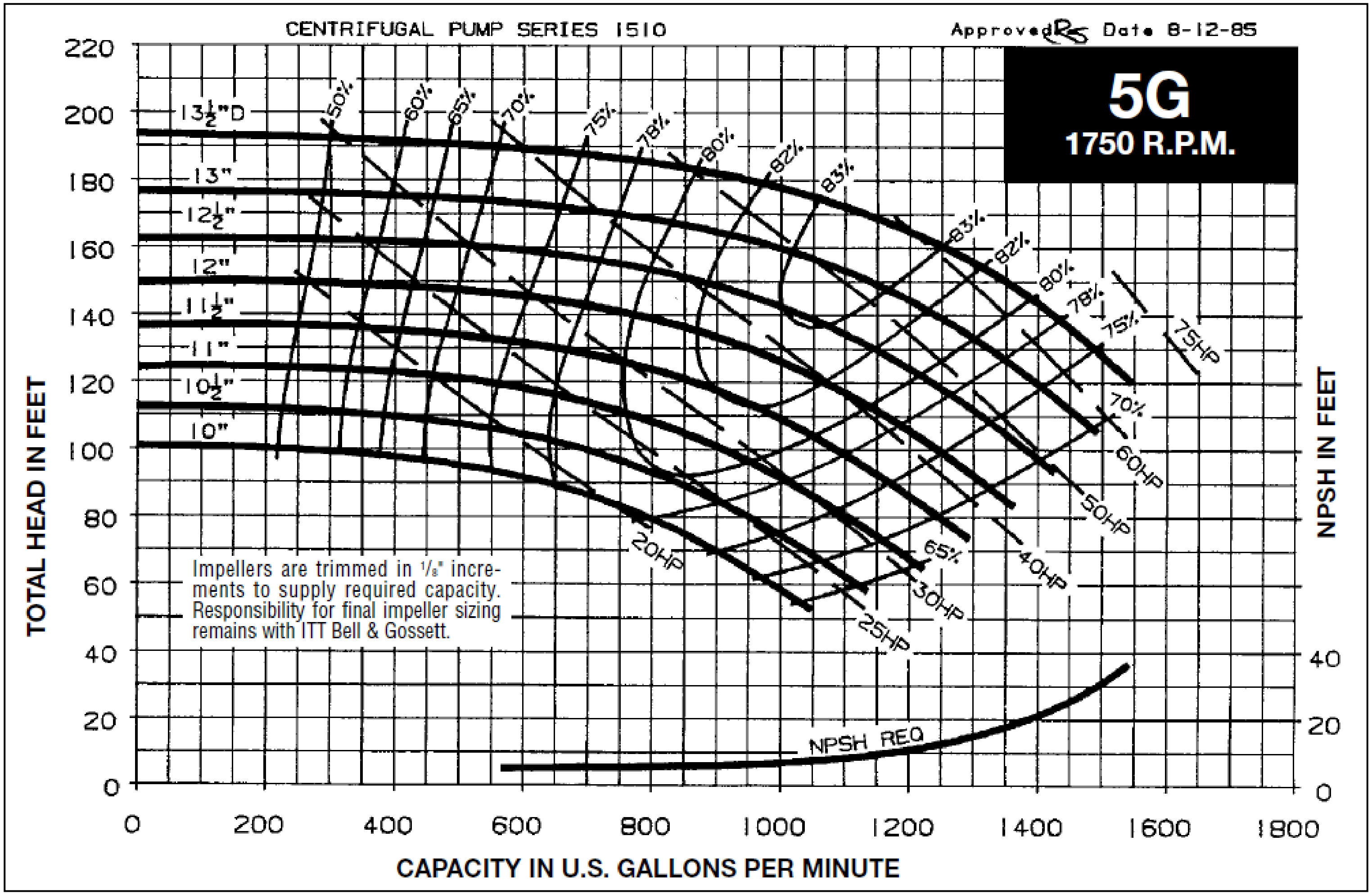
Affinity laws do not account for leakage and hydraulic losses. Predicted performance may not match actual.



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.

Pump Analysis Activity

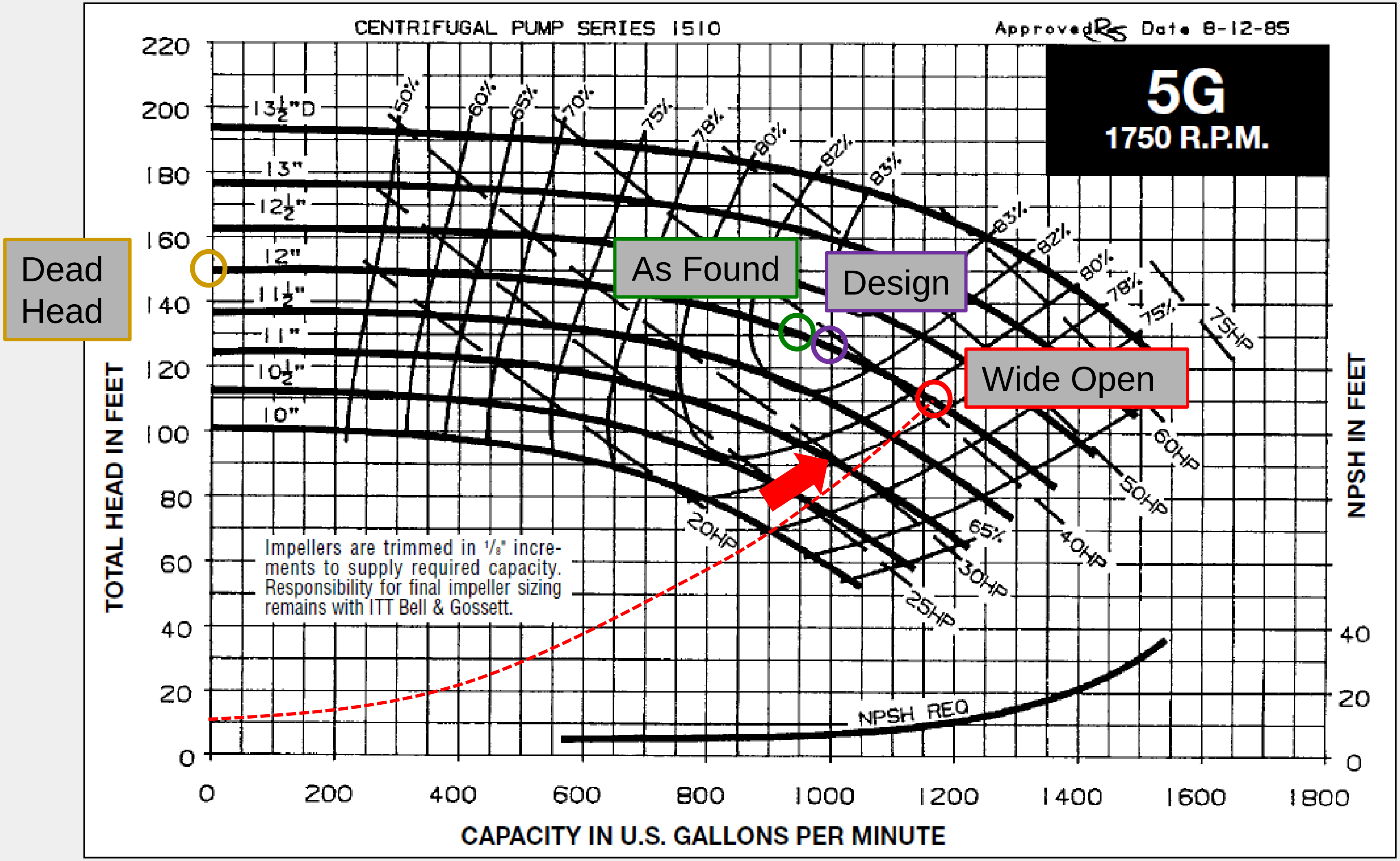


Credit: Bell and Gossett catalog.

Your Turn!

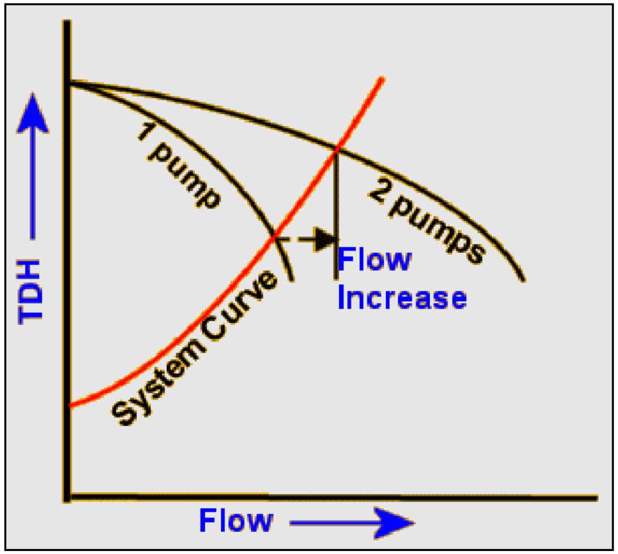
Pump Analysis Activity

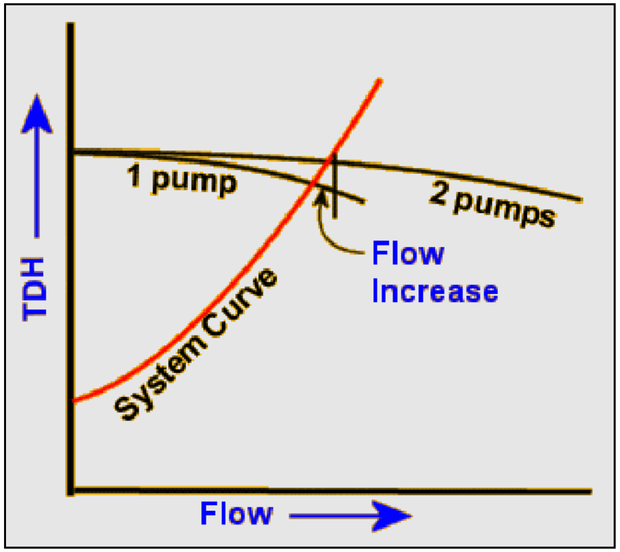
Investigation



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

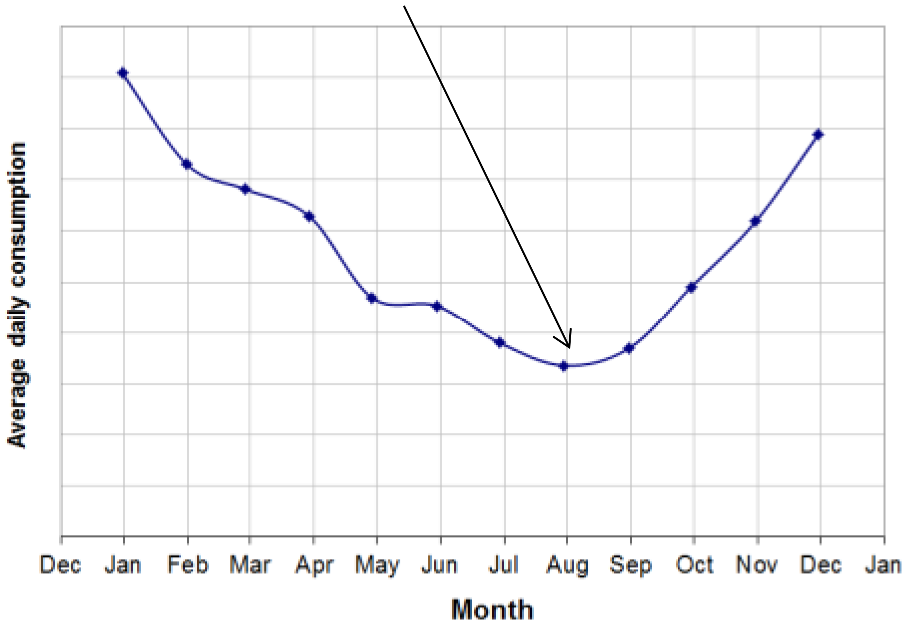
Common opportunities:

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

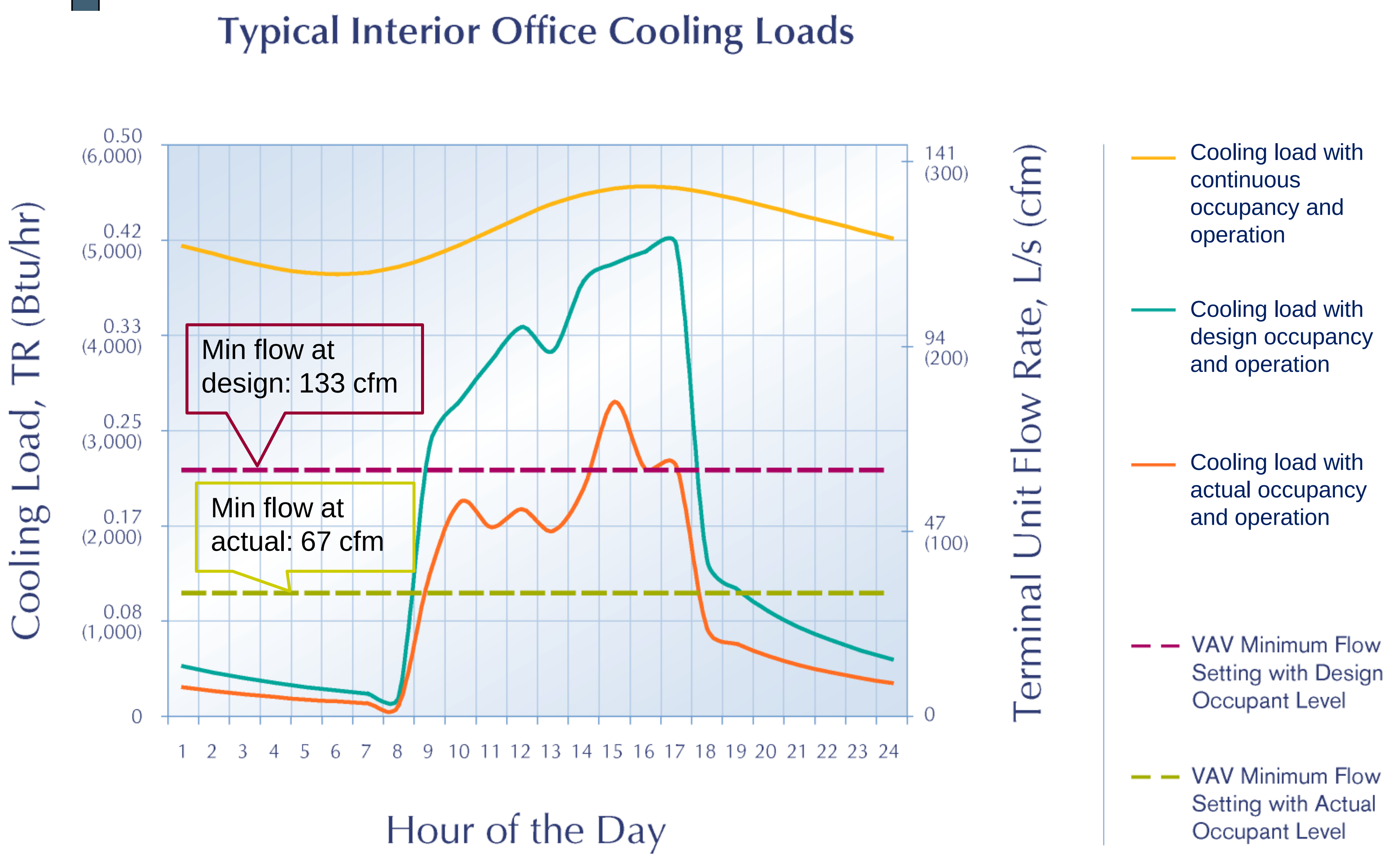
Evaluate Ventilation

Clues to identify ventilation issues:

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



VAV? Or mostly CAV?



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

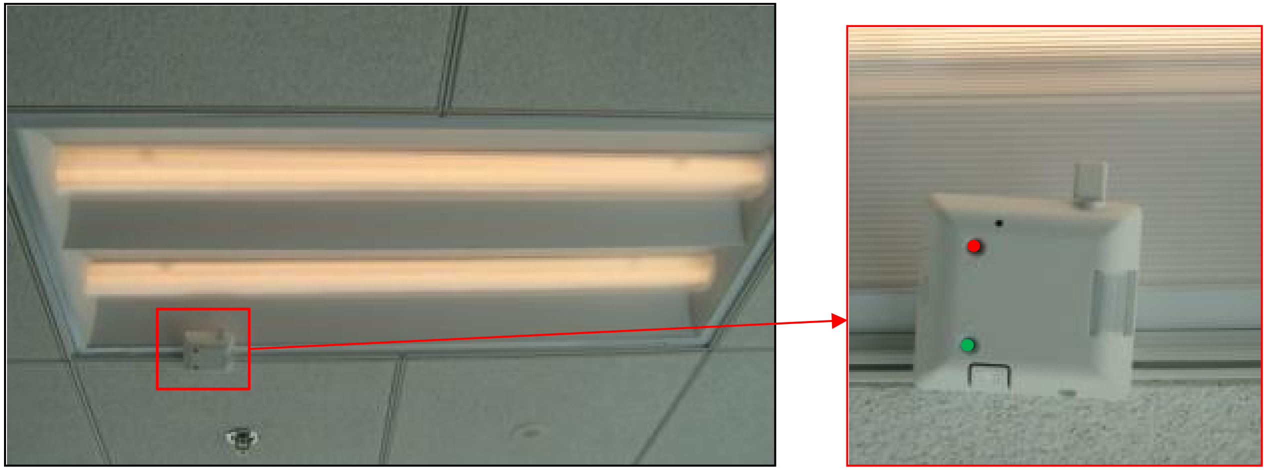
Measure lighting levels, compare to CFR

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

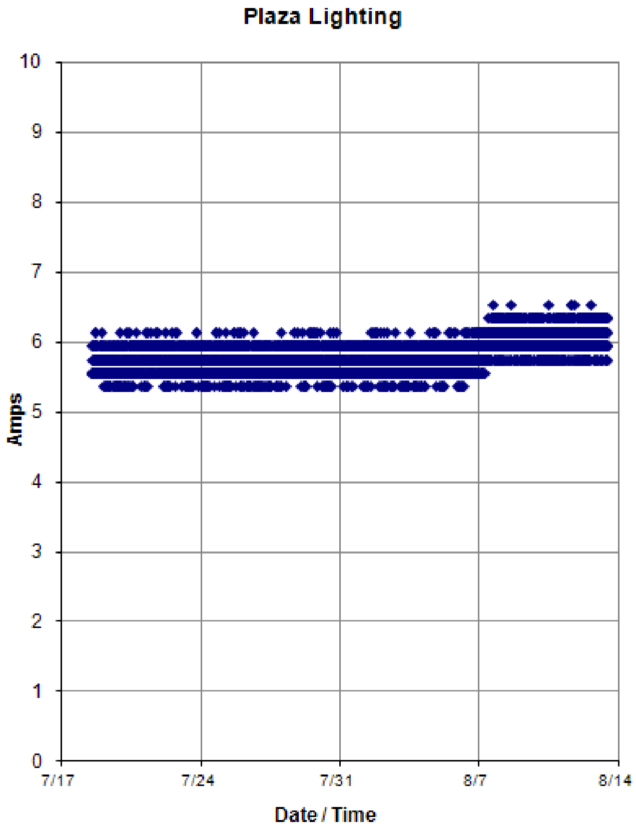
How could this issue be investigated?

What methods could be used?

Your Turn!

Evaluate Lighting Performance

Verify suspicions



Evaluate Envelope Performance

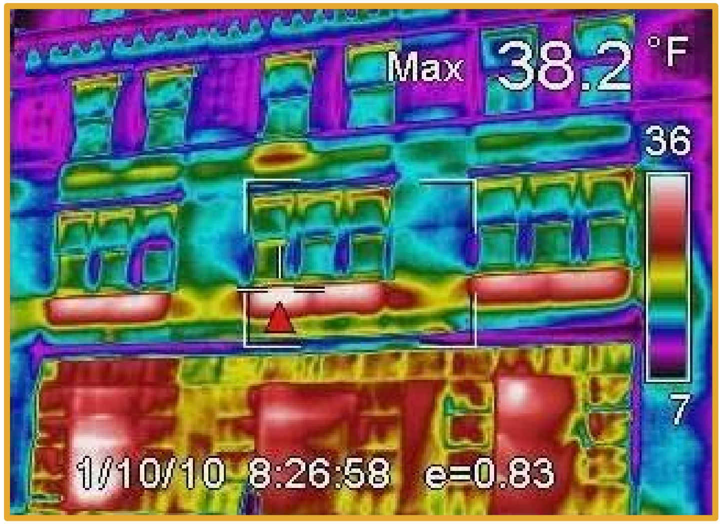
General considerations

- 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.

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

Analyze Measures

Estimate:

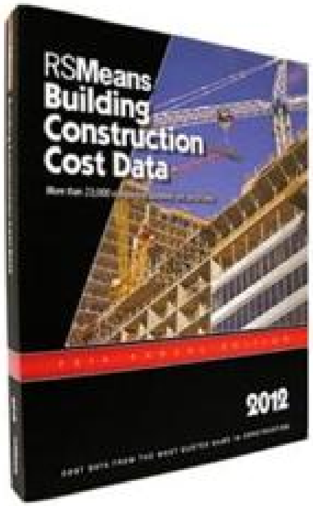
- Implementation cost
- Benefits (e.g., energy savings)
- Financial metrics

Existing Chiller Plant Operation																
						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												

Analyze Measures

Implementation cost considerations

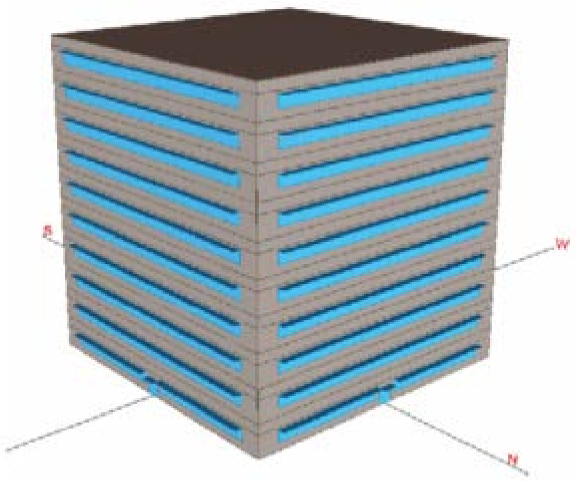
- Contractor or in-house labor
- Materials and equipment
- Contractor markups
- Engineering, training and M&V fees
- Updating documentation
- Project contingency



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

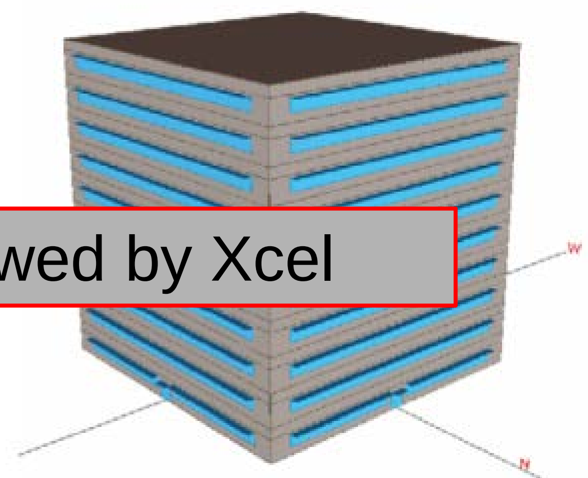


Analyze Measures

Energy and demand savings calculation methodology options

- Whole building energy modeling software
- Stipulated savings from utility programs
- 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)
Line #	a	b	c	d	e	f	g
Source		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**

46% reduction

More Typical Custom Spreadsheet

Assumptions and Equations

	units	AH-0401 Base	AH-0401 ECM	AH-0402 Base	AH-0402 ECM	AH-0404 Base	AH-0404 ECM	AH-0405 Base	AH-0405 ECM	AH-0407 Base	AH-0407 ECM	AH-0408 Base	AH-0408 ECM	AH-0413 Base	AH-0413 ECM	AH-0414 Base	AH-0414 ECM	
Supply fan flow rate	cfm	17,097	17,097	22,521	22,521	40,280	40,280	7,900	7,900	26,060	26,060	9,560	9,560	12,920	12,920	13,920	13,920	*From spot measurements. Units are constant volume.*
Supply fan motor	HP	30 (est.)	30 (est.)	30	30	30 (est.)	30 (est.)	30 (est.)	30 (est.)	30	30	30	30	25	25	25	25	*From nameplate data*
Minimum outside air damper position	%	10%	10%	30%	10%	18%	10%	18%	10%	18%	10%	12%	10%	33%	10%	33%	10%	*Baseline from functional testing. ECM from drawings.*
Supply fan heat pick up	°F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	*Engineering estimate*
Damper leakage	%	10%	5%	30%	5%	18%	5%	18%	5%	18%	5%	12%	5%	33%	5%	33%	5%	*Engineering estimate*
Linear Regressions		Variable	Constant	Variable	Constant	Variable	Constant	Variable	Constant	Variable	Constant	Variable	Constant	Variable	Constant	Variable	Constant	
Baseline MAT f(OAT)	°F	0.034	68.231															*Curve fit from trend data*
RAT f(OAT)	°F			0.00	70.00	0.05	68.75	0.05	68.75	0.05	72.61	-0.14	77.83	0.00	70.25	0.00	70.25	*Curve fit from trend data*
SAT f(OAT)	°F	0.02	56.09	0.04	51.79	0.03	53.43	0.00	52.37	0.00	56.98	0.00	61.65	0.00	55.00	0.00	55.00	*Curve fit from trend data*

Equations Used:

Eq2	Economizer status = "n" if OA>RAT, "y" otherwise
Eq3	% OA = (MAT - RAT) / (OAT - RAT)
Eq4	Sensible Cooling = 1.08 * CFM * (MAT - SAT)
Eq5	CHW kWh = sensible cooling load * Chiller efficiency * hours
Eq6	Chiller Demand Savings = (Base Cooling Load * Chiller efficiency)-(ECM Cooling Load * Chiller Efficiency)

Savings Summary

AHU	Annual kWh savings	Summer Peak Hours (M-F June-Sept 12pm-6pm)	Summer Mid-Peak Hours (M-F June-Sept 8am-12pm, 6pm-11pm)	Summer Off-Peak Hours	Winter Mid-Peak Hours (M-F Oct-May 8am-9pm)	Winter Off-Peak Hours	CPUC Demand Savings, kW
AH-0401	**58,553**	102	2,360	7,250	14,874	33,967	**0.4**
AH-0402	**50,927**	162	2,255	6,813	12,790	28,908	**6.1**
AH-0404	**129,578**	761	6,121	17,919	32,897	71,879	**4.7**
AH-0405	**24,418**	130	1,231	3,612	6,151	13,294	**1.0**
AH-0407	**120,980**	2,231	7,042	18,363	31,166	62,179	**2.6**
AH-0408	**20,101**	13	761	2,551	5,219	11,557	**0.4**
AH-0413	**28,638**	111	1,243	3,734	7,258	16,292	**3.9**
AH-0414	**30,854**	120	1,339	4,022	7,820	17,553	**4.2**
Total	**464,050**	3,630	22,351	64,265	118,174	255,630	**23.3**
	7.4%	% of base building usage					

Calculations

AH-0401

Dry-bulb outside air temperature, °F	Operation bin hours (continuous operation)	Summer Peak Hours (M-F June-Sept 12pm-6pm)	Summer Mid-Peak Hours (M-F June-Sept 8am-12pm, 6pm-11pm)	Summer Off-Peak Hours	Winter Mid-Peak Hours (M-F Oct-May 8am-9pm)	Winter Off-Peak Hours	Supply airflow, cfm	SAT, °F	RAT, °F
Equations Used:								regression	regression
95	1	0	0	1	0	0	17,097	57.6	68.8
93	0	0	0	0	0	0	17,097	57.6	69.0
91	2	0	0	2	0	0	17,097	57.5	69.1
89	2	1	0	1	0	0	17,097	57.5	69.3
87	7	1	0	5	1	0	17,097	57.5	69.4
85	13	1	3	5	2	2	17,097	57.4	69.6
83	15	2	1	3	6	3	17,097	57.4	69.7
81	38	6	3	7	17	5	17,097	57.4	69.8
79	52	10	8	6	20	8	17,097	57.4	70.0
77	47	12	11	6	13	5	17,097	57.3	70.1
75	180	60	41	34	33	12	17,097	57.3	70.3
73	390	124	64	72	81	49	17,097	57.3	70.4
71	470	122	101	102	102	43	17,097	57.2	70.6
69	622	101	91	190	174	66	17,097	57.2	70.7
67	856	53	146	263	224	170	17,097	57.2	70.9
65	912	22	154	326	216	194	17,097	57.1	71.0
63	986	6	102	275	300	303	17,097	57.1	71.2
61	919	1	46	223	297	352	17,097	57.1	71.3
59	484	0	6	66	153	259	17,097	57.0	71.5
57	846	0	6	28	228	584	17,097	57.0	71.6
55	934	0	0	8	250	676	17,097	57.0	71.8
53	432	0	0	0	77	355	17,097	56.9	71.9
51	269	0	0	0	39	230	17,097	56.9	72.1
49	148	0	0	0	13	135	17,097	56.9	72.2
47	81	0	0	0	3	78	17,097	56.8	72.4
45	30	0	0	0	0	30	17,097	56.8	72.5
43	19	0	0	0	0	19	17,097	56.8	72.6
41	2	0	0	0	0	2	17,097	56.7	72.8
39	3	0	0	0	0	3	17,097	56.7	72.9
	8760	522	783	1623	2249	3583			

Dry-bulb outside air temperature, °F	Baseline: Economizer operation?	Baseline: MAT, °F	Baseline: % OSA	Baseline: Sensible cooling coil load, tons	Baseline: Chilled water plant efficiency, kW/ton	Baseline: Chilled water usage, kWh	ECM: Economizer operation?	ECM: MAT, °F	ECM: % OSA	ECM: Sensible cooling coil load, tons	ECM: Chilled water plant efficiency, kW/ton	ECM: Chilled water usage, kWh
Equations Used:				eq4	regression	eq5	eq2	eq3	eq3	eq4	regression	eq5
95	n	71.4	10%	23	0.53	12	n	71.4	10%	23	0.52	12
93	n	71.4	10%	23	0.53	0	n	71.4	10%	23	0.52	0
91	n	71.3	10%	23	0.53	24	n	71.3	10%	23	0.51	23
89	n	71.2	10%	23	0.53	24	n	71.2	10%	23	0.51	23
87	n	71.2	10%	23	0.52	83	n	71.2	10%	23	0.51	81
85	n	71.1	10%	23	0.52	153	n	71.1	10%	23	0.51	150
83	n	71.0	10%	22	0.52	175	n	71.0	10%	22	0.51	172
81	n	71.0	10%	22	0.52	439	n	71.0	10%	22	0.51	433
79	n	70.9	10%	22	0.51	596	n	70.9	10%	22	0.51	589
77	n	70.8	10%	22	0.51	535	n	70.8	10%	22	0.51	530
75	n	70.8	10%	22	0.51	2,031	n	70.8	10%	22	0.50	2,019
73	n	70.7	10%	22	0.50	4,365	n	70.7	10%	22	0.50	4,325
71	n	70.6	10%	22	0.50	5,220	n	70.6	10%	22	0.50	5,173
69	n	70.6	10%	22	0.50	6,857	n	70.6	10%	22	0.59	8,151
67	n	70.5	10%	22	0.50	9,372	y	67.2	95%	17	0.55	8,023
65	n	70.4	10%	22	0.63	12,650	y	65.3	95%	14	0.53	6,841
63	n	70.4	10%	22	0.61	13,200	y	63.4	95%	11	0.51	5,602
61	n	70.3	10%	22	0.59	11,951	y	61.5	95%	8	0.49	3,795
59	n	70.2	10%	22	0.58	6,148	y	59.6	95%	6	0.55	1,462
57	n	70.2	10%	22	0.57	10,544	y	57.7	95%	3	0.74	1,673
55	n	70.1	10%	22	0.57	11,462	y	56.0	94%	0	1.19	0
53	n	70.0	10%	22	0.56	5,234	y	55.9	84%	0	1.20	0
51	n	70.0	10%	22	0.55	3,224	y	55.9	77%	0	1.20	0
49	n	69.9	10%	22	0.55	1,756	y	55.9	70%	0	1.20	0
47	n	69.8	10%	22	0.55	952	y	55.8	65%	0	1.20	0
45	n	69.7	10%	21	0.54	349	y	55.8	61%	0	1.20	0
43	n	69.7	10%	21	0.54	219	y	55.8	57%	0	1.20	0
41	n	69.6	10%	21	0.53	23	y	55.7	54%	0	1.20	0
39	n	69.5	10%	21	0.53	34	y	55.7	51%	0	1.20	0

Dry-bulb outside air temperature, °F	Chiller demand savings, kW	Summer Peak Chiller Energy Reduction (kWh)	Summer Mid-Peak Chiller Energy Reduction (kWh)	Summer Off-Peak Chiller Energy Reduction (kWh)	Winter Mid-Peak Chiller Energy Reduction (kWh)	Winter Off-Peak Chiller Energy Reduction (kWh)	Chiller savings, kWh	Dry-bulb outside air temperature, °F	Mean coincident dew point, °F
Equations Used:	eq6								
95	0.4	0	0	0	0	0	0	95	30.1
93	0.4	0	0	0	0	0	0	93	0.0
91	0.3	0	0	1	0	0	1	91	36.7
89	0.3	0	0	0	0	0	1	89	41.8
87	0.3	0	0	1	0	0	2	87	35.5
85	0.2	0	1	1	0	0	3	85	41.6
83	0.2	0	0	1	1	1	3	83	47.2
81	0.2	1	1	1	3	1	7	81	49.8
79	0.1	1	1	1	3	1	7	79	52.0
77	0.1	1	1	1	1	1	5	77	55.5
75	0.1	4	3	2	2	1	12	75	57.5
73	0.1	13	7	7	8	5	40	73	56.4
71	0.1	12	10	10	10	4	47	71	57.5
69	-2.1	-210	-189	-395	-362	-137	-1,294	69	57.1
67	1.6	84	230	414	353	268	1,349	67	55.9
65	6.4	140	981	2,076	1,376	1,236	5,809	65	56.1
63	7.7	46	786	2,119	2,312	2,335	7,598	63	54.4
61	8.9	9	408	1,979	2,636	3,124	8,156	61	51.8
59	9.7	0	58	639	1,481	2,507	4,685	59	50.9
57	10.5	0	63	294	2,391	6,124	8,871	57	49.4
55	12.3	0	0	98	3,068	8,296	11,462	55	47.0
53	12.1	0	0	0	933	4,301	5,234	53	43.9
51	12.0	0	0	0	467	2,756	3,224	51	42.0
49	11.9	0	0	0	154	1,602	1,756	49	40.3
47	11.8	0	0	0	35	917	952	47	35.6
45	11.6	0	0	0	0	349	349	45	33.3
43	11.5	0	0	0	0	219	219	43	27.8
41	11.4	0	0	0	0	23	23	41	24.1
39	11.3	0	0	0	0	34	34	39	23.9
		102	2,360	7,250	14,874	33,967	**58,553**		

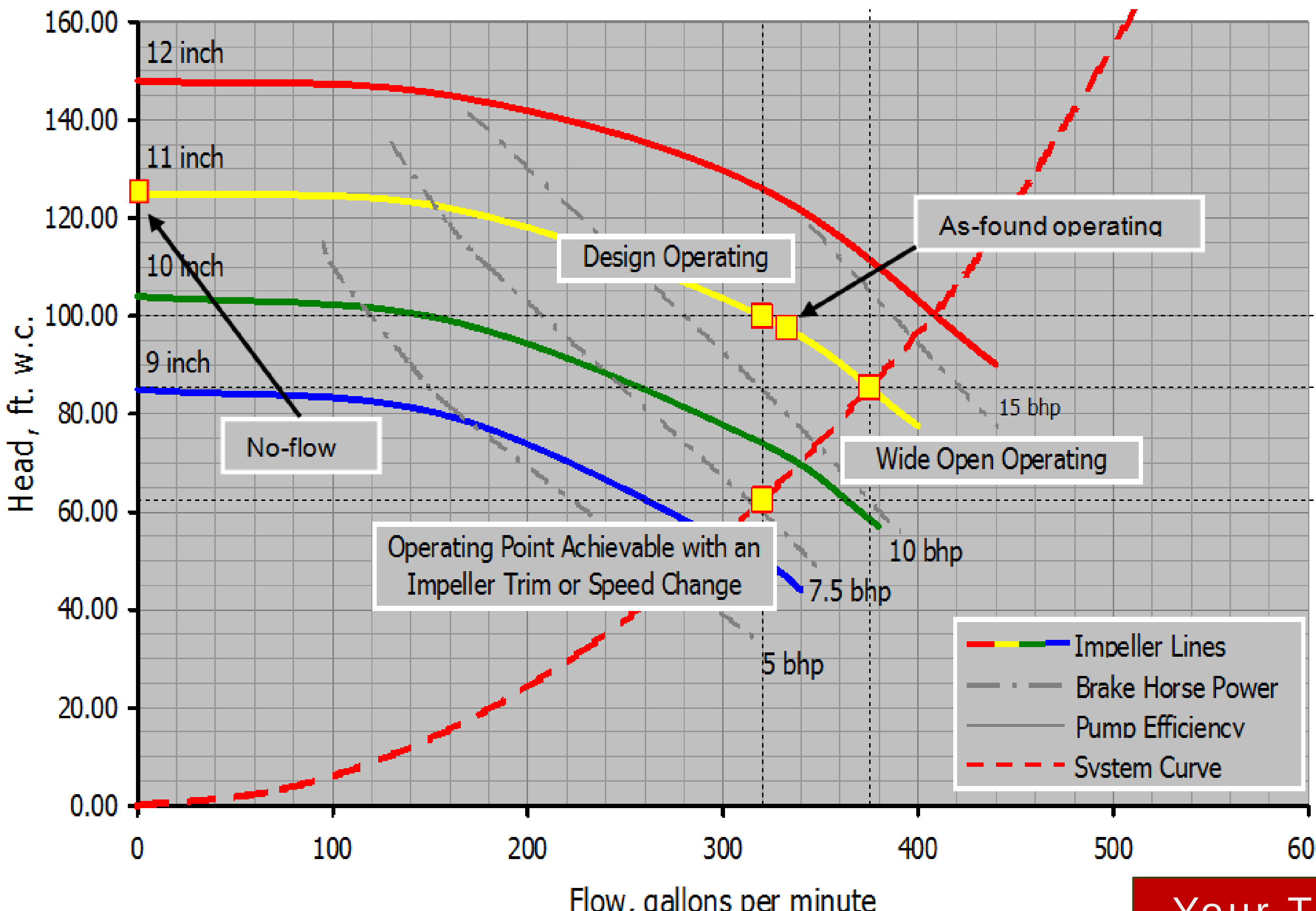
Custom Spreadsheets

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?

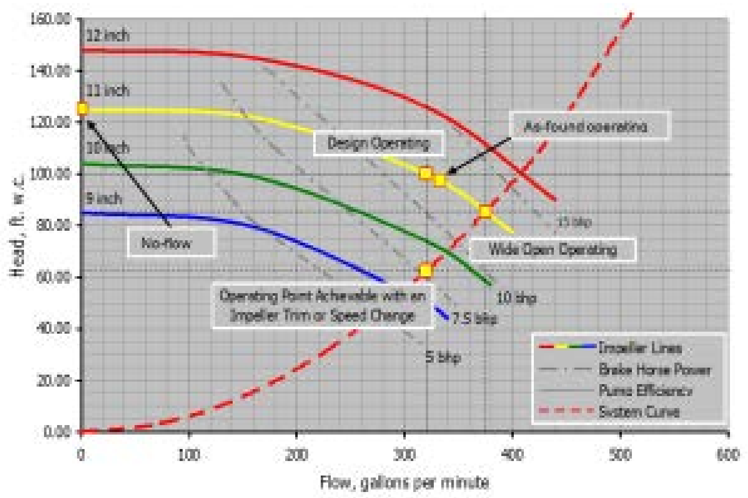


Your Turn!

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

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

Implementation Phase Summary

- Select measures for implementation
- Prepare implementation plan
- Implement measures
- Verify successful measure implementation

Implementation Phase

Owner's considerations when selecting measures

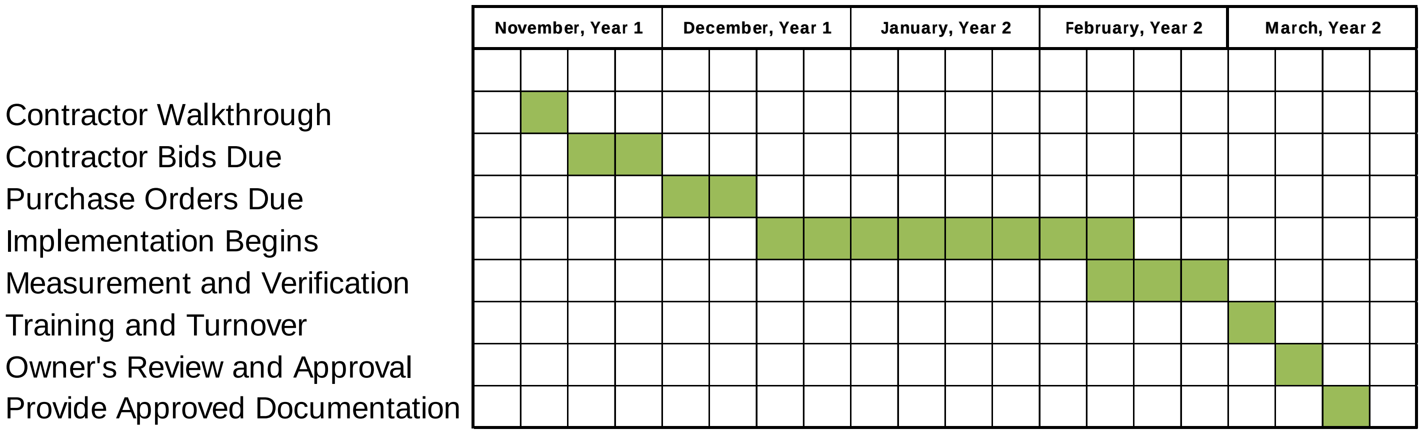
- Benefits
- Costs and available incentives
- Return on investment
- Work done in-house or by contractors?
- Timing (seasonal, budget, etc.)
- Drawbacks, risks

Implementation Phase

Implementation plan topics

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

Implementation Phase Schedule



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.

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

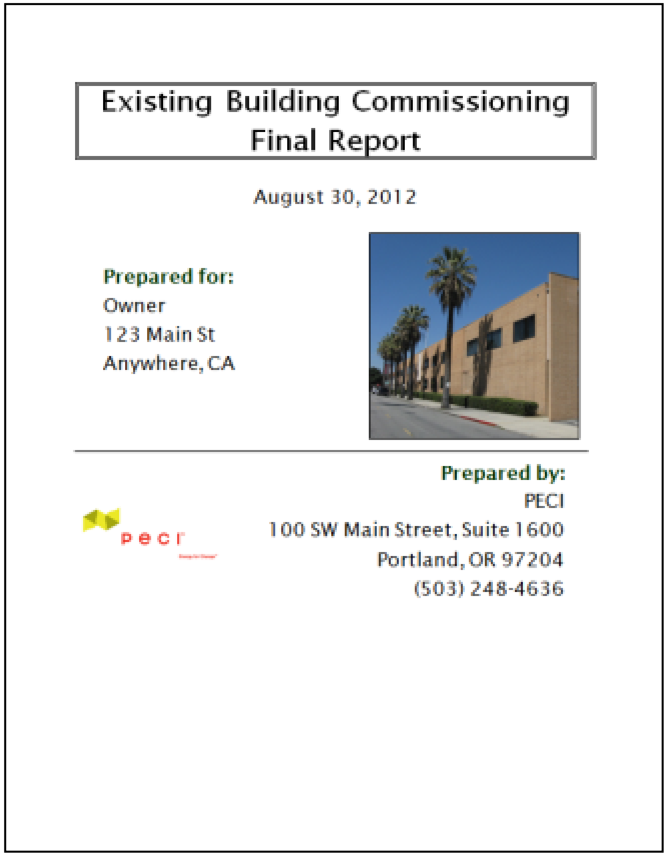
Document the training

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

Hand-Off Phase

Final Report purpose:

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



Existing Building Commissioning
Final Report

August 30, 2012

Prepared for:
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Anywhere, CA

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Portland, OR 97204
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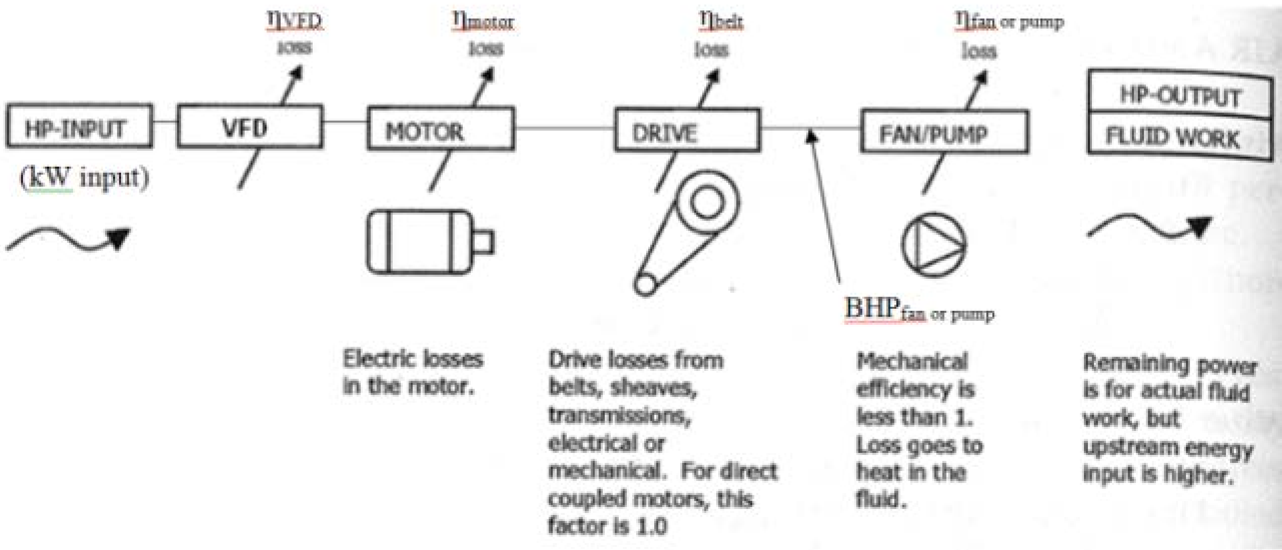
Hand-Off Phase

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



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**

Questions / Discussion

Thank you!

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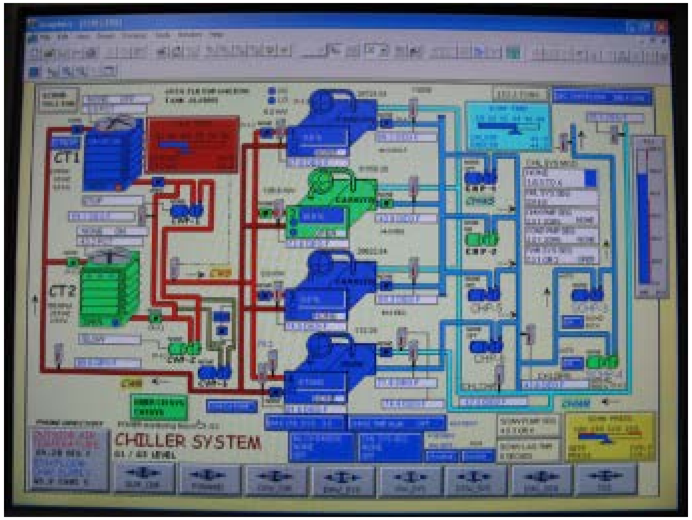

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