An Overview of Commissioning

Presented By:

David Sellers; Facility Dynamics Engineering

Senior Engineer

January 18, 2018

A Bit About Me

1972

- Set out to be an airplane mechanic and aircraft maintenance engineer

A Bit About Me

1976

- Reality intervenes

Image Courtesy www.kpluwonders.org/

A Bit About Me

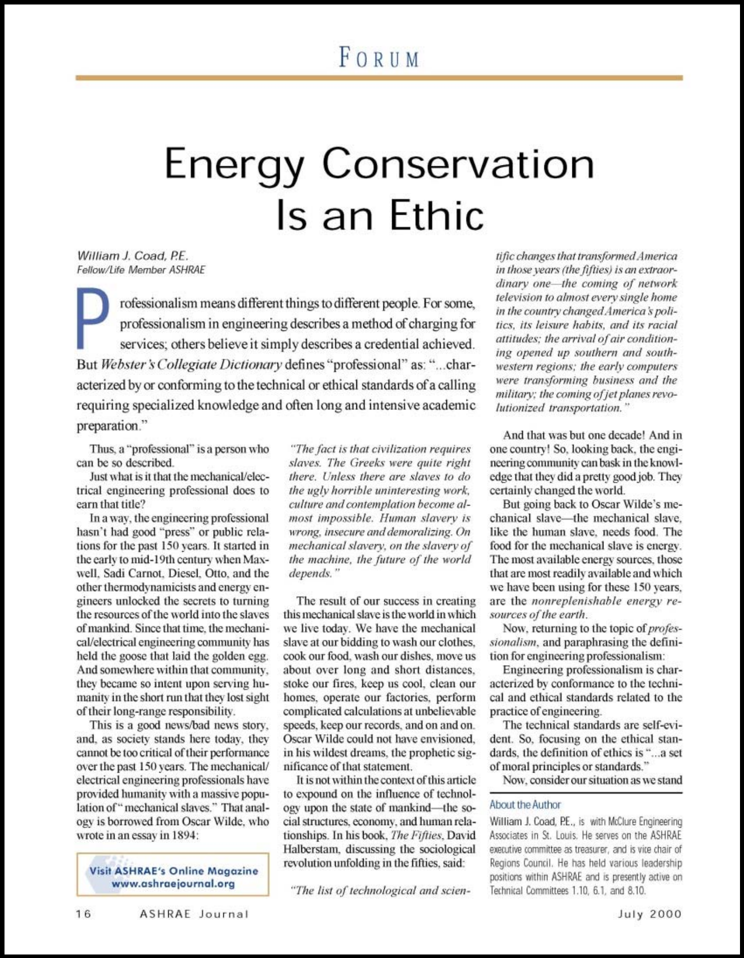
1976

- Bill Coad inspires me to think a different way…

  … that is to practice our profession with an emphasis upon our responsibility to protect the long-range interests of the society we serve and, specifically, to incorporate the ethics of energy conservation and environmental preservation in everything we do.

  ASHRAE Journal, vol. 42, no. 7, p. 16-21

  www.ASHRAE.org



Energy Conservation Is an Ethic

William J. Coad, P.E.
Fellow/Life Member ASHRAE

Professionalism means different things to different people. For some, professionalism in engineering describes a method of charging for services; others believe it simply describes a credential achieved. But *Webster's Collegiate Dictionary* defines "professional" as: "...characterized by or conforming to the technical or ethical standards of a calling requiring specialized knowledge and often long and intensive academic preparation."

Thus, a "professional" is a person who can be so described.

Just what is it that the mechanical/electrical engineering professional does to earn that title?

In a way, the engineering professional hasn't had good "press" or public relations for the past 150 years. It started in the early to mid-19th century when Maxwell, Sadi Carnot, Diesel, Otto, and the other thermodynamicists and energy engineers unlocked the secrets to turning the resources of the world into the slaves of mankind. Since that time, the mechanical/electrical engineering community has held the goose that laid the golden egg. And somewhere within that community, they became so intent upon serving humanity in the short run that they lost sight of their long-range responsibility.

This is a good news/bad news story, and, as society stands here today, they cannot be too critical of their performance over the past 150 years. The mechanical/electrical engineering professionals have provided humanity with a massive population of "mechanical slaves." That analogy is borrowed from Oscar Wilde, who wrote in an essay in 1894:

"The fact is that civilization requires slaves. The Greeks were quite right there. Unless there are slaves to do the ugly horrible uninteresting work, culture and contemplation become almost impossible. Human slavery is wrong, insecure and demoralizing. On mechanical slavery, on the slavery of the machine, the future of the world depends."

The result of our success in creating this mechanical slave is the world in which we live today. We have the mechanical slave at our bidding to wash our clothes, cook our food, wash our dishes, move us about over long and short distances, stoke our fires, keep us cool, clean our homes, operate our factories, perform complicated calculations at unbelievable speeds, keep our records, and on and on. Oscar Wilde could not have envisioned, in his wildest dreams, the prophetic significance of that statement.

It is not within the context of this article to expound on the influence of technology upon the state of mankind—the social structures, economy, and human relationships. In his book, *The Fifties*, David Halberstam, discussing the sociological revolution unfolding in the fifties, said:

"The list of technological and scientific changes that transformed America in those years (the fifties) is an extraordinary one—the coming of network television to almost every single home in the country changed America's politics, its leisure habits, and its racial attitudes; the arrival of air conditioning opened up southern and southwestern regions; the early computers were transforming business and the military; the coming of jet planes revolutionized transportation."

And that was but one decade! And in one country! So, looking back, the engineering community can bask in the knowledge that they did a pretty good job. They certainly changed the world.

But going back to Oscar Wilde's mechanical slave—the mechanical slave, like the human slave, needs food. The food for the mechanical slave is energy. The most available energy sources, those that are most readily available and which we have been using for these 150 years, are the *nonreplenishable energy resources of the earth*.

Now, returning to the topic of *professionalism*, and paraphrasing the definition for engineering professionalism:

Engineering professionalism is characterized by conformance to the technical and ethical standards related to the practice of engineering.

The technical standards are self-evident. So, focusing on the ethical standards, the definition of ethics is "...a set of moral principles or standards."

Now, consider our situation as we stand

About the Author

William J. Coad, P.E., is with McClure Engineering Associates in St. Louis. He serves on the ASHRAE executive committee as treasurer, and is vice chair of Regions Council. He has held various leadership positions within ASHRAE and is presently active on Technical Committees 1.10, 6.1, and 8.10.

A Bit About Me

1976 - 1984

- I change career paths and go to work for McClure Engineering in St. Louis, MO
  - Field technician
  - Control system designer
  - Mechanical designer
  - Project engineer
- I am blessed with great mentors (through-out my career)

A Bit About Me

1984 - 1986

- I go on sabbatical to work for MCC Powers
  - Immersed in a specific system
  - Exposed to process control
  - I figure out how to (inadvertently) crash a control system
  - Begin to realize there is a fundamental lack of understanding of control systems on the part of many designers

A Bit About Me

1984 - 1986

- My sabbatical continues as I work for Murphy Company, Mechanical Contractors
  - Control guy
  - Start-up guy
- I (inadvertently) develop a destructive test procedure to verify duct pressure class
- I understand what David St.Clair meant when he said *It's all about the lags*
- I discover I don't like gambling

A Bit About Me

1986 - 1997

- I return to McClure Engineering as a Project Engineer
  - Migrate their control design standards and specs from pneumatics to DDC
  - Do a lot of Health Care work

A Bit About Me

1997

- Move to Oregon to become a facilities engineer at Komatsu Silicon's Hillsboro facility where I become
  - HVAC system owner
  - Process exhaust air side system owner
  - Central chilled water plant system co-owner
  - DDC system co-owner
  - Fire protection system owner (inadvertently)

A Bit About Me

1999 - 2005

- Semiconductor industry market turns down
  - Plant idled
  - I move to PECI
    - Not-for-profit focused in energy efficiency and sustainability
    - Develop infrastructure for the commissioning industry
    - Discover I can teach if its hands on and technical

A Bit About Me

2005 - Present

- I move to FDE
  - Some new construction Cx
  - Mostly EBCx
  - Third party control system design work
  - A lot of hands-on training
    - Pacific Energy Center
    - Marriott
    - CERL/IMCOM
  - Assume leadership role for FDE's Not-For-Profit division (inadvertently)

What Is Commissioning?

Merriam-Webster

Main Entry: commission \kə-ˈmi-shən\

Function: transitive verb

Inflected Form(s): -mis·sioned; com·mis·sion·ing /-'mi-sh(&-)ni[ng]/

1 : to furnish with a commission: as a : to confer a formal commission on <was commissioned lieutenant> b : to appoint or assign to a task or function <was commissioned to do the biography>

2 : to order to be made <commissioned a portrait>

3 : to put (a ship) in commission

An analogy to a ship's sea trials or "shake-down" cruise

Image courtesy www.public-domain-image.com

Commissioning;

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the Owner's operational needs

- Begins in predesign
- Documents the design intent
- Continues through construction, acceptance, the warranty period, and through the building's life cycle
- Includes functional testing
- Includes training
- Documents performance

Commissioning;

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the Owner's operational needs

- Begins in predesign
- Documents the design intent
- Continues through construction, acceptance, the warranty period, and through the building's life cycle
- Includes functional testing
- Includes training
- Documents performance

Commissioning;

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the Owner's operational needs

- Begins in predesign
- Documents the design intent
- Continues through construction, acceptance, the warranty period, and through the building's life cycle
- Includes functional testing
- Includes training
- Documents performance

Commissioning;

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the Owner’s operational needs

- Begins in predesign
- Documents the design intent
- Continues through construction, acceptance, the warranty period, and through the building’s life cycle
- Includes functional testing
- Includes training
- Documents performance

Commissioning;

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the Owner's operational needs

- Begins in predesign
- Documents the design intent
- Continues through construction, acceptance, the warranty period, and through the building's life cycle
- Includes functional testing
- Includes training
- Documents performance

Commissioning;

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the Owner's operational needs

- Begins in predesign
- Documents the design intent
- Continues through construction, acceptance, the warranty period, and through the building's life cycle
- Includes functional testing
- Includes training
- Documents performance

Commissioning;

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the Owner's operational needs

- Begins in predesign
- Documents the design intent
- Continues through construction, acceptance, the warranty period, and through the building's life cycle
- Includes functional testing
- Includes training
- Documents performance

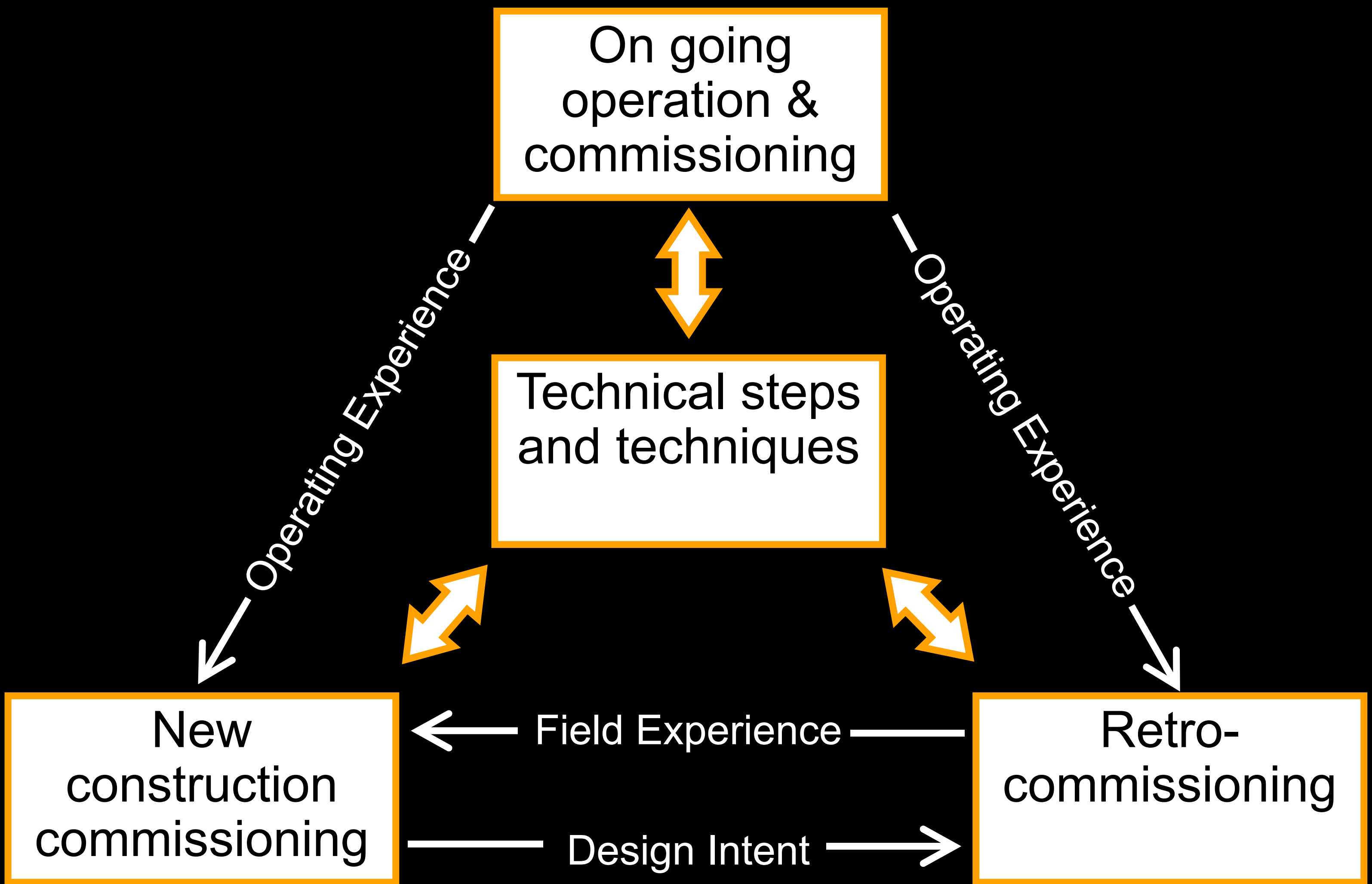
Commissioning; Bottom line

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the Owner's operational needs

- Begins in predesign
- Documents the design intent
- Continues through construction, acceptance, the warranty period, and through the building's life cycle
- Includes functional testing
- Includes training
- Documents performance

Commissioning is about performance and integration

Commissioning Comes in a Number of Styles



What Is Retrocommissioning

In general terms, it's the same thing as:

- RCx
- Existing Building Commissioning
- EBCx
- Recommissioning
- Building tune-up
- MRCx is Marriott's version of Retrocommissioning

What is On-going Commissioning?

Continuous Commissioning™

A Trademarked Process Developed by Texas A&M

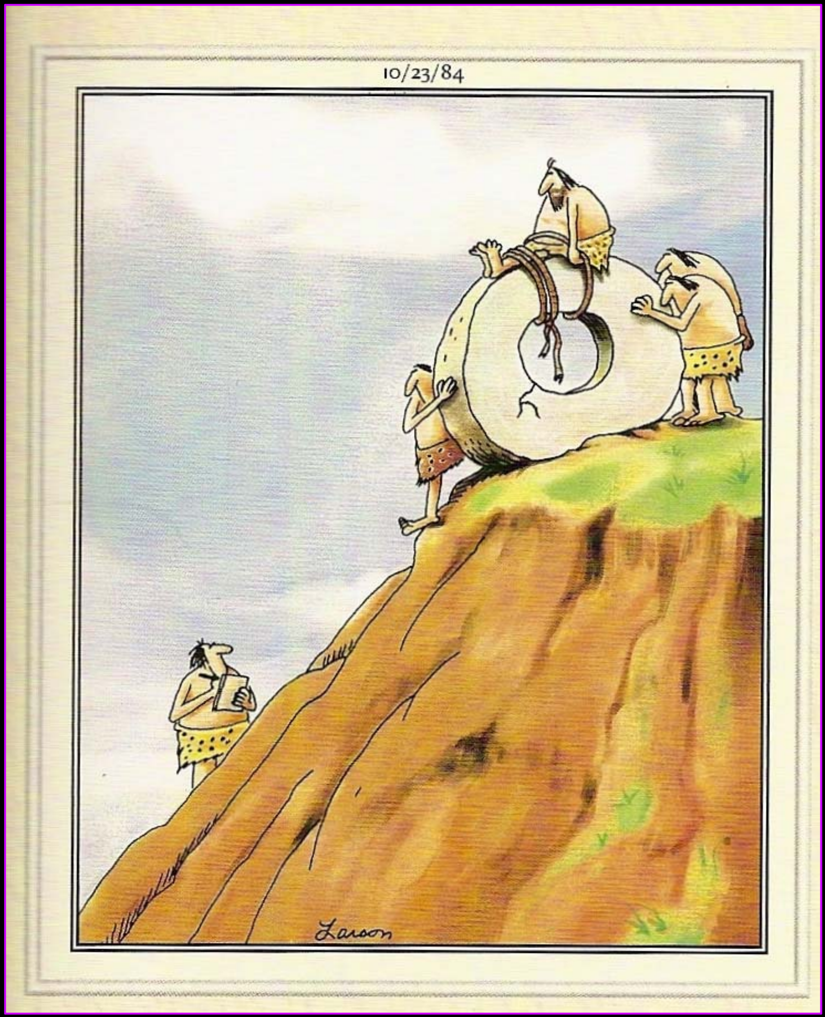
Operating the Building Properly

What folks called it when I started doing this stuff (1976)

No Matter What "Flavor"

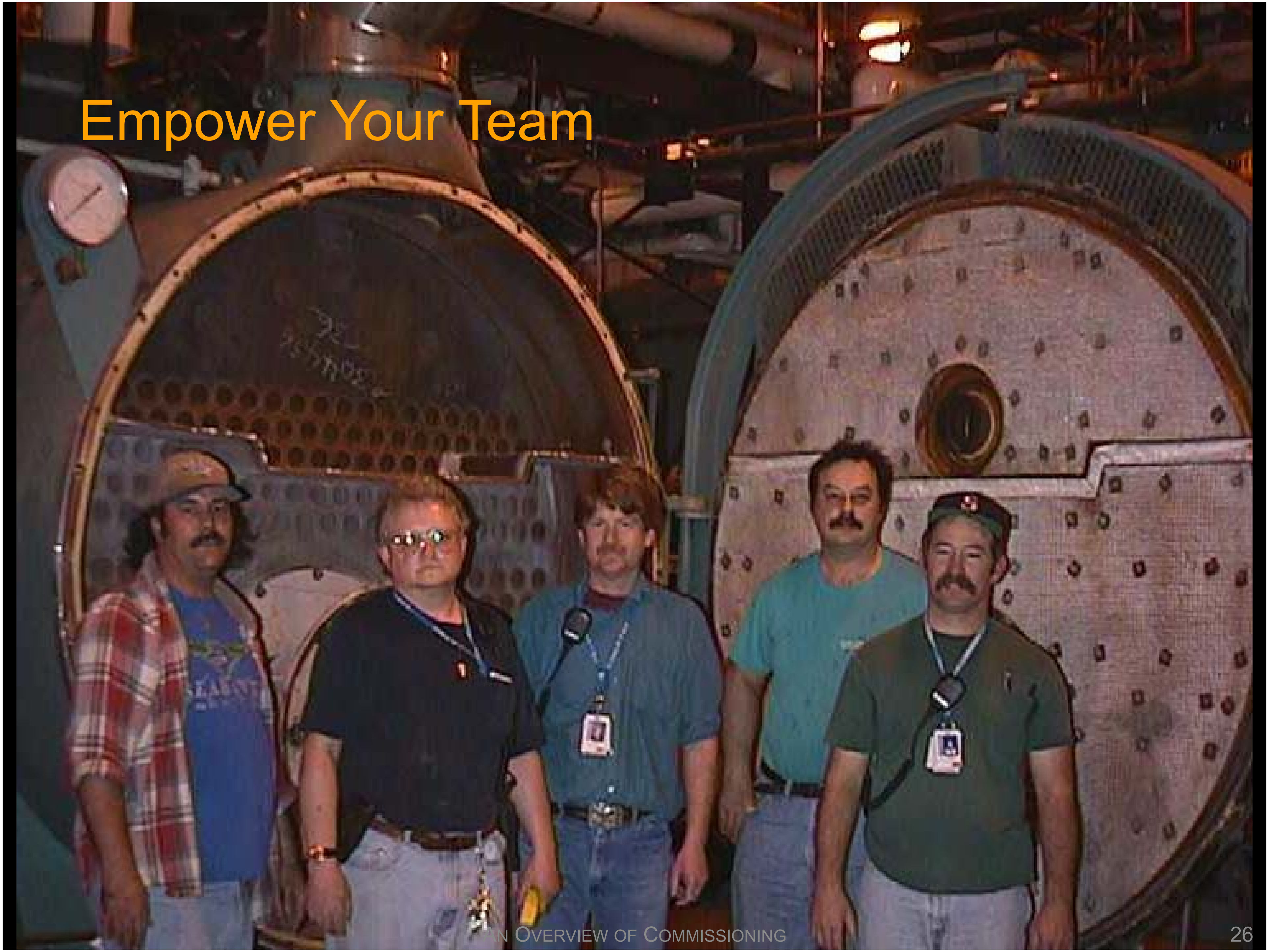
… Cx is a team effort!

The building systems aren't the only thing that will be interactive and require integration from the Cx provider



Prehistoric Commissioning Team

Empower Your Team

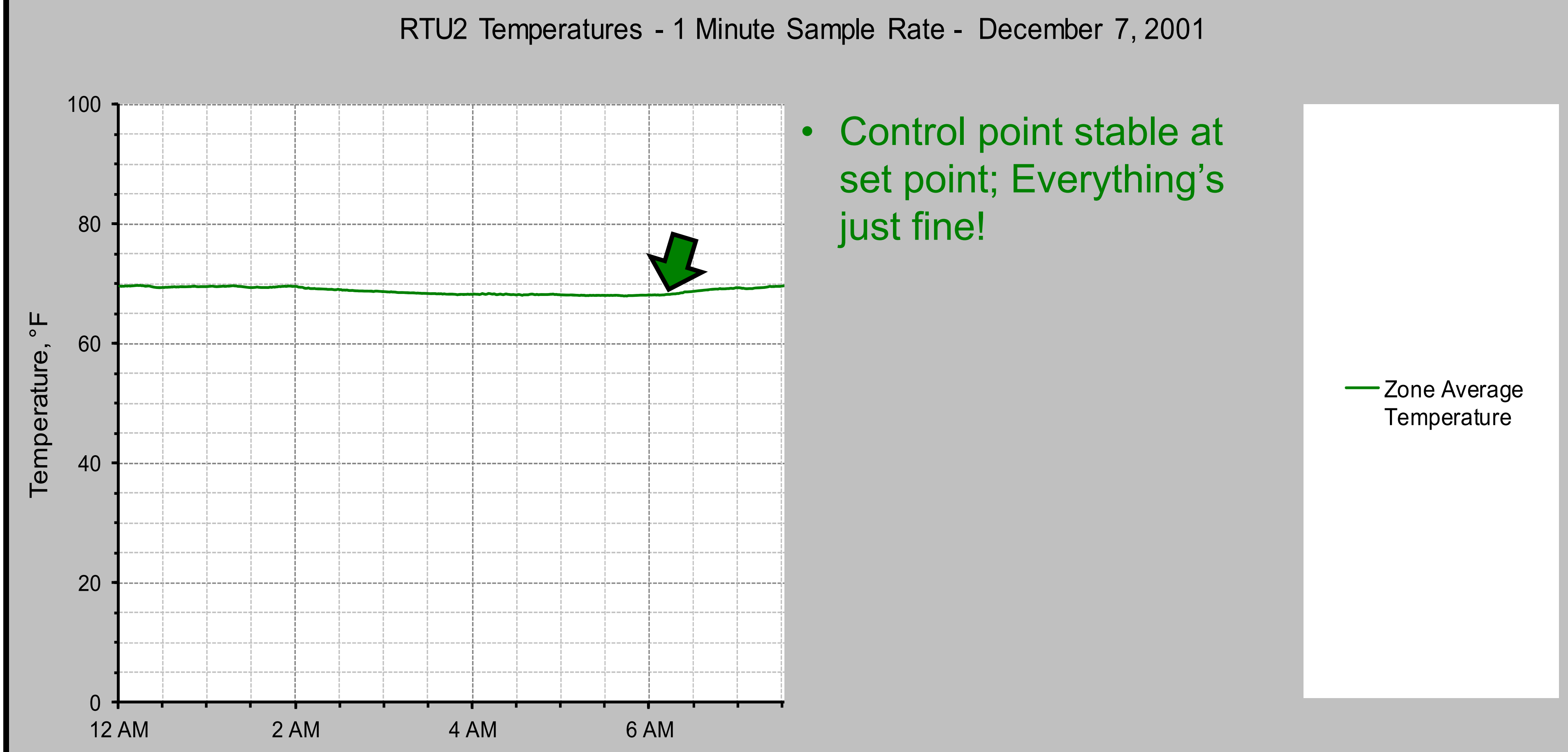


Why Do We Need to Commission?

"Madame, if you are piloting an untested vehicle on its first test flight and that vehicle contains more propellant than was ever placed on a launch pad before and the vehicle was assembled by the low bidder and you aren't a little nervous, then you don't fully comprehend the situation"

Paraphrased; John Young to Barbara Walters when asked if he would be nervous as the test pilot on the first manned shuttle flight

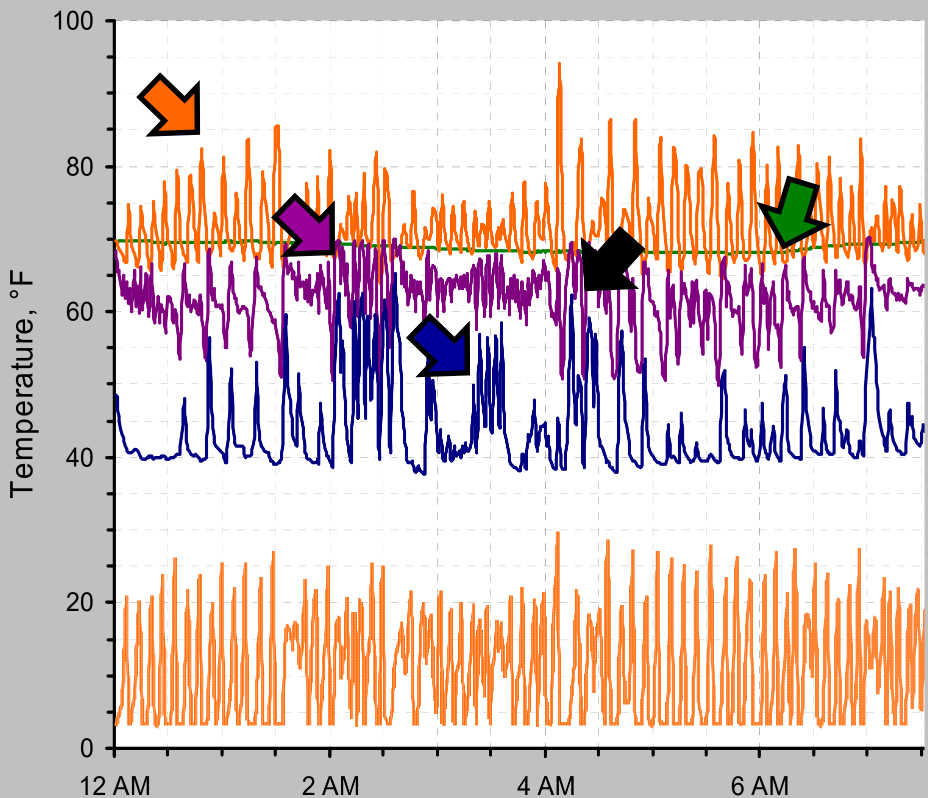
To the Casual Observer, We're Doing O.K.



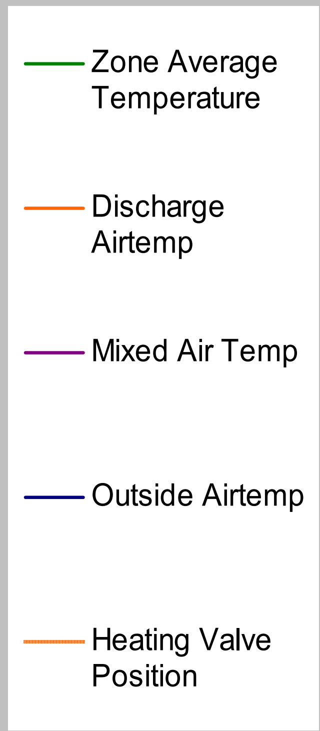
- Control point stable at set point; Everything's just fine!

But They May Not Comprehend the Situation

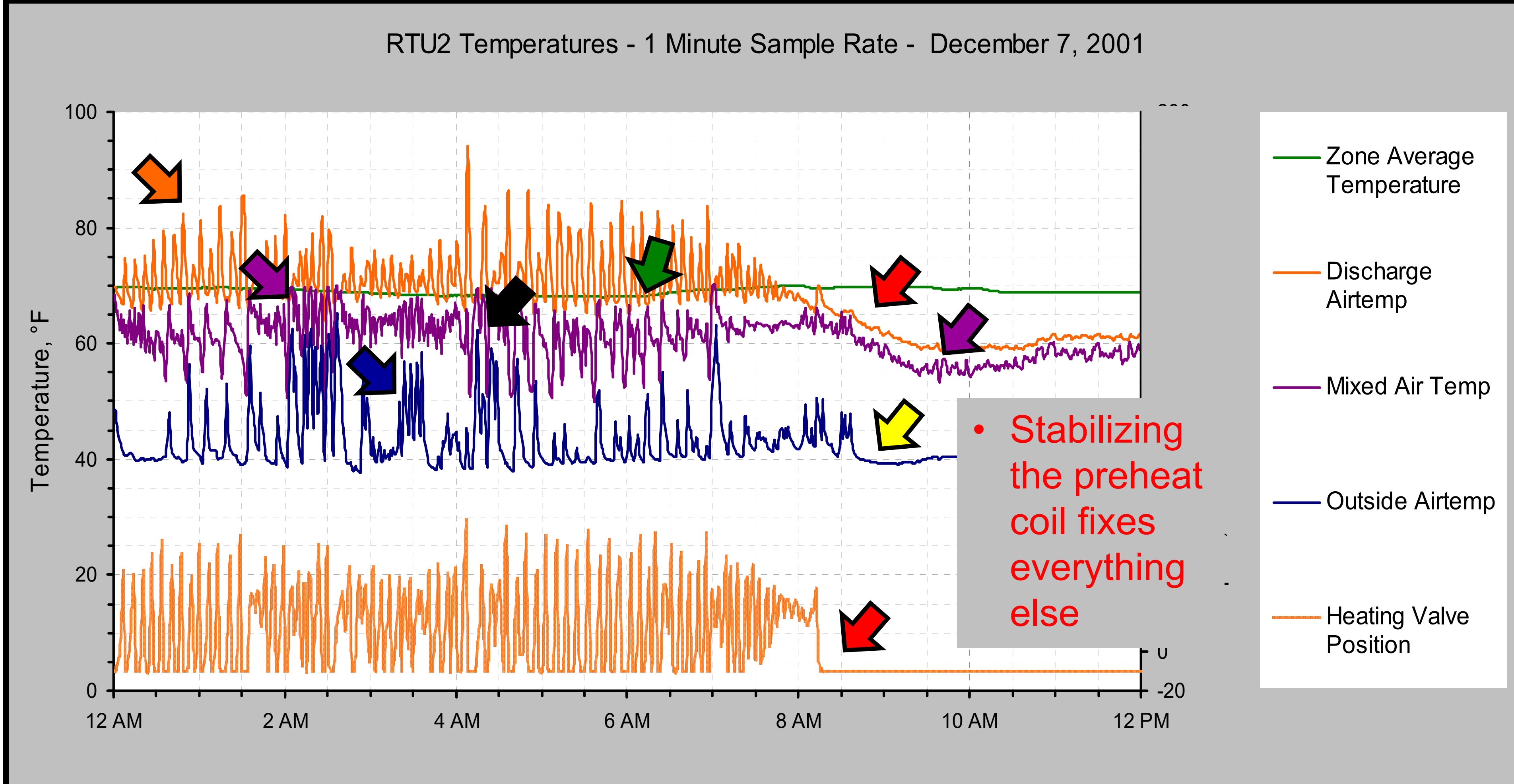
RTU2 Temperatures - 1 Minute Sample Rate - December 7, 2001



- Control point stable at set point; Everything's just fine!
- Preheat coil discharge temperature becomes unstable
- Mixed air temperature becomes unstable
- Outdoor air temperature becomes unstable?
- Chiller plant starts are triggered!



But They May Not Comprehend the Situation



- Stabilizing the preheat coil fixes everything else

Why Do We Need to Retrocommission Systems?

The future is not in plastics, my boy, the future is in construction.

Dr. Joseph Lstiburek

Why Do We Need to Retrocommission Systems?

The future is not in plastics, my boy, the future is in construction. Actually, the future is in fixing construction.

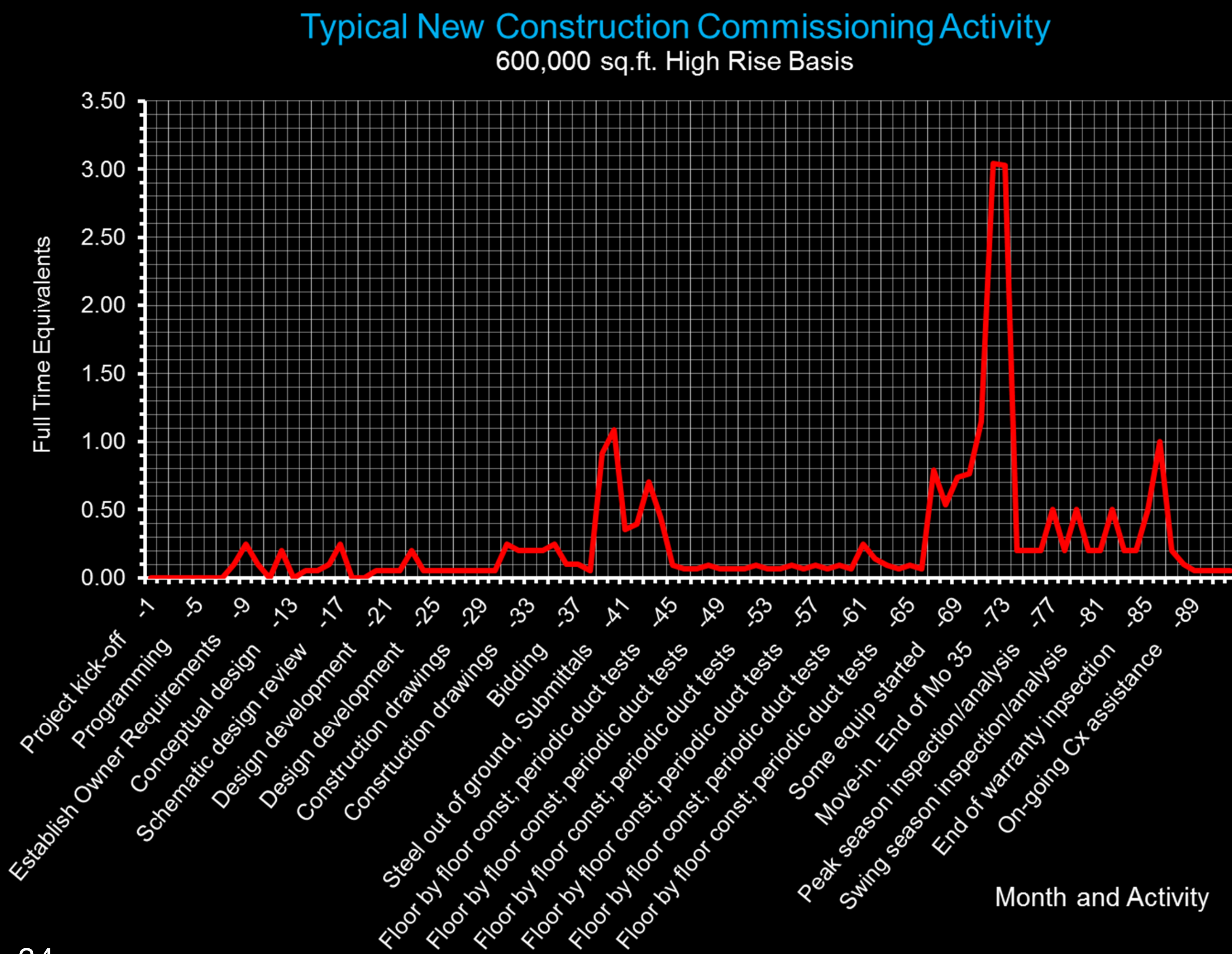
Dr. Joseph Lstiburek

Why Do We Need to Keep On Commissioning Systems?

In a system, a process that occurs will tend to increase the total entropy of the universe.

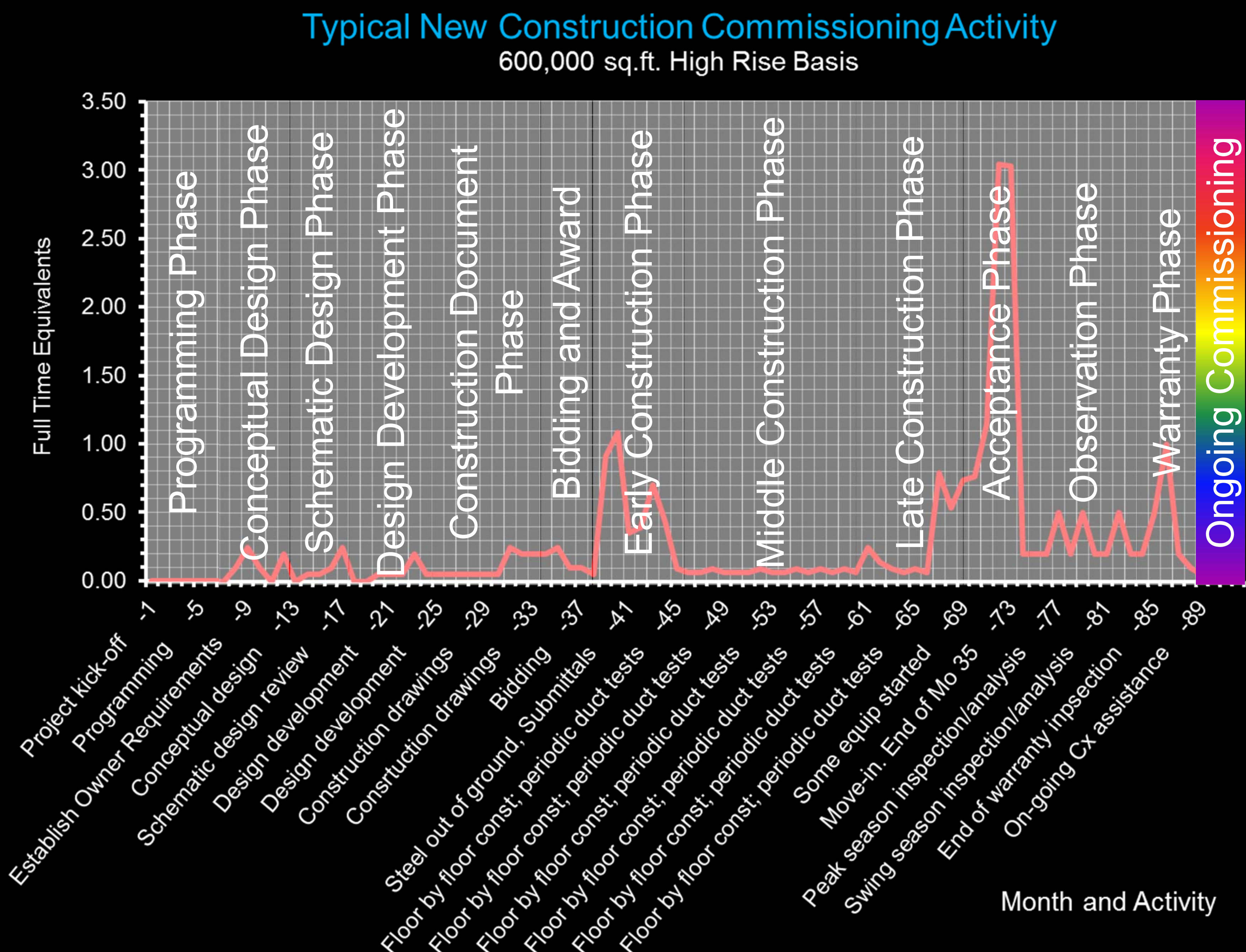
2nd Law of Thermodynamics

- Things wear
- Heat transfer characteristics change
- Things break
- People forget



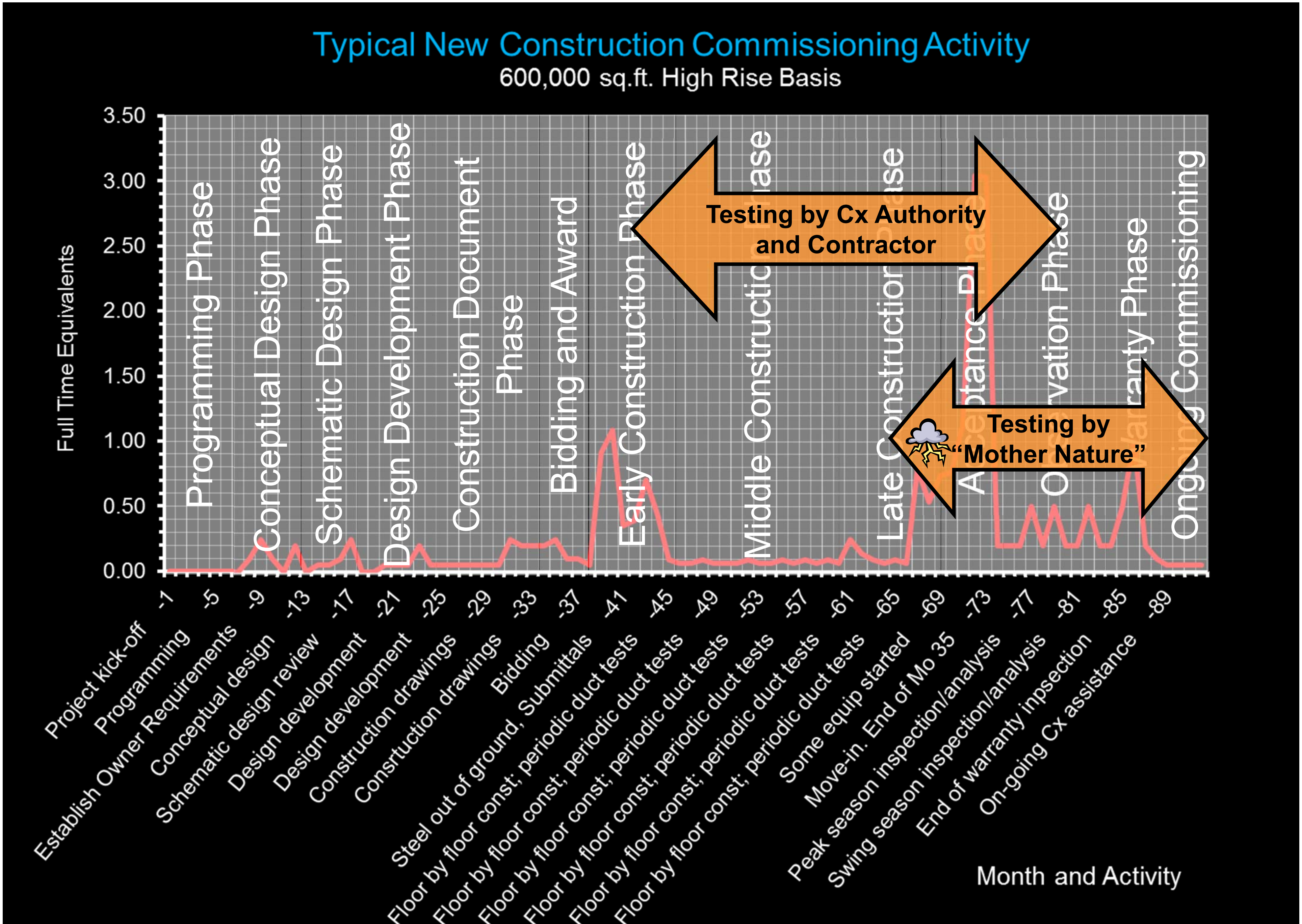
Typical New Construction Commissioning Activity
600,000 sq.ft. High Rise Basis
Full Time Equivalents
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-1
-5
-9
-13
-17
-21
-25
-29
-33
-37
-41
-45
-49
-53
-57
-61
-65
-69
-73
-77
-81
-85
-89
Project kick-off
Programming
Establish Owner Requirements
Conceptual design
Schematic design review
Design development
Design development
Construction drawings
Consrtuction drawings
Bidding
Steel out of ground, Submittals
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Some equip started
Move-in. End of Mo 35
Peak season inspection/analysis
Swing season inspection/analysis
End of warranty inpsection
On-going Cx assistance
Month and Activity

34

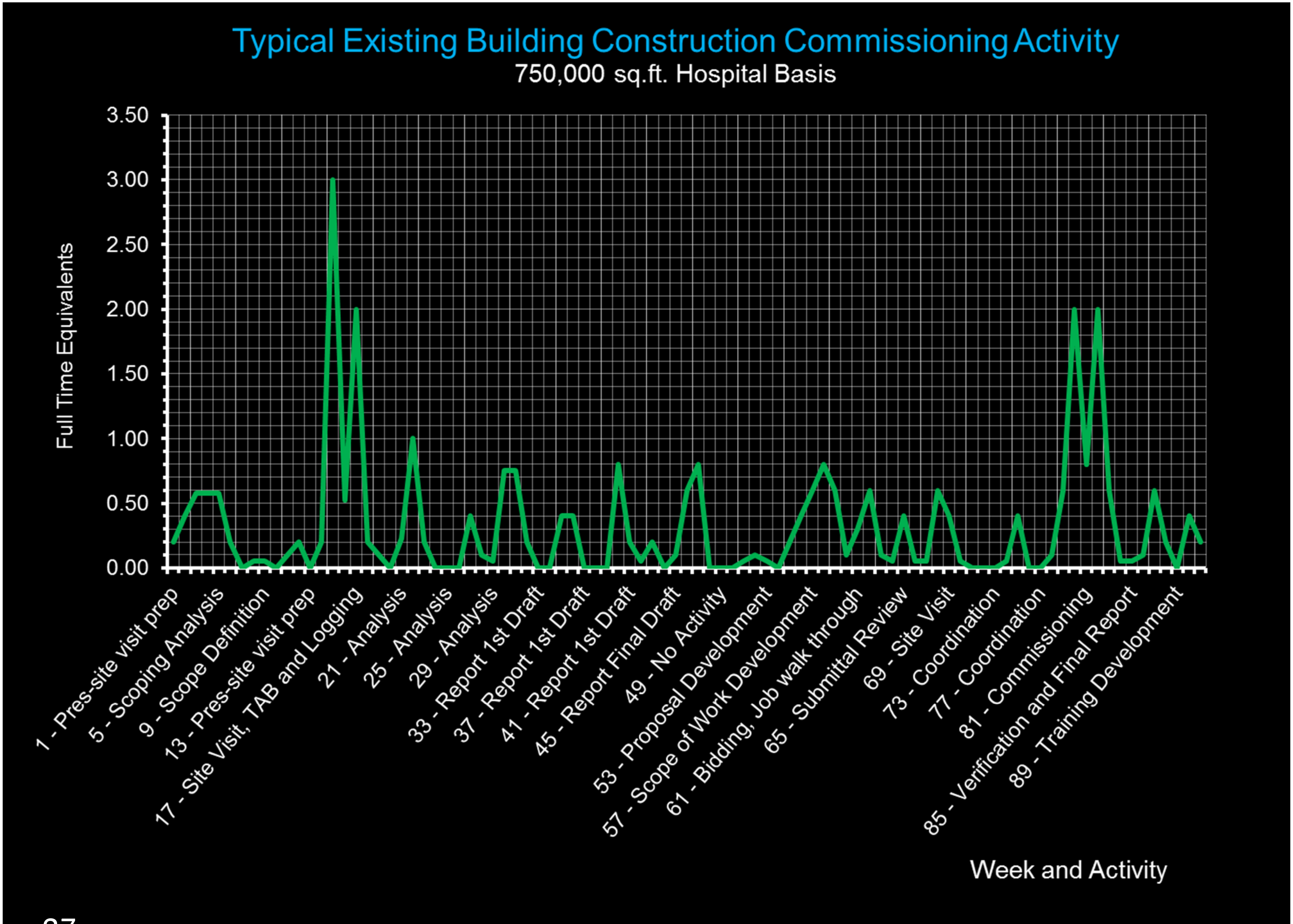


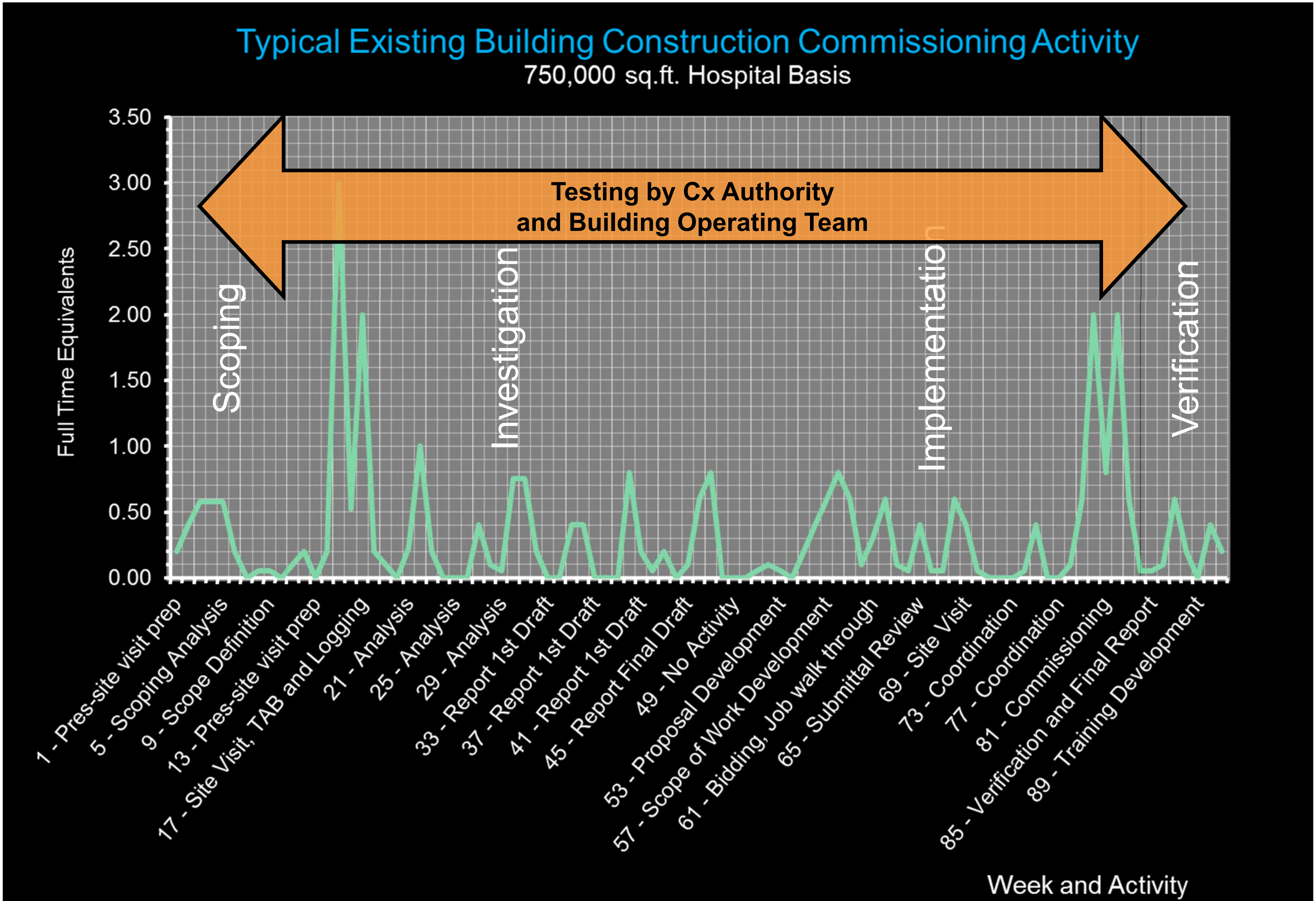
Typical New Construction Commissioning Activity
600,000 sq.ft. High Rise Basis
Full Time Equivalents
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Programming Phase
Conceptual Design Phase
Schematic Design Phase
Design Development Phase
Construction Document Phase
Bidding and Award
Early Construction Phase
Middle Construction Phase
Late Construction Phase
Acceptance Phase
Observation Phase
Warranty Phase
Ongoing Commissioning
-1
-5
-9
-13
-17
-21
-25
-29
-33
-37
-41
-45
-49
-53
-57
-61
-65
-69
-73
-77
-81
-85
-89
Project kick-off
Programming
Establish Owner Requirements
Conceptual design
Schematic design review
Design development
Design development
Construction drawings
Consrtuction drawings
Bidding
Steel out of ground, Submittals
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Some equip started
Move-in. End of Mo 35
Peak season inspection/analysis
Swing season inspection/analysis
End of warranty inpsection
On-going Cx assistance
Month and Activity

35

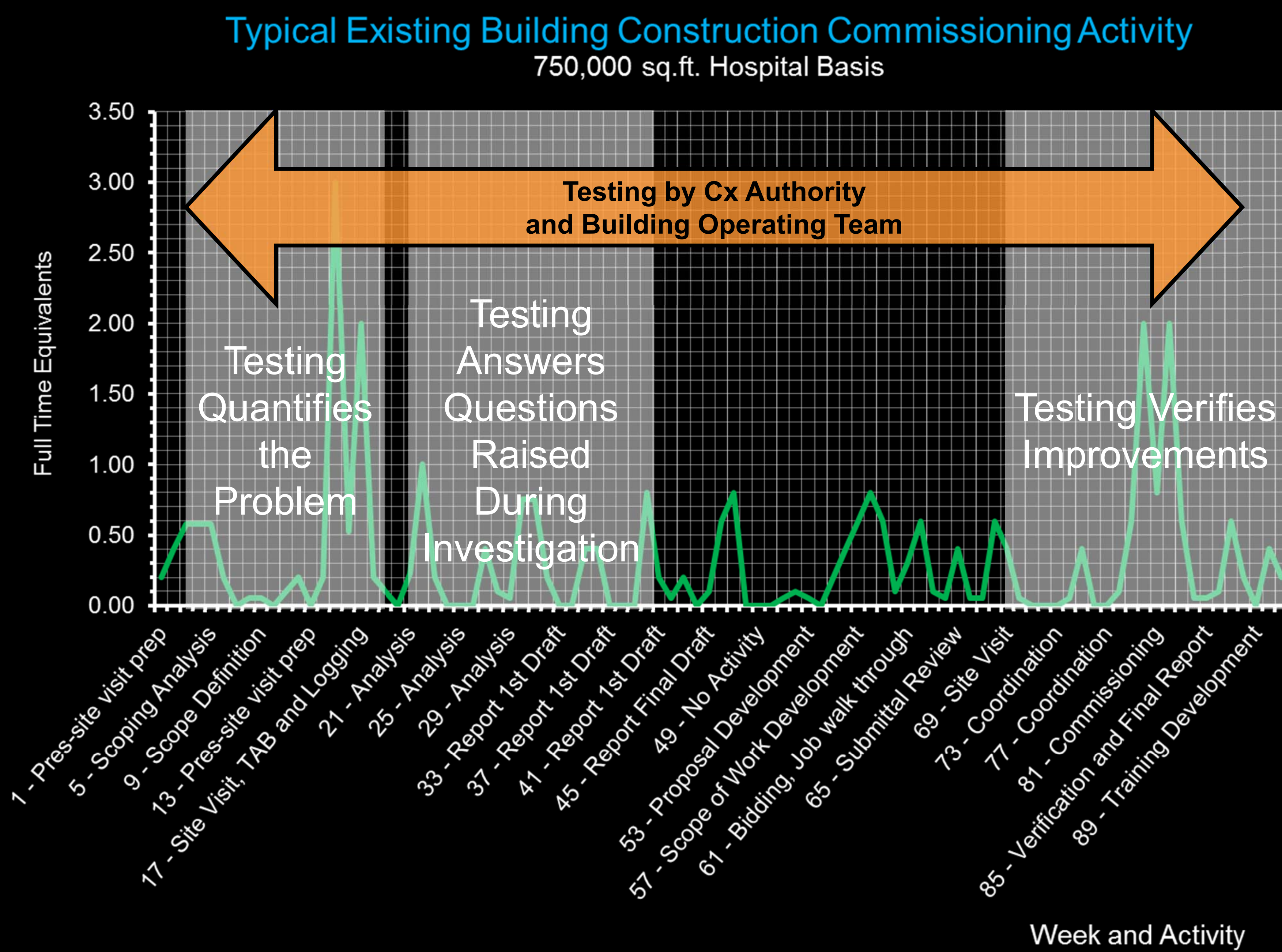

Typical New Construction Commissioning Activity
600,000 sq.ft. High Rise Basis
Full Time Equivalents
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Programming Phase
Conceptual Design Phase
Schematic Design Phase
Design Development Phase
Construction Document Phase
Bidding and Award
Early Construction Phase
Middle Construction Phase
Late Construction Phase
Acceptance Phase
Occupancy and Operation Phase
Warranty Phase
Ongoing Commissioning
Testing by Cx Authority and Contractor
Testing by "Mother Nature"
-1 -5 -9 -13 -17 -21 -25 -29 -33 -37 -41 -45 -49 -53 -57 -61 -65 -69 -73 -77 -81 -85 -89
Project kick-off
Programming
Establish Owner Requirements
Conceptual design
Schematic design review
Design development
Design development
Construction drawings
Consrtuction drawings
Bidding
Steel out of ground, Submittals
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Floor by floor const; periodic duct tests
Some equip started
Move-in. End of Mo 35
Peak season inspection/analysis
Swing season inspection/analysis
End of warranty inpsection
On-going Cx assistance
Month and Activity

36


Typical Existing Building Construction Commissioning Activity
750,000 sq.ft. Hospital Basis
Full Time Equivalents
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 - Pres-site visit prep
5 - Scoping Analysis
9 - Scope Definition
13 - Pres-site visit prep
17 - Site Visit, TAB and Logging
21 - Analysis
25 - Analysis
29 - Analysis
33 - Report 1st Draft
37 - Report 1st Draft
41 - Report 1st Draft
45 - Report Final Draft
49 - No Activity
53 - Proposal Development
57 - Scope of Work Development
61 - Bidding, Job walk through
65 - Submittal Review
69 - Site Visit
73 - Coordination
77 - Coordination
81 - Commissioning
85 - Verification and Final Report
89 - Training Development
Week and Activity
37


Typical Existing Building Construction Commissioning Activity
750,000 sq.ft. Hospital Basis
Full Time Equivalents
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Testing by Cx Authority
and Building Operating Team
Scoping
Investigation
Implementation
Verification
1 - Pres-site visit prep
5 - Scoping Analysis
9 - Scope Definition
13 - Pres-site visit prep
17 - Site Visit, TAB and Logging
21 - Analysis
25 - Analysis
29 - Analysis
33 - Report 1st Draft
37 - Report 1st Draft
41 - Report 1st Draft
45 - Report Final Draft
49 - No Activity
53 - Proposal Development
57 - Scope of Work Development
61 - Bidding, Job walk through
65 - Submittal Review
69 - Site Visit
73 - Coordination
77 - Coordination
81 - Commissioning
85 - Verification and Final Report
89 - Training Development
Week and Activity

38



Typical Existing Building Construction Commissioning Activity
750,000 sq.ft. Hospital Basis
Full Time Equivalents
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Testing by Cx Authority
and Building Operating Team
Testing Quantifies the Problem
Testing Answers Questions Raised During Investigation
Testing Verifies Improvements
1 - Pres-site visit prep
5 - Scoping Analysis
9 - Scope Definition
13 - Pres-site visit prep
17 - Site Visit, TAB and Logging
21 - Analysis
25 - Analysis
29 - Analysis
33 - Report 1st Draft
37 - Report 1st Draft
41 - Report 1st Draft
45 - Report Final Draft
49 - No Activity
53 - Proposal Development
57 - Scope of Work Development
61 - Bidding, Job walk through
65 - Submittal Review
69 - Site Visit
73 - Coordination
77 - Coordination
81 - Commissioning
85 - Verification and Final Report
89 - Training Development
Week and Activity

39

New Construction versus Existing Building Cx

New Construction

- Trying to prove design intent
- Demonstrate all elements of the system meet requirements
- Verification and quality assurance process

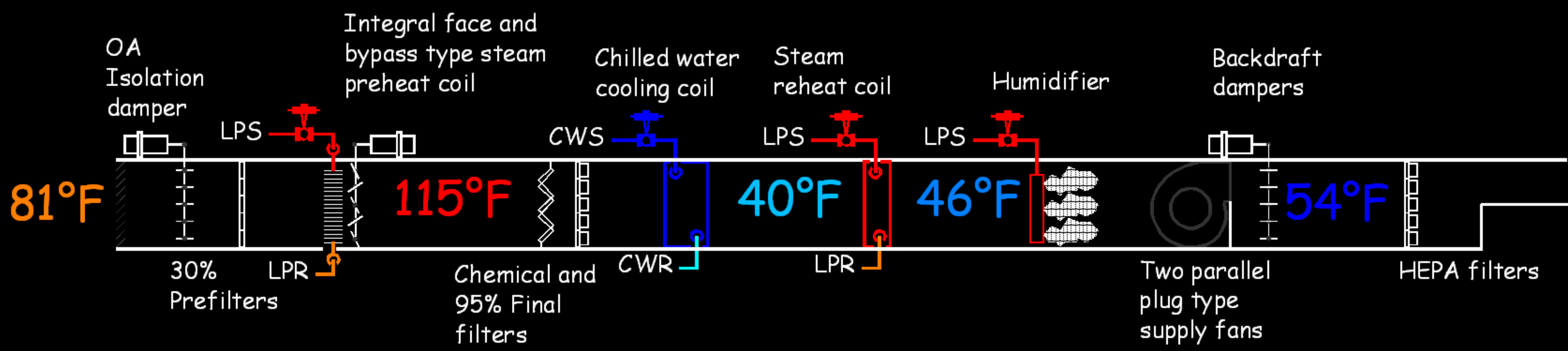
EBCx

- Trying to understand design intent
- Focused on certain elements of the system
- Diagnostic and troubleshooting process

The System Concept

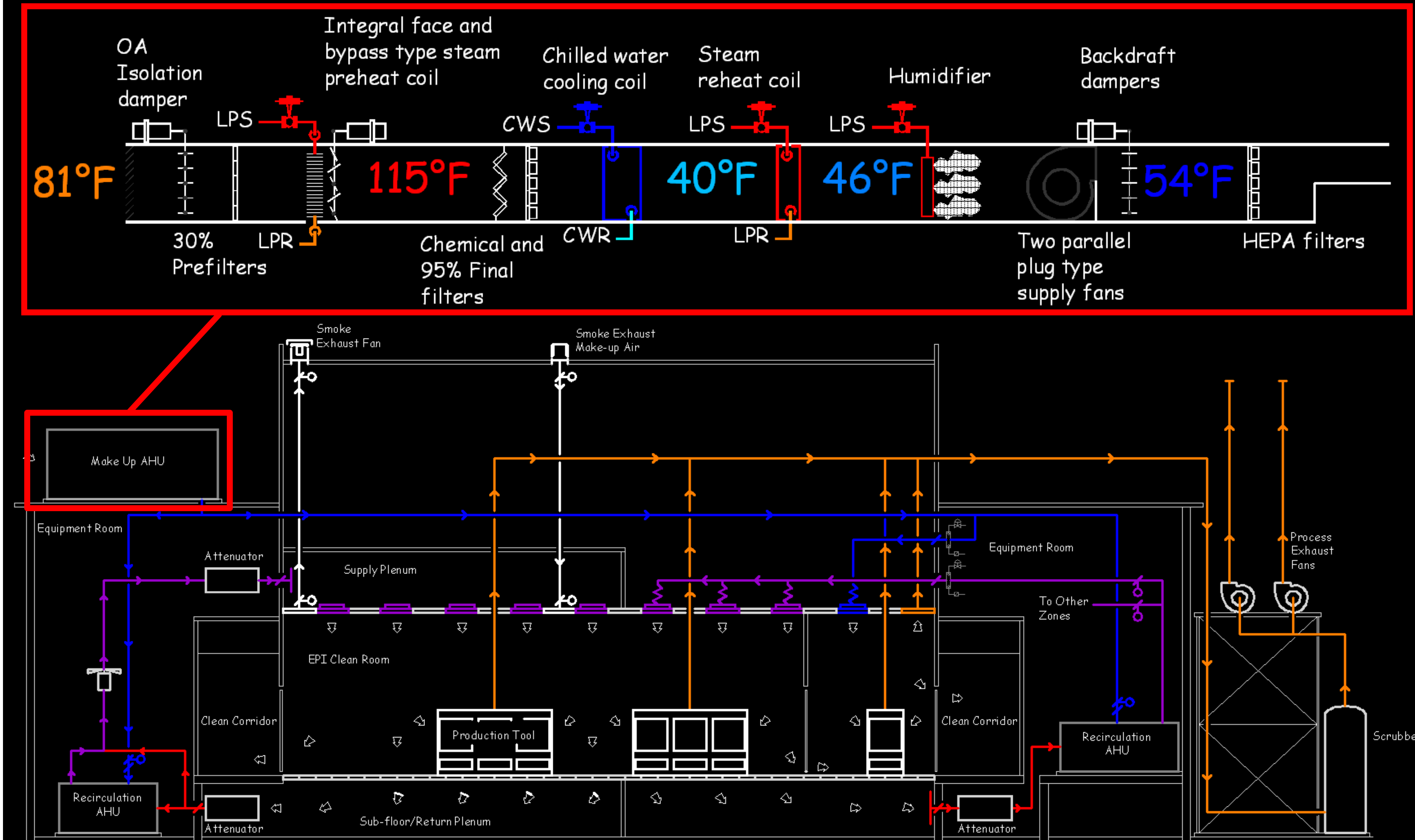
Critical to success for design, commissioning and operation

Its Not Just an Air Handling Unit …

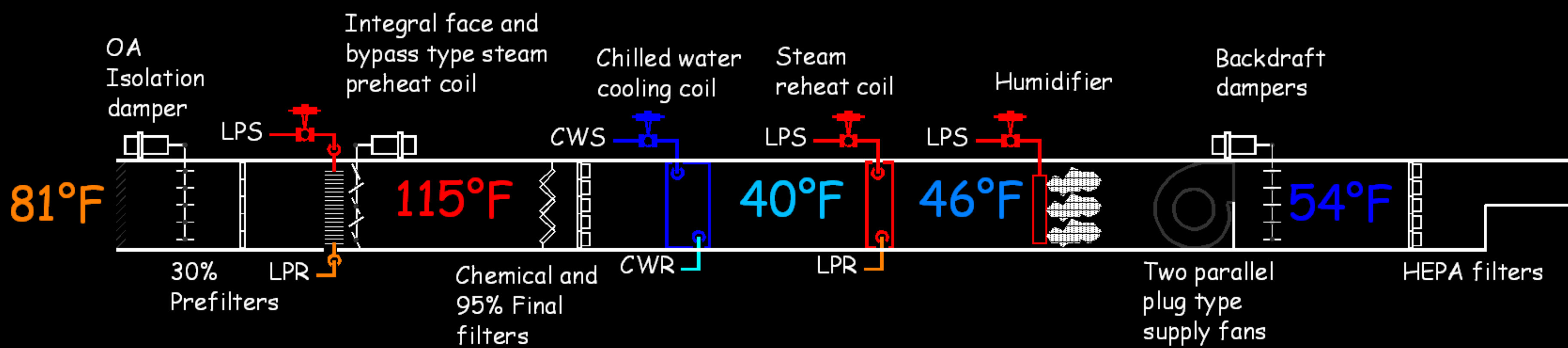


Its Not Just an Air Handling Unit …

…It's an Air Handling System



Its Not Just an Air Handling Unit …



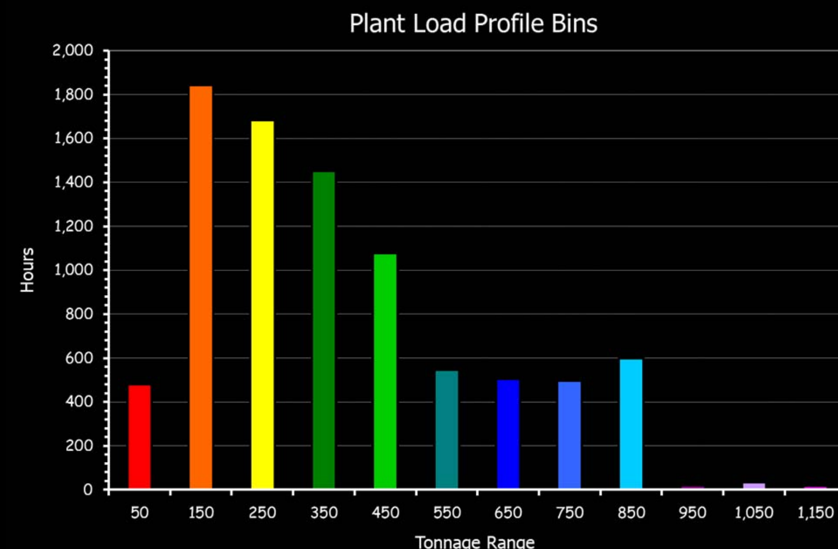
Visit http://www.av8rdas.com/case-studies.html#MAUOptimize for details

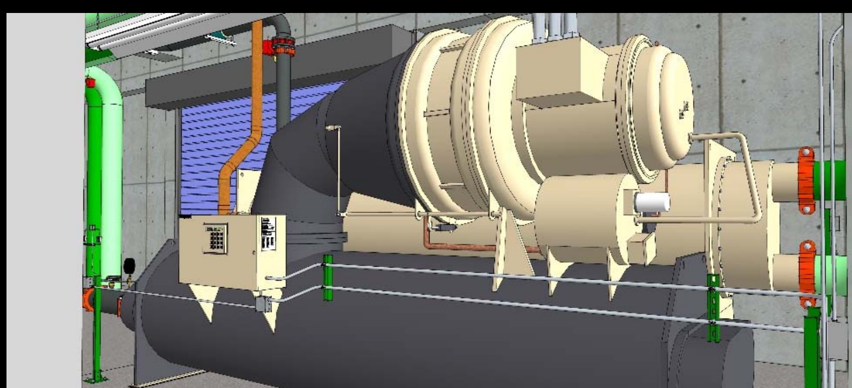
The System
Concept in Action

The System Design Intent and the System Configuration Need to Complement Each Other

The System Concept in Action

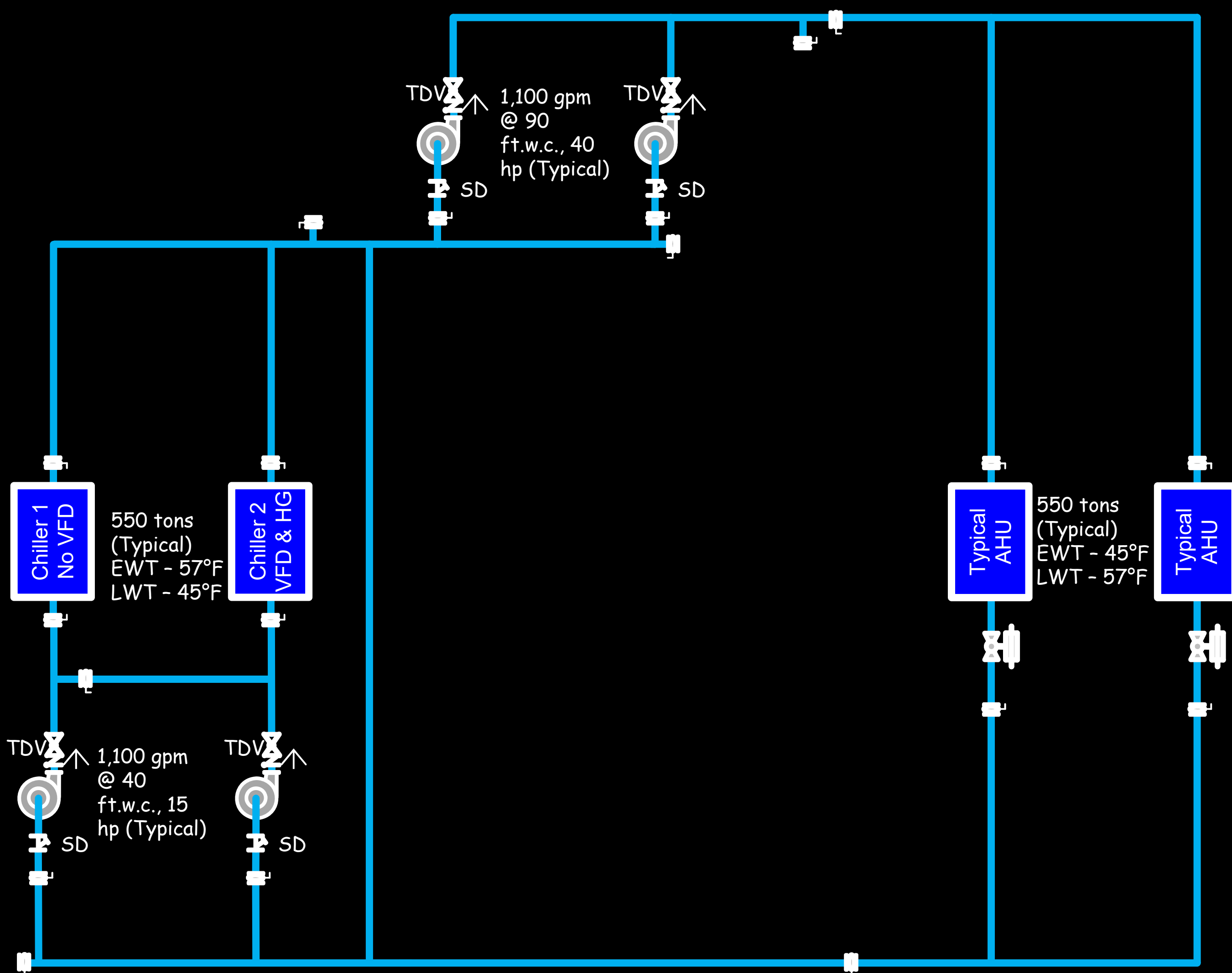
- Variable flow, primary/secondary design
- Significant number of part load hours
- Variable speed chiller optimized for low and part load
- Fixed speed chiller optimized for full load





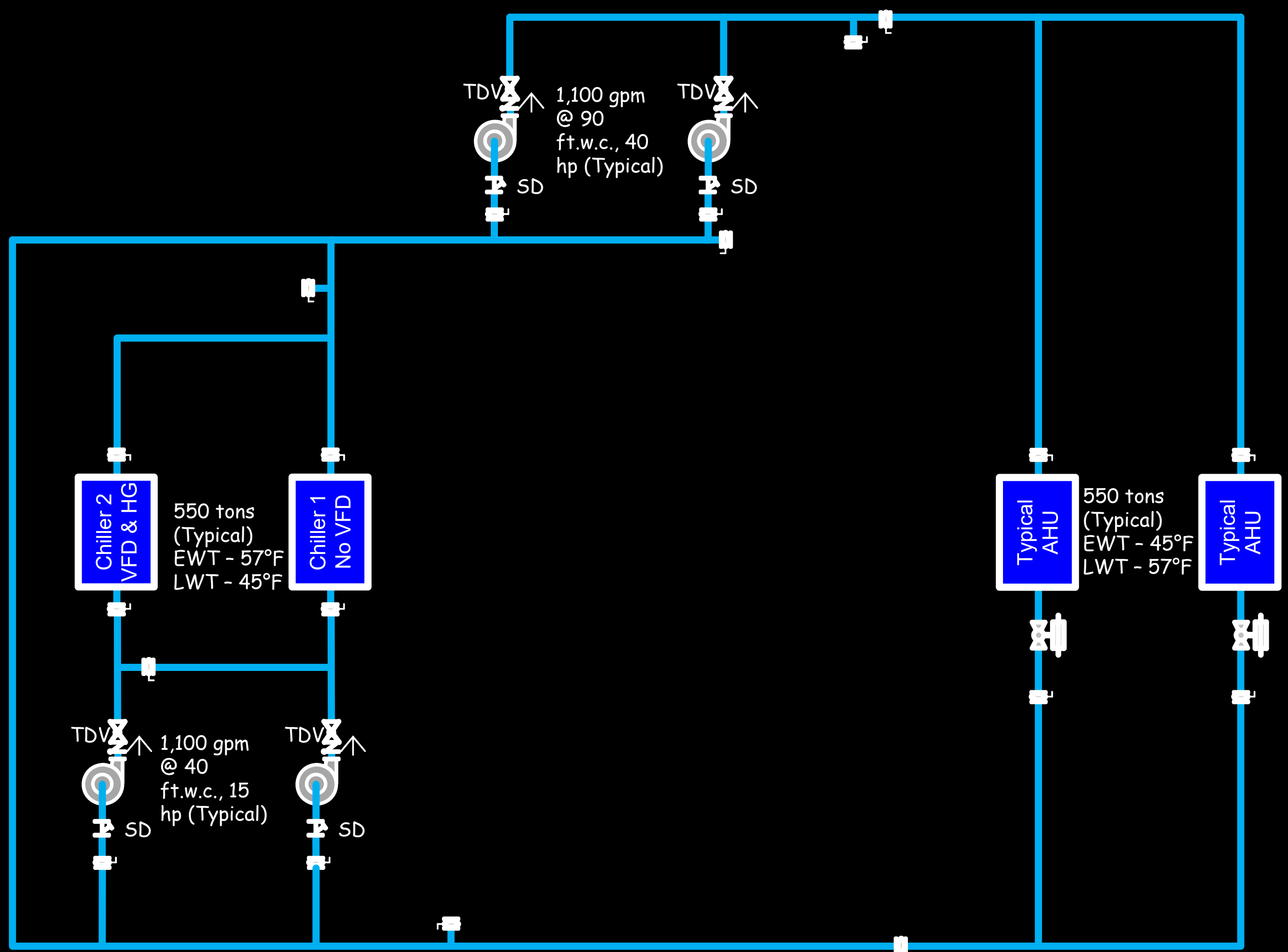
The System Concept in Action

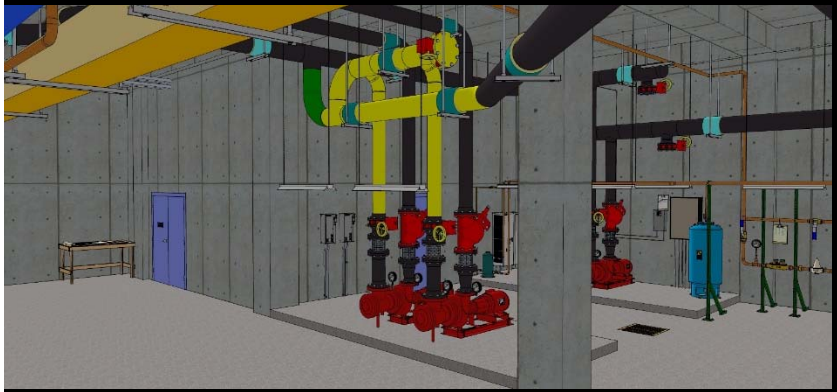
As Installed System Diagram



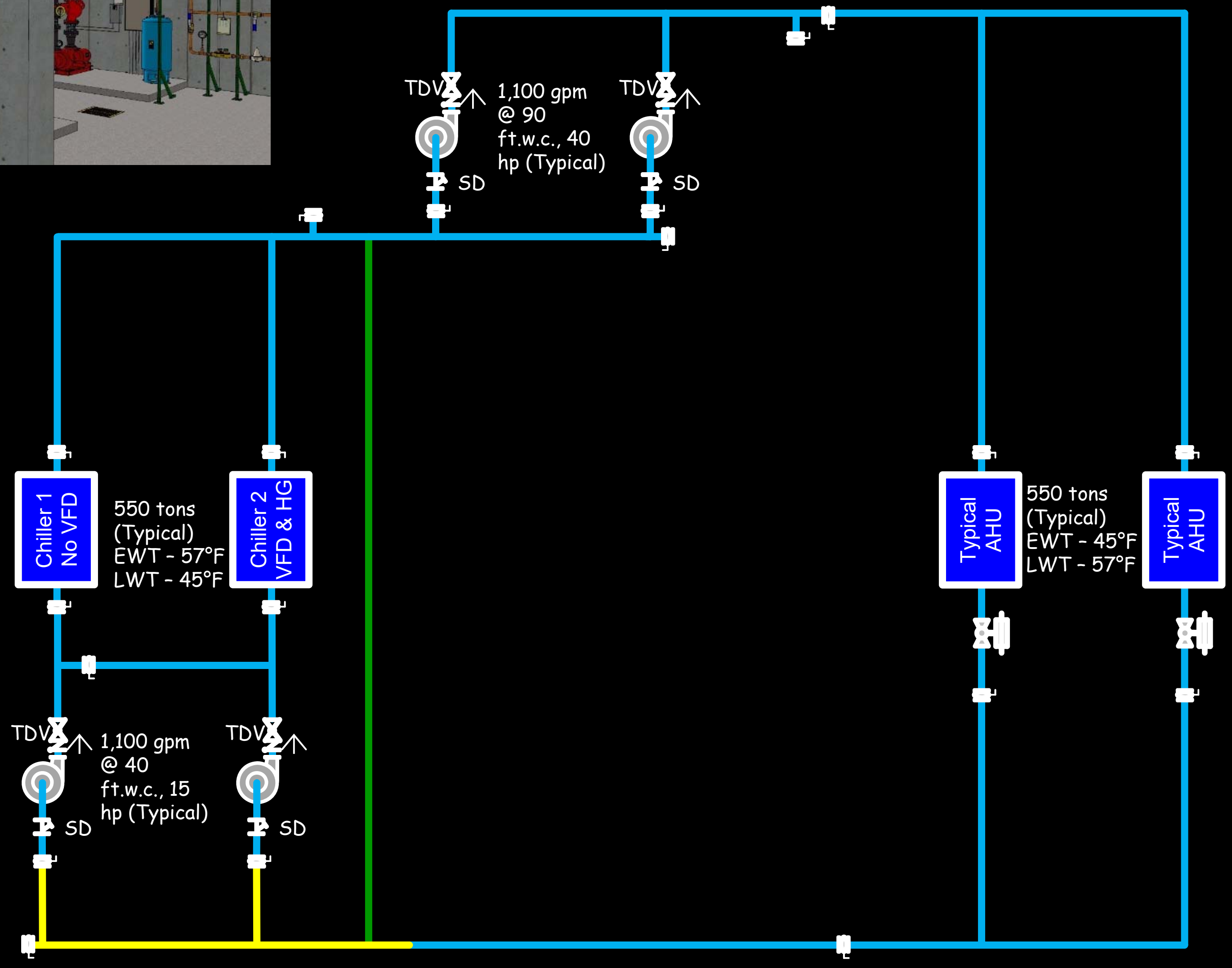
The System Concept in Action

As Intended System Diagram

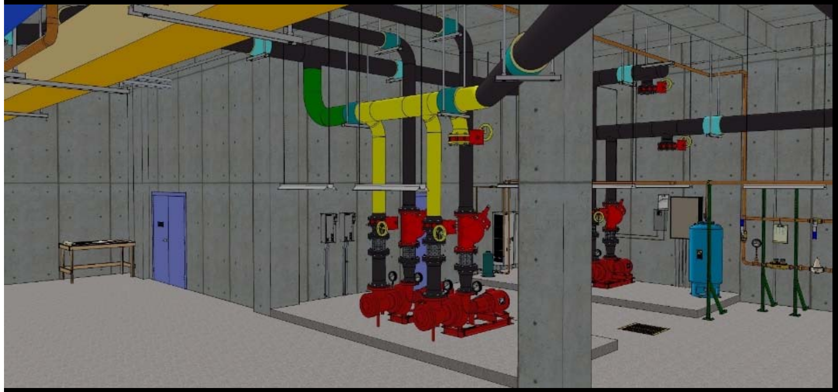


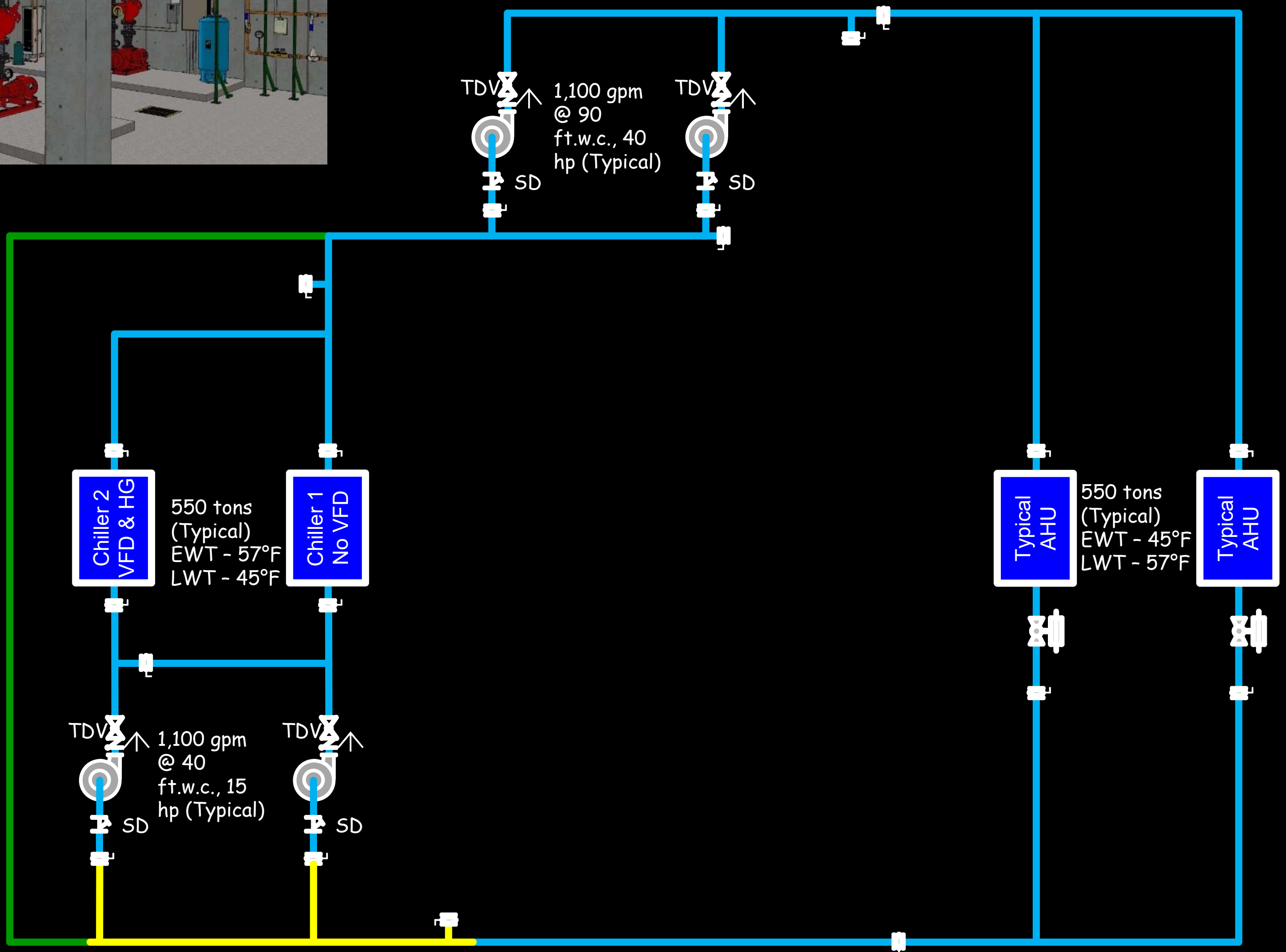


As Installed System Diagram



As Intended System Diagram



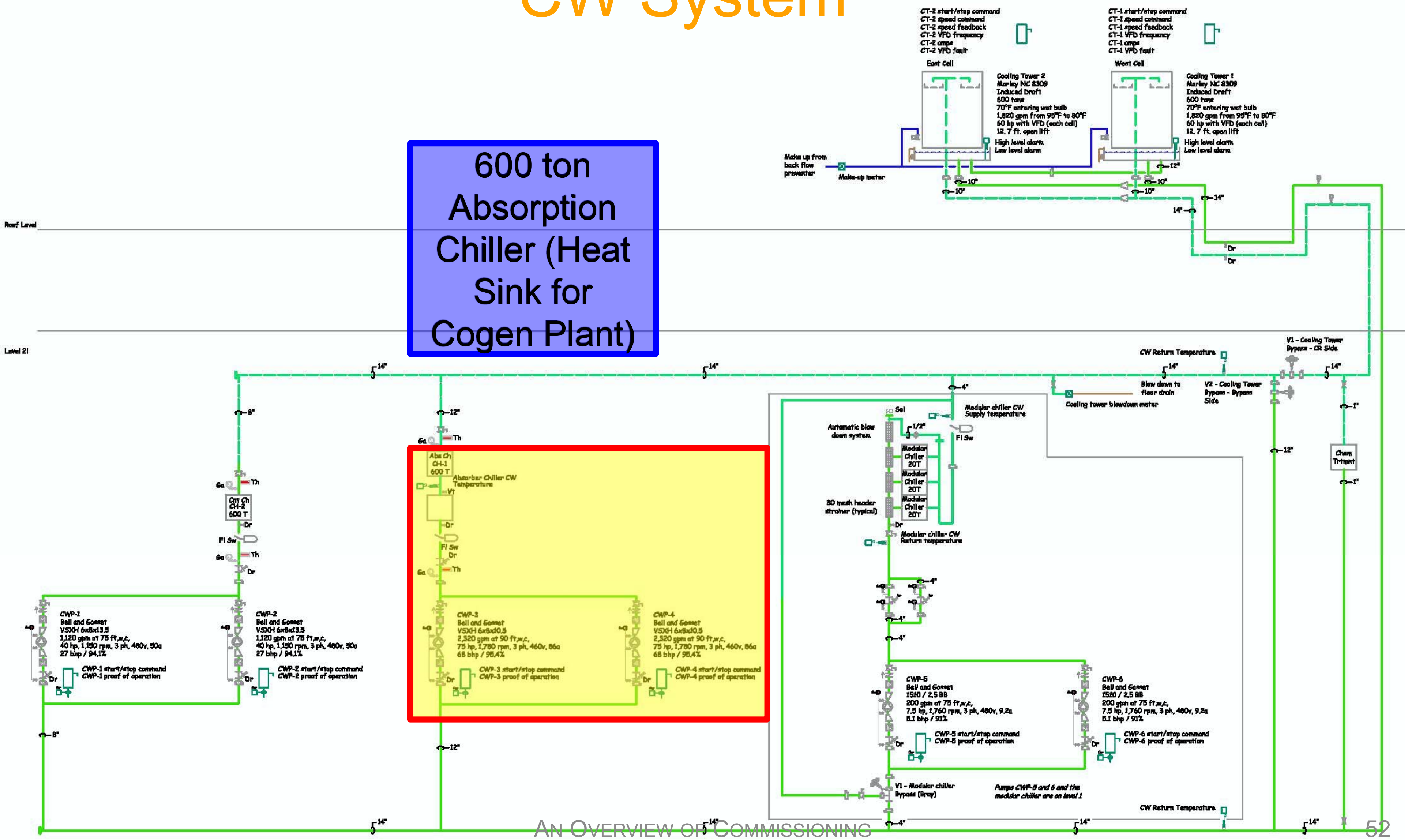


The System Concept in Action

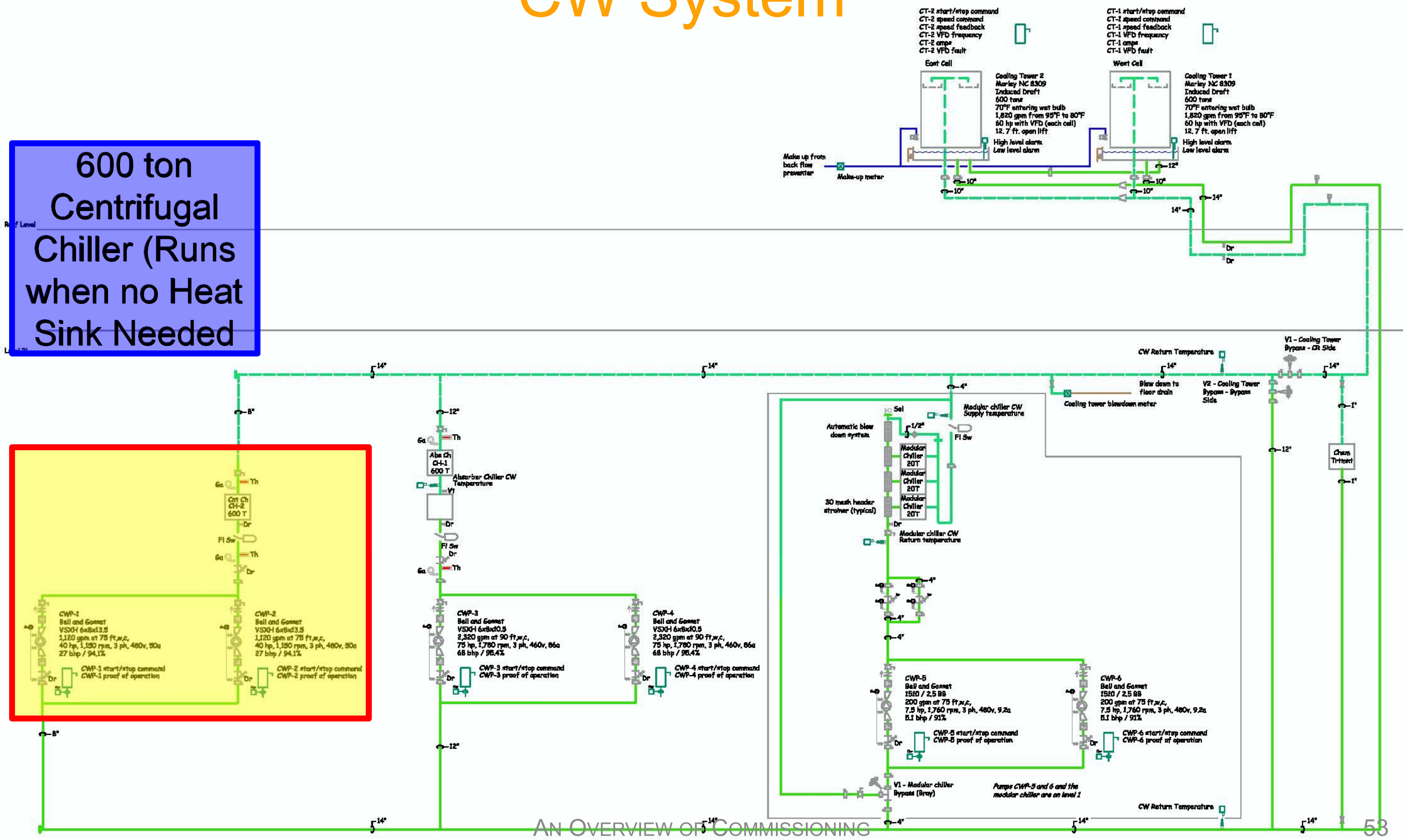
The System Design Concept and the System Physics Need to Complement Each Other

Multi Pump Constant Volume CW System

600 ton Absorption Chiller (Heat Sink for Cogen Plant)

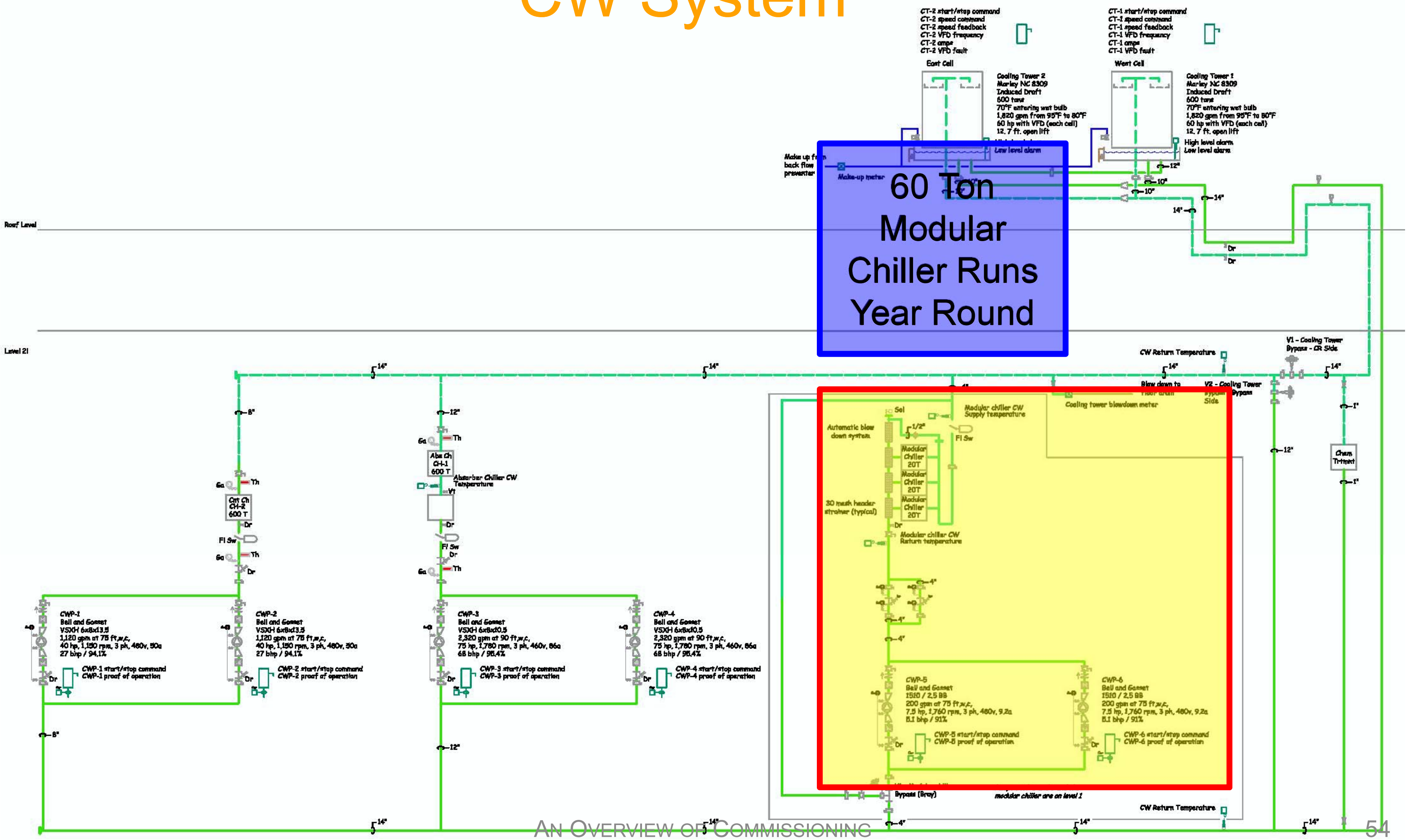


Multi Pump Constant Volume CW System

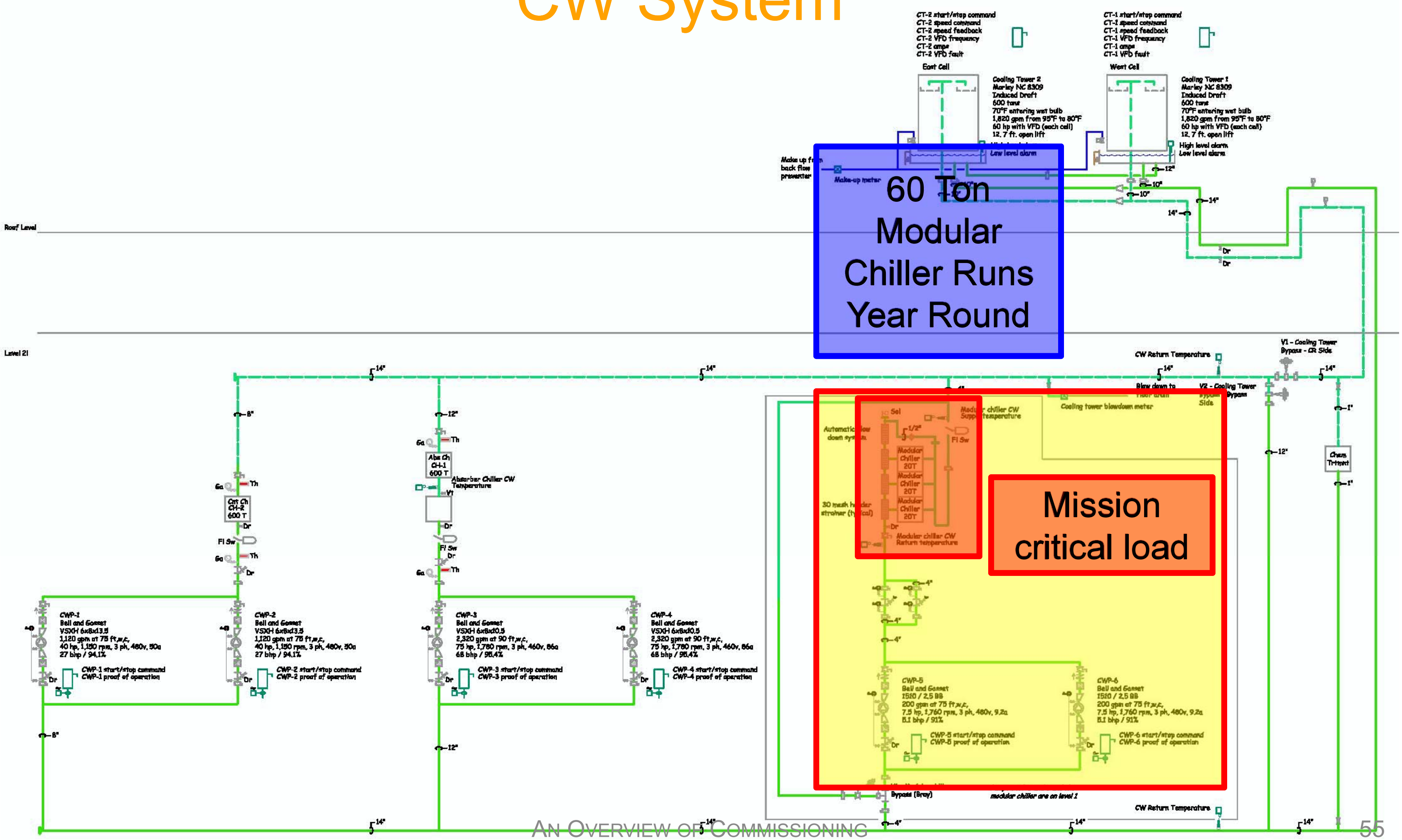


600 ton Centrifugal Chiller (Runs when no Heat Sink Needed

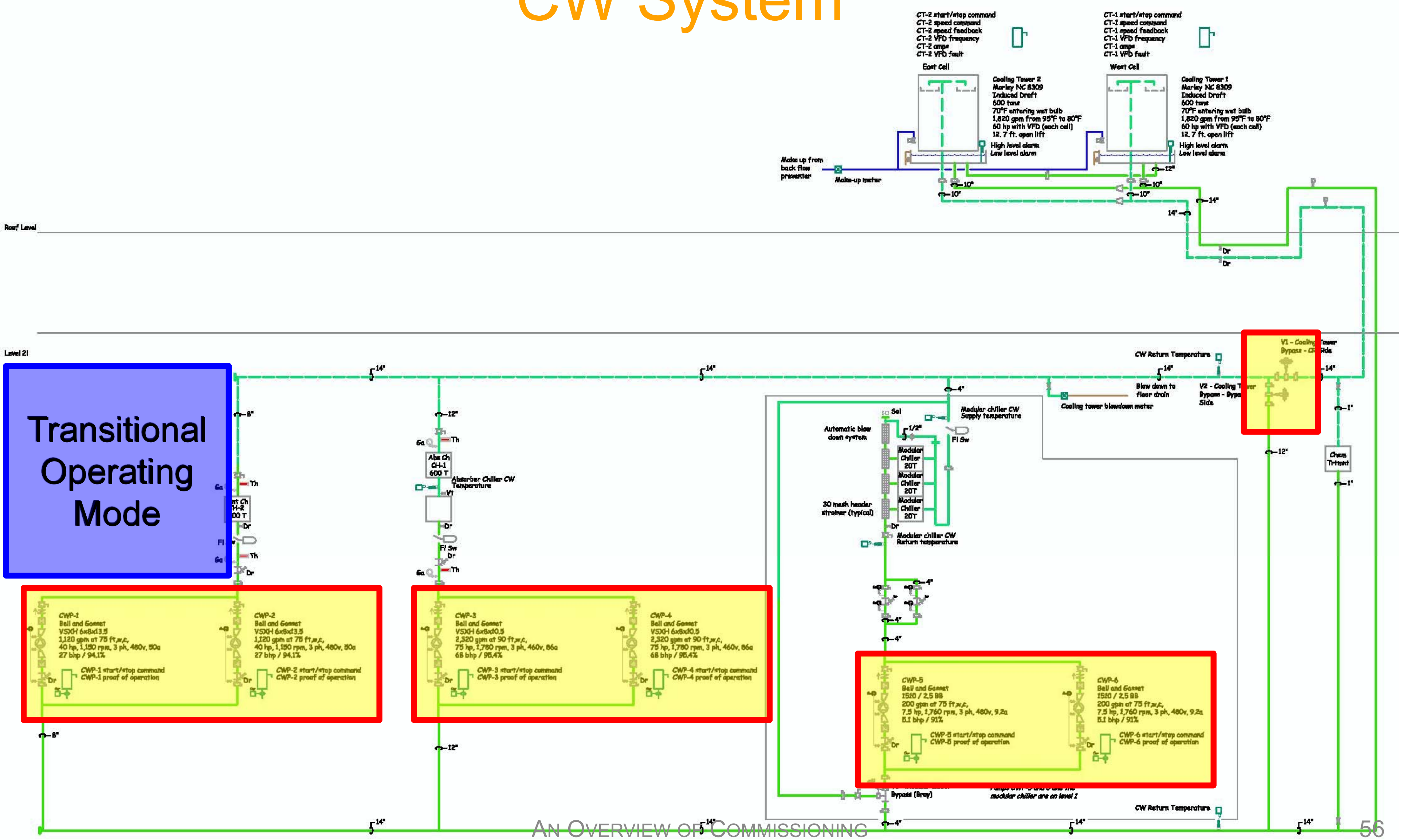
Multi Pump Constant Volume CW System



Multi Pump Constant Volume CW System

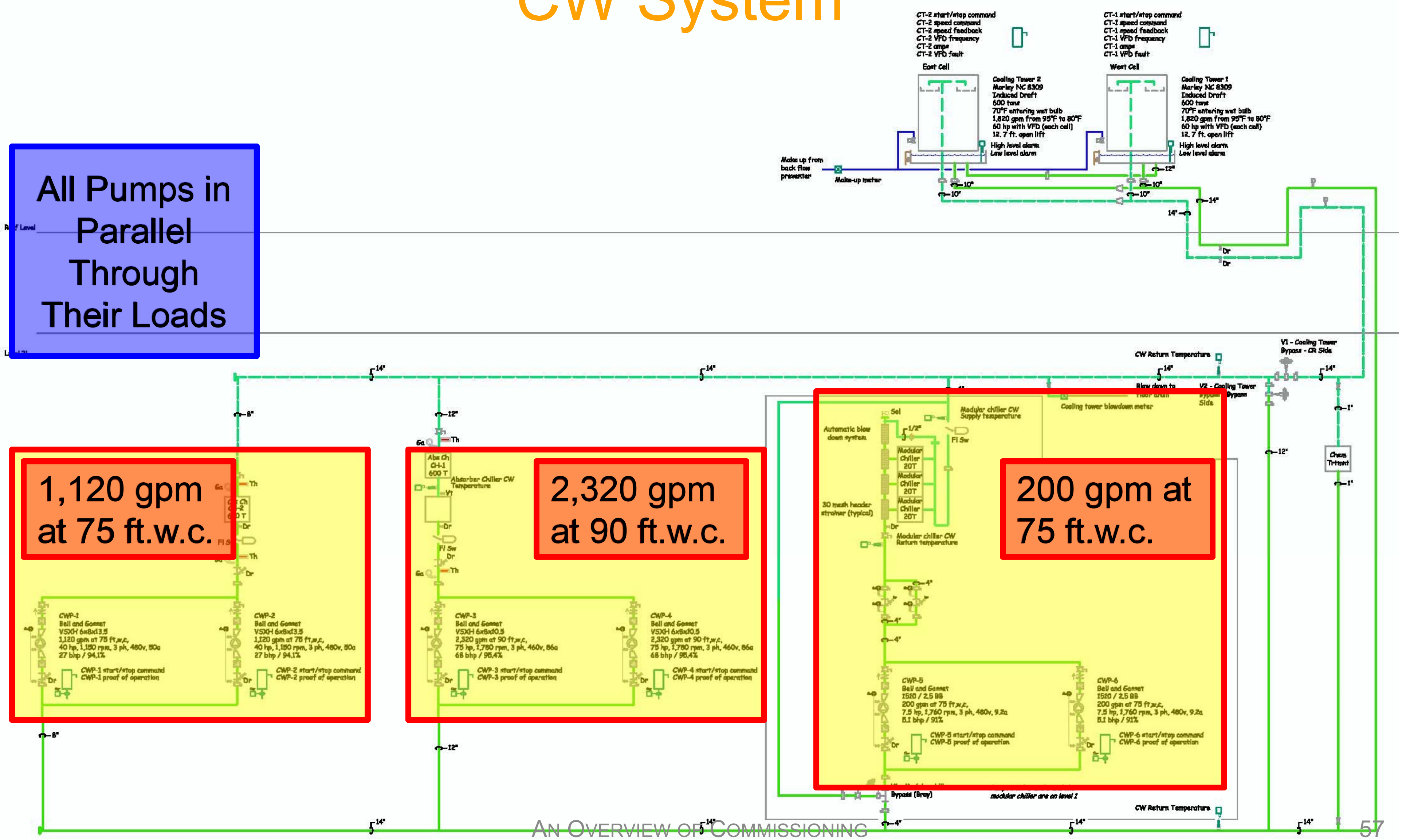


Multi Pump Constant Volume CW System



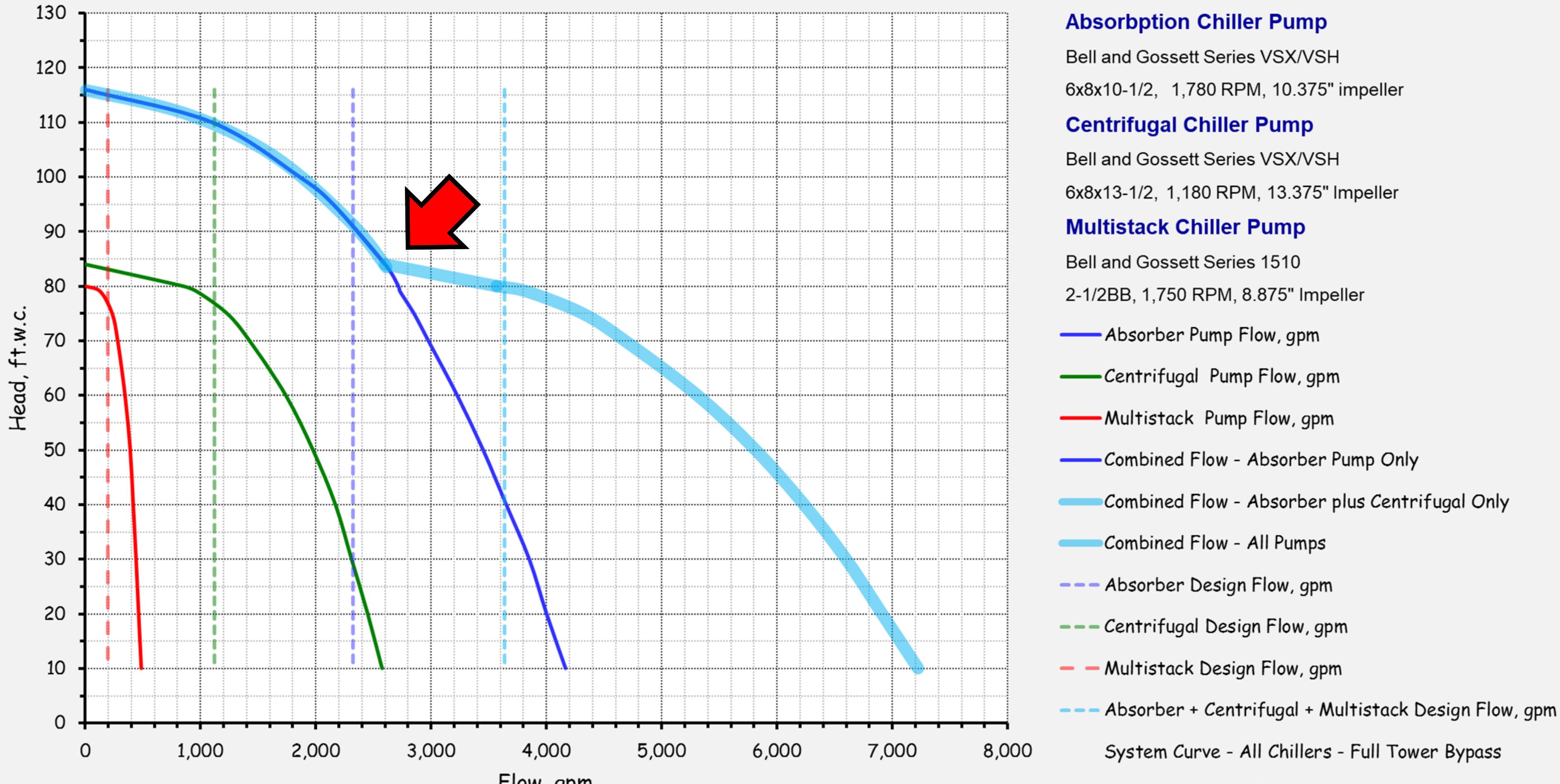
Transitional Operating Mode

Multi Pump Constant Volume CW System



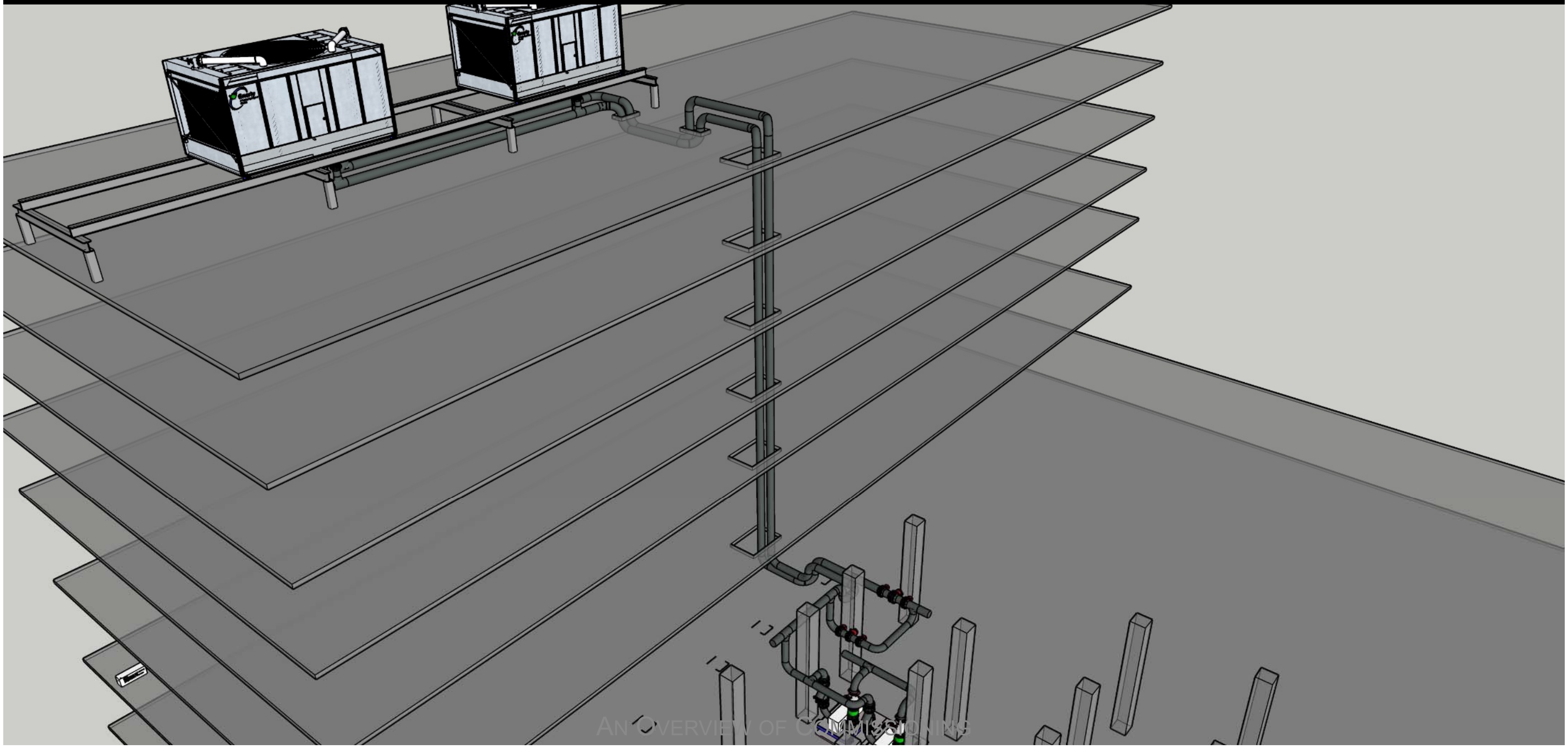
Different Size Parallel Pumps

The Combined Curve can have an Odd Shape



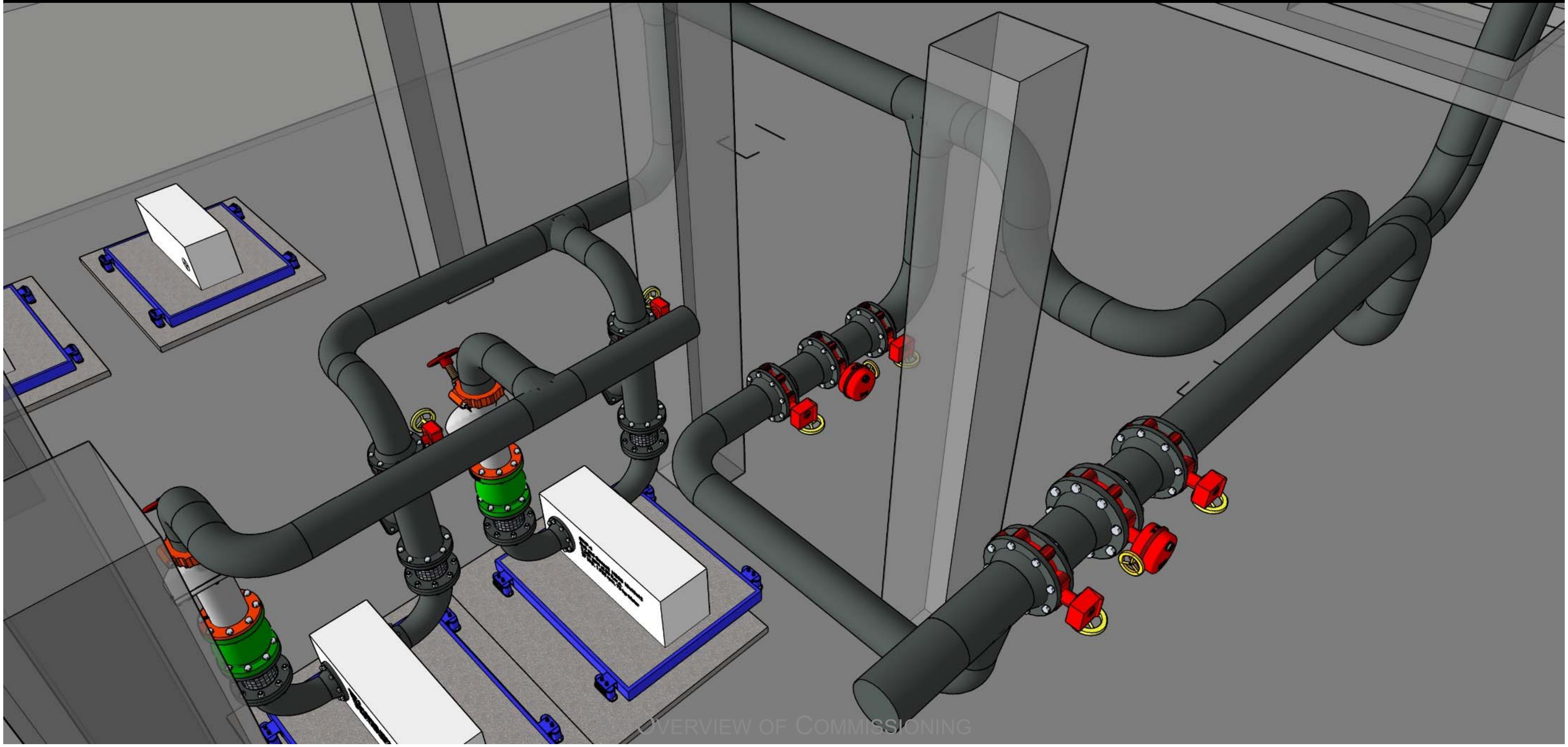
Different Size Parallel Pumps

System Curves Can Be Dynamic



Different Size Parallel Pumps

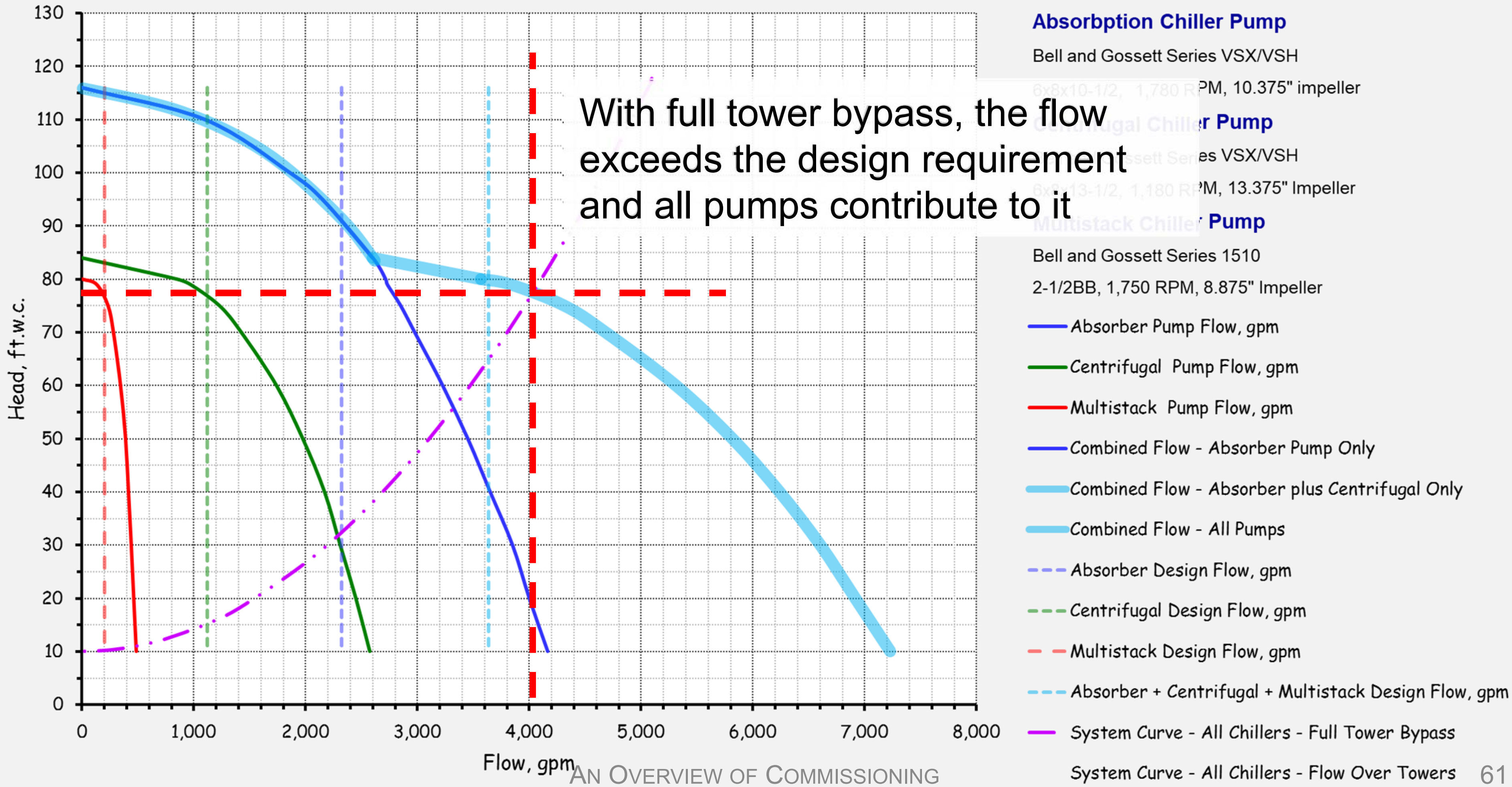
System Curves Can Be Dynamic



Different Size Parallel Pumps

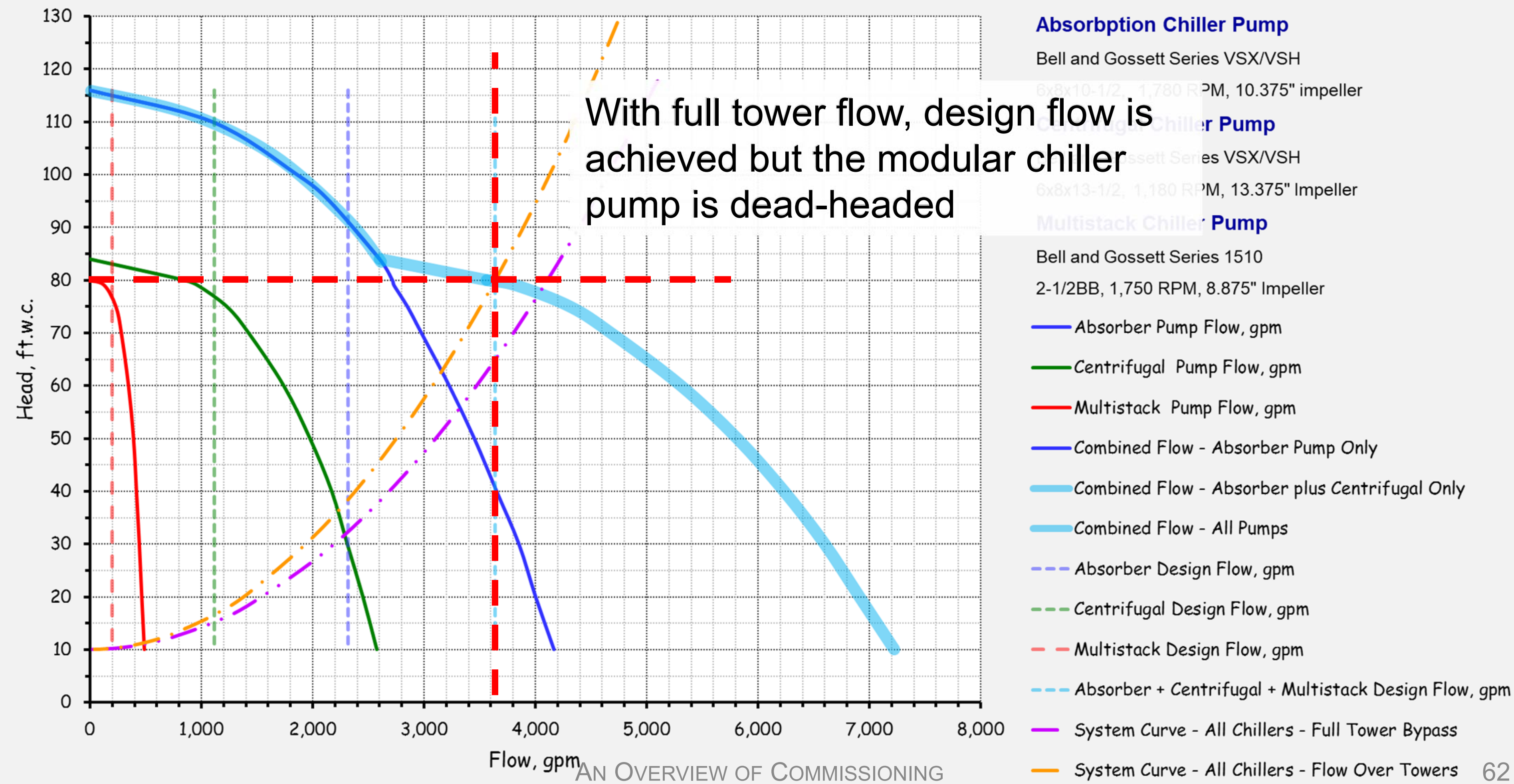
Odd Shapes + Dynamic aSystems can lead to Odd Events

With full tower bypass, the flow exceeds the design requirement and all pumps contribute to it



Different Size Parallel Pumps

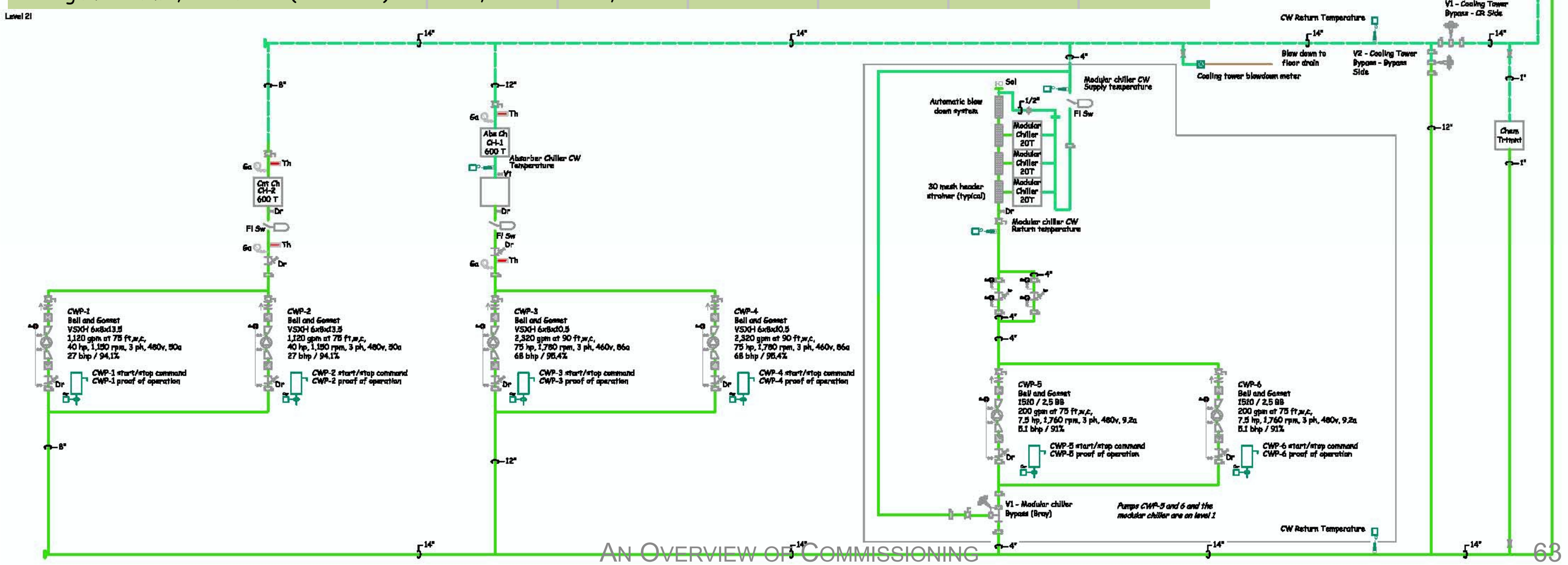
Odd Shapes + Dynamic aSystems can lead to Odd Events



With full tower flow, design flow is achieved but the modular chiller pump is dead-headed

Multi Pump ~~Constant Volume~~ CW System

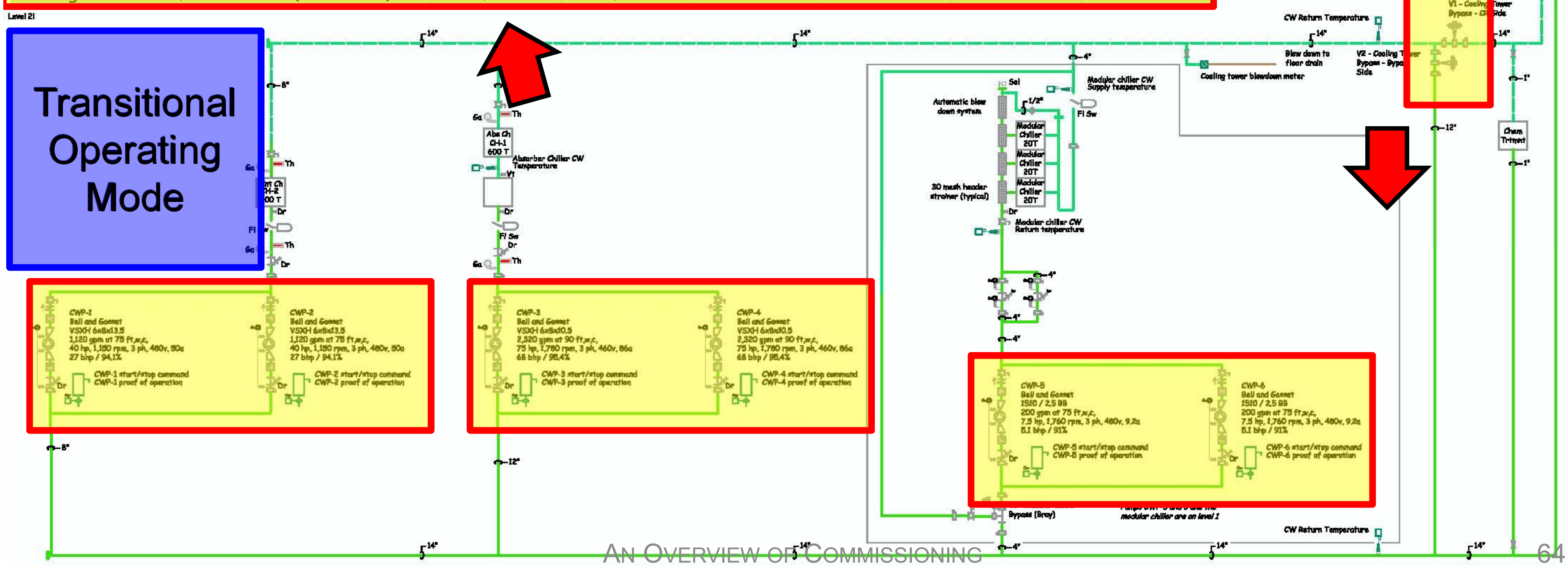
Test Data Summary						
Design Targets	Total Flow, gpm					
Centrifugal Chiller	1120					
Absorption Chiller	2320					
Modular Chiller	200					
Absorber plus Centrifugal Chiller	3440					
Absorber plus Modular Chiller	2520					
Centrifugal plus Modular Chiller	1320					
All Chillers	3640					
Test Mode (V2 at 100% = Full Cooling Tower Bypass)	Total Flow, gpm	Target	% of Target	Centrifugal % Design Flow	Absorber % Design Flow	Modular % Design Flow
Testing Mode: M.S. Stand-Alone (V-2 0%)	205	200	103%			103%
Testing Mode: M.S. (V-2 100%)	235	200	118%			118%
Testing Mode: M.S. & Abs (V-2 0%)	2,510	2,520	100%		101%	80%
Testing Mode: M.S. & Abs (V-2 100%)	2,740	2,520	109%		112%	70%
Testing Mode: M.S. & Cent (V-2 0%)	1,475	1,320	112%	116%		88%
Testing Mode: M.S. & Cent (V-2 100%)	1,625	1,320	123%	132%		88%
Testing Mode: M.S, Abs & Cent (V-2 0%)	3,183	3,640	87%	92%	93%	0%
Testing Mode: M.S, Abs & Cent (V-2 100%)	4,045	3,640	111%	118%	110%	85%



Multi Pump ~~Constant Volume~~ CW System

Test Data Summary

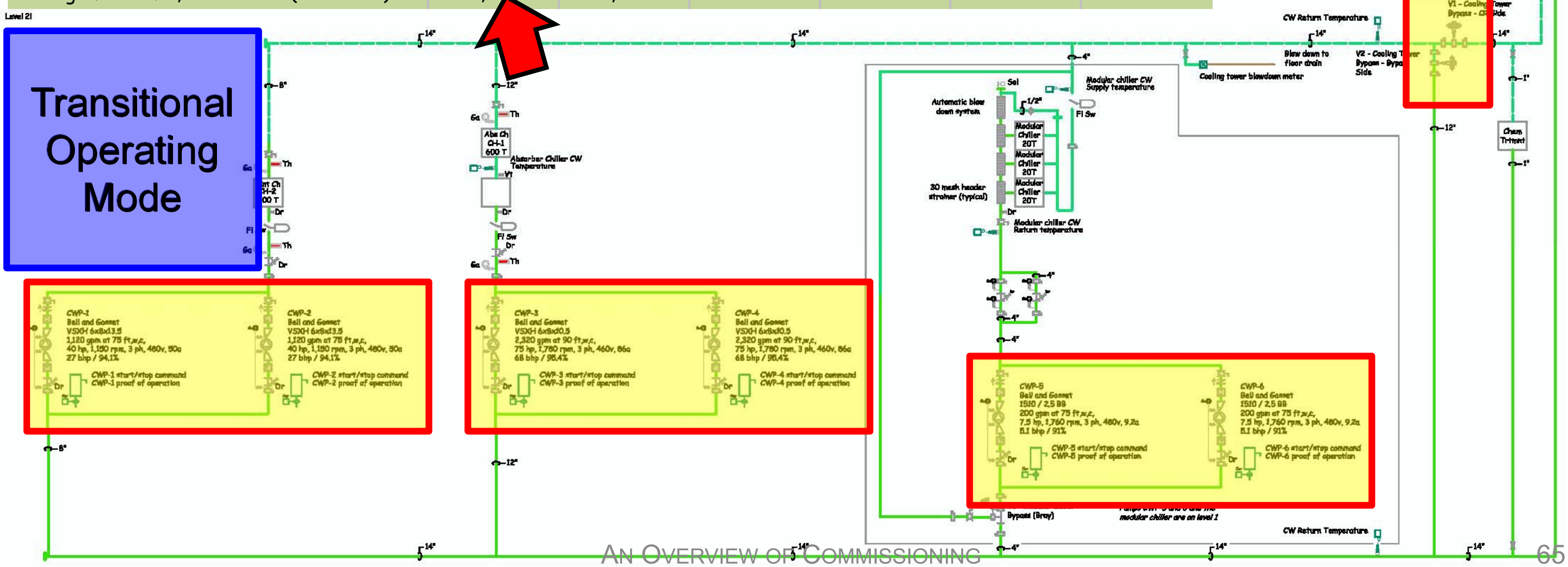
Design Targets	Total Flow, gpm					
Centrifugal Chiller	1120					
Absorption Chiller	2320					
Modular Chiller	200					
Absorber plus Centrifugal Chiller	3440					
Absorber plus Modular Chiller	2520					
Centrifugal plus Modular Chiller	1320					
All Chillers	3640					
Test Mode (V2 at 100% = Full Cooling Tower Bypass)	**Total Flow, gpm**	**Target**	**% of Target**	**Centrifugal % Design Flow**	**Absorber % Design Flow**	**Modular % Design Flow**
Testing Mode: M.S. Stand-Alone (V-2 0%)	205	200	103%			103%
Testing Mode: M.S. (V-2 100%)	235	200	118%			118%
Testing Mode: M.S. & Abs (V-2 0%)	2,510	2,520	100%		101%	80%
Testing Mode: M.S. & Abs (V-2 100%)	2,740	2,520	109%		112%	70%
Testing Mode: M.S. & Cent (V-2 0%)	1,475	1,320	112%	116%		88%
Testing Mode: M.S. & Cent (V-2 100%)	1,625	1,320	123%	132%		88%
Testing Mode: M.S. Abs & Cent (V-2 0%)	3,183	3,640	87%	92%	93%	0%
Testing Mode: M.S, Abs & Cent (V-2 100%)	4,045	3,640	111%	118%	110%	85%



Multi Pump ~~Constant Volume~~ CW System

Test Data Summary

Design Targets	Total Flow, gpm					
Centrifugal Chiller	1120					
Absorption Chiller	2320					
Modular Chiller	200					
Absorber plus Centrifugal Chiller	3440					
Absorber plus Modular Chiller	2520					
Centrifugal plus Modular Chiller	1320					
All Chillers	3640					
Test Mode (V2 at 100% = Full Cooling Tower Bypass)	**Total Flow, gpm**	**Target**	**% of Target**	**Centrifugal % Design Flow**	**Absorber % Design Flow**	**Modular % Design Flow**
Testing Mode: M.S. Stand-Alone (V-2 0%)	205	200	103%			103%
Testing Mode: M.S. (V-2 100%)	235	200	118%			118%
Testing Mode: M.S. & Abs (V-2 0%)	2,510	2,520	100%		101%	80%
Testing Mode: M.S. & Abs (V-2 100%)	2,740	2,520	109%		112%	70%
Testing Mode: M.S. & Cent (V-2 0%)	1,475	1,320	112%	116%		88%
Testing Mode: M.S. & Cent (V-2 100%)	1,625	1,320	123%	132%		88%
Testing Mode: M.S, Abs & Cent (V-2 0%)	3,183	3,640	87%	92%	93%	0%
Testing Mode: M.S, Abs & Cent (V-2 100%)	4,045	3,640	111%	118%	110%	85%

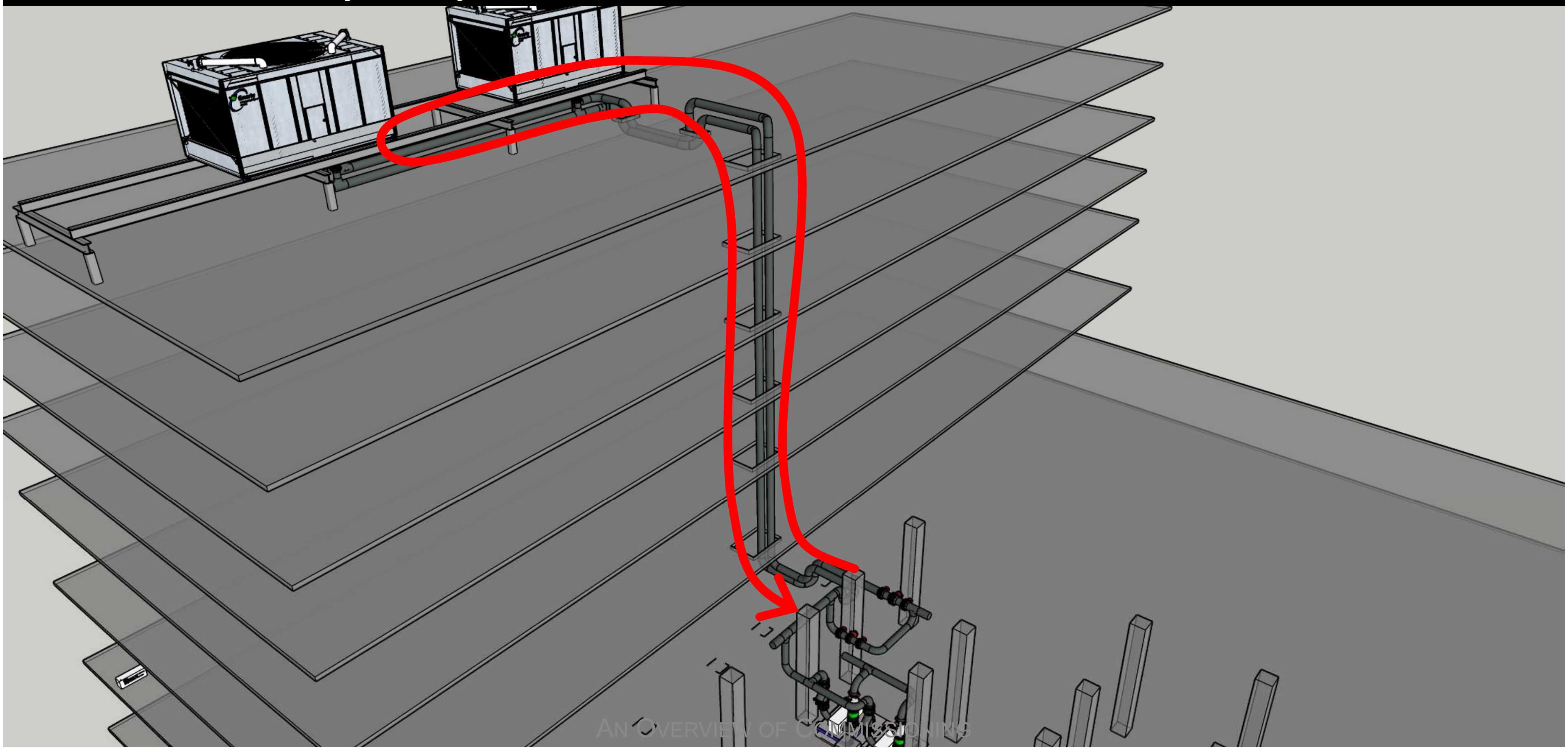


The System Concept in Action

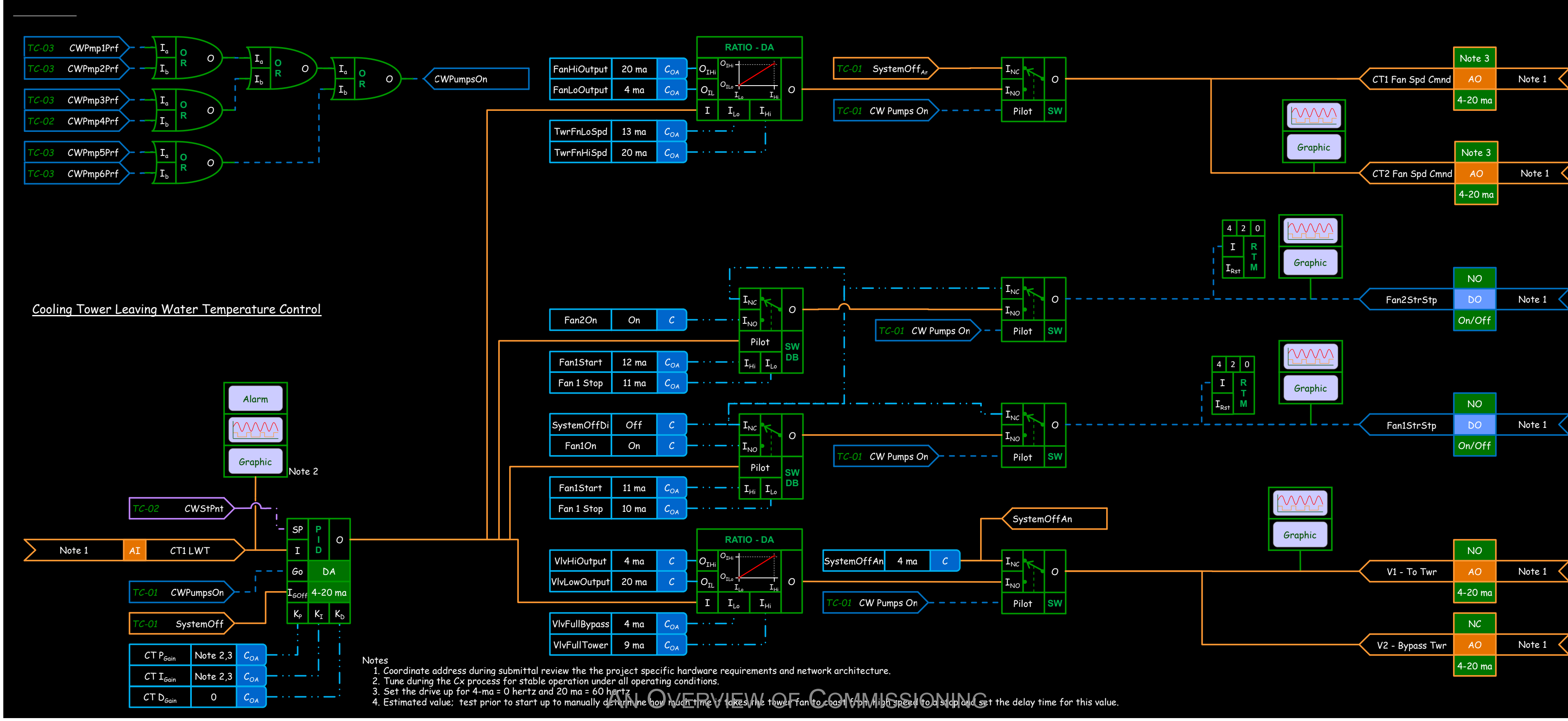
The System Control Logic and the System Physics Need to Complement Each Other

The System
Concept in Action

1. At design flow, it takes about 1-1/2 minutes for a gallon of water to travel from the bypass valves to the towers and back
2. At minimum flow, it takes about 15 minutes for a gallon of water to make the same journey

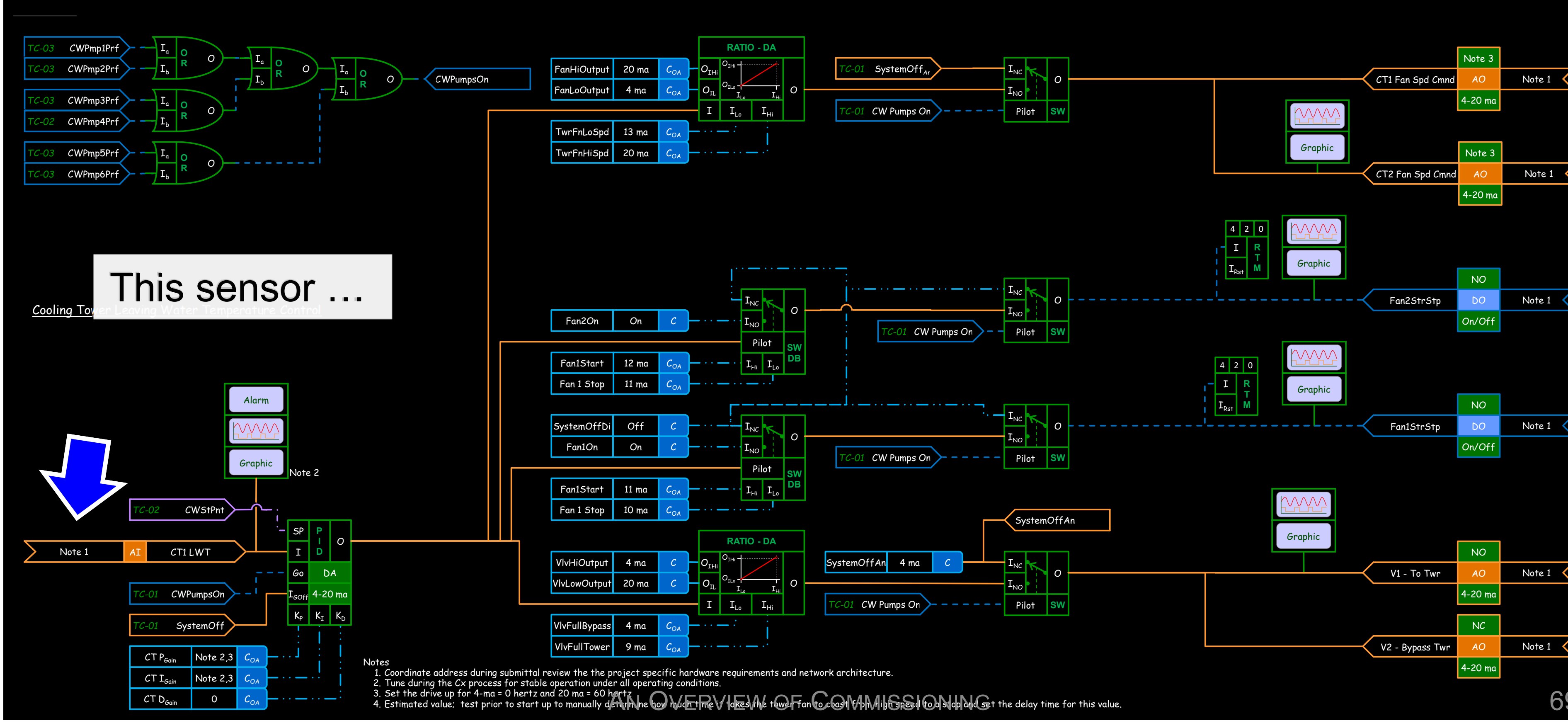


The System Concept in Action



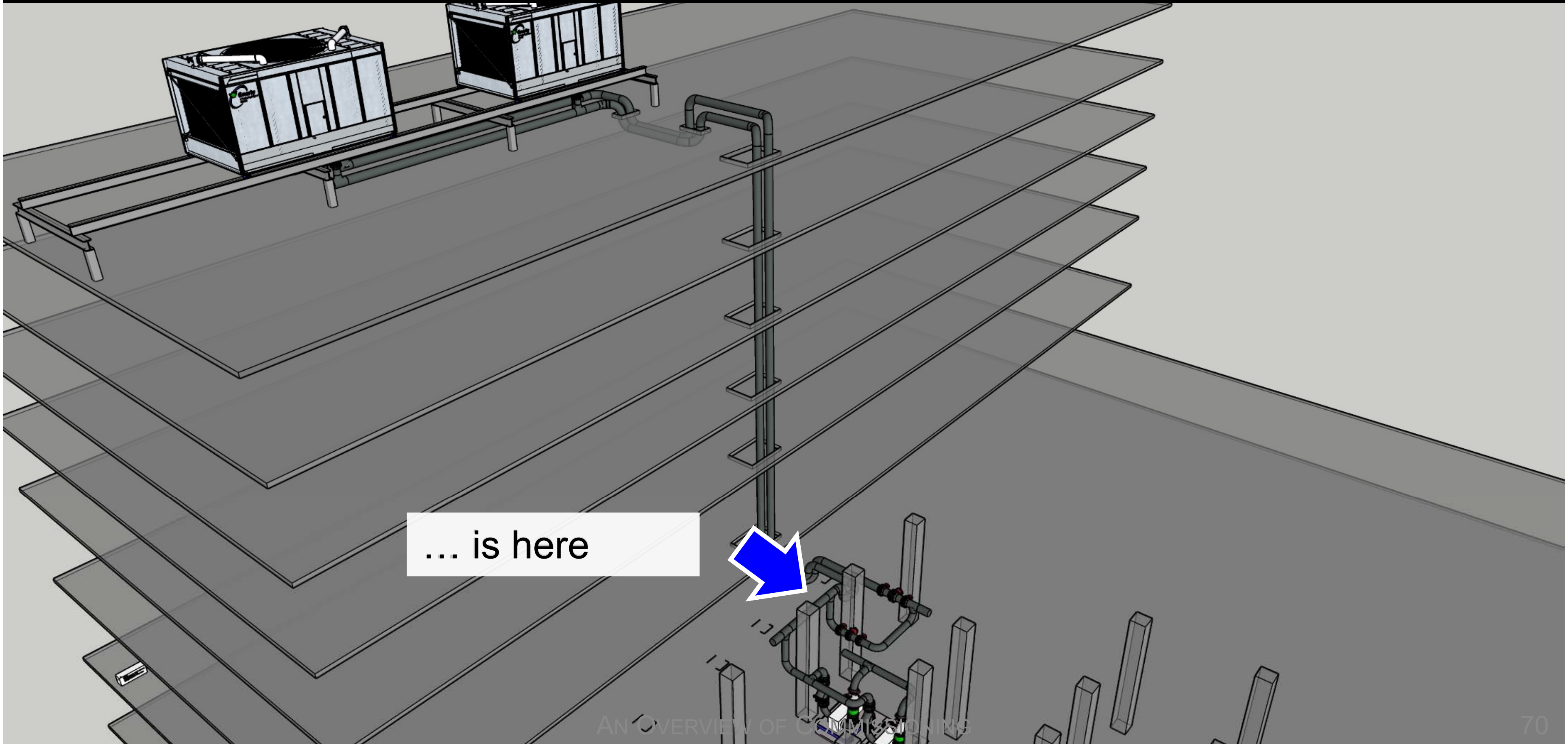
Notes
1. Coordinate address during submittal review the the project specific hardware requirements and network architecture.
2. Tune during the Cx process for stable operation under all operating conditions.
3. Set the drive up for 4-ma = 0 hertz and 20 ma = 60 hertz
4. Estimated value; test prior to start up to manually determine how much time it takes the tower fan to coast from high speed to a stop and set the delay time for this value.

The System Concept in Action



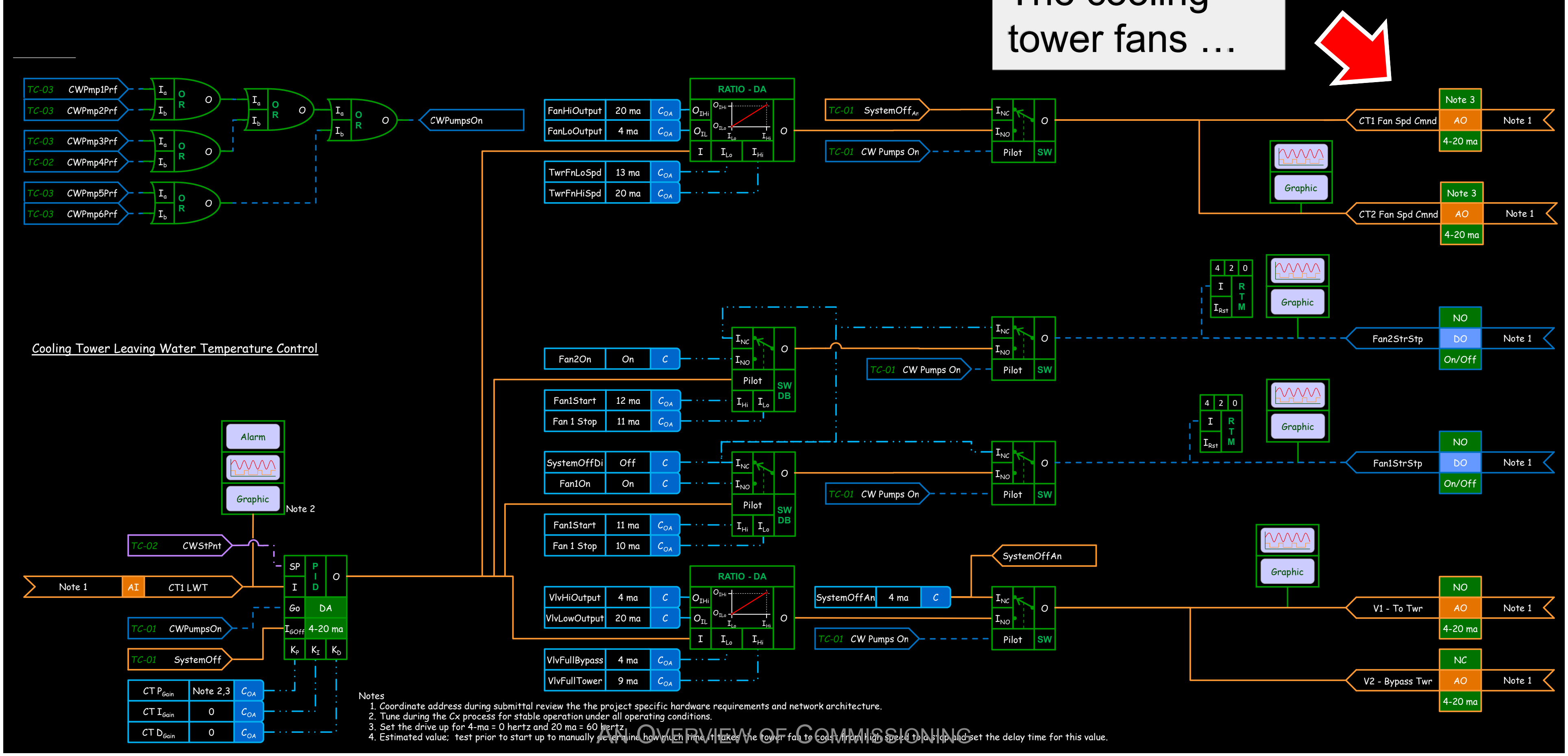
This sensor …

The System Concept in Action

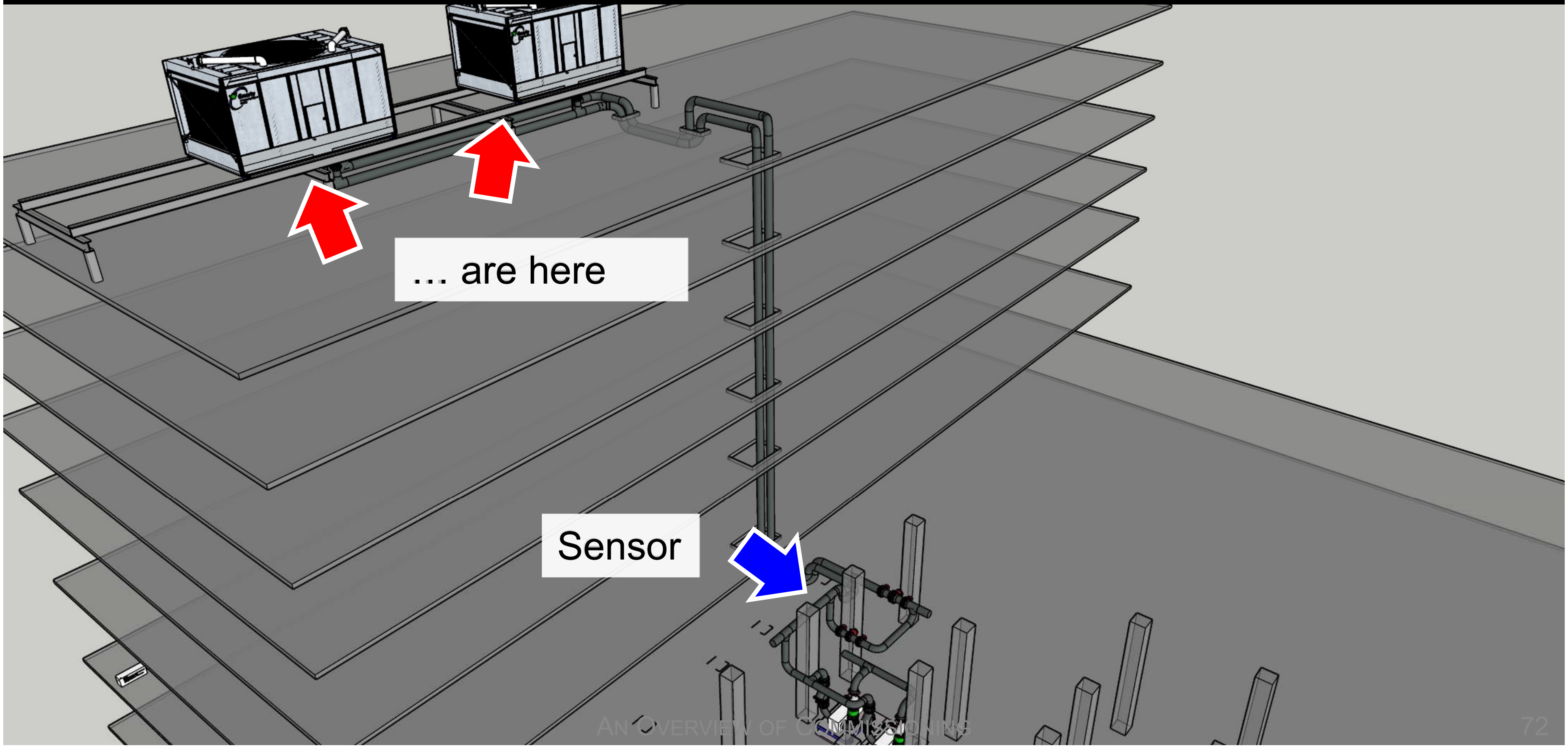


The System Concept in Action

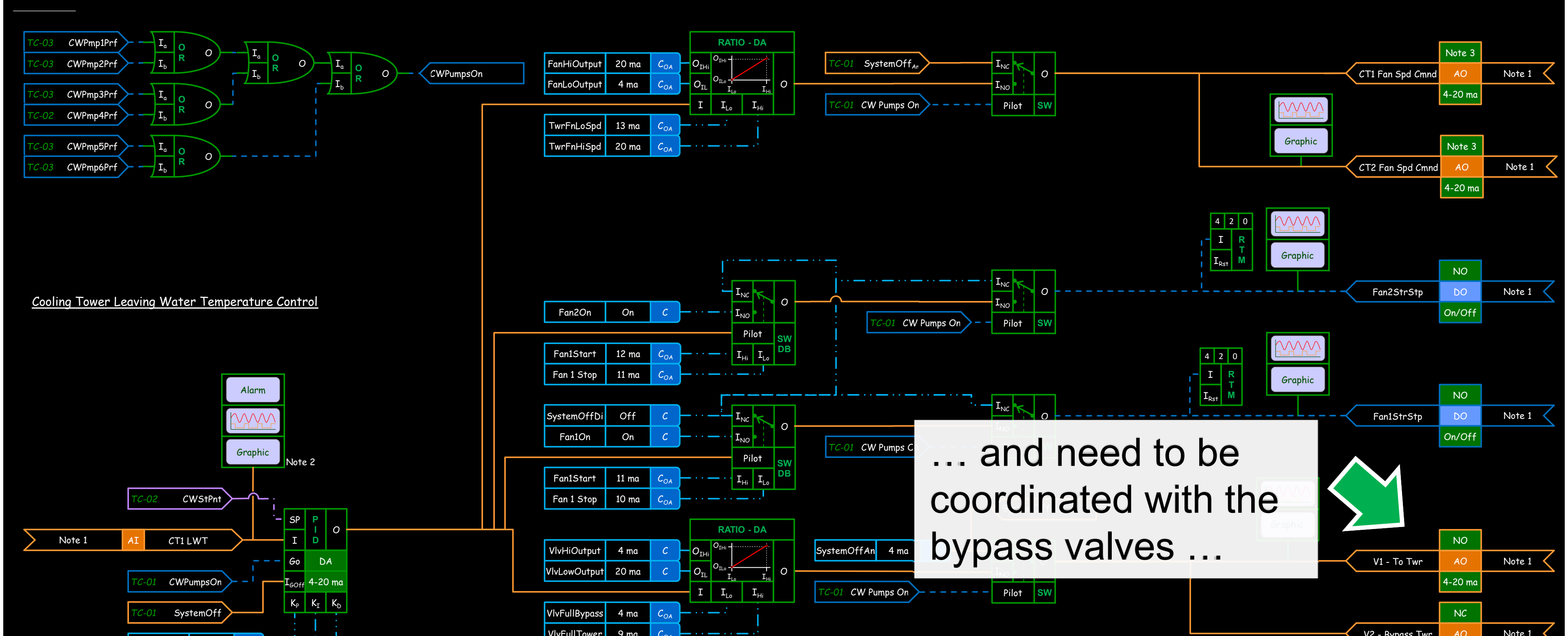
The cooling tower fans …



The System
Concept in Action



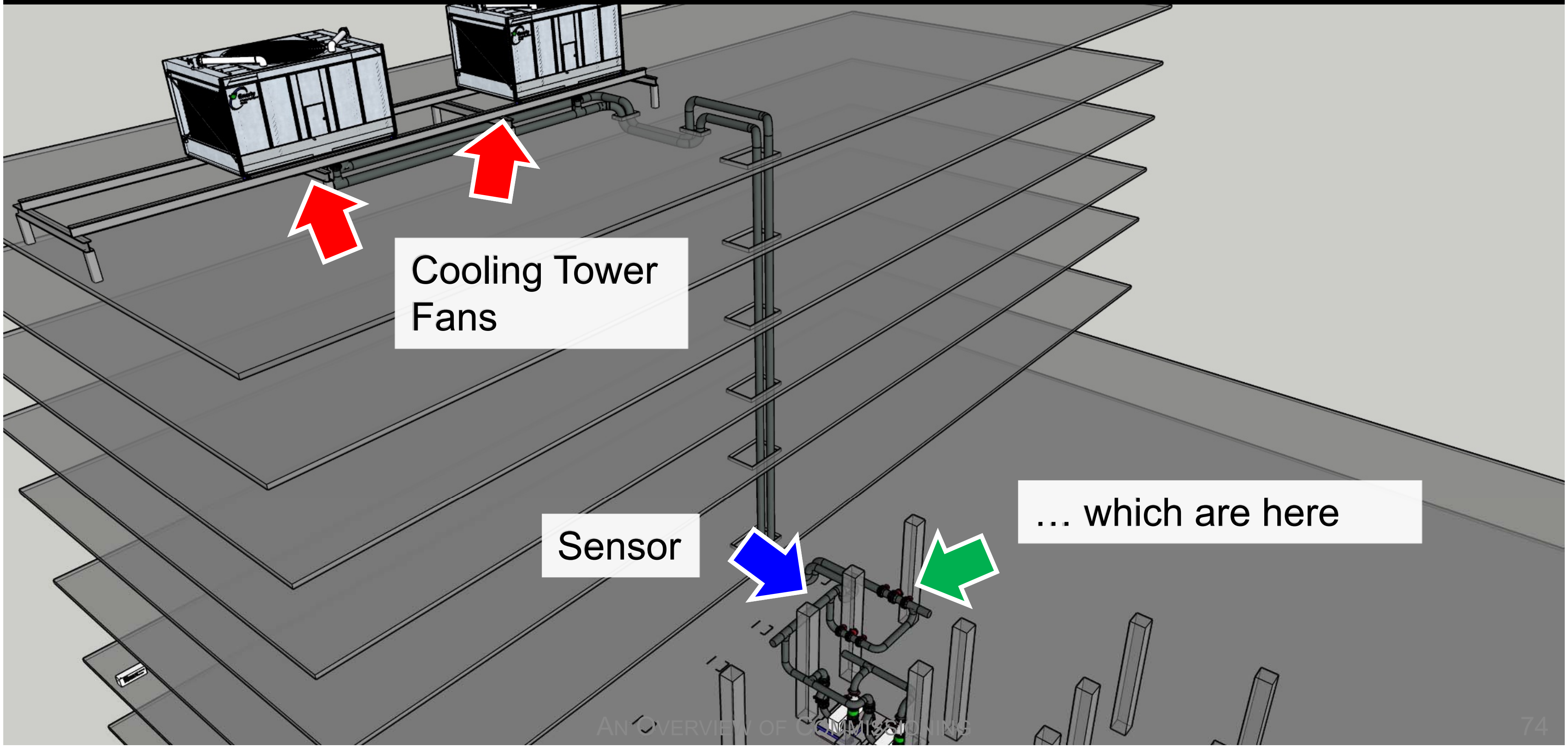
Transportation Delays can be Dynamics



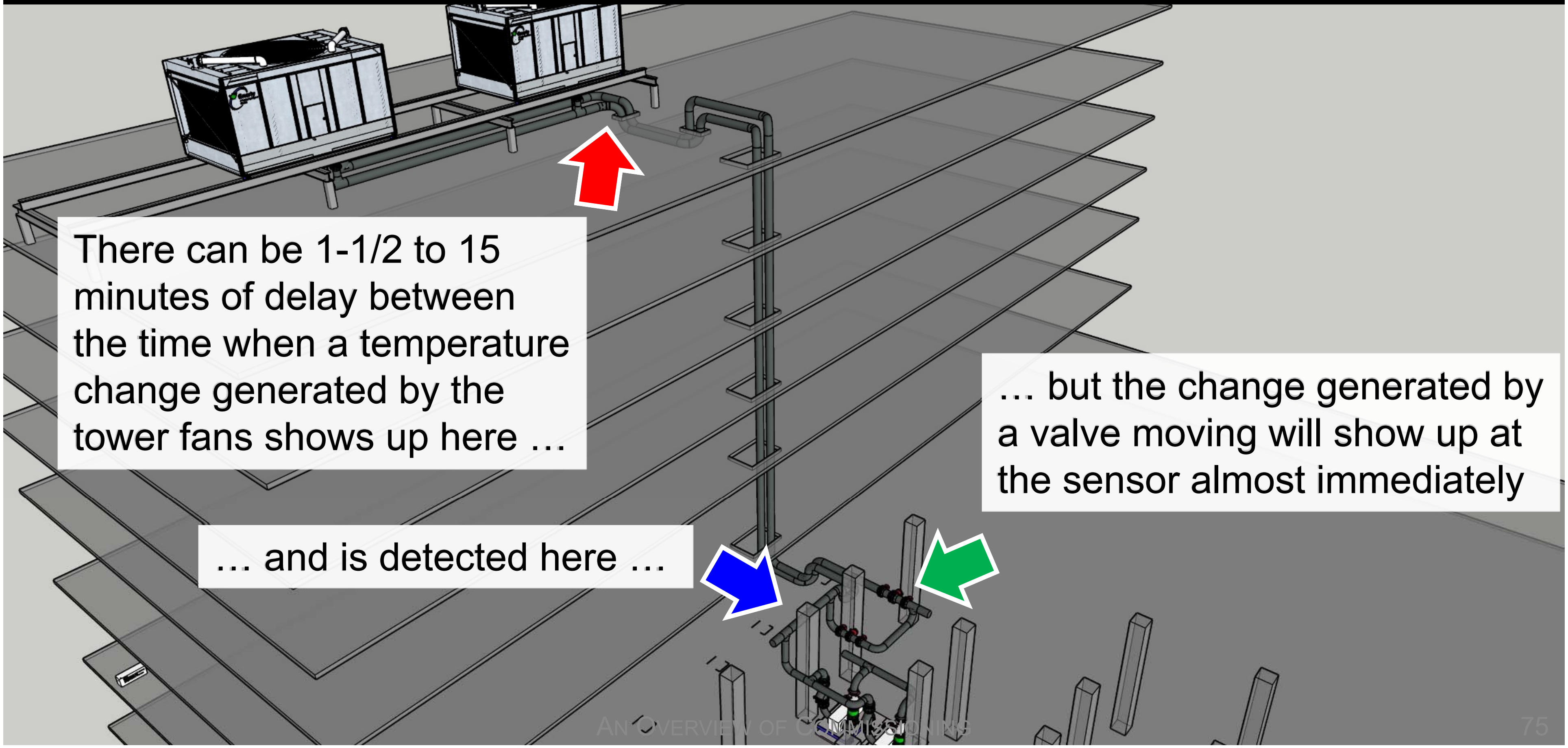
Notes

1. Coordinate address during submittal review the the project specific hardware requirements and network architecture.
2. Tune during the Cx process for stable operation under all operating conditions.
3. Set the drive up for 4-ma = 0 hertz and 20 ma = 60 hertz.
4. Estimated value; test prior to start up to manually determine how much time it takes the tower fan to coast from high speed to a stop and set the delay time for this value.

The System Concept in Action

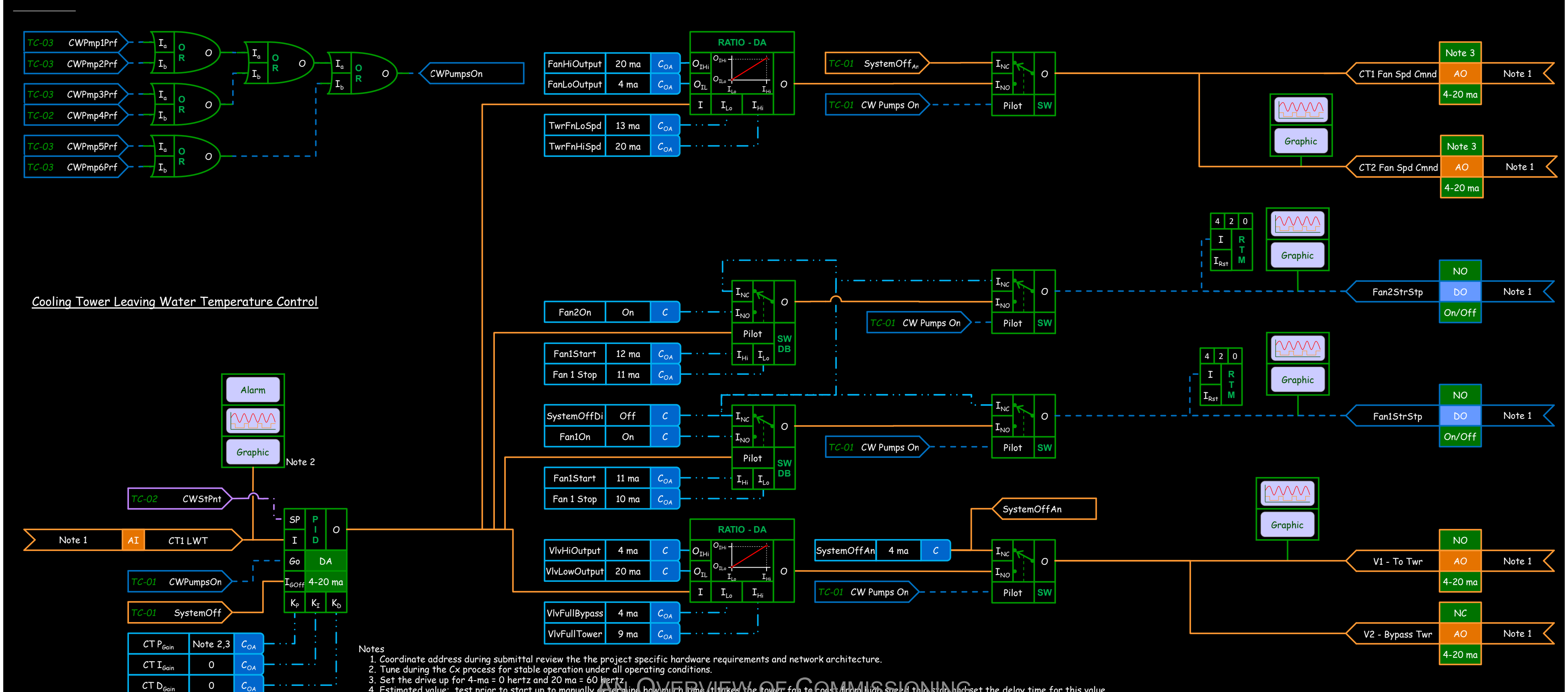


The System Concept in Action

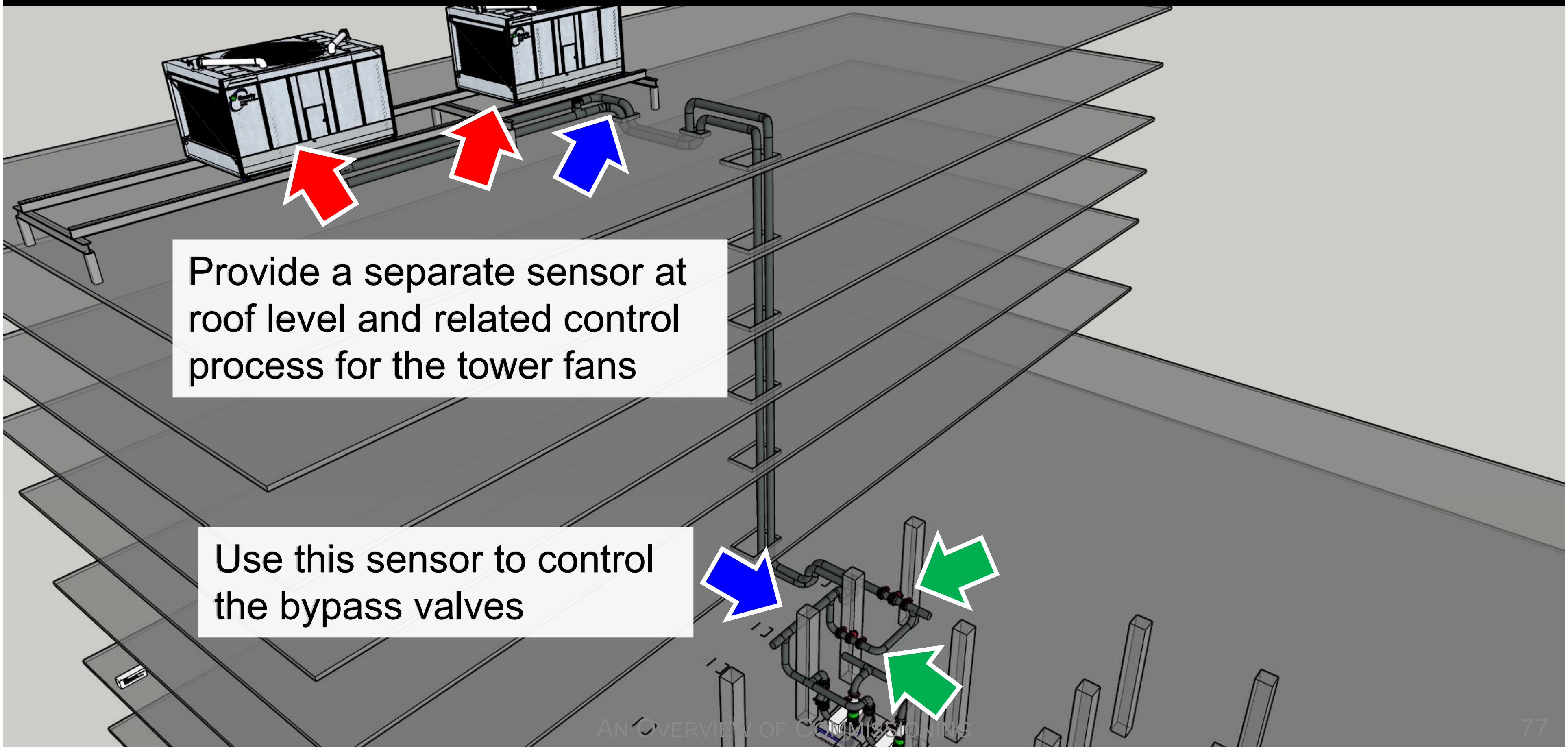


Lags are the Enemy of Tight Control

The variable transportation delay introduces a lag into the control process that can make it difficult or impossible to tune

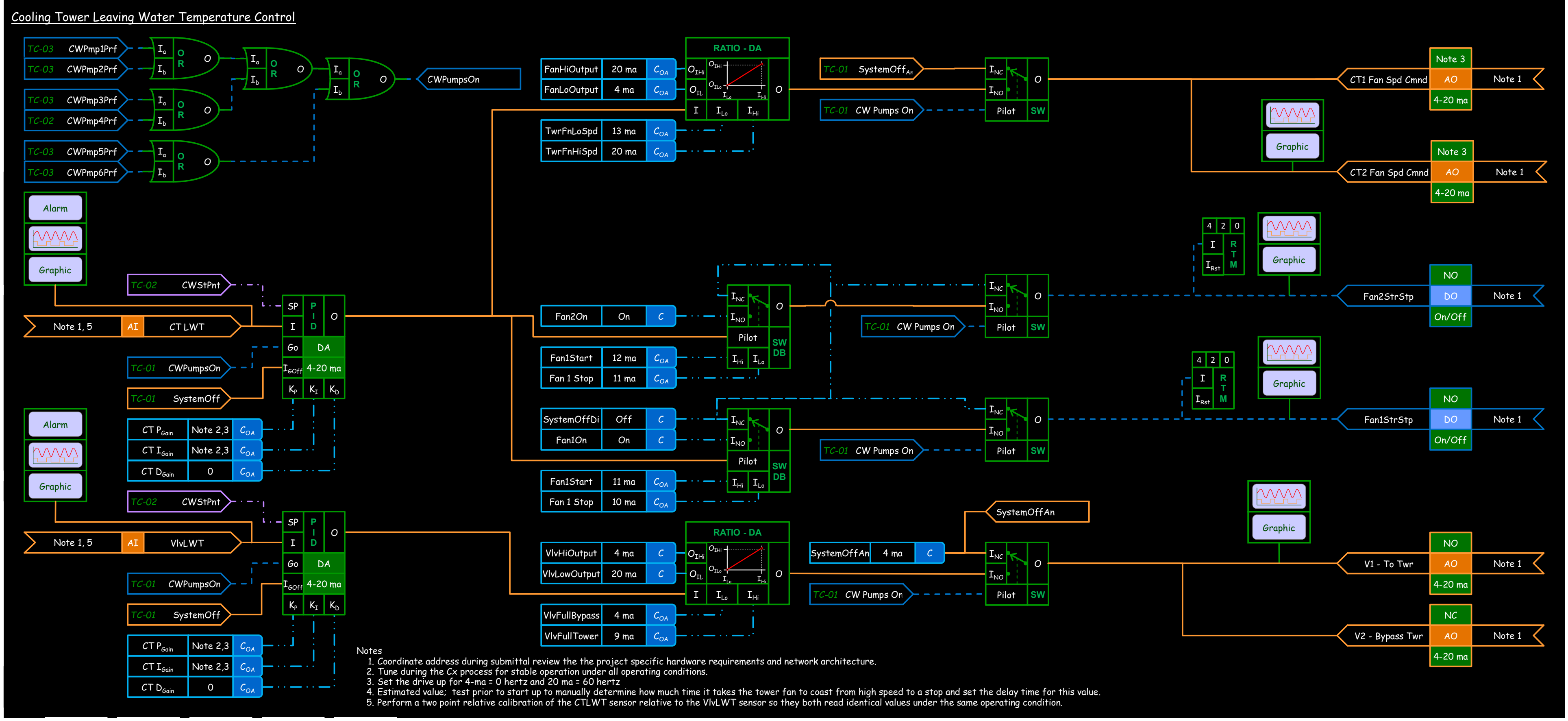


Resolving the Problem



Resolving the Problem

- Coordinate the set points for the two loops
- Perform relative calibration for the two sensors that are inputs to the loops



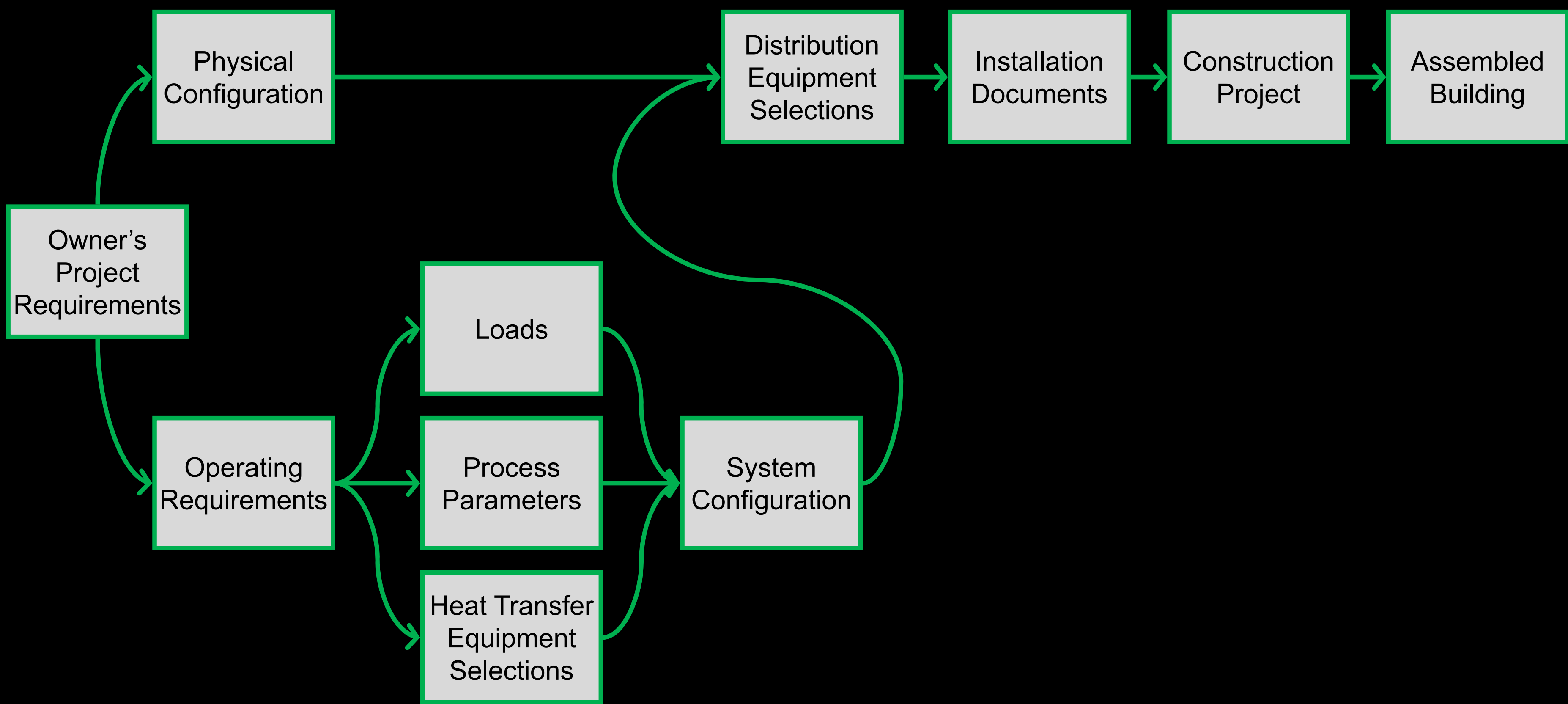
Functional Testing

- Core element of any commissioning process
- Validates machinery and systems
    - Do they deliver?
    - Why don't they deliver?
    - Do the work well together?
    - Why aren't they working well together
    - Was it big enough?
    - How big should it be?

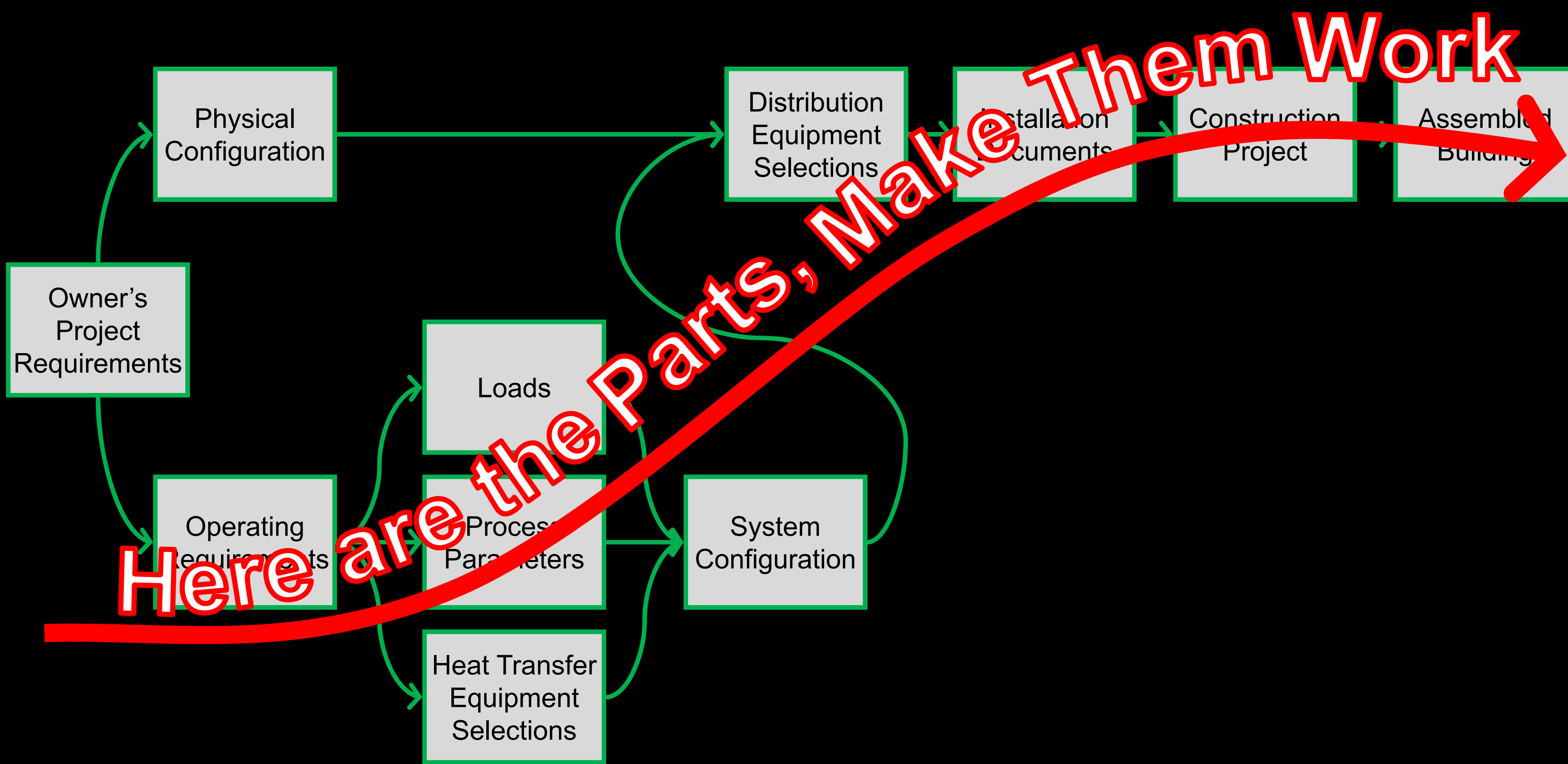
Functional Testing

- Core element of any commissioning process
- Validates machinery and systems
  - Do they deliver?
  - Why don’t they deliver?
  - Do the work well together?
  - Why aren’t they working well together
  - Was it big enough?
  - How big should it be?

Functional Testing as it Relates to the Metrics of the Systems We Test

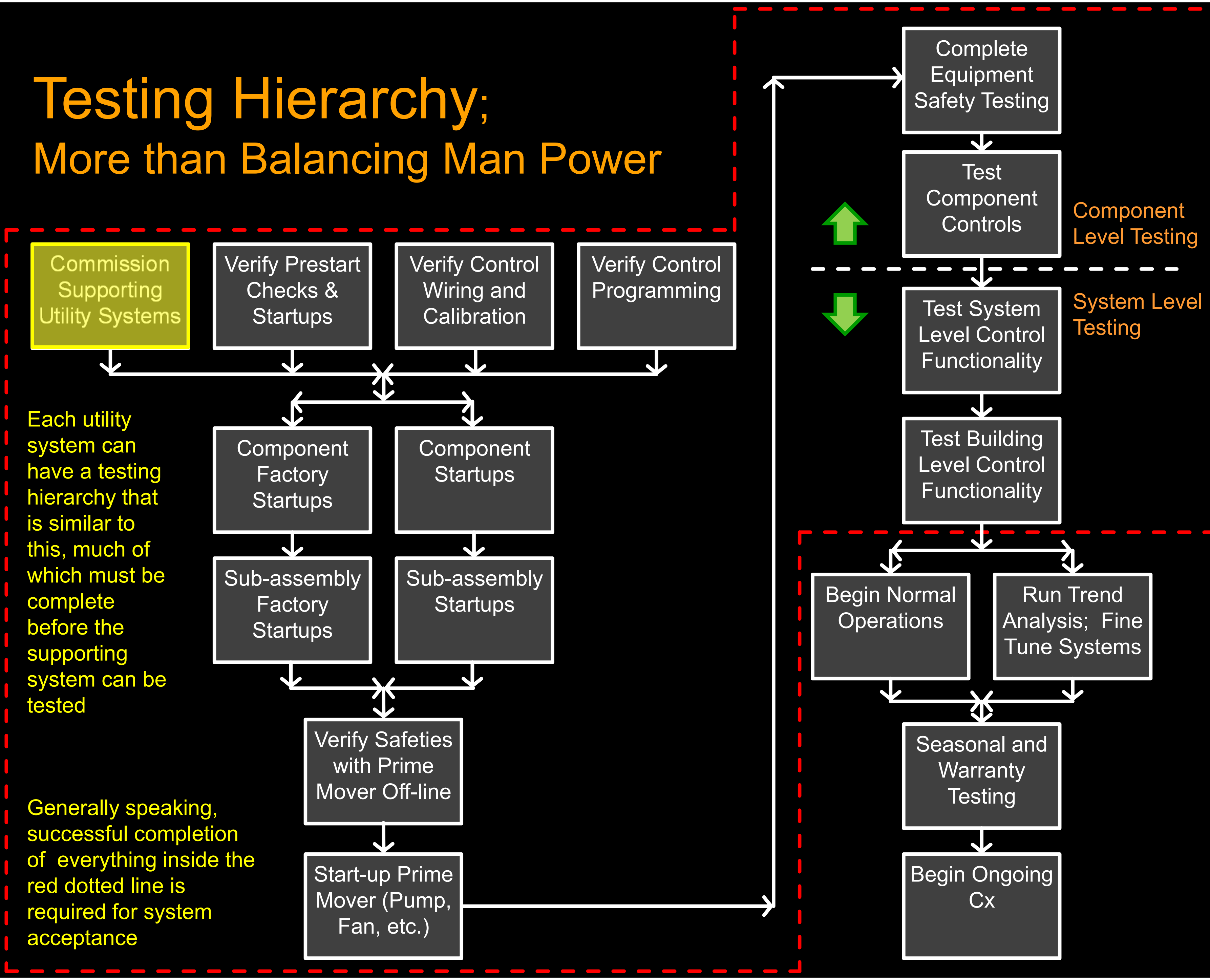


Functional Testing as it Relates to the Metrics of the Systems We Test

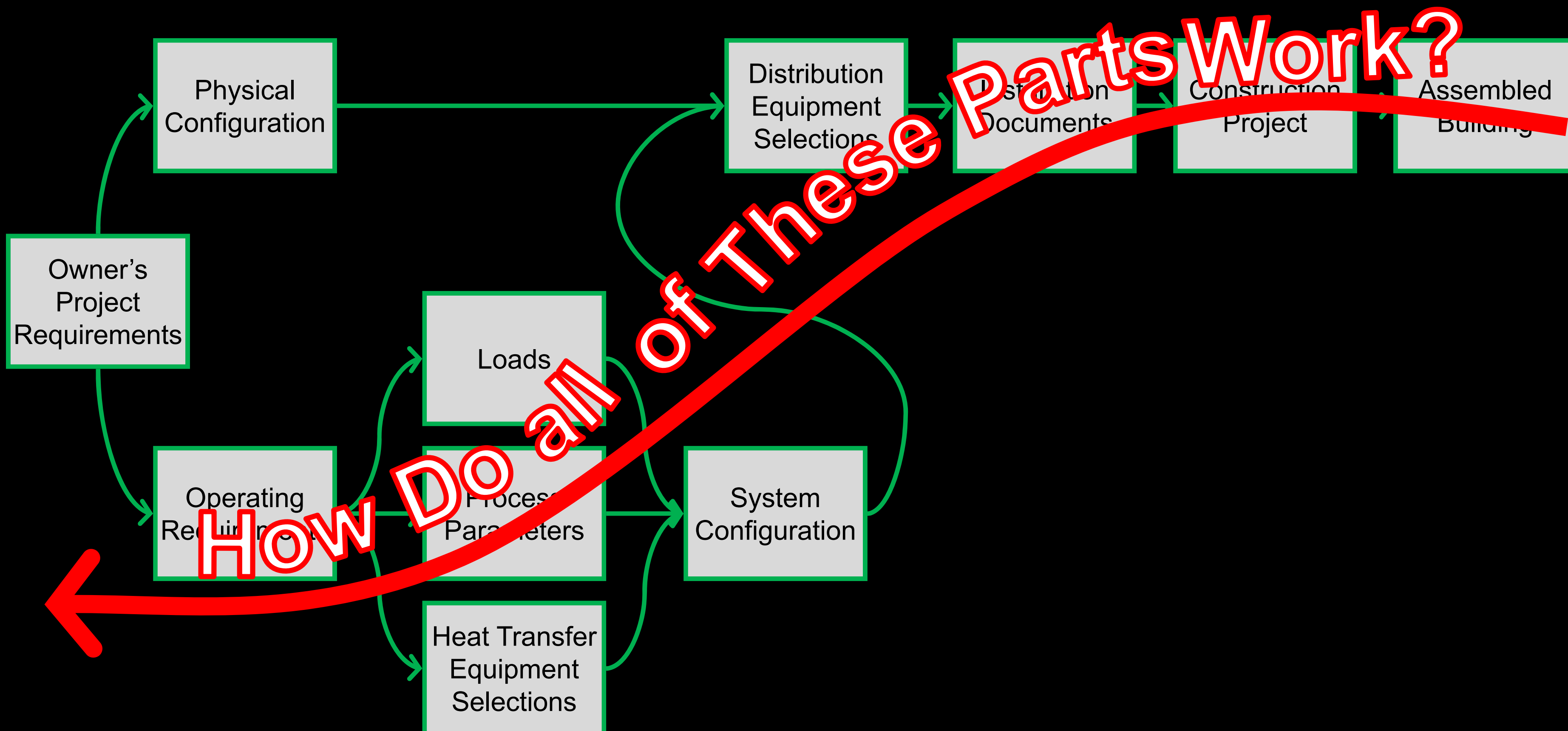


Testing Hierarchy;

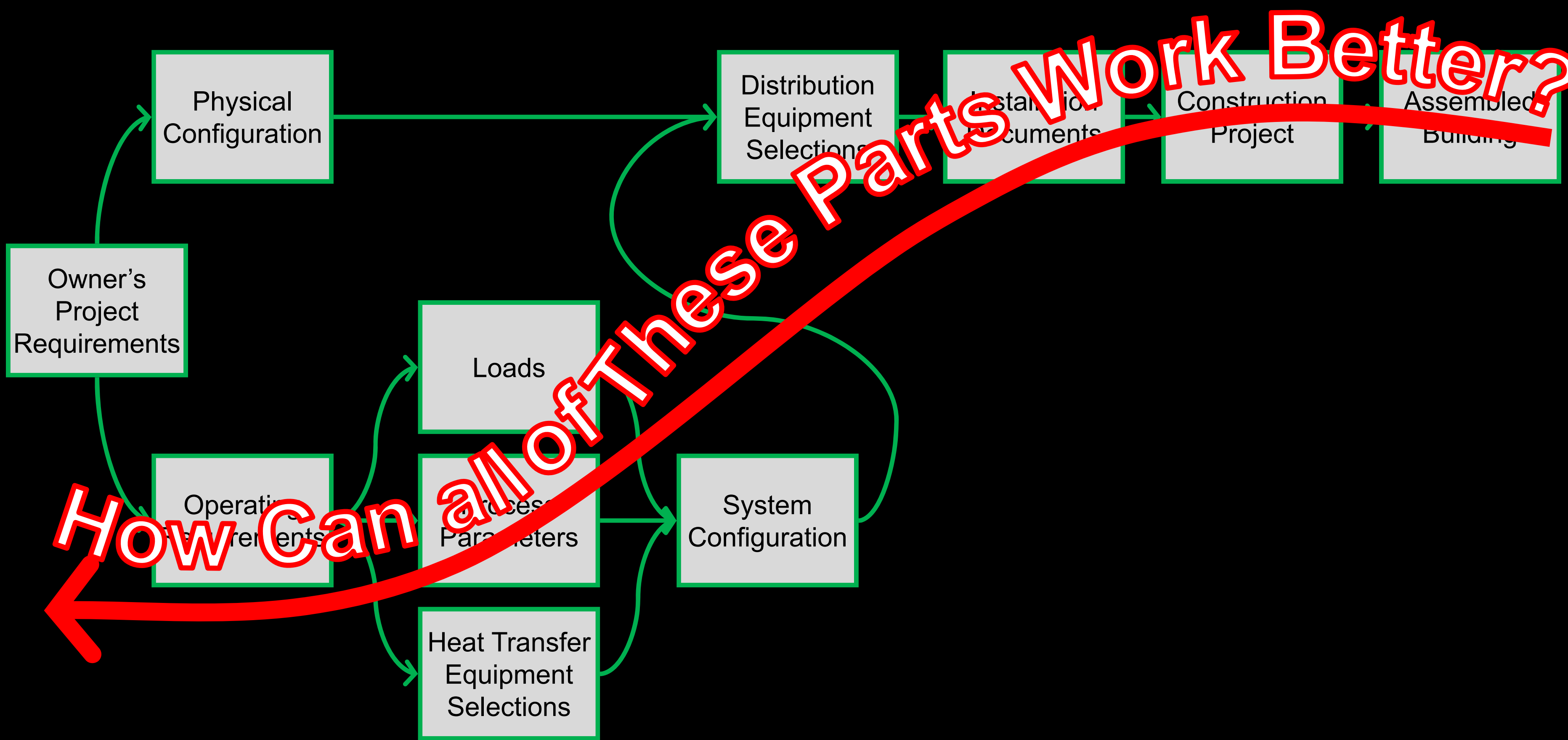
More than Balancing Man Power



Functional Testing as it Relates to the Metrics of the Systems We Test



Functional Testing as it Relates to the Metrics of the Systems We Test



Forced vs. Natural Response Testing

Forced Response Testing

I force a change and watch how the system responds

Forced vs. Natural Response Testing

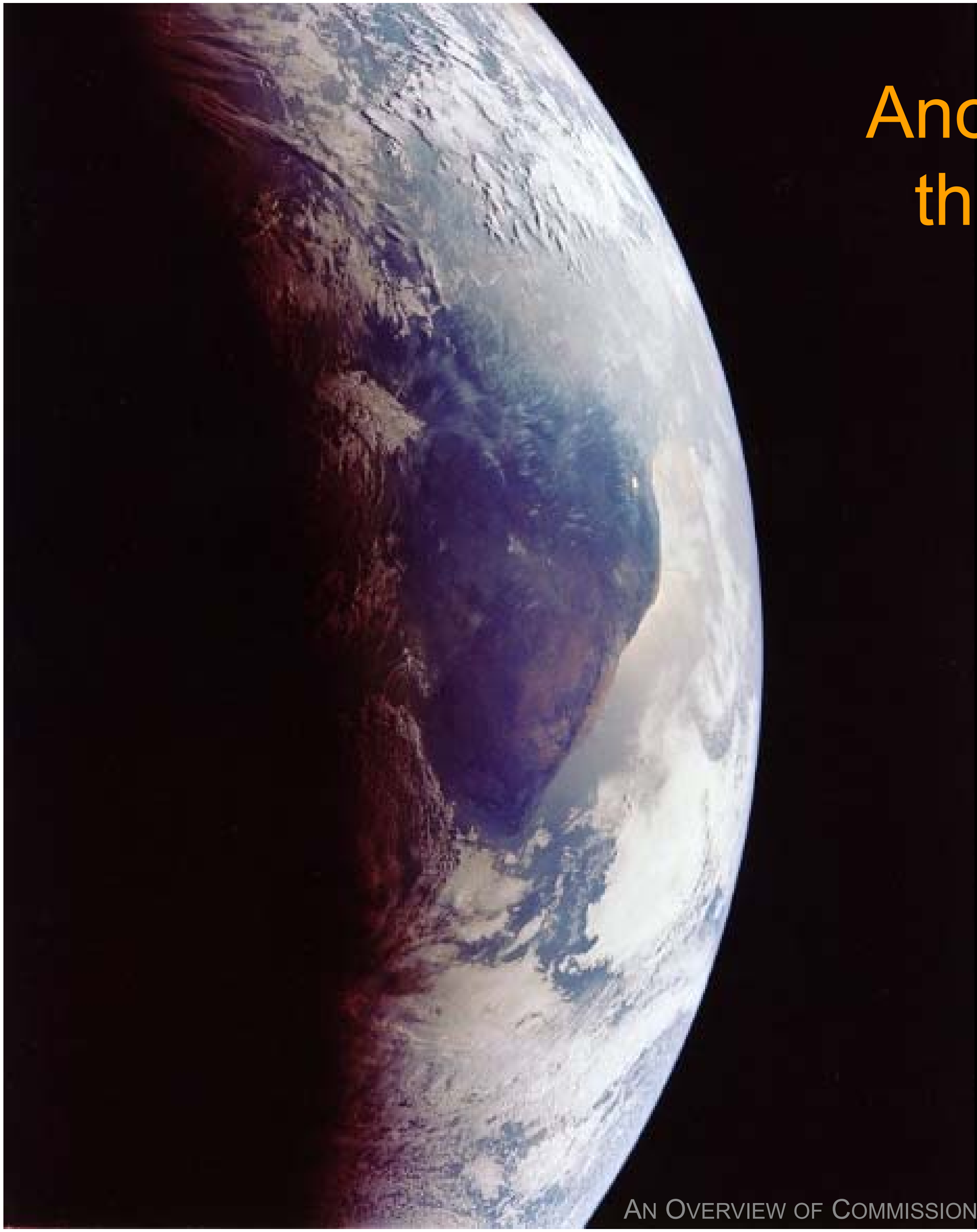
Forced Response Testing

I force a change and watch how the system responds

View the video on Youtube at
http://tinyurl.com/MR-1-Launch

Natural Response Testing

I observe how a system responds to the normal course of events



Another Lesson from the Space Program

We went to explore the Moon, and in fact discovered the Earth

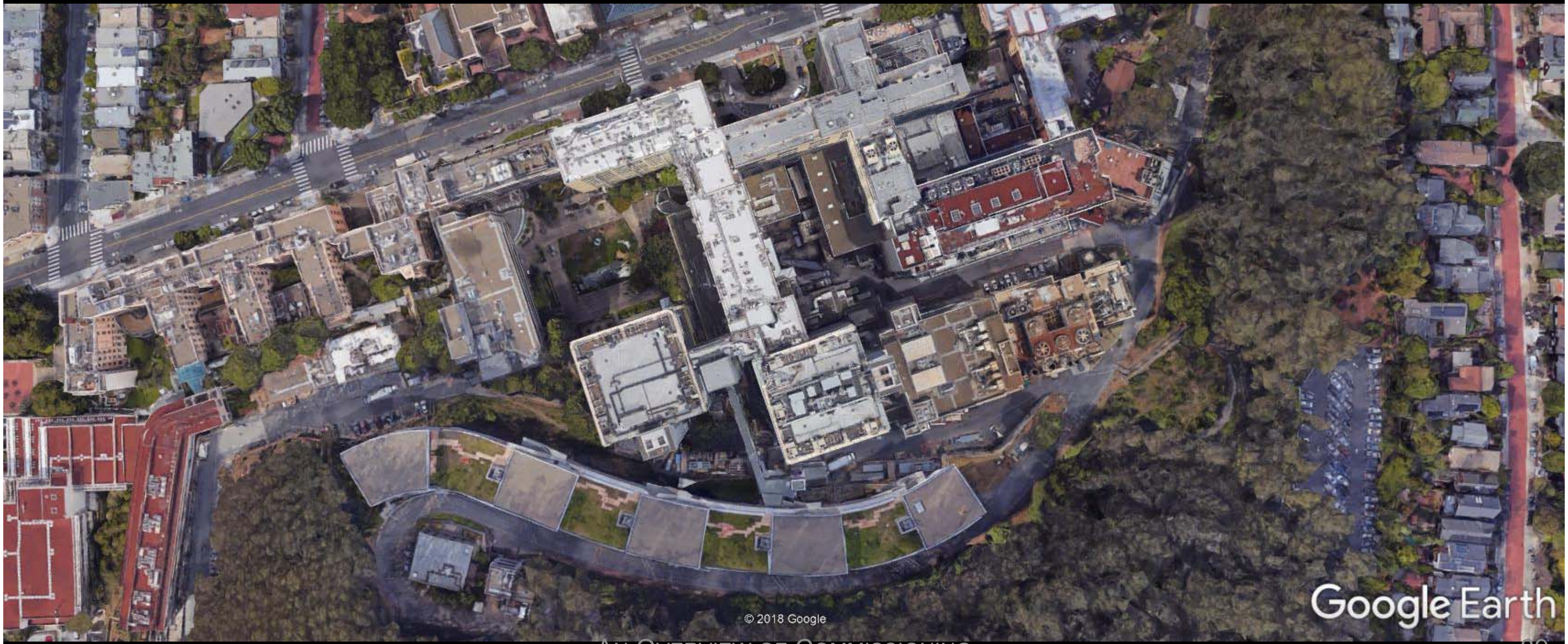
Gene Cernan

Apollo 17 Commander

Image courtesy NASA Image Archives; https://www.nasa.gov/multimedia/imagegallery/index.html

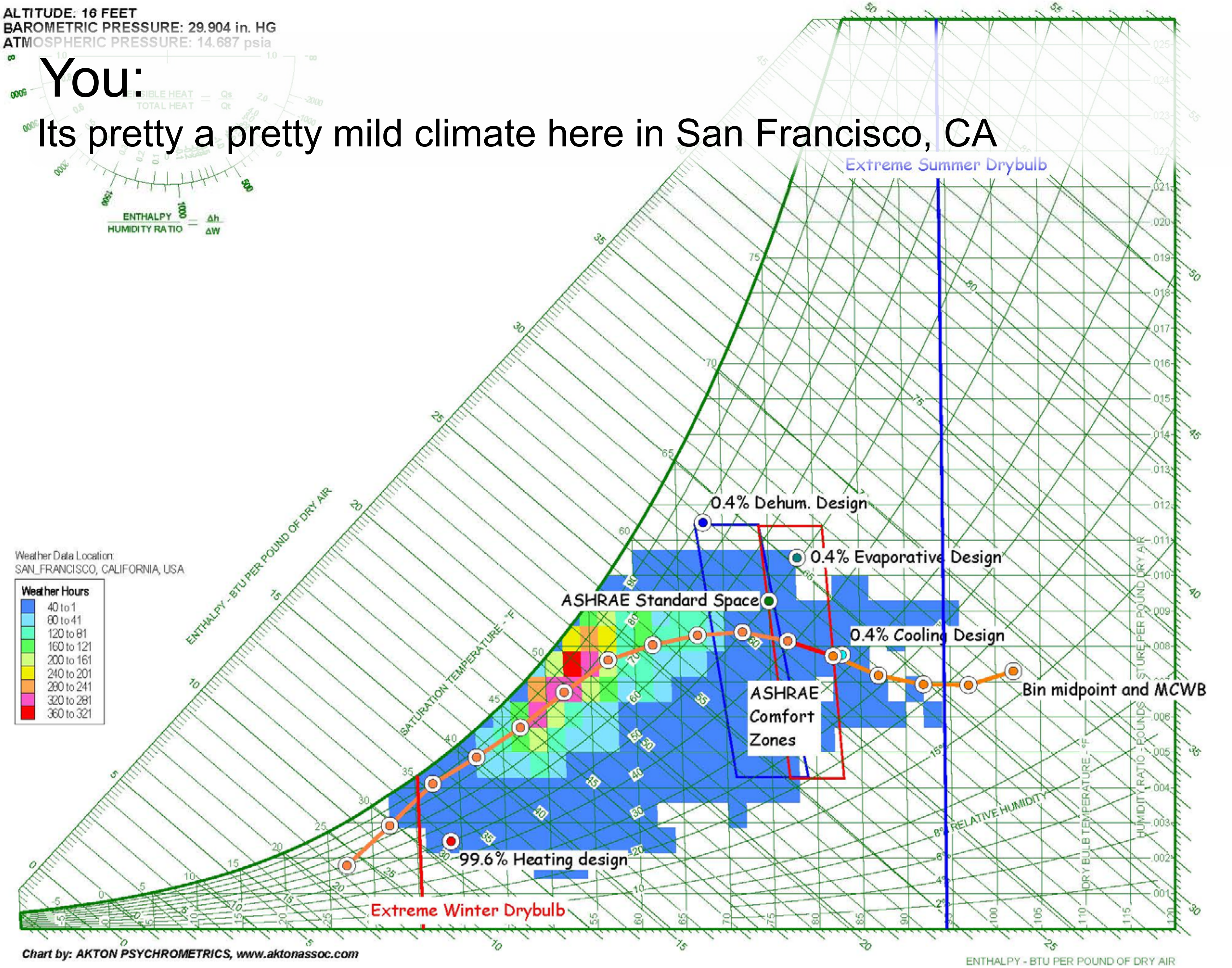
The Machines are Talking To Us

In the bigger picture, commissioning is about having a dialog with a building and functional testing is one way to have the conversation



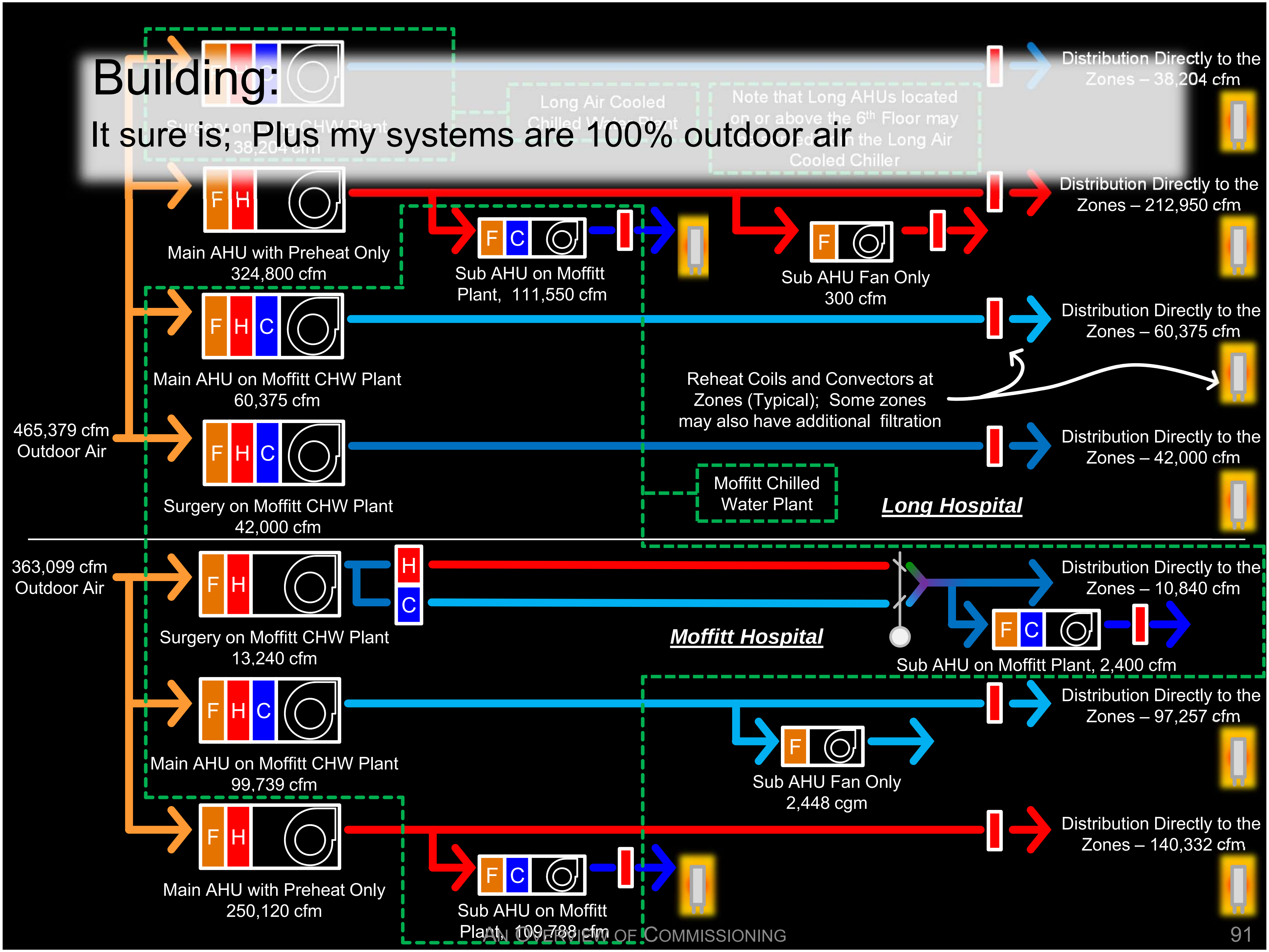
You:

Its pretty a pretty mild climate here in San Francisco, CA



Building:

It sure is; Plus my systems are 100% outdoor air

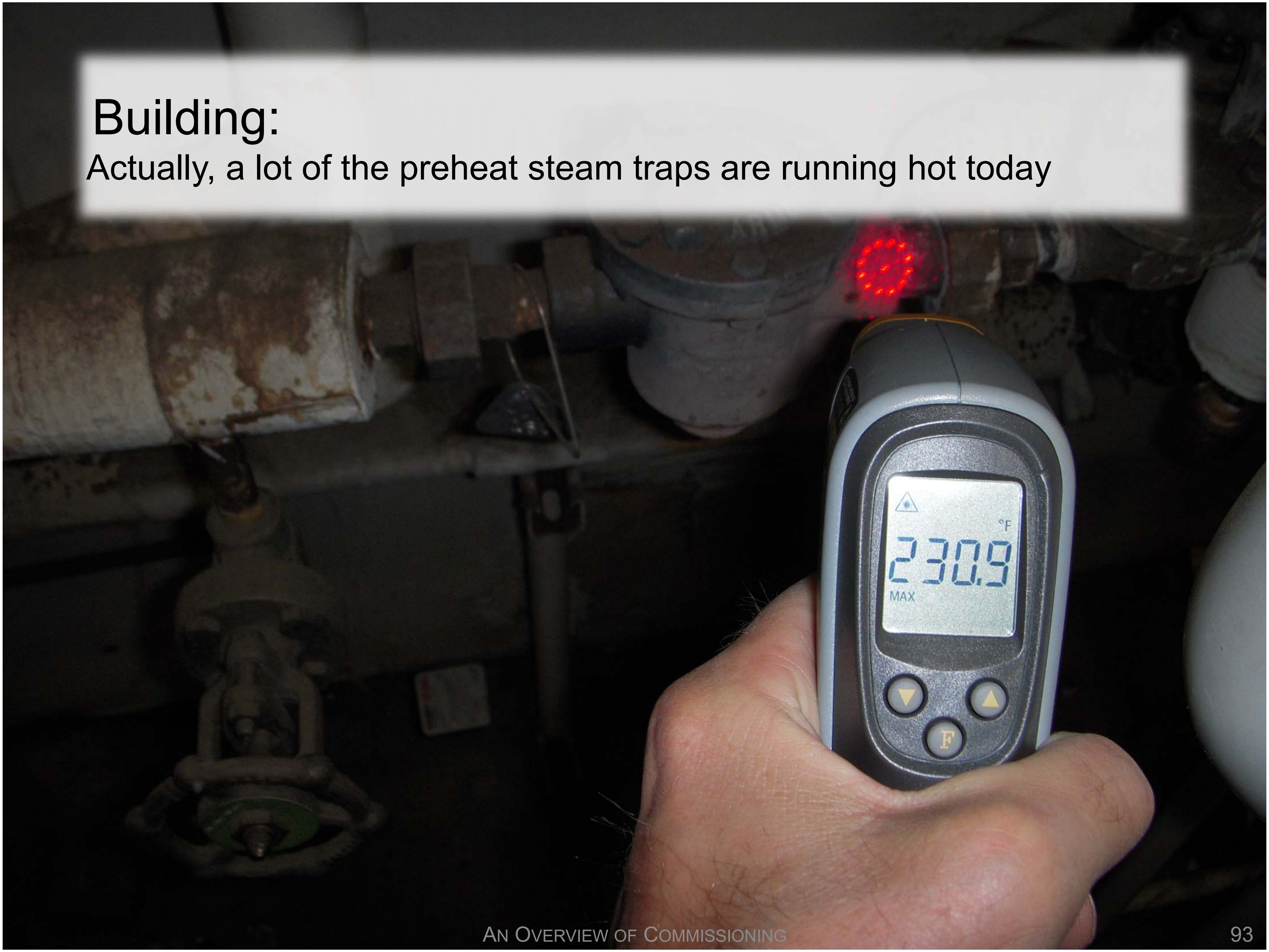


You:

I doubt if your preheat coils will be doing much since its over 55°F outside

Building:

Actually, a lot of the preheat steam traps are running hot today

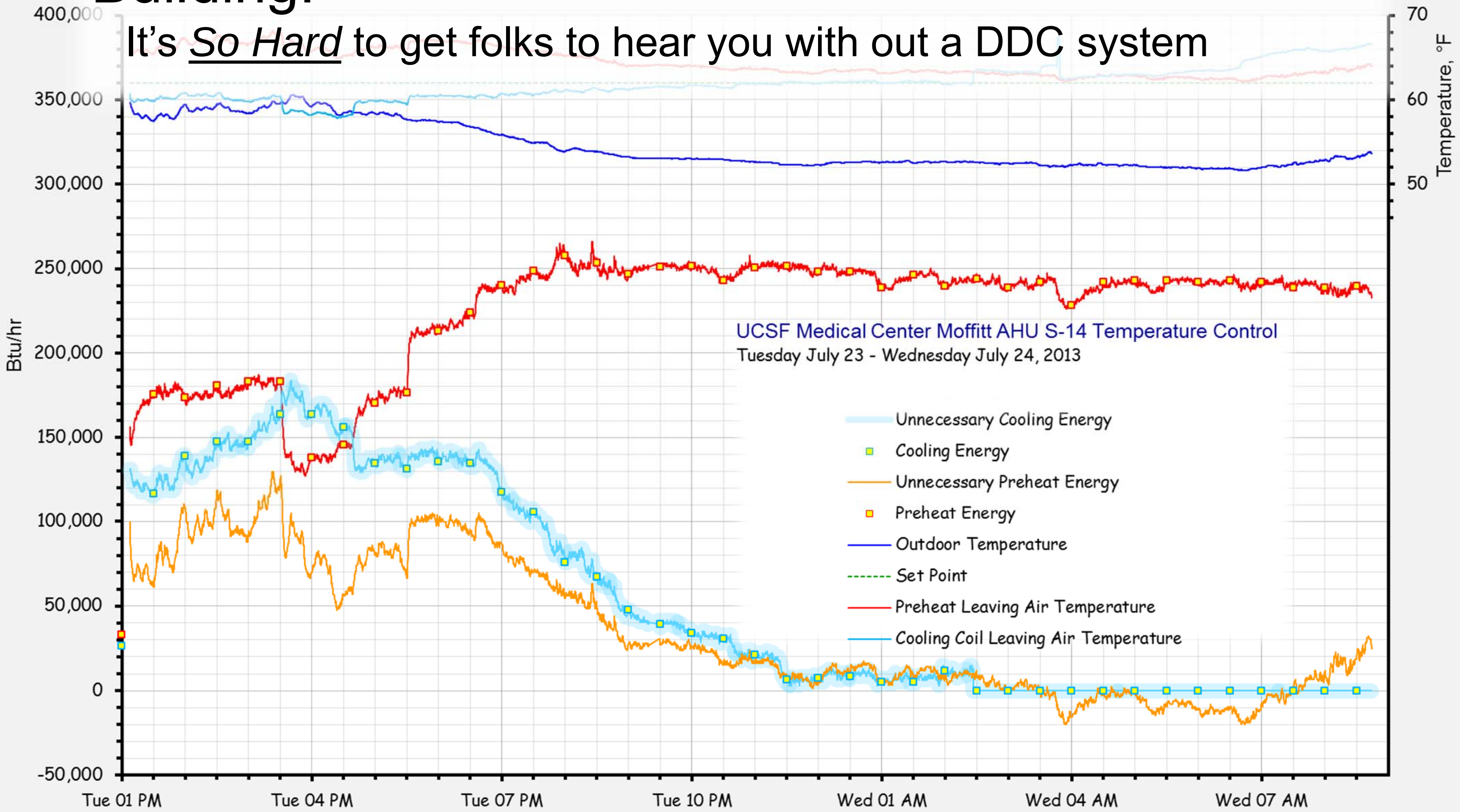


You:

Hmmm.   Can we chat a bit?

Building:

It's *So Hard* to get folks to hear you with out a DDC system



You:

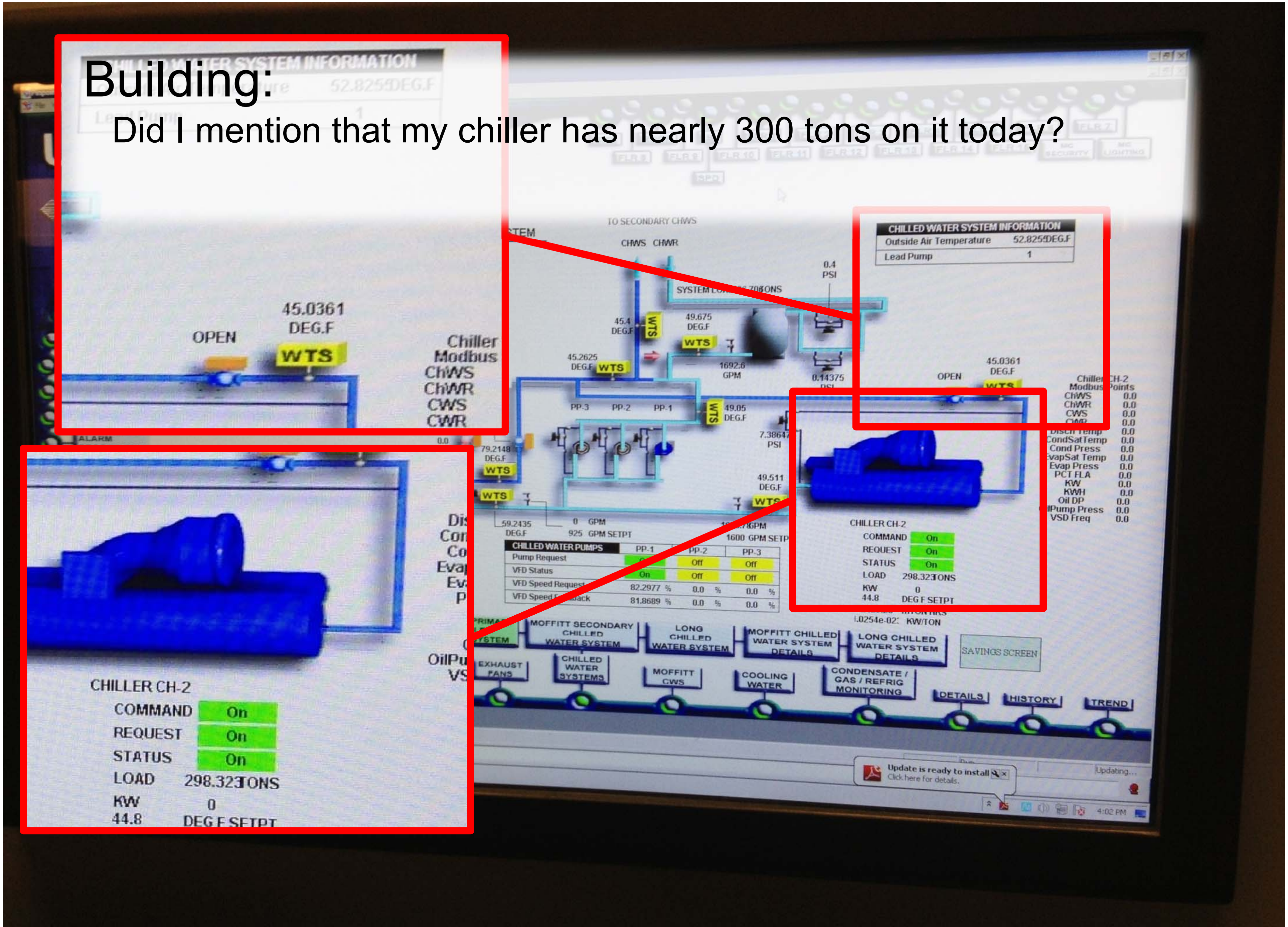
With a bit of time and maybe a bit more data, I suspect I can help you with that

Unnecessary Steam Use and Cost Per Day			
Steam consumption per day based on the logged data -	4,530,371	Btu per day	
-	4,788	pounds of steam per day	
-	199	pounds of steam per hour	
-	$99	per day	
-	$4.11	per hour	
Gas input at the plant -	5,662,964	Btu per day	
-	57	therms per day	
Approximate annual savings potential based on bin data -	Low End	High End	
	426,029	852,058	pounds of steam per year
	$8,772	$17,543	$ per year

Unnecessary Chilled Water Use and Cost Per Day			
Chilled water consumption based on the logged data -	113	ton-hours per day	
-	96	kWh per day at the assumed net plant efficiency	
-	4	kWh per hour	
-	$11	per day	
	$0.45	per hour	
Approximate annual savings potential based on bin data -	Low End	High End	
	8,523	17,046	kWh per year
	$966	$1,933	$ per year

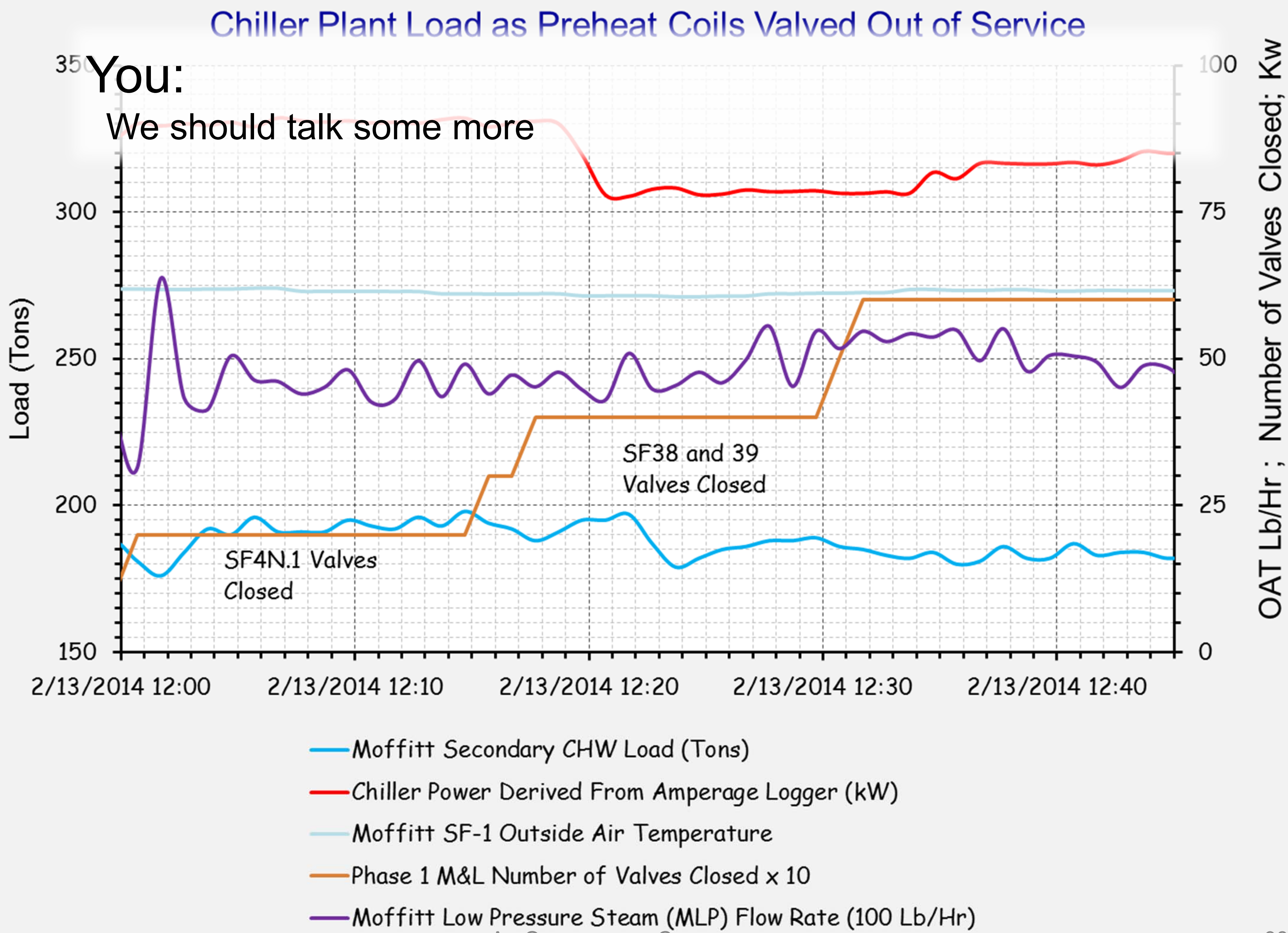
Building:

Did I mention that my chiller has nearly 300 tons on it today?



You:

We should talk some more



The Bottom Line

Cost/Benefit Summary - Recommended Option

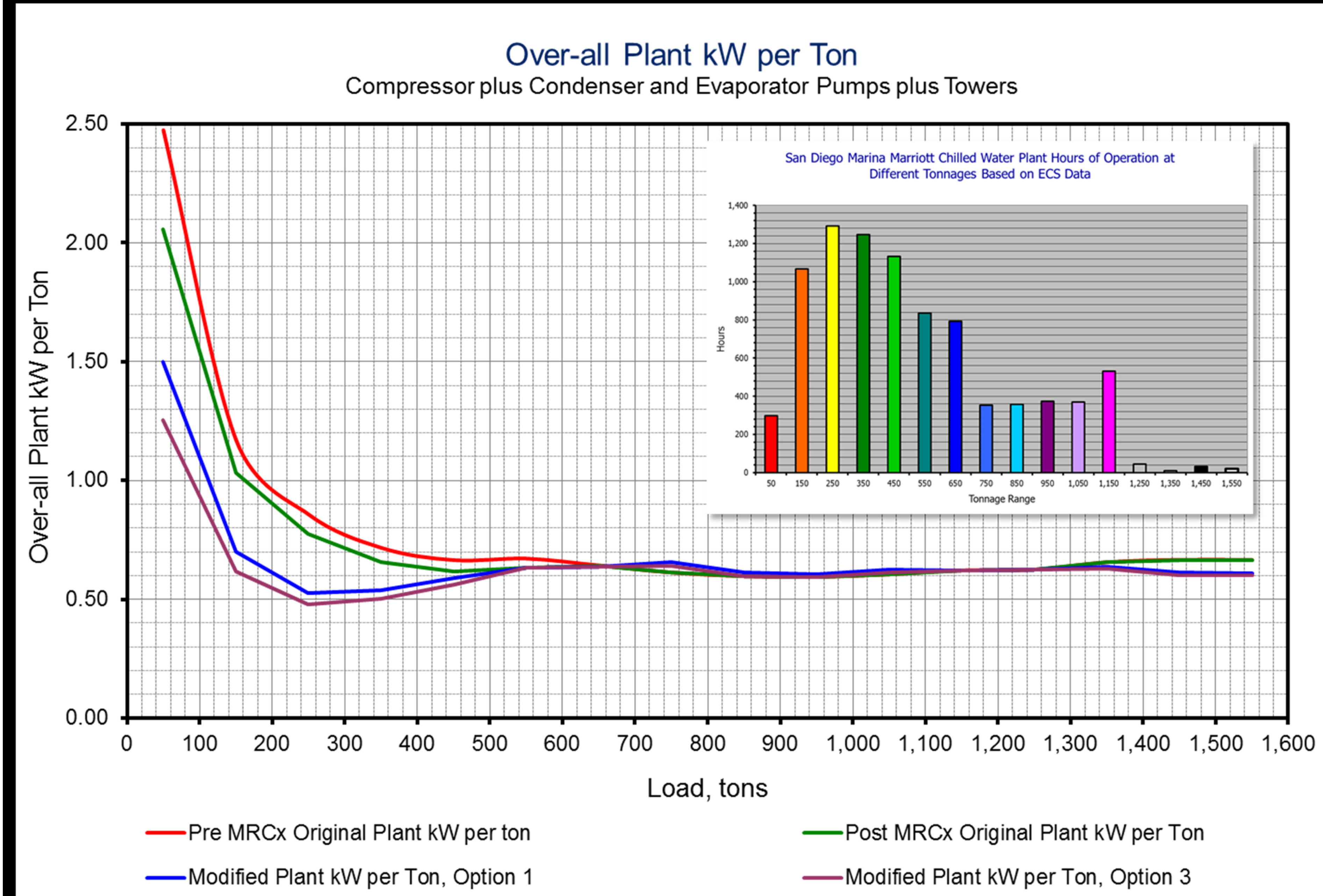
			Units Included:		
Main AHU Controls Plus 2 Token Zones per System Upgrade Costs -	$542,165				
Savings:	Dollars	Energy	Wing A		Wing B
Wing B Electricity Savings -	$53,819	484,856	SF-9 thru 13	SF-5.3	SF-10
Wing B Steam Savings -	$34,428	1,831	SF-14	SF-23	SF-38
Wing A Electricity Savings -	$29,954	269,852	SF-15	SF-5.4	SF-14
Wing A Steam Savings -	$222,784	11,850	SF-25	SF-5.5	SF-15
Total Savings -	$340,984		SF-1		SF-39
Potential Electrical Incentive -	$181,130		SF-2		
Potential Thermal Incentive -	$171,018				
Simple payback (before incentive) -	1.6	years (Construction cost basis for comparison to the other options)			
Owner Soft Costs -	$189,758				
Project Budget with Owner Soft Costs -	$731,923				
Avoided to					

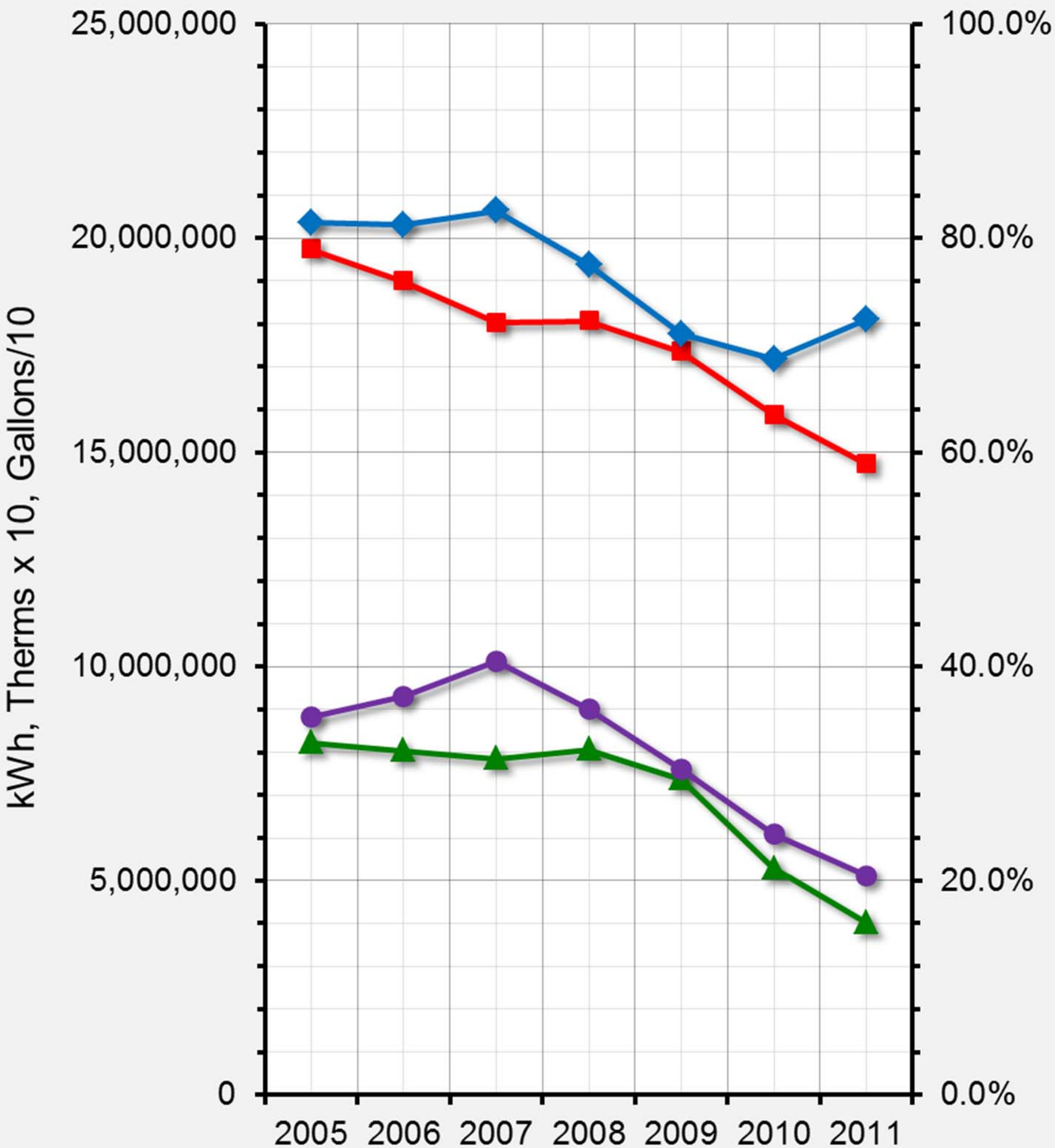
Cost/Benefit Summary - Recommended Option

Main AHU Controls Plus 2 Token Zones per System Upgrade Costs -	$542,165	
Savings:	Dollars	Energy
Wing B Electricity Savings -	$53,819	484,856
Wing B Steam Savings -	$34,428	1,831
Wing A Electricity Savings -	$29,954	269,852
Wing A Steam Savings -	$222,784	11,850
Total Savings -	$340,984	
Potential Electrical Incentive -	$181,130	
Potential Thermal Incentive -	$171,018	
Simple payback (before incentive) -	1.6	years (Construct
Owner Soft Costs -	$189,758	
Project Budget with Owner Soft Costs -	$731,923	
Total potential Incentive -	$352,148	
Project Cost after Incentive -	$379,774	
Simple payback (after incentive) -	1.1	years
Avoided tonnage/installed chiller purchase cost for the Wubg B chilled water plant project -	96	$671,293

The Bottom Line

Keep Asking Questions and You Will Learn (and Save) A Lot


Over-all Plant kW per Ton
Compressor plus Condenser and Evaporator Pumps plus Towers
Over-all Plant kW per Ton
Load, tons
San Diego Marina Marriott Chilled Water Plant Hours of Operation at Different Tonnages Based on ECS Data
Hours
Tonnage Range
Pre MRCx Original Plant kW per ton
Post MRCx Original Plant kW per Ton
Modified Plant kW per Ton, Option 1
Modified Plant kW per Ton, Option 3



Total kWh

Total Gas, Therms x 10

Water, gallons/10

Average Occupancy

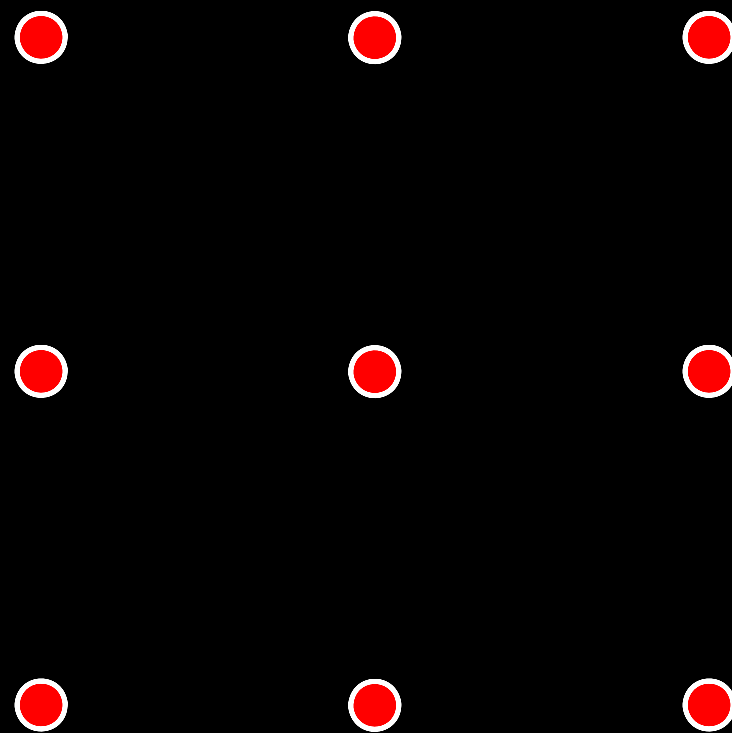
San Diego Marriott Marquis and Marina

Utility Consumption

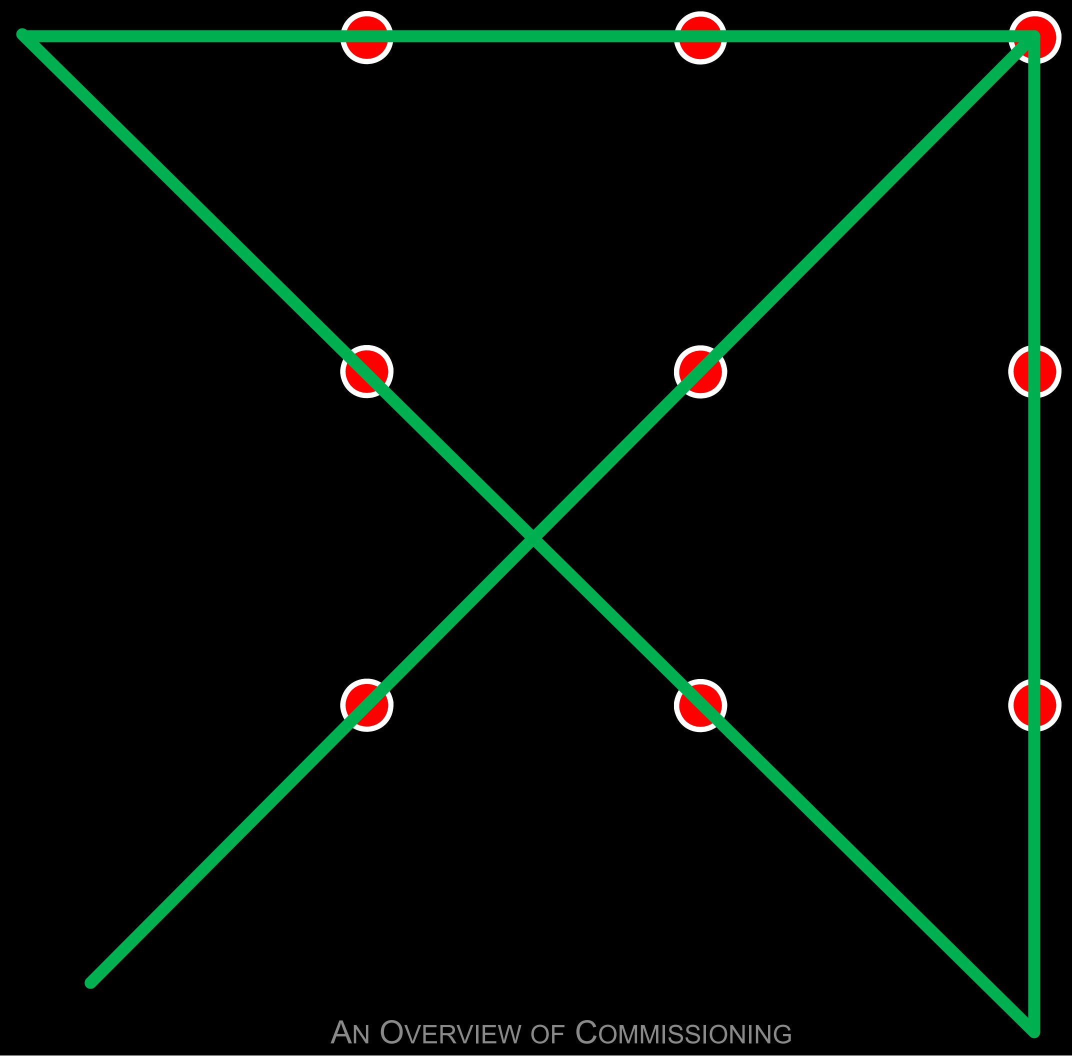
Facility Dynamics Engineering

A Puzzle

Connect all of the dots with 4 straight lines with out lifting your pencil and with out retracing a line

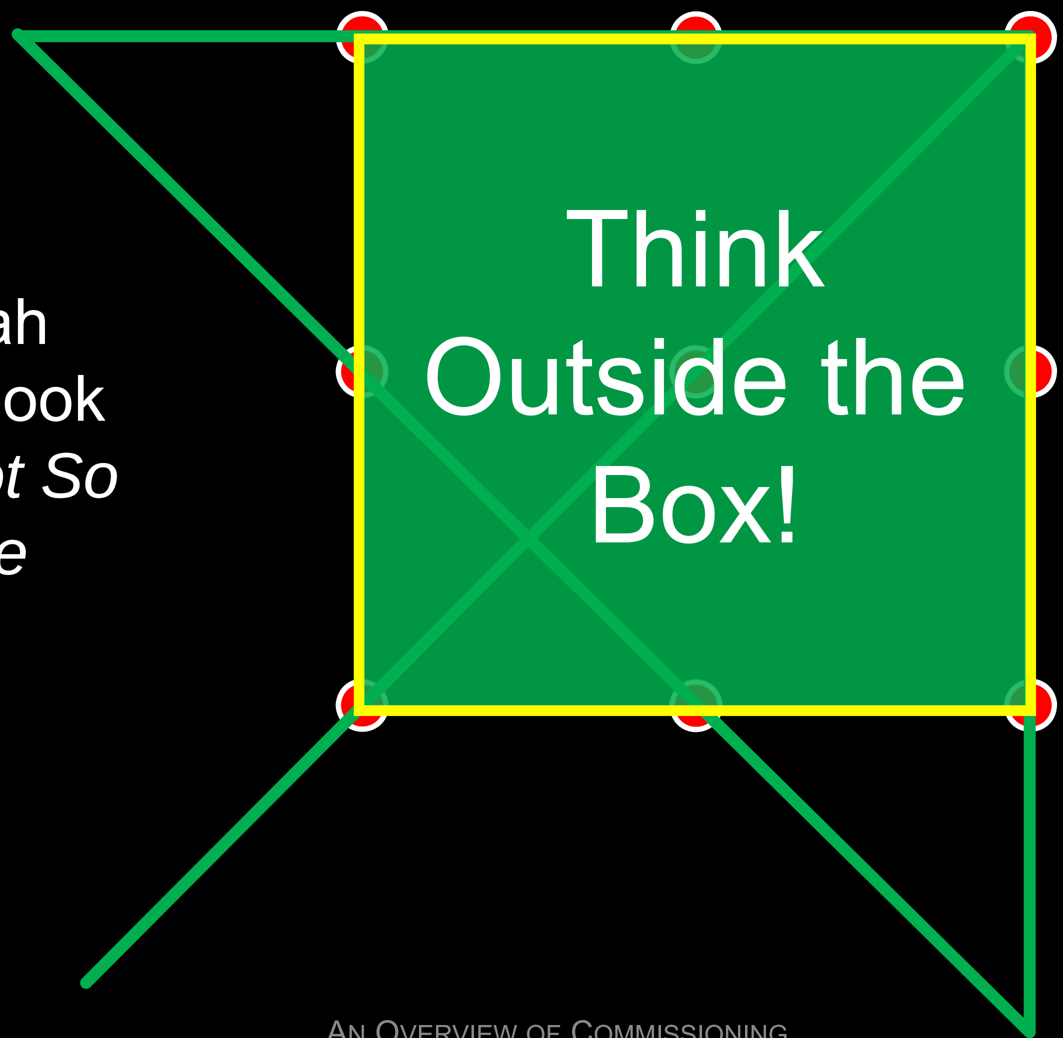


A Puzzle



A Puzzle

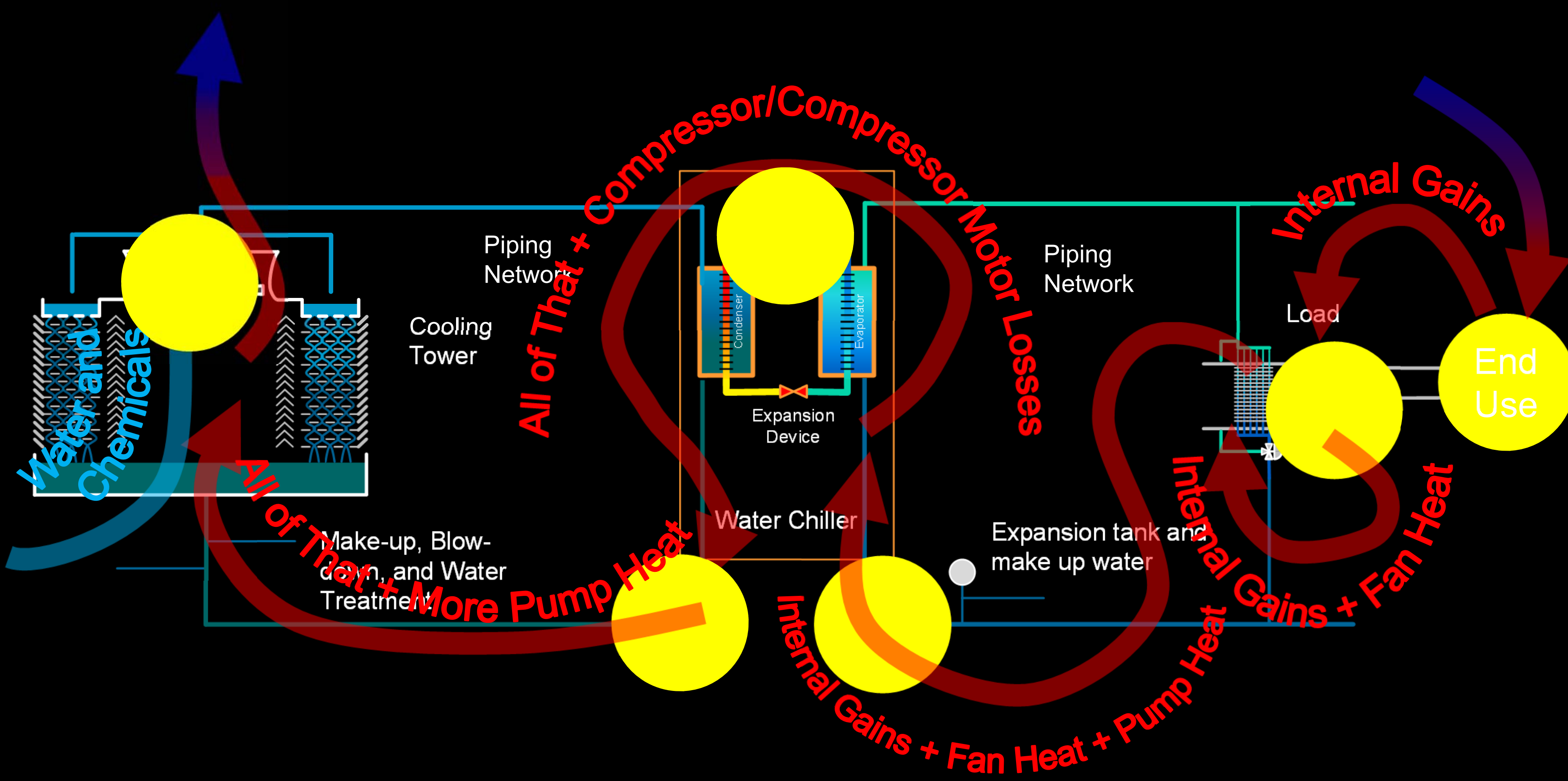
From Sarah Susanka's book titled *The Not So Big House*



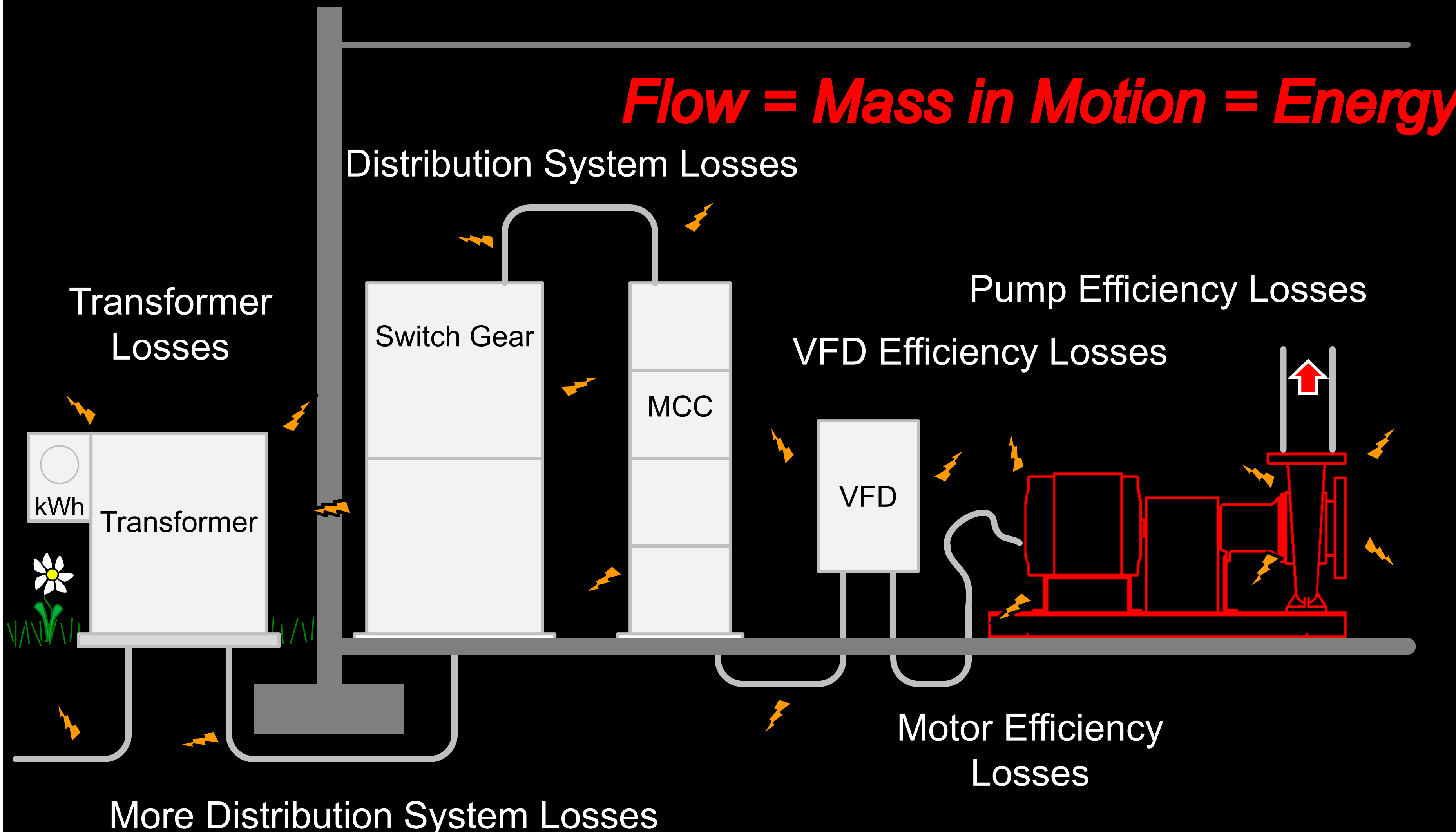
We can't solve problems by using the same kind of thinking we used when we created them

Albert Einstein

Thinking About the Bigger Picture

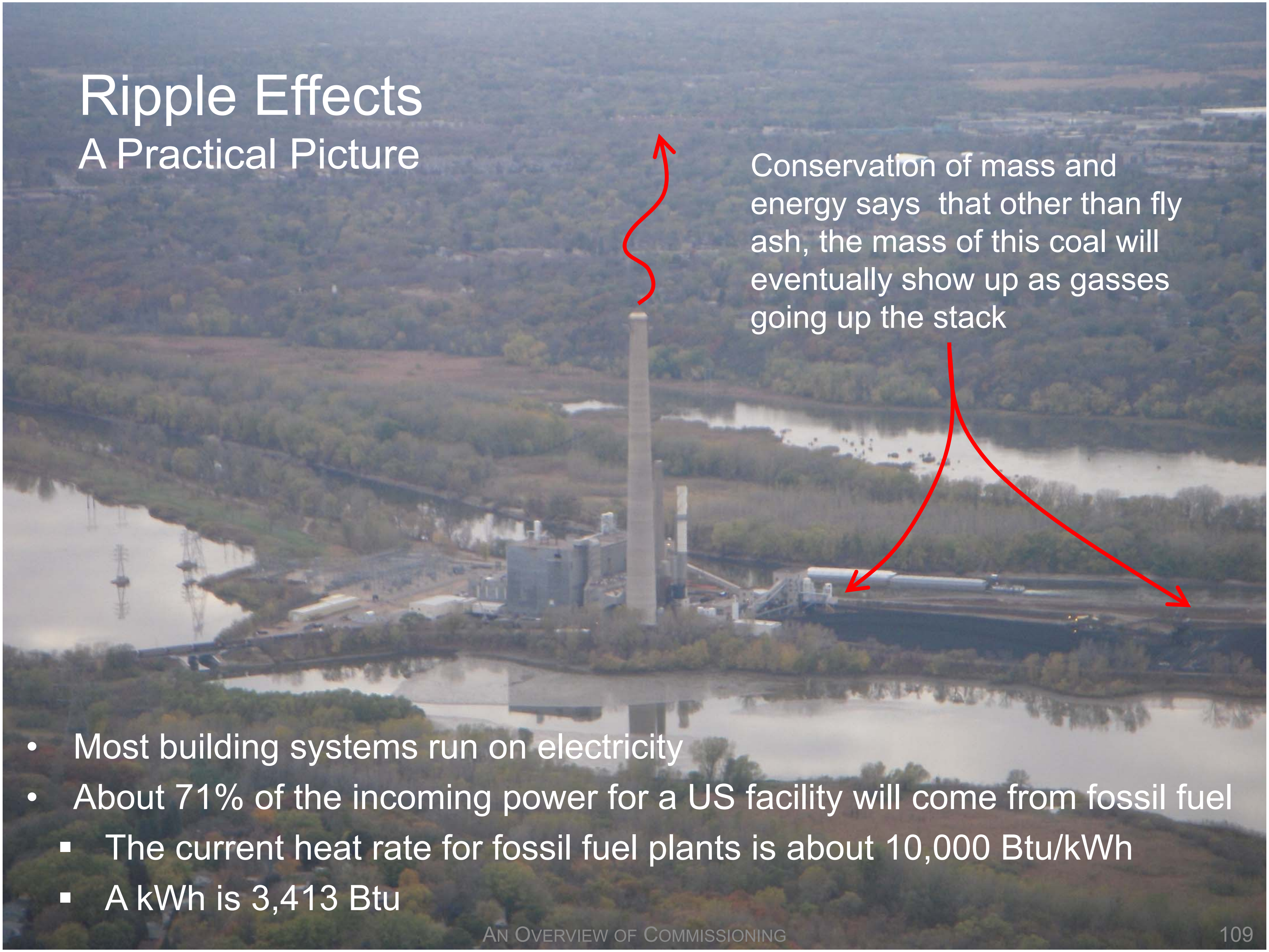


Thinking About the Bigger Picture



Ripple Effects

A Practical Picture

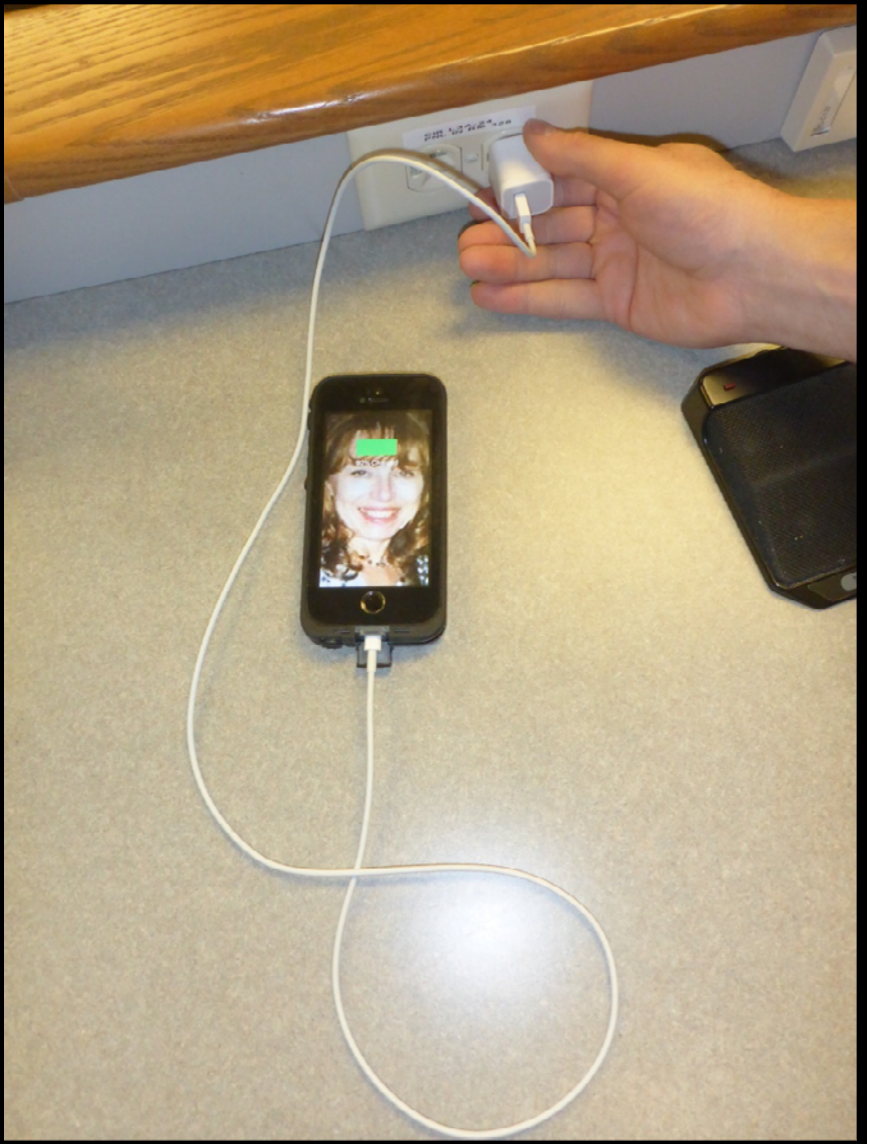


- Most building systems run on electricity
- About 71% of the incoming power for a US facility will come from fossil fuel
  - The current heat rate for fossil fuel plants is about 10,000 Btu/kWh
  - A kWh is 3,413 Btu

State	% of Total Electric Power Generation											Non-renewable Percent of Total	Renewable Percent of Total	Non-hydro Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
	Non-Renewable					Renewable					Nuclear					
	Combustion Processes						Non-Combustion Processes									
	Coal	Oil	Gas	Other Fossil Fuel	Purchased, Fuel Generated	Biomass	Hydro	Wind	Solar	Geothermal						
AK	9.2	13.9	55.6	0.0	0.0	0.1	21.1	0.2	0.0	0.0	0.0	78.7	21.3	[illegible]	78.7	21.3
AL	41.4	0.1	25.8	0.2	0.0	1.8	5.7	0.0	0.0	0.0	24.9	92.5	7.5	1.8	69.3	30.7
AR	46.2	0.1	20.4	0.0	0.0	2.7	6.0	0.0	0.0	0.0	24.6	91.3	8.7	2.7	69.4	30.6
AZ	39.1	0.1	26.6	0.0	0.0	0.2	6.1	0.1	0.0	0.0	27.9	93.6	6.4	0.3	65.8	34.2
CA	1.0	1.2	52.7	0.2	0.3	3.0	16.3	3.0	0.4	6.2	15.8	71.3	28.7	12.5	58.4	41.6
CO	68.1	0.0	21.9	0.0	0.1	0.1	2.9	6.8	0.1	0.0	0.0	90.1	9.9	7.0	90.2	9.8
CT	7.8	1.2	35.2	2.2	0.0	2.1	1.2	0.0	0.0	0.0	50.2	96.7	3.3	2.1	48.6	51.4
DC	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	[illegible]	0.0	100.0	0.0
DE	45.6	1.0	50.9	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	97.5	[illegible]	2.5	100.0	0.0
FL	26.1	4.0	56.2	0.6	0.7	1.9	0.1	0.0	0.0	0.0	10.4	98.0	2.0	1.9	89.4	10.6
GA	53.3	0.5	17.4	0.0	0.0	2.3	2.2	0.0	0.0	0.0	24.4	95.5	4.5	2.3	73.4	26.6
HI	14.3	74.8	0.0	3.5	0.0	2.5	0.6	2.4	0.0	1.9	0.0	92.6	7.4	6.8	95.1	4.9
IA	71.8	0.3	2.3	0.0	0.0	0.3	1.6	15.9	0.0	0.0	7.7	82.1	17.9	16.2	74.7	25.3
ID	0.7	0.0	14.0	0.0	0.7	4.2	76.1	3.7	0.0	0.6	0.0	15.4	84.6	8.4	19.6	80.4
													2.6	2.6	50.0	50.0
													2.9	2.6	97.3	2.7
													7.2	7.2	72.9	27.1
													3.1	0.4	97.4	2.6
													3.4	2.4	81.0	19.0
													4.4	2.8	84.7	15.3
													5.1	1.3	64.1	35.9
													46.7	24.3	74.7	25.3
													2.7	2.5	72.9	27.1
													13.9	12.3	64.4	35.6
													3.7	1.1	86.6	13.4
													2.8	2.8	82.3	17.7
													34.8	3.1	65.2	34.8
													5.6	1.6	64.5	35.5
													17.6	11.7	82.4	17.6
													4.9	1.3	65.1	34.9
													12.2	5.5	43.8	56.2
													1.2	1.2	50.2	49.8
													5.7	5.1	94.3	5.7
													12.6	6.5	87.4	12.6
NY	9.9	1.5	35.7	0.7	0.0	1.6	18.2	1.9	0.0	0.0	30.6	78.3	21.7	3.4	49.3	50.7
OH	82.1	1.0	5.0	0.2	0.0	0.5	0.3	0.0	0.0	0.0	11.0	99.2	0.8	0.5	88.7	11.3
OK	43.5	0.0	47.0	0.0	0.0	0.5	3.7	5.3	0.0	0.0	0.0	90.6	9.4	5.8	91.1	8.9
OR	7.5	0.0	28.4	0.1	0.0	1.5	55.4	7.1	0.0	0.0	0.0	36.0	64.0	8.6	37.5	62.5
PA	48.0	0.3	14.7	0.6	0.0	1.0	0.7	0.8	0.0	0.0	33.9	97.4	2.6	1.8	64.6	35.4
RI	0.0	0.2	98.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	98.1	1.9	1.8	99.9	0.1
SC	36.2	0.2	10.5	0.1	0.0	1.8	1.4	0.0	0.0	0.0	49.9	96.8	[illegible]	1.8	48.7	51.3
SD	32.8	0.1	1.3	0.0	0.0	0.0	52.1	13.6	0.0	0.0	0.0	34.2	[illegible]	13.6	34.2	65.8
TN	53.3	0.3	2.8	0.0	0.0	1.2	8.6	0.0	0.0	0.0	33.9	90.2	9.8	1.2	57.5	42.5
TX	36.5	0.8	45.3	0.2	0.1	0.4	0.3	6.4	0.0	0.0	10.1	93.0	7.0	6.7	83.3	16.7
UT	80.6	0.2	15.3	0.0	0.4	0.1	1.6	1.1	0.0	0.7	0.0	96.5	3.5	1.8	96.6	3.4
VA	34.9	1.8	23.3	0.6	0.0	3.0	0.0	0.0	0.0	0.0	36.4	97.0	3.0	3.0	63.6	36.4
VT	0.0	0.1	0.1	0.0	0.0	7.1	20.3	0.2	0.0	0.0	72.2	72.4	27.6	7.3	7.2	92.8
WA	8.3	0.3	9.9	0.1	0.0	1.8	66.2	4.5	0.0	0.0	8.9	27.5	72.5	6.3	20.4	79.6
WI	62.5	1.1	8.5	0.0	0.1	2.2	3.3	1.7	0.0	0.0	20.7	92.9	7.1	3.8	74.4	25.6
WV	96.7	0.2	0.2	0.1	0.0	0.0	1.7	1.2	0.0	0.0	0.0	97.1	2.9	[illegible]	97.1	2.9
WY	89.3	0.1	1.0	0.6	0.1	0.0	2.1	6.7	0.0	0.0	0.0	91.1	8.9	[illegible]	91.1	8.9
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	0.0	0.0	7.2	0.0
Maximum	96.7	100.0	98.0	3.5	0.9	21.4	76.1	15.9	0.6	6.2	72.2	100.0	84.6	24.3	100.0	92.8
Average	41.9	4.3	22.5	0.4	0.1	1.8	9.2	2.5	0.0	0.3	17.0	86.1	13.9	4.7	71.0	29.0

State	Non-renewable Percent of Total	Renewable Percent of Total	Non-hydro Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
Minimum	15.4	0.0	0.0	7.2	0.0
Maximum	100.0	84.6	24.3	100.0	92.8
Average	86.1	13.9	4.7	71.0	29.0

The iPhone Food Chain



Gas Fired Power Plant as the Energy Source

Location in the "Food Chain"	Watt-hours at the point in the system	Conversion Loss				
		Device Efficiency	Loss at the Location		Accumulated Losses	
			watt-hours	%	watt-hours	%
End use - Provide a full charge for an iPhone SE Battery	6.17	End Use				
iPhone Charger	8.34	74.0%	2.17	26.0%	2.17	26.0%
Building Electical Distribution System Losses (wires, panels, terminations, etc.)	8.42	99.0%	0.08	1.0%	2.25	26.7%
Transformer Losses	8.50	99.1%	0.07	0.9%	2.33	27.4%
Transmission From the Power Plant to the Building Transformer	8.92	95.3%	0.42	4.7%	2.74	30.8%
Gas Fired Power Plant Efficiency	20.57	43.3%	11.66	56.7%	14.40	70.0%
Delivering Gas from the Natural Gas Well	21.66	95.0%	1.08	5.0%	15.49	71.5%
Bottom Lines						
Energy into the process - watt - hours	21.66					
Energy delivered - watt-hour	6.17					
Losses - watt-hours	15.49					
	71.5%					
Average price of electricity; $/kWh	Residential	Commercial				
(U.S. Average for May, 2017)	$0.1302	$0.1058				
Cost to charge an iPhone	$0.0008	$0.0007				
Annual charge cycles (1 per day)	365	365				
Annual cost to keep the iPhone charged	$0.2933	$0.2383				
Associated Emmissions for One Year, lb.						
CO_2 (Carbon Dioxide)	2.0762	Believed by some to be the primary greenhouse gas emitted by human activities; Respiratory problems occur at high concentrations.				
SO_2 (Sulfur Dioxide)	0.0022	Resiratory system harm and difficult breathing; Harms trees and plants by decreasing foliage and growth; Reacts to create haze.				
NOx (Nitrous Oxide)	0.0016	Reacts to form ozone, aerosols, and NO_2; Respiratory harm; Contributes to acid rain; Impacts water and air quality; Greenhouse				

Coal Fired Power Plant as the Energy Source

Location in the "Food Chain"	Watt-hours at the point in the system	Conversion Loss				
		Device Efficiency	Loss at the Location		Accumulated Losses	
			watt-hours	%	watt-hours	%
End use - Provide a full charge for an iPhone SE Battery	6.17	End Use				
iPhone Charger	8.34	74.0%	2.17	26.0%	2.17	26.0%
Building Electical Distribution System Losses (wires, panels, terminations, etc.)	8.42	99.0%	0.08	1.0%	2.25	26.7%
Transformer Losses	8.50	99.1%	0.07	0.9%	2.33	27.4%
Transmission From the Power Plant to the Building Transformer	8.92	95.3%	0.42	4.7%	2.74	30.8%
Coal Fired Power Plant Efficiency	27.41	32.5%	18.49	67.5%	21.24	77.5%
Delivering Coal from the Coal Mine	28.85	95.0%	1.44	5.0%	22.68	78.6%

Bottom Lines		
Energy into the process - watt - hours	28.85	
Energy delivered - watt-hour	6.17	
Losses - watt-hours	22.68	
	78.6%	
Average price of electricity; $/kWh	Residential	Commercial
(U.S. Average for May, 2017)	$0.1302	$0.1058
Cost to charge an iPhone	$0.0008	$0.0007
Annual charge cycles (1 per day)	365	365
Annual cost to keep the iPhone charged	$0.2933	$0.2383

Associated Emmissions, lb.		
CO_2 (Carbon Dioxide)	3.6500	Believed by some to be the primary greenhouse gas emitted by human activities; Respiratory problems occur at high concentrations.
SO_2 (Sulfur Dioxide)	0.0039	Resiratory system harm and difficult breathing; Harms trees and plants by decreasing foliage and growth; Reacts to create haze.
NOx (Nitrous Oxide)	0.0029	Reacts to form ozone, aerosols, and NO_2; Respiratory harm; Contributes to acid rain; Impacts water and air quality; Greenhouse

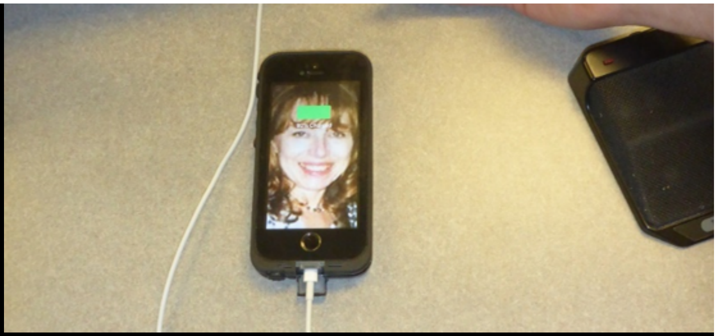
The AHU Food Chain

Coal Fired Power Plant as the Energy Source						
Location in the "Food Chain"	kWh at the point in the system	Conversion Loss				
		Device Efficiency	Loss at the Location		Accumulated Losses	
			watt-hours	%	watt-hours	%
End use - Cool the Air Delivered to a Ball Room for 1 Hour on a Design Day in St. Louis,	334	End Use				
End use - Move Cool Air from the Equipment Room to the Ball Room for One Hour on a	7	End Use				
kW into the Cooling Plant (The device producing the cooling uses 1 unit of energy to	69	Energy Into the Electrical Panel Serving the Cooling Plant				
kW into the Air Handling Unit Fan and it's Drive System (Motor, Belts, and Motor Speed	12	60.2%	Energy Into the Electrical Panel Serving the Air Handling Unit			
Total kW into the Cooling Plant and the Air Handling Unit	81	This is the electricity that was delivered by the electrical panels in the chiller and air handling system mechanical rooms.				
Building Electical Distribution System Losses (wires, panels, terminations, etc.)	82	99.0%	12.71	15.5%	12.71	15.5%
Transformer Losses	83	99.1%	0.71	0.9%	13.42	16.2%
Transmission From the Power Plant to the Building Transformer	87	95.3%	4.08	4.7%	17.50	20.1%
Coal Fired Power Plant Efficiency	267	32.5%	180.18	67.5%	197.68	74.0%
Delivering Coal from the Coal Mine	281	95.0%	14.06	5.0%	211.74	75.3%

Bottom Lines		
Energy into the process - kWh	281	
Energy delivered to the cooling plant - kWh	81	
Losses - kWh	200	
	71.1%	
Average price of electricity; $/kWh	Residential	Commercial
(U.S. Average for May, 2017)	$0.1302	$0.1058
Cost to cool a Ball Room on a Design Day in St. Louis, Missouri for an Hour (Note 3)	$10.58	$8.60
Cost to Cool a Ball Room for a Typical Hot Day in St. Louis, Missouri (Note 3)	$144.92	$117.76

Associated Emmissions for One Day, lb.		
CO_2 (Carbon Dioxide)	4.8191	Believed by some to be the primary greenhouse gas emitted by human activities; Respiratory problems occur at high concentrations.
SO_2 (Sulfur Dioxide)	0.0051	Resiratory system harm and difficult breathing; Harms trees and plants by decreasing foliage and growth; Reacts to create haze.
NOx (Nitrous Oxide)	0.0038	Reacts to form ozone, aerosols, and NO_2; Respiratory harm; Contributes to acid rain; Impacts water and air quality; Greenhouse gas.

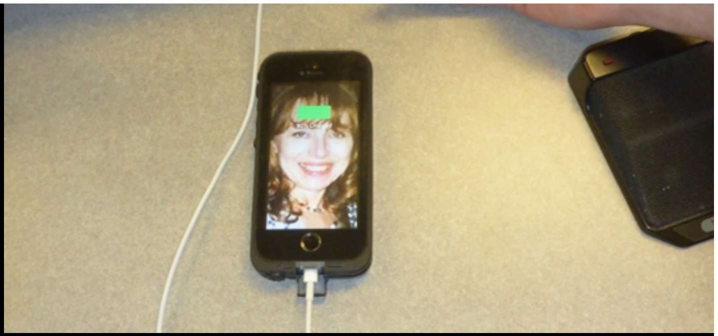
Using People Power



Say I wanted to charge my cell phone with some magic machine that was powered by the motion I use to walk. If I wanted to do it in an hour walk, I would need to provide the additional 6.17 watts of delivered energy to the cell phone battery along with the efficiency losses of the magic machine I was using along with the efficiency losses associated with my body working.

Delivered power -	6.17 watts
Magic machine efficiency -	74%
Power out of body into magic machine -	8.34 watts
Body efficiency -	22%
Additional power into body -	37.90 watts
Walking plus charging phone -	302.88 watts
Equivalent pace -	4.30 mph
	13.95 minutes per mile
Kathy's and my walking power rate at 3.6 mph -	264.98 watts
Walking power if some of it went to charge an iPhone -	227.08
Equivalent pace -	2.90 mph

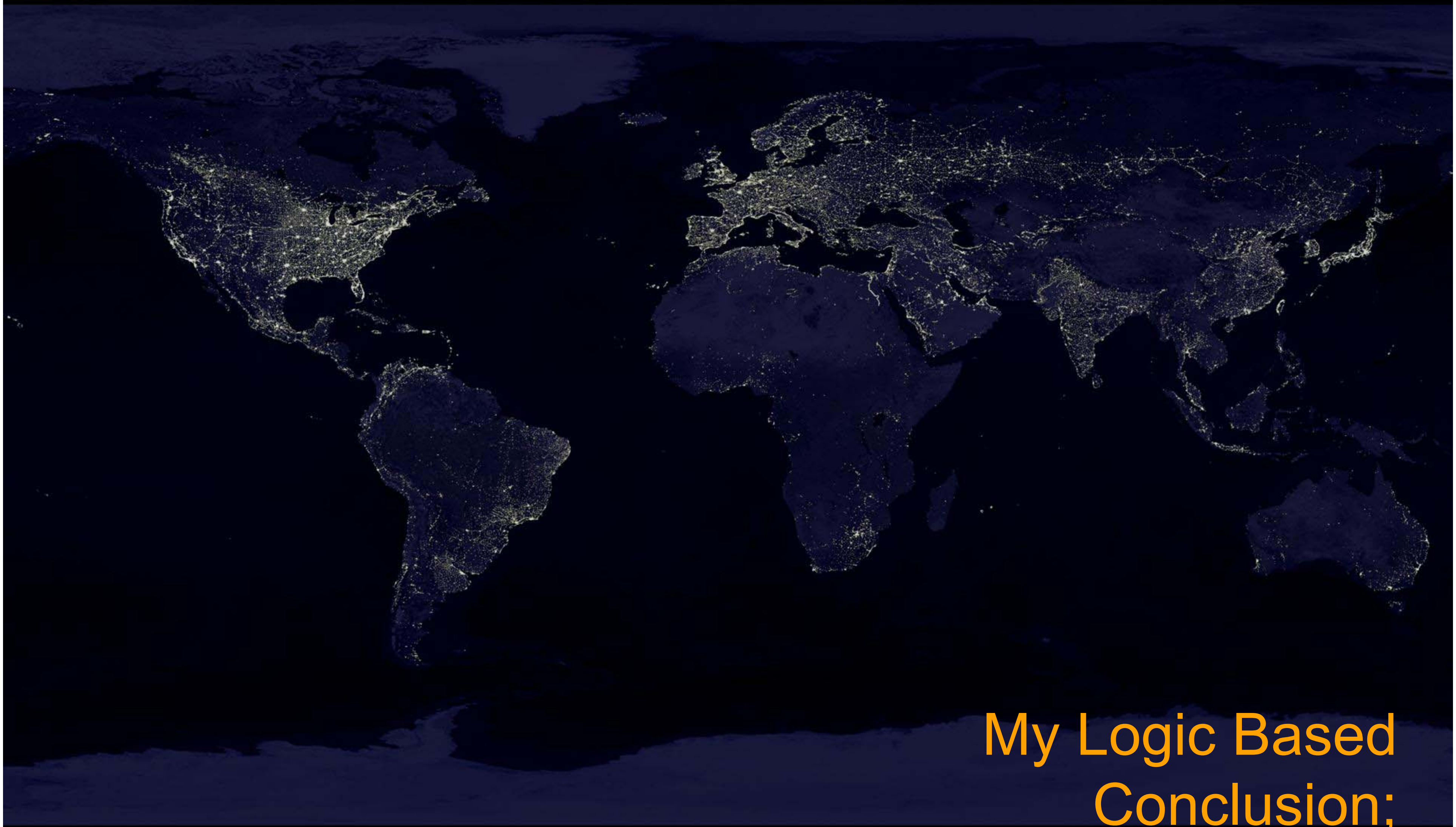
Using People Power



Say I wanted to charge my cell phone with some magic machine that was powered by the motion I use to walk. If I wanted to do it in an hour walk, I would need to provide the additional 6.17 watts of delivered energy to the cell phone battery along with the efficiency losses of the magic machine I was using along with the efficiency losses associated with my body working.

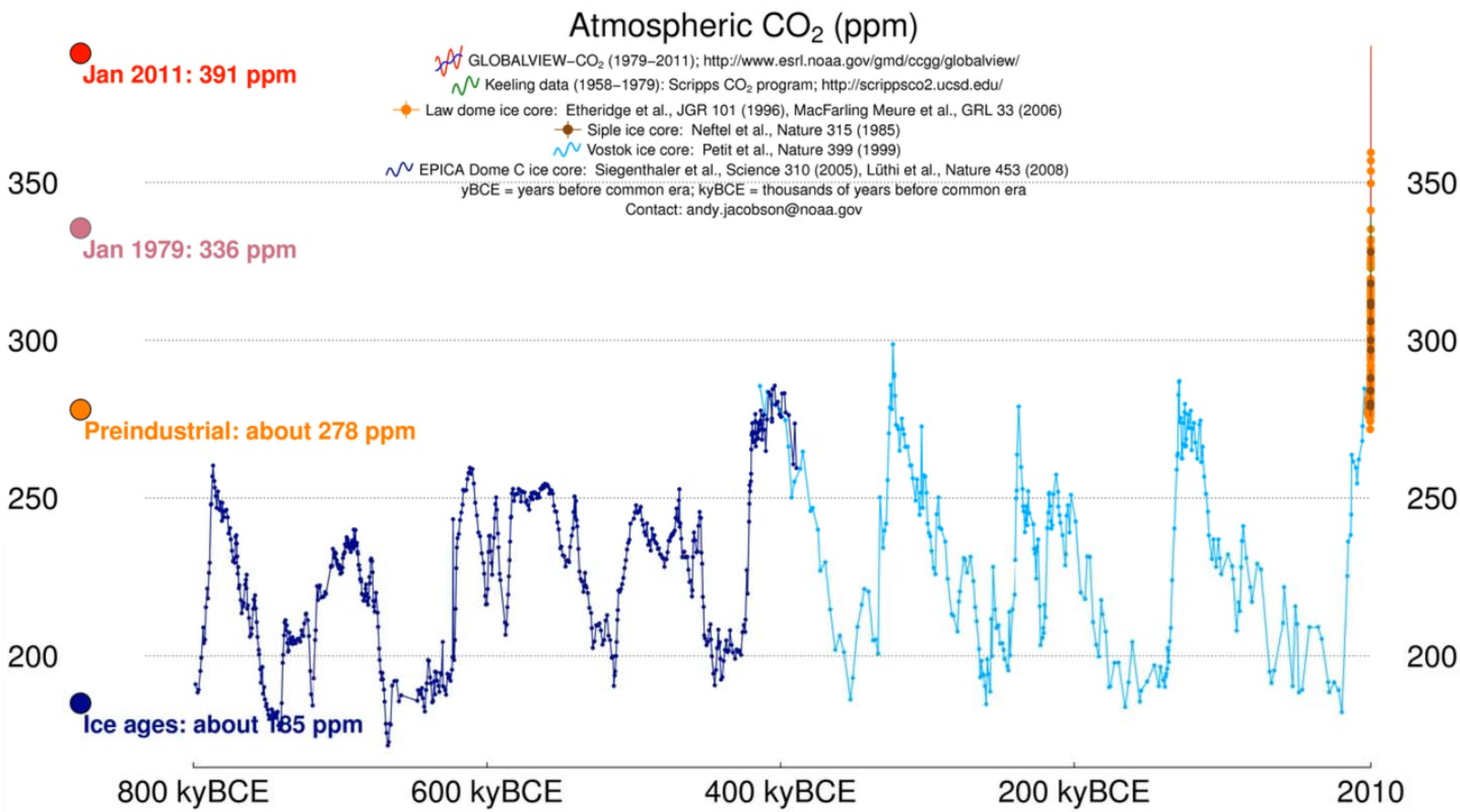
Delivered power -	6.17 watts
Magic machine efficiency -	74%
Power out of body into magic machine -	8.34 watts
Body efficiency -	22%
Additional power into body -	37.90 watts
Walking plus charging phone -	302.88 watts
Equivalent pace -	4.30 mph
	13.95 minutes per mile
Kathy's and my walking power rate at 3.6 mph -	264.98 watts
Walking power if some of it went to charge an iPhone -	227.08
Equivalent pace -	2.90 mph
Number of people with the magic machine required to keep the ball room cool for an hour	
	13,169

Public Domain Image Courtesy NASA Earth Observatory http://eoimages.gsfc.nasa.gov/images/imagerecords/47000/47687/ISS026-E-006255_lrg.jpg



My Logic Based Conclusion;

We Have to be Having Some Sort of Impact



Video downloaded from the Earth System Research Laboratory Global Monitoring Division at http://www.esrl.noaa.gov/gmd/ccgg/trends/history.html

We Don’t Inherit the World from our Ancestors,
We Borrow it From Our Children

Unknown


Commissioning is Fun
AN OVERVIEW OF COMMISSIONING
121

Ten Key Retrocommissioning Skills

1. Be Able to Benchmarking and Perform Utility Analysis
2. Be able to Scope a Facility
3. Be Familiar with Fundamental Principles and HVAC
4. Understand and Apply the System Concept
5. Be Able to Perform Data Logging and Trend Analysis
6. Be Familiar with Functional Testing Techniques
7. Be Familiar with Data Analysis Techniques
8. Be Familiar with Basic HVAC and Energy Calculations
9. Be Familiar with Cost/Benefit and Return on Investment Calculations
10. Develop a Competency with Control Systems

Ten Key Retrocommissioning Skills

1. Be Able to Benchmarking and Perform Utility Analysis
2. Be able to Scope a Facility
3. Be Familiar with Fundamental Principles and HVAC
4. Understand and Apply the System Concept
5. Be Able to Perform Data Logging and Trend Analysis
6.
7.
8.
9.
10

Be Familiar with Fundamental Principles:

1. Loads
2. Centrifugal Machines
3. Piping Systems
4. Refrigeration and Cooling Equipment
5. Heating Equipment
6. Variable Flow Water Systems
7. Duct Systems
8. Economizers
9. Makeup and Exhaust Systems
10. Variable Air Volume Systems

More info at https://av8rdas.wordpress.com/2014/01/14/key-retrocommissioning-skills/;

A technical guide and checklist is available at http://www.av8rdas.com/ebcx-skills-guidebook.html

Questions?

Thank you for participating!

Company Website - www.FacilityDynamics.com

Field Guide to Engineering Blog - https://av8rdas.wordpress.com/

Commissioning Resource Website - http://www.av8rdas.com/