Commissioning Heat Pump Systems: Existing Building

Please Visit This Link While We Are Waiting to Begin

https://tinyurl.com/HeatPumpD4Refresh

Presented By:
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Learning Objectives – Class Series

1. Attendees will be able to discuss some of the issues and opportunities associated with applying heat pumps as a source of heat for buildings as we move towards electrification

Learning Objectives – Class Series

2. Attendees will be able to name the common heat pump types and describe their general characteristics (ground source, air source, water source, variable flow refrigeration, etc.)

Learning Objectives – Class Series

3. Attendees will be able to discuss ventilation strategies that can be applied in conjunction with heat pump systems and how they can be integrated with the heat pumps and the zones they serve

Learning Objectives – Class Series

4. Attendees will be able to discuss the design and commissioning issues associated with applying heat pumps to new construction and retrofit projects

Learning Objectives – Class Series

5. Attendees will be able to identify existing building commissioning issues and opportunities associated with heat pumps and heat pump systems

Learning Objectives – Today's Session

1. Attendees will be able to identify existing building commissioning issues and opportunities associated with heat pumps and heat pump systems

Learning Objectives – Today's Session

2. Attendees will be able to list common heat pump issues that can be identified by observation during facility walk-throughs

Learning Objectives – Today's Session

3. Attendees will recognize that the nature of functional tests applied to existing building heat pump systems will be different from the nature of the functional tests applied to heat pump systems in new construction and can be used to inform persistence as well as improving and adapting the systems to the ever-changing needs most facilities undergo

Learning Objectives – Today’s Session

4. Attendees will understand the difference between natural and forced response tests and how each type of test can be applied to a heat pump system

Learning Objectives – Today's Session

5. Attendees will recognize the value of trend data for evaluating heat pump system performance to ensure that the design intent persists and/or is adapted to the ongoing requirements of the facility

Today’s Agenda

1. Review key commissioning concepts in light of an existing building commissioning process
2. Explore EBCx opportunities in a water source heat pump loop
3. Explore VRF systems and related commissioning opportunities
4. Explore a heat pump application in a central plant and the ongoing commissioning process behind it

Introduction

A Bit About Me

My Bio and Resume are With the Class Materials (or you can see what I said the first day when the recording is available)

Key Commissioning Skills

Key Cx Skills

1. Be able to benchmark and perform utility analysis
2. Be able to scope a facility for obvious indicators of opportunity
3. Be familiar with fundamental principles and building systems
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. Be familiar with implementation strategies and techniques

https://tinyurl.com/KeySkillsBlogPost

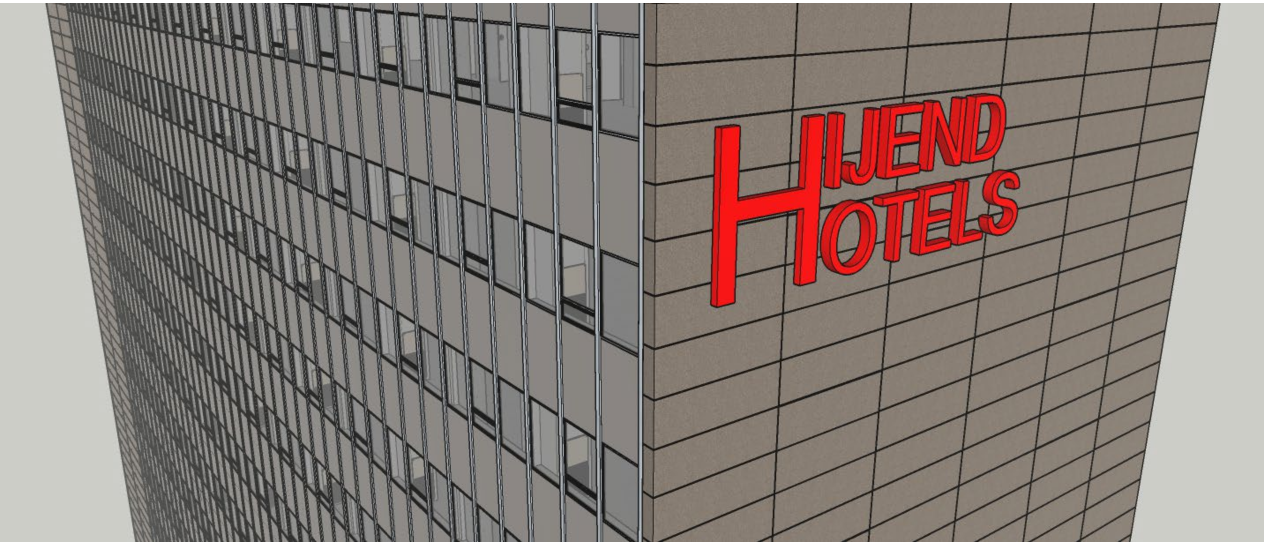
Resources for Developing the Skills

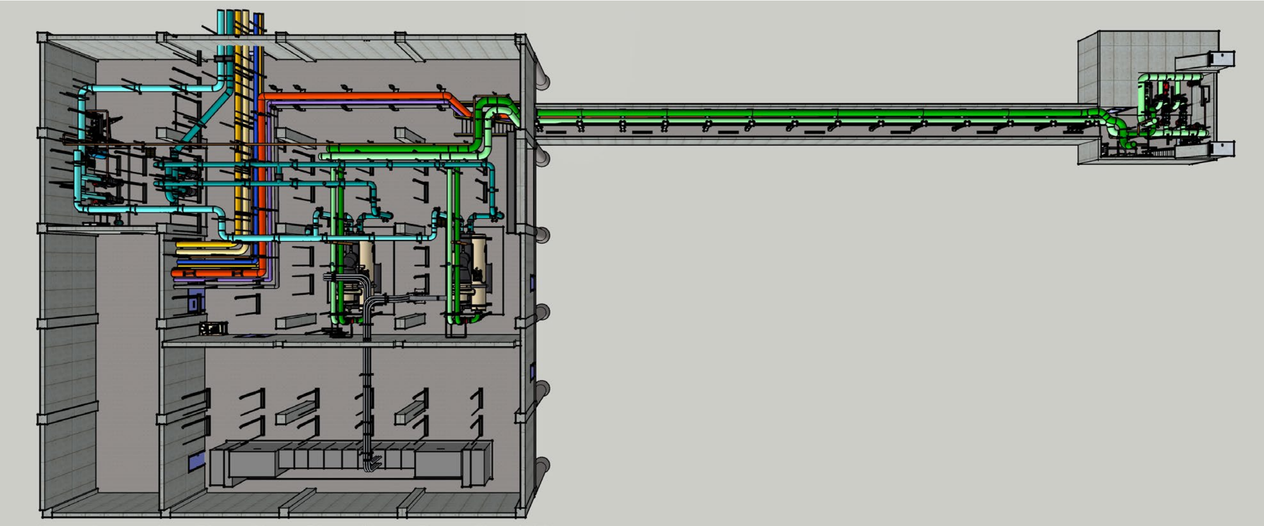
- Everything in the presentation on *Commissioning Heat Pumps for New Construction Projects*
- Scoping Resources

  https://tinyurl.com/ScopingResources

- Scoping Practice

  https://tinyurl.com/ScopingPractice

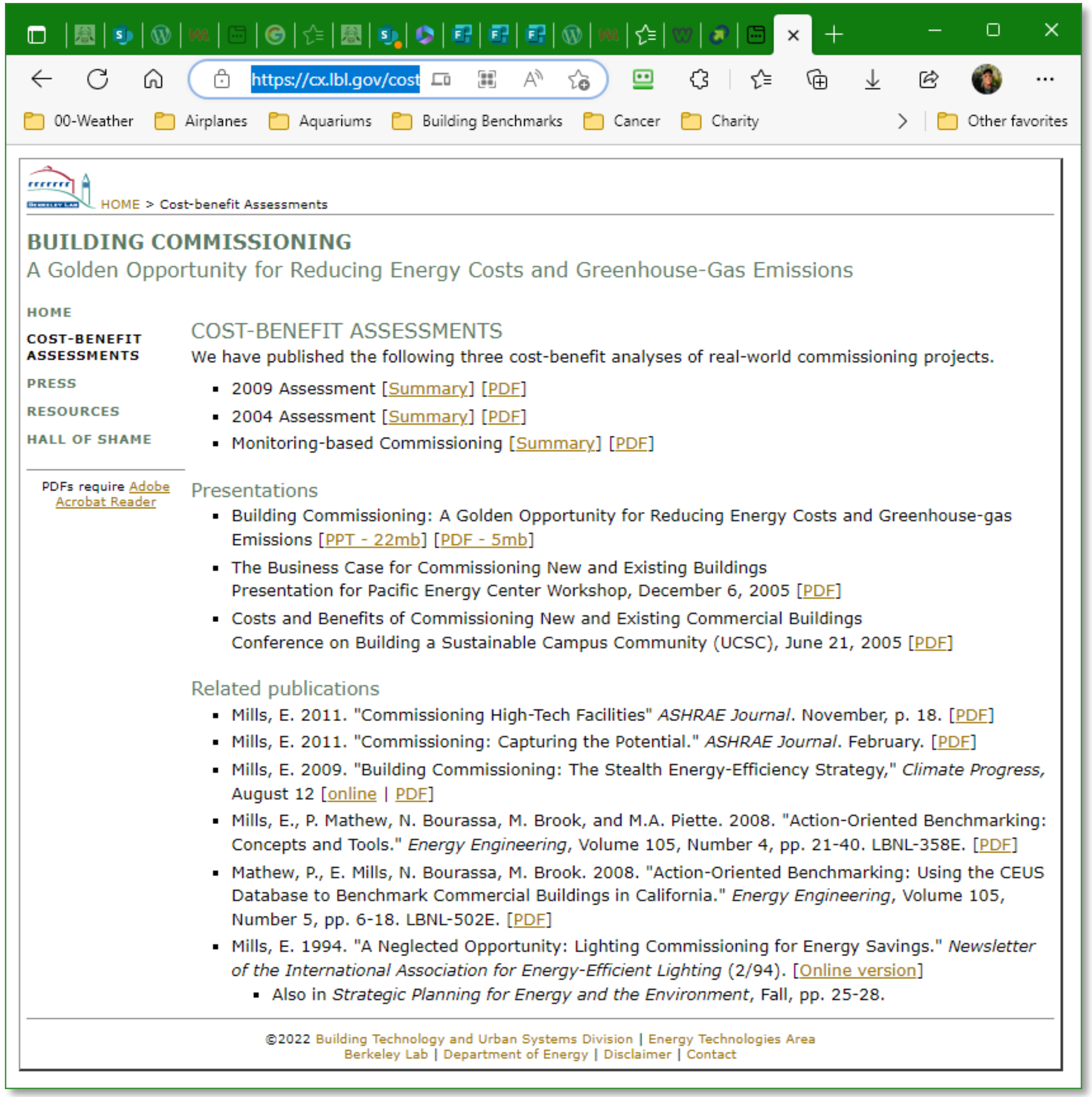




Resources for Making the Case for Cx

LBNL's Commissioning Cost/Benefit Reports

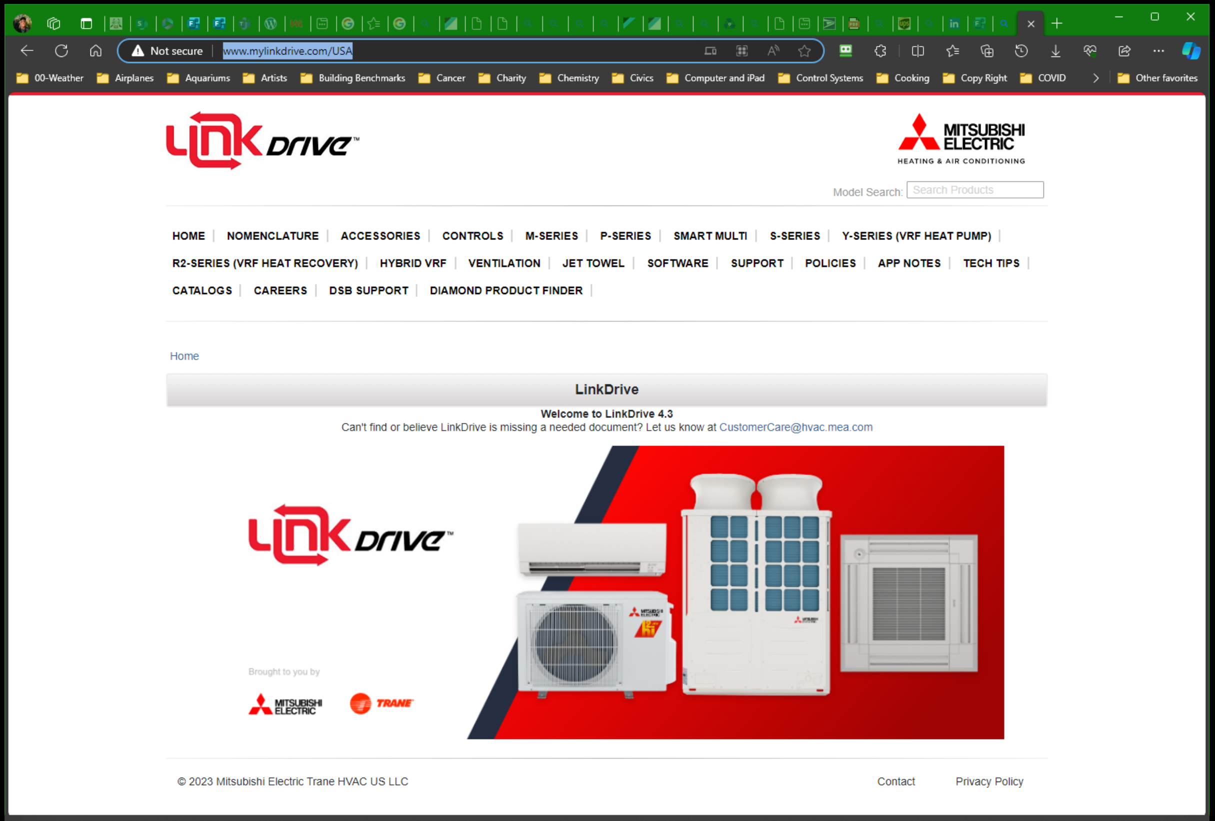
https://tinyurl.com/LBNLCostBenefit

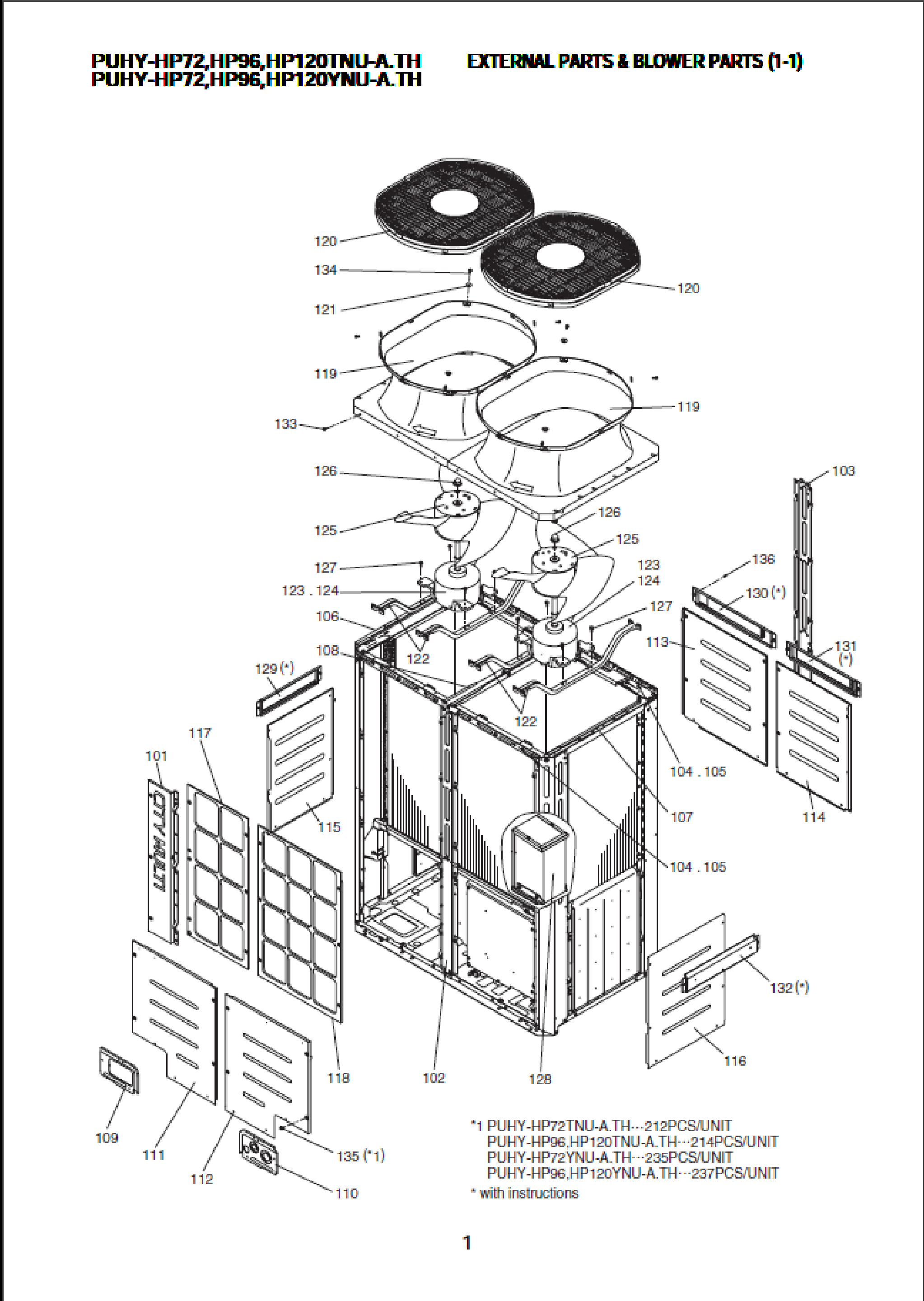


Identifying Equipment Parts

Using a Parts Diagram

http://www.mylinkdrive.com/USA





EBCx Commissioning Process

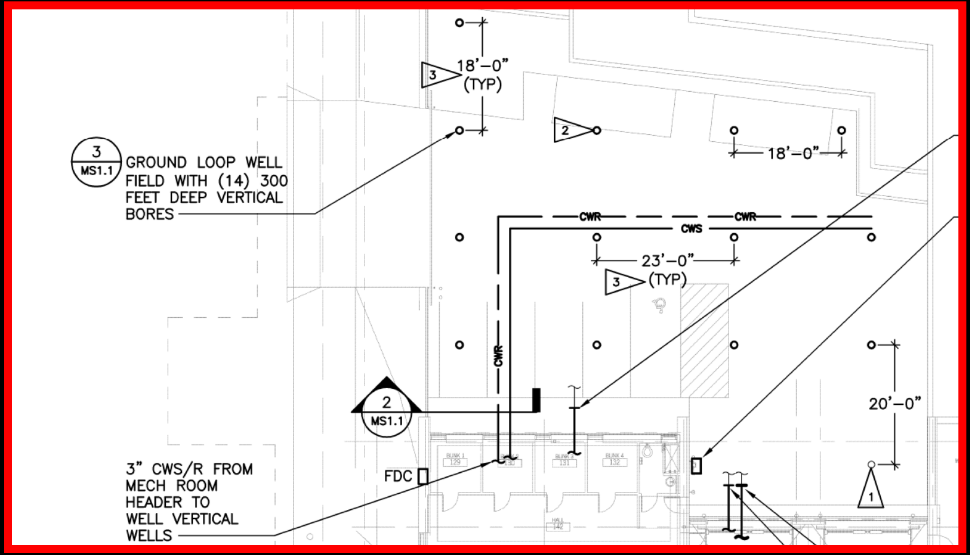
EBCx Commissioning Phases

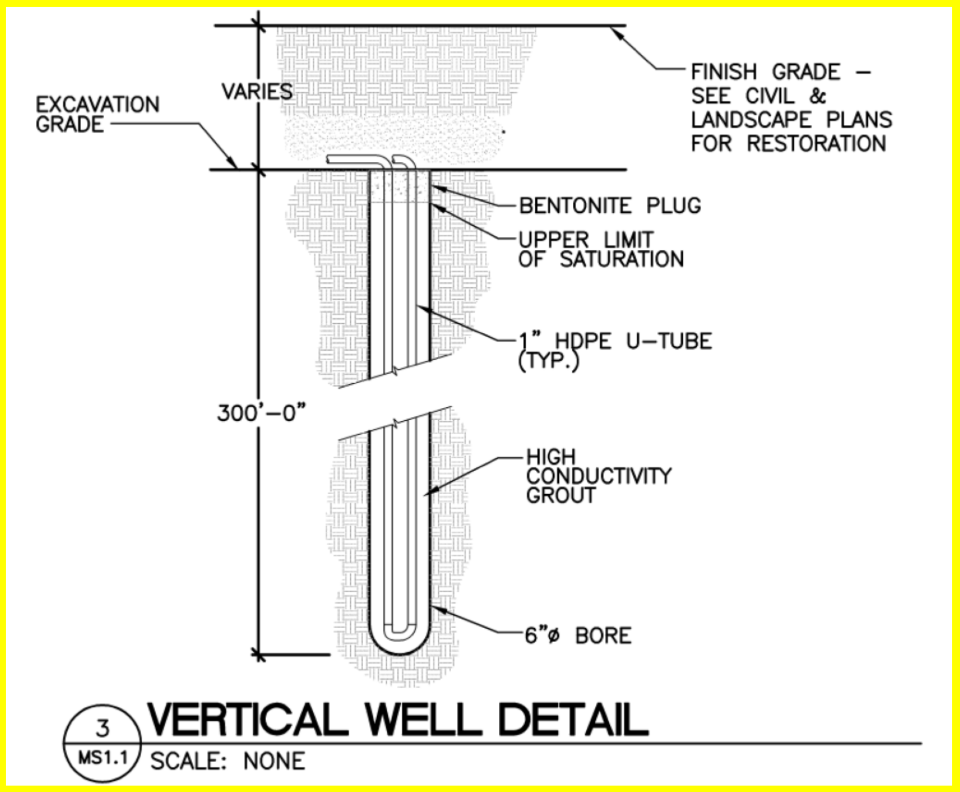
- Scoping
  - Benchmarking and utility analysis
  - Site Visit
    - Start to learn the facility
    - Look for obvious indicators
- Investigation
  - Data logging and trend analysis
  - Functional testing
  - Cost/benefit analysis
- Implementation
  - Make improvements based on the results of investigation
  - Owner vetted
- Verification
  - Make sure things work as expected
  - Make sure targeted saving are delivered
  - A mini new construction commissioning process

This, That, and the Other Thing

A Question For You

https://tinyurl.com/HeatPumpD3Glycol





Freezing Point								
Ethylene Glycol Solution (% by volume)		**0**	**10**	**20**	**30**	**40**	**50**	**60**
Temperature	(°F)	32	25.9	17.8	7.3	-10.3	-34.2	-63
	(°C)	0	-3.4	-7.9	-13.7	-23.5	-36.8	-52.8

Dynamic Viscosity - μ - (centiPoise)								
Temperature		**Ethylene Glycol Solution (% by volume)**						
(°F)	**(°C)**	**25**	**30**	**40**	**50**	**60**	**65**	**100**
0	-17.8	1)	1)	15	22	35	45	310
40	4.4	3	3.5	4.8	6.5	9	10.2	48
80	26.7	1.5	1.7	2.2	2.8	3.8	4.5	14
120	48.9	0.9	1	1.3	1.5	2	2.4	7
160	71.1	0.65	0.7	0.8	0.95	1.3	1.5	3.8
200	93.3	0.48	0.5	0.6	0.7	0.88	0.98	1.4
240	115.6	2)	2)	2)	2)	2)	2)	1.8
280	137.8	2)	2)	2)	2)	2)	2)	1.4

1. below freezing point
2. above boiling point

Specific Gravity- *SG* -								
Temperature		Ethylene Glycol Solution (% by volume)						
(° F)	(° C)	25	30	40	50	60	65	100
-40	-40	1)	1)	1)	1)	1.12	1.13	1)
0	-17.8	1)	1)	1.08	1.1	1.11	1.12	1.16
40	4.4	1.048	1.057	1.07	1.088	1.1	1.11	1.145
80	26.7	1.04	1.048	1.06	1.077	1.09	1.095	1.13
120	48.9	1.03	1.038	1.05	1.064	1.077	1.082	1.115
160	71.1	1.018	1.025	1.038	1.05	1.062	1.068	1.1
200	93.3	1.005	1.013	1.026	1.038	1.049	1.054	1.084
240	115.6	2)	2)	2)	2)	2)	2)	1.067
280	137.8	2)	2)	2)	2)	2)	2)	1.05

1. below freezing point
2. above boiling point

Specific Heat Capacity of Ethylene Glycol based Water Solutions

Specific Heat - c_p - of ethylene glycol based water solutions at various temperatures are indicated below

Specific Heat - c_p - (Btu/lb. ° F)								
Temperature		Ethylene Glycol Solution (% by volume)						
(° F)	(° C)	25	30	40	50	60	65	100
-40	-40	1)	1)	1)	1)	0.68	0.703	1)
0	-17.8	1)	1)	0.83	0.78	0.723	0.7	0.54
40	4.4	0.913	0.89	0.845	0.795	0.748	0.721	0.562
80	26.7	0.921	0.902	0.86	0.815	0.768	0.743	0.59
120	48.9	0.933	0.915	0.875	0.832	0.788	0.765	0.612
160	71.1	0.94	0.925	0.89	0.85	0.81	0.786	0.64
200	93.3	0.953	0.936	0.905	0.865	0.83	0.807	0.66
240	115.6	2)	2)	2)	2)	2)	0.828	0.689
280	137.8	2)	2)	2)	2)	2)	2)	0.71

1 Btu/(lb_m ° F) = 4,186.8 J/(kg K) = 1 kcal/(kg° C)

1. below freezing point
2. above boiling point

Boiling Points Ethylene Glycol Solutions

		Boiling Point										
Ethylene Glycol Solution (% by volume)		**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Temperature	(°F)	212	214	216	220	220	225	232	245	260	288	386
	(°C)	100	101.1	102.2	104.4	104.4	107.2	111.1	118	127	142	197

Increase in Flow required for a 50% Ethylene Glycol Solution

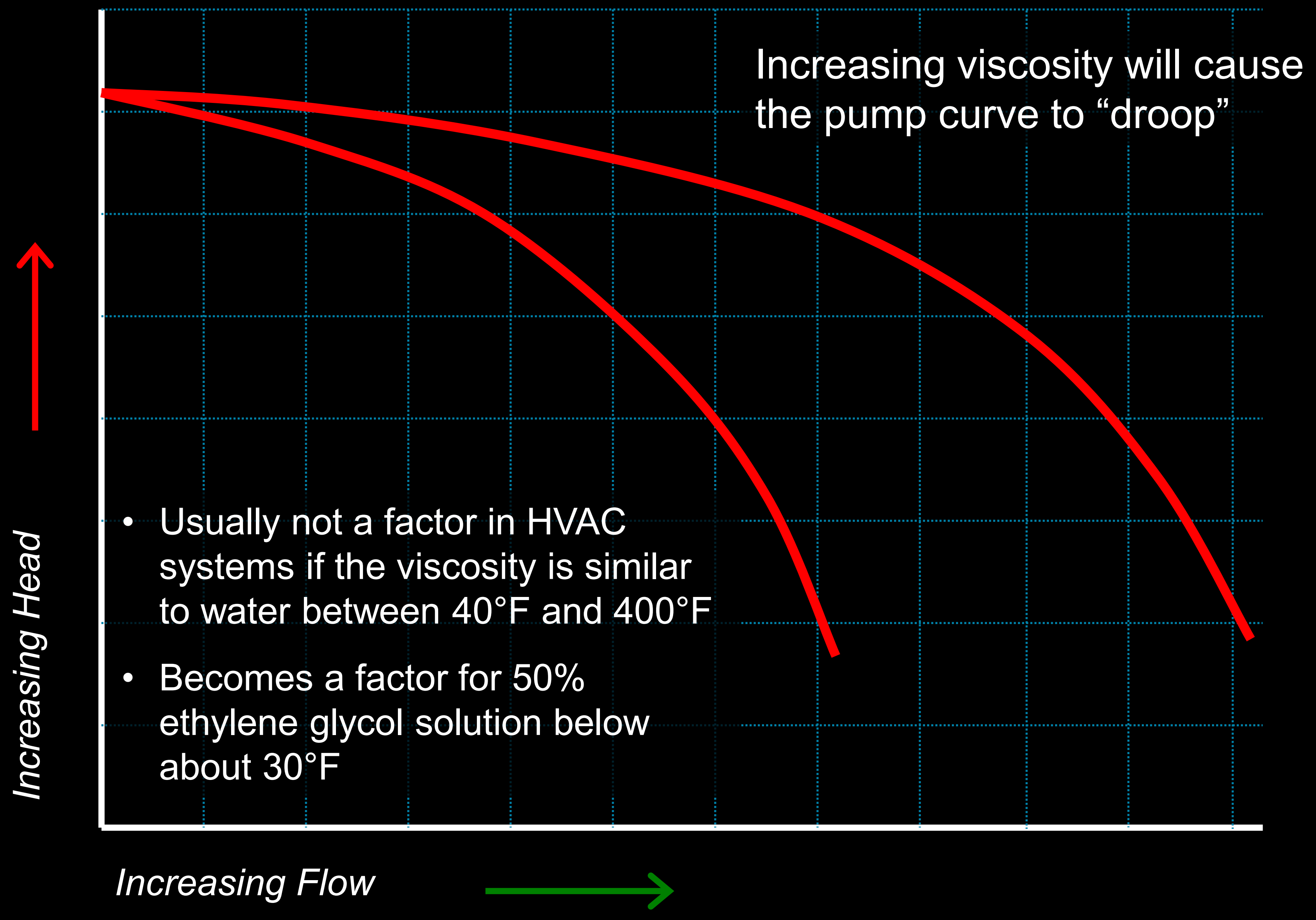
Increase in circulated flow for 50% ethylene glycol solutions compared with clean water are indicated in the table below

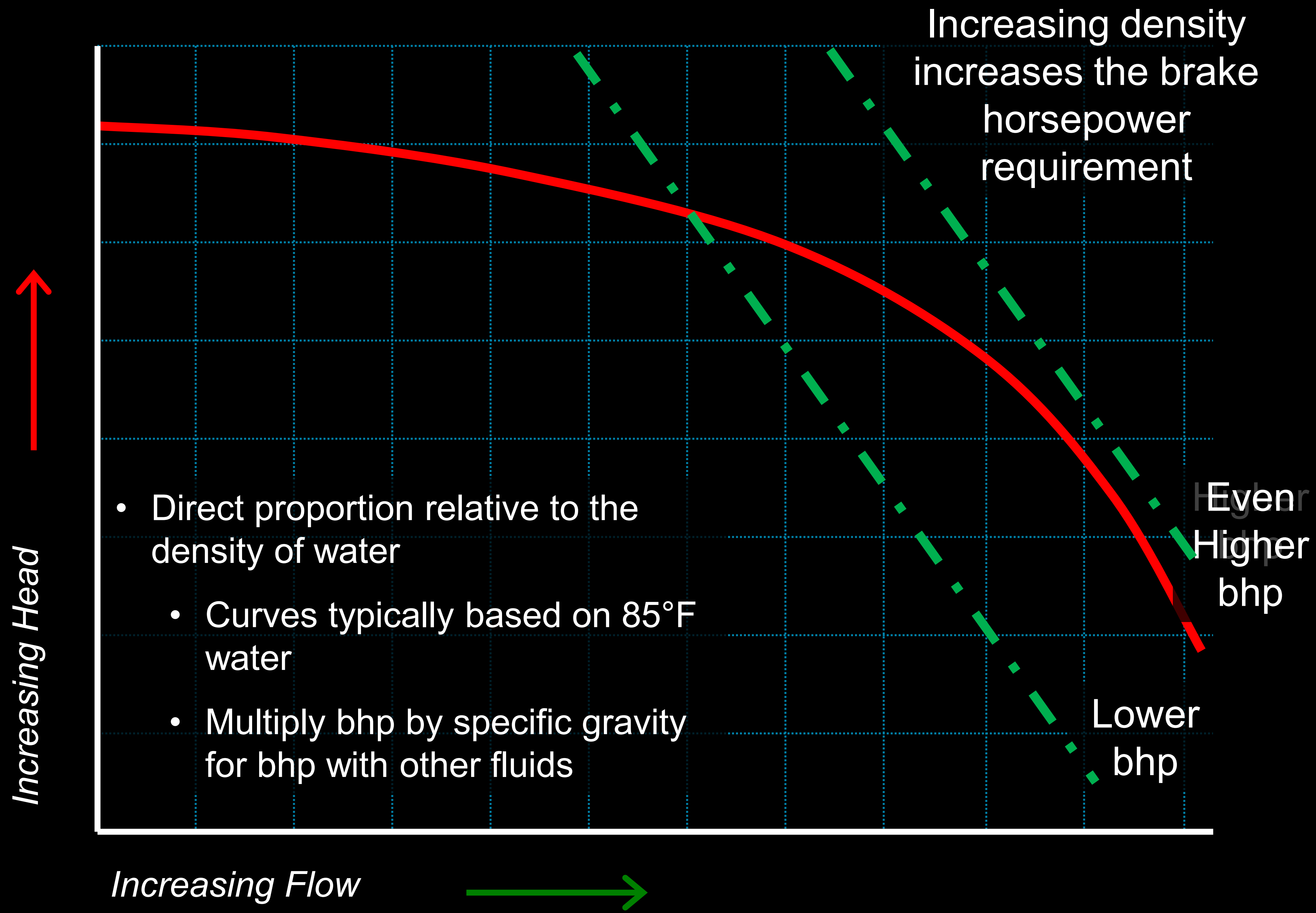
Fluid Temperature		**Flow Increase**
(°F)	**(°C)**	**(%)**
40	4.4	22
100	37.8	16
140	60	15
180	82.2	14
220	104.4	14

Pressure Drop Correction and Combined Pressure Drop and Volume Flow Correction for 50% Ethylene Glycol Solution

Pressure drop correction and combined pressure drop and flow increase correction for 50% ethylene glycol solutions compared with clean water are ed in the table below

Fluid Temperature		**Pressure Drop Correction with Flow Rates Equal**	**Combined Pressure Drop and Flow Rate Correction**
(°F)	**(°C)**	**(%)**	**(%)**
40	4.4	45	114
100	37.8	10	49
140	60	0	32
180	82.2	-6	23
220	104.4	-10	18


Increasing viscosity will cause
the pump curve to “droop”
• Usually not a factor in HVAC systems if the viscosity is similar to water between 40°F and 400°F
• Becomes a factor for 50% ethylene glycol solution below about 30°F
Increasing Head
Increasing Flow

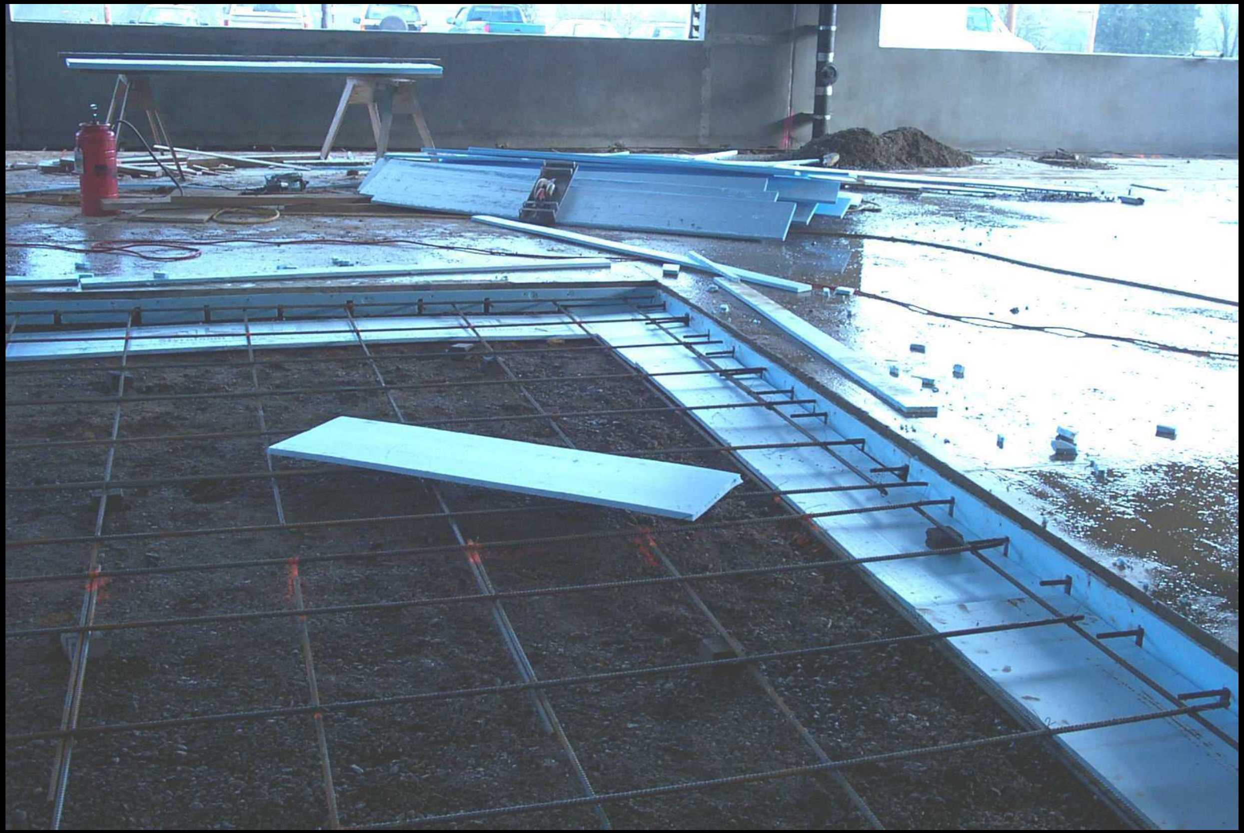


- Direct proportion relative to the density of water
  - Curves typically based on 85°F water
  - Multiply bhp by specific gravity for bhp with other fluids

A Few Words About Radiant Slabs

Radiant slabs give us an attractive way to serve space heating loads with low temperature water

A Few Words About Radiant Slabs

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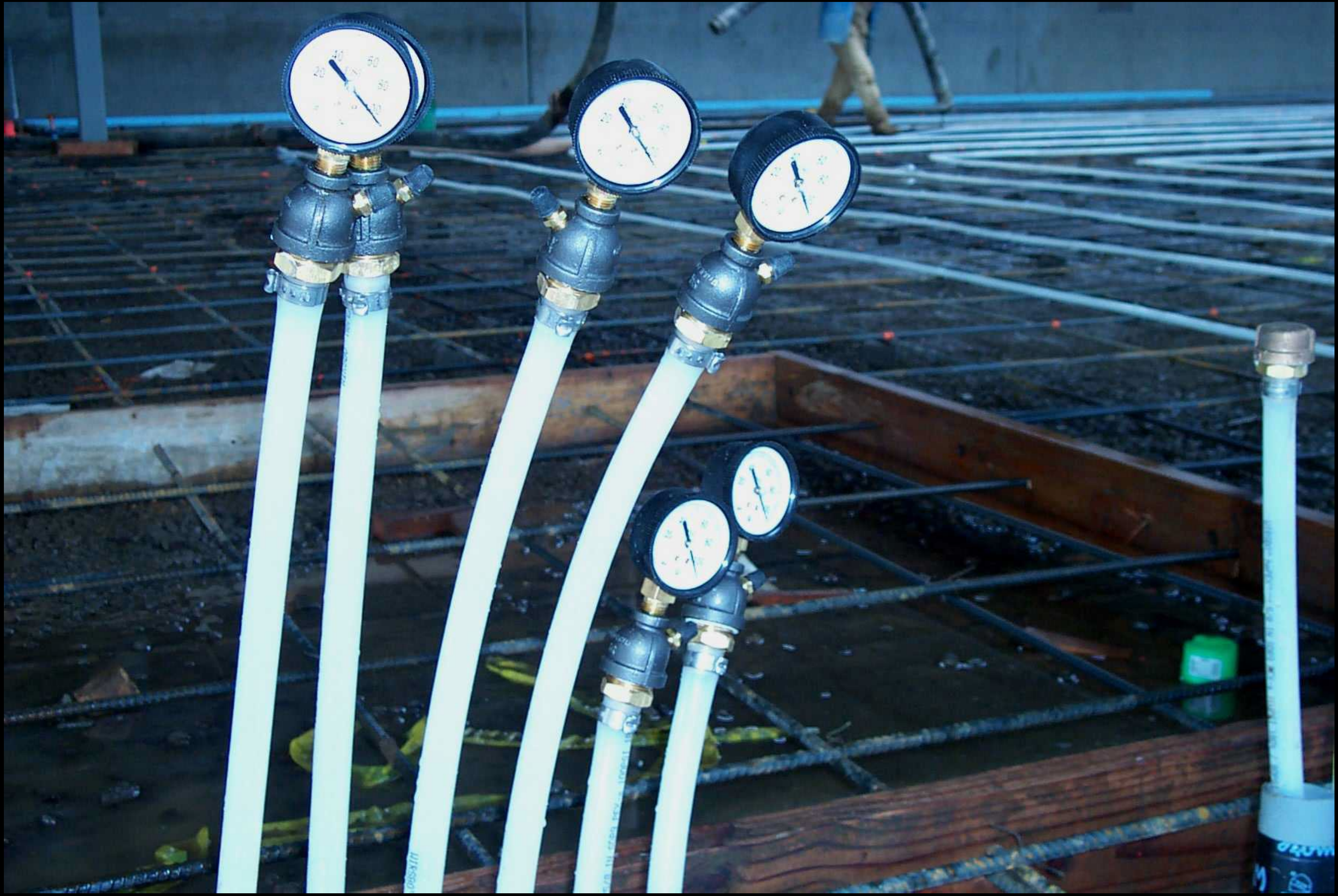

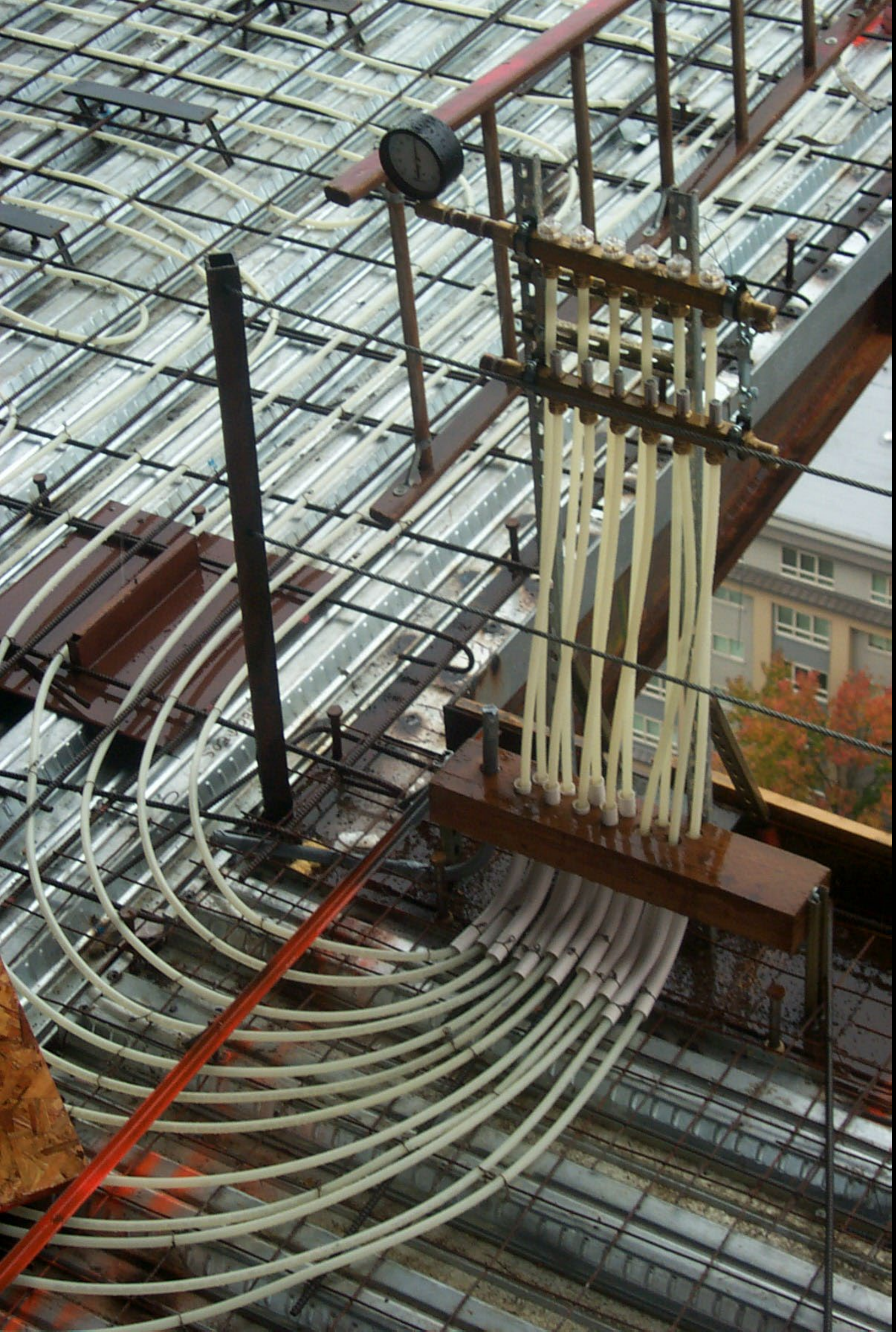

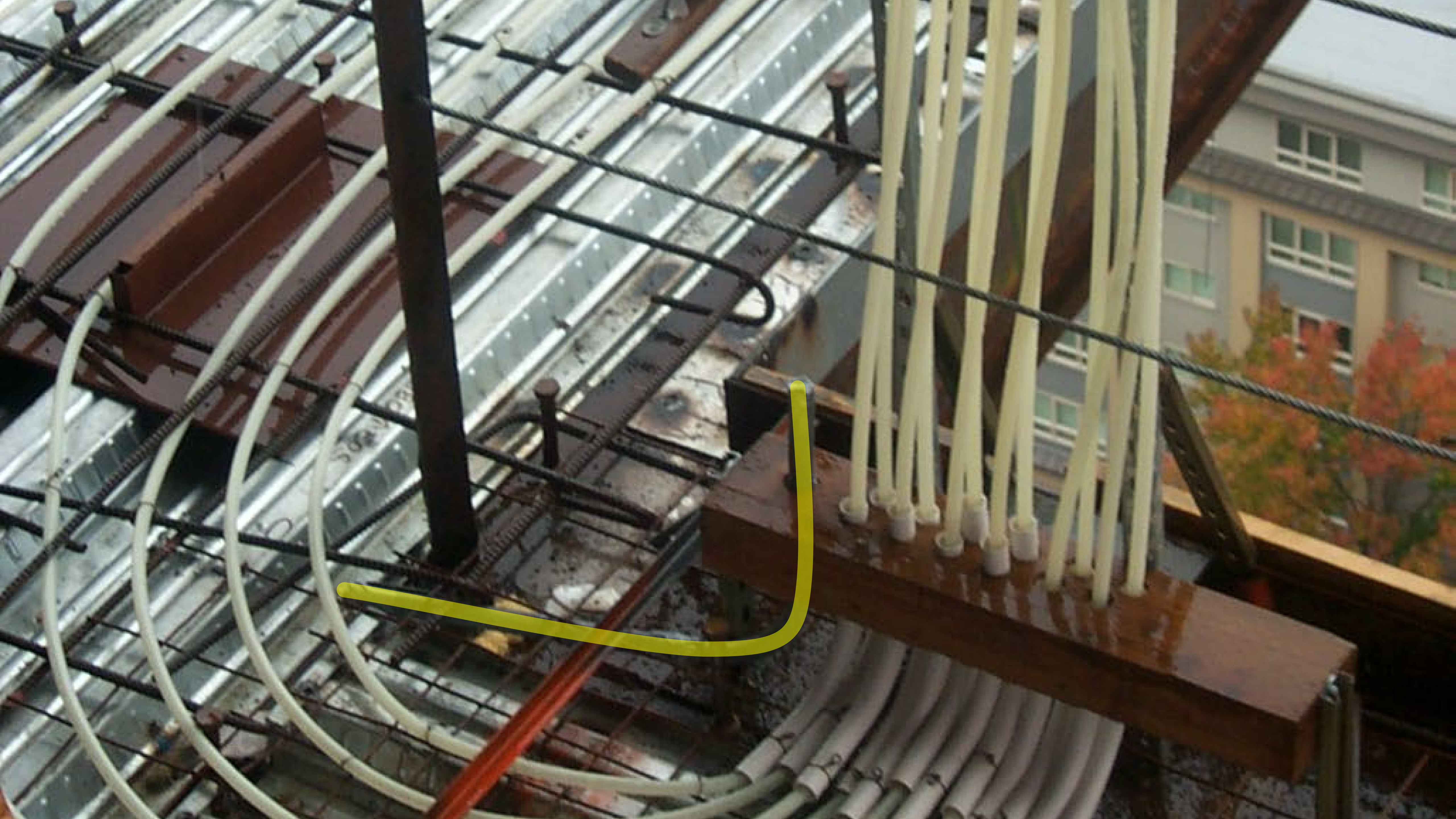


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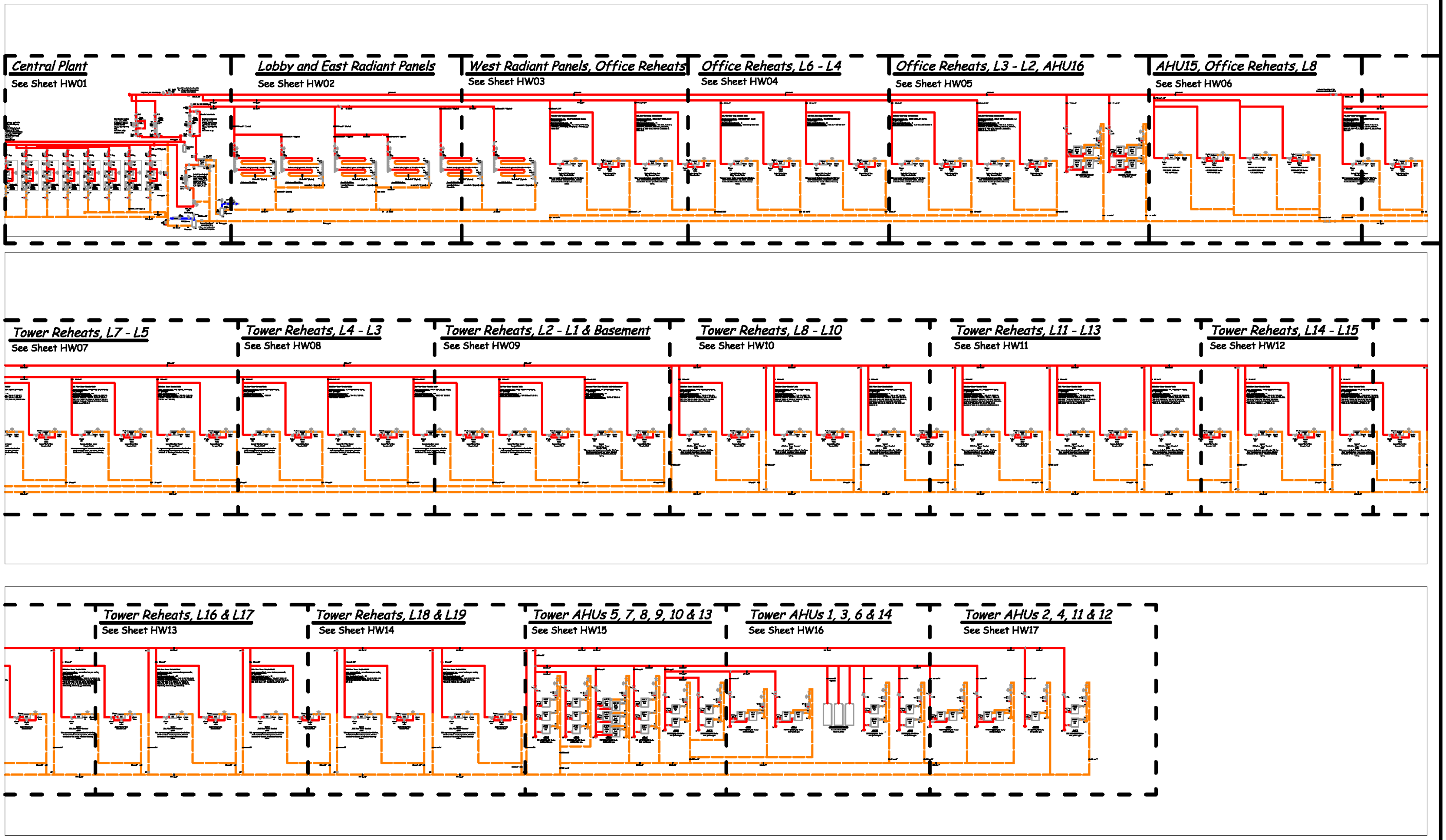

New Seattle Court House Heating Water System Flow Diagram

Revisions: 1 - Revised boiler piping to match actual factory piping.
Revisions: 2 - 1-24-02 - Modified arrangement of factory piping to make it clearer
Revisions: 3 - 12-15-03 - Updated and detailed to include radiant panel heat exchanger and HP12.
Revisions: 4 - Release 3/23/04
Revisions: 5 - Corrected return piping at boiler return headers

Drawn by: DAS	Date: April 29, 2002	HW00
Checked by:	Plot date: December 09, 2003	

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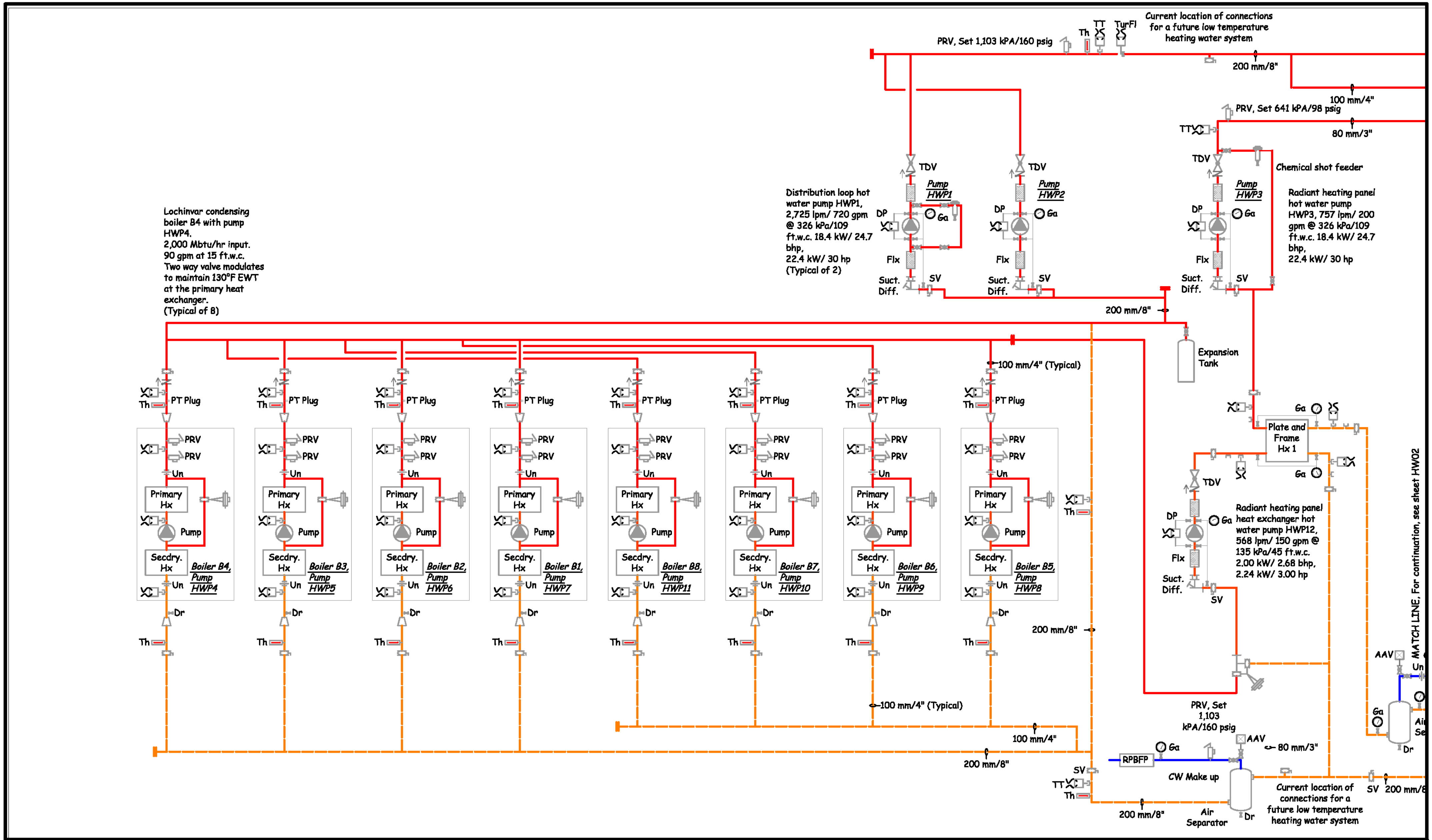
David Sellers, Facility Dynamics Engineering, Adobe PDF



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Revisions: 4 - Release 3/23/04
Revisions: 5 - 7-6-04 - Revised radiant panel pump connections.
Revisions: 5.1 - 7-7-04 - Revised radiant panel connection to the boiler header.

Drawn by: DAS	Date: April 29, 2002
Checked by:	Plot date: December 16, 2003

HW01

A Low Temperature Hot Water Application Resource

https://tinyurl.com/ACEEELowTempHW

Making Energy Intensive HVAC Processes More Sustainable via Low Temperature Heat Recovery

David Sellers, Portland Energy Conservation Inc.
Tom Stewart, Memorial Hospital of Carbondale

ABSTRACT

This paper looks at low temperature hot water distribution and heat recovery as an approach that can be used in health care and laboratory applications to reduce the energy intensity of the HVAC reheat and preheat process. The concepts presented could easily be applied to reheat and preheat processes in other applications such as semiconductor and pharmaceutical clean rooms. The paper also looks at radiant slabs as an opportunity to use low temperature hot water for comfort heating applications in new construction. A case study of an application in a health care environment is included.

Introduction

Current air handling system configurations, such as Variable Air Volume (VAV) systems, have led to significant reductions in HVAC energy requirements in many applications. However, there are some applications that require precise control of the pressure relationships between adjacent spaces and precise control of the temperature and humidity at the load. These requirements often eliminate the VAV approach as an option and force designers to use a constant volume reheat system. Examples of such applications include surgical suites, laboratories, and clean rooms. The reheat process of these systems is typically very energy intensive since it often involves simultaneous heating and cooling. In addition, the large volumes of outdoor air required often result in significant preheat loads.

There are some characteristics of the preheat and reheat loads associated with these processes that make them ideal low heating water temperature loads. These characteristics are often complemented by the nature of the load served by the system since they typically represent very high internal gains, and are a source of recoverable heat. In new construction, radiant slabs can represent an opportunity to use this recovered energy for comfort heating in addition to the preheat and reheat processes.

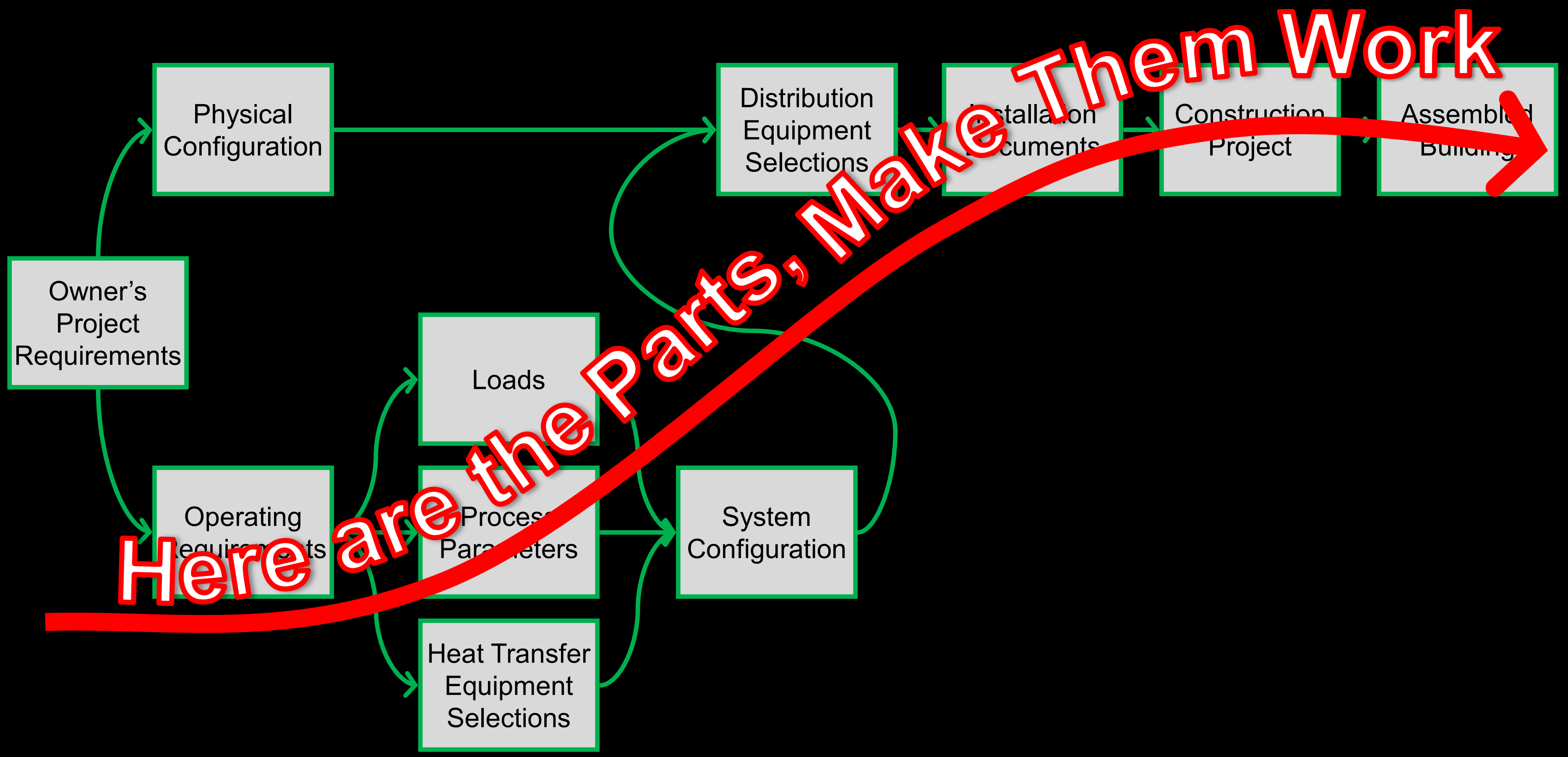
The information presented in this paper is based on actual installations and experience with low temperature hot water systems in the context of a distribution and utilization strategy that is readily adaptable to recovered energy. An overview of technical considerations is followed by a case study of a low temperature hot water system at the Memorial Hospital of Carbondale, Illinois (MHC).

Technical Discussion

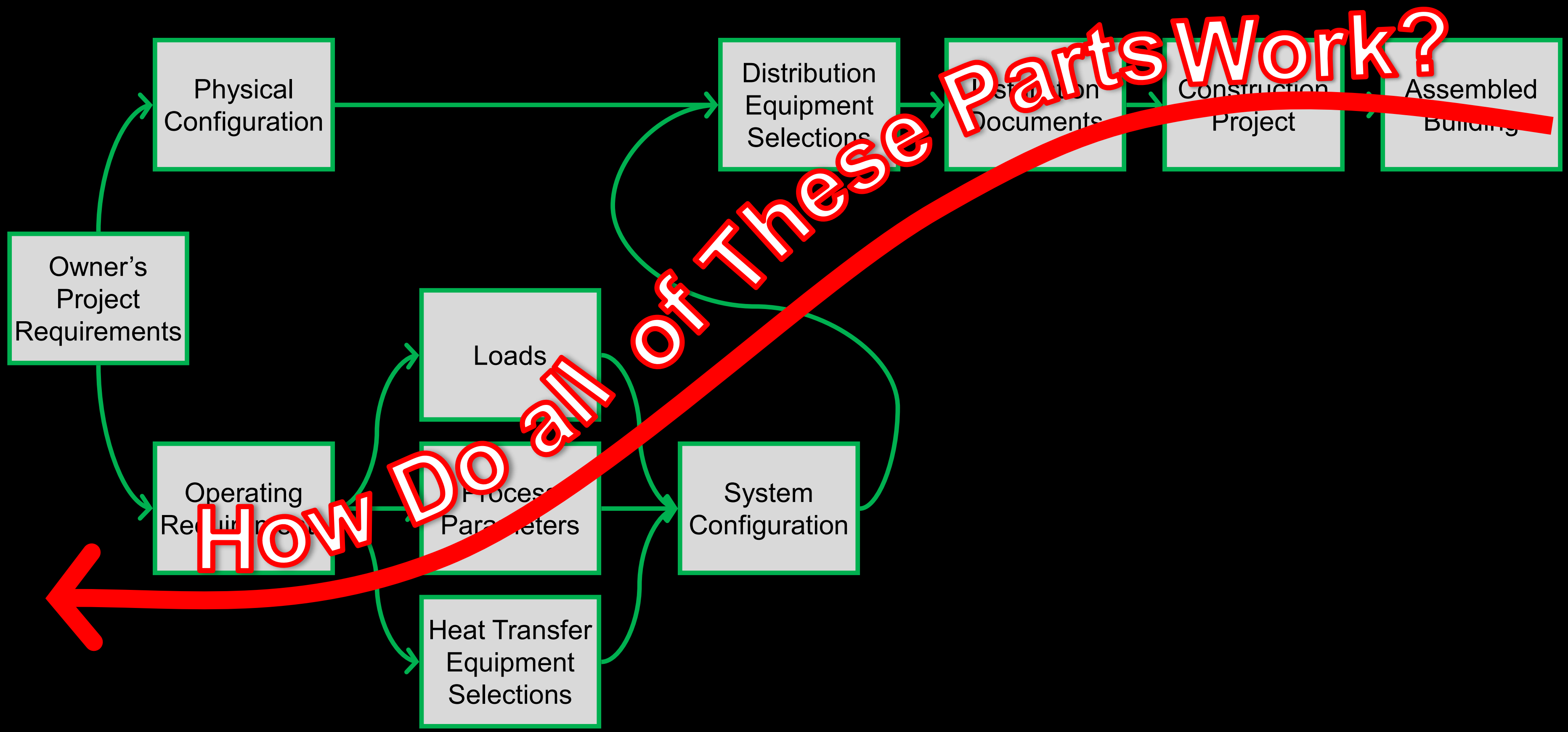
The following paragraphs explore some of the technical issues associated with low temperature hot water systems. Figure 1 illustrates a typical system configuration as extracted from schematic design documents for a project in the Northwest. The arrangement

EBCx Functional Testing

Functional Testing as it Relates to the Metrics of the Systems We Test – New Construction Perspective



Functional Testing as it Relates to the Metrics of the Systems We Test – Existing Building Perspective



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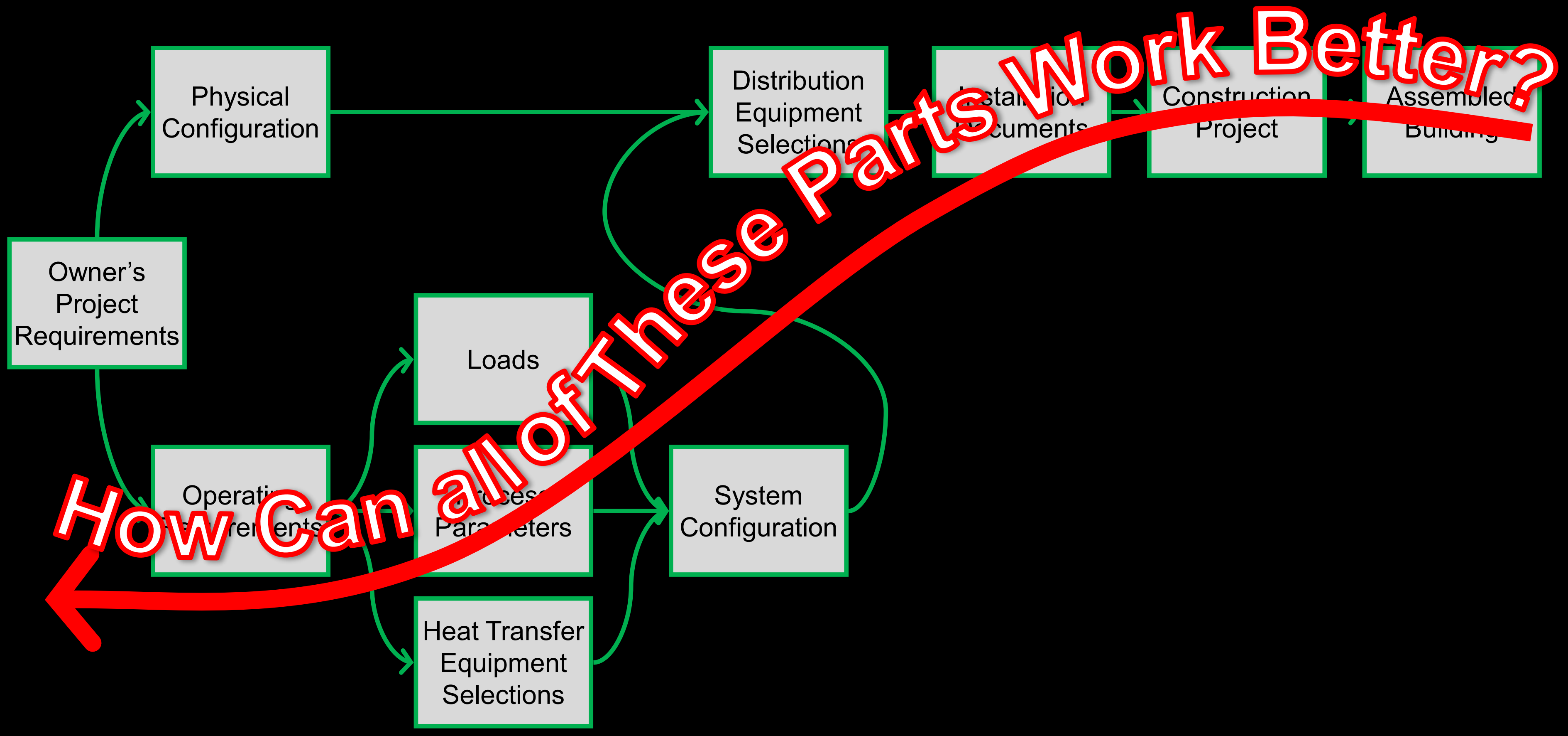
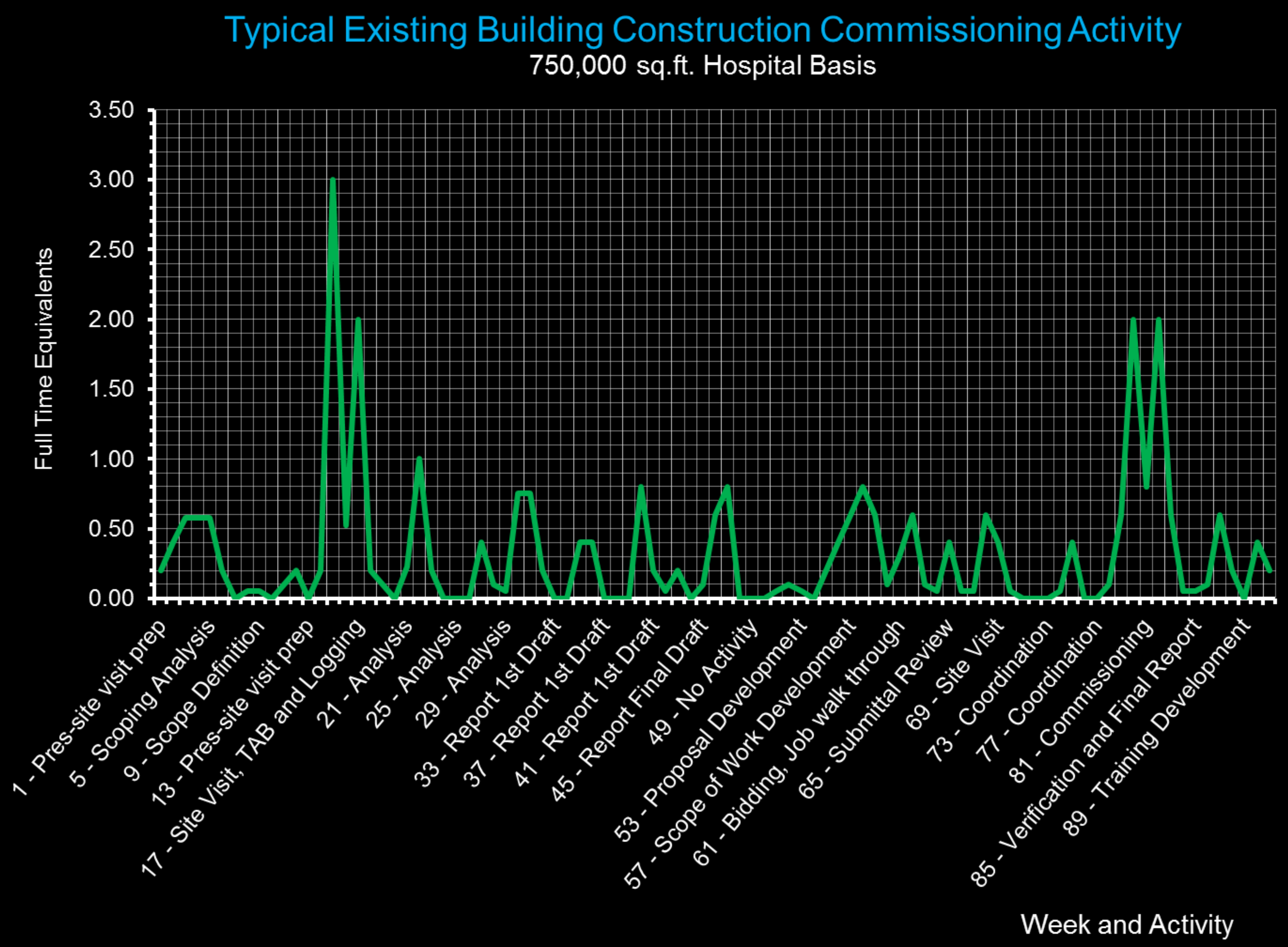
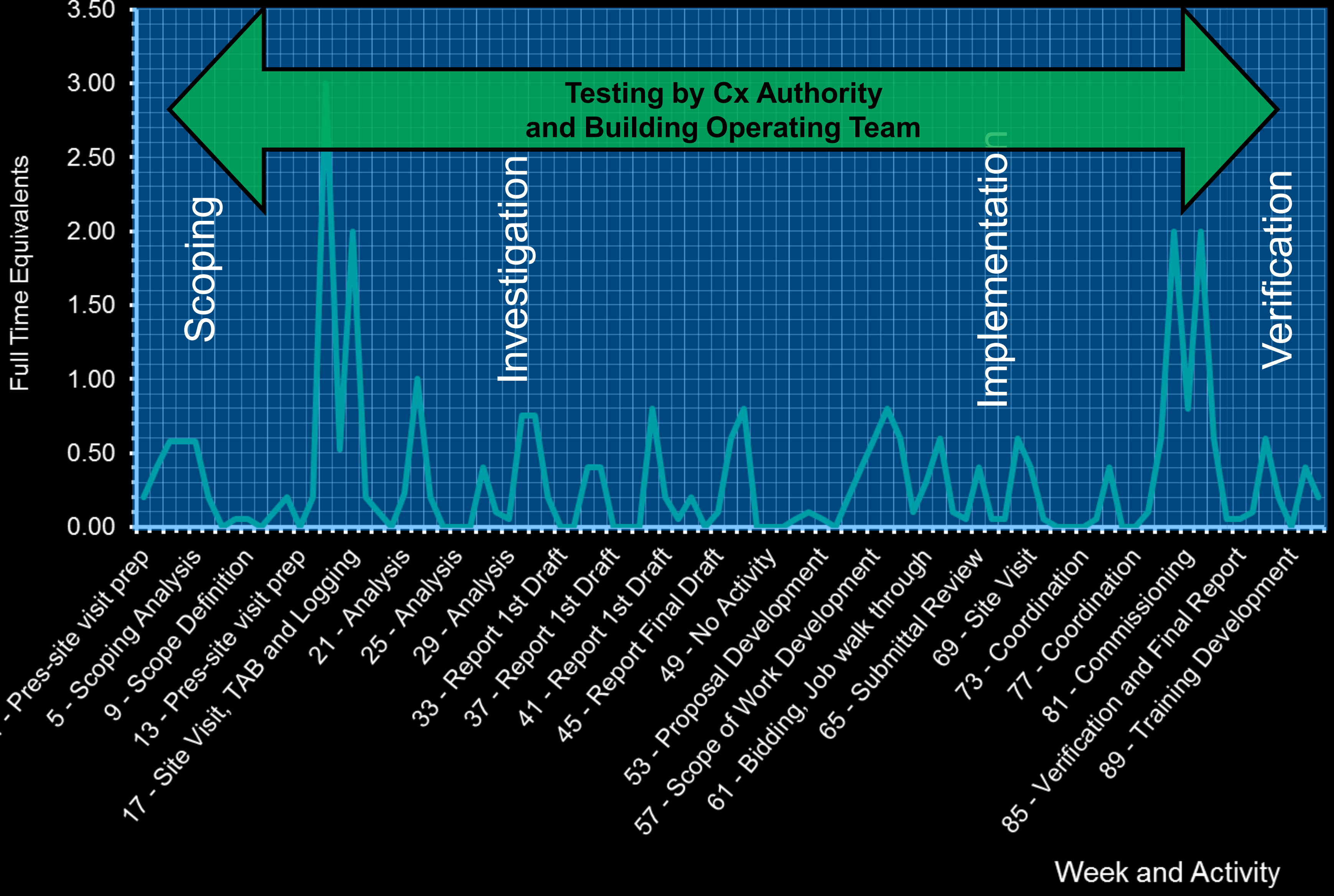


Functional Testing as it Relates to the Project Timeline


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

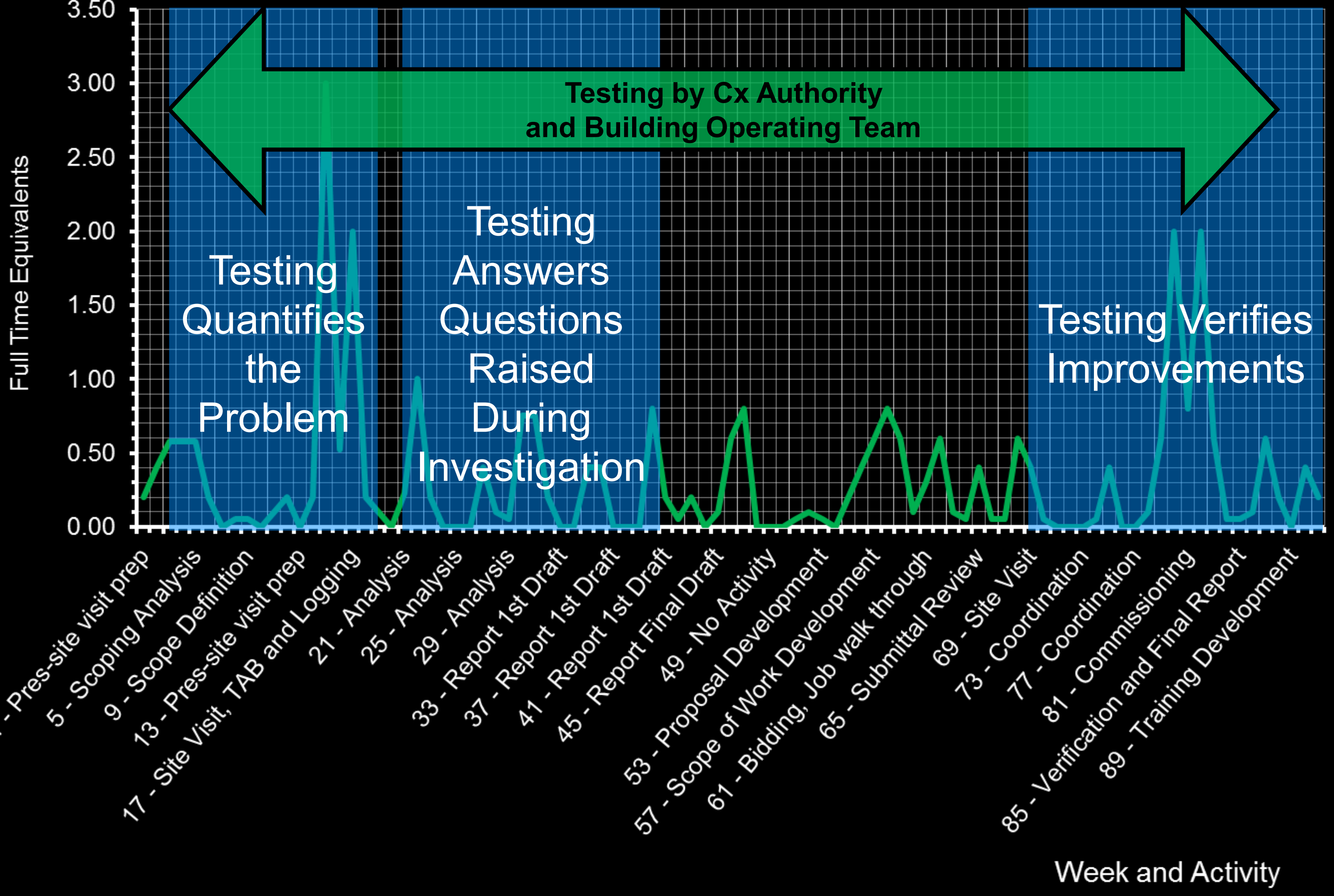
Typical Existing Building Construction Commissioning Activity

750,000 sq.ft. Hospital Basis



Typical Existing Building Construction Commissioning Activity

750,000 sq.ft. Hospital Basis



New Construction versus EBCx Testing

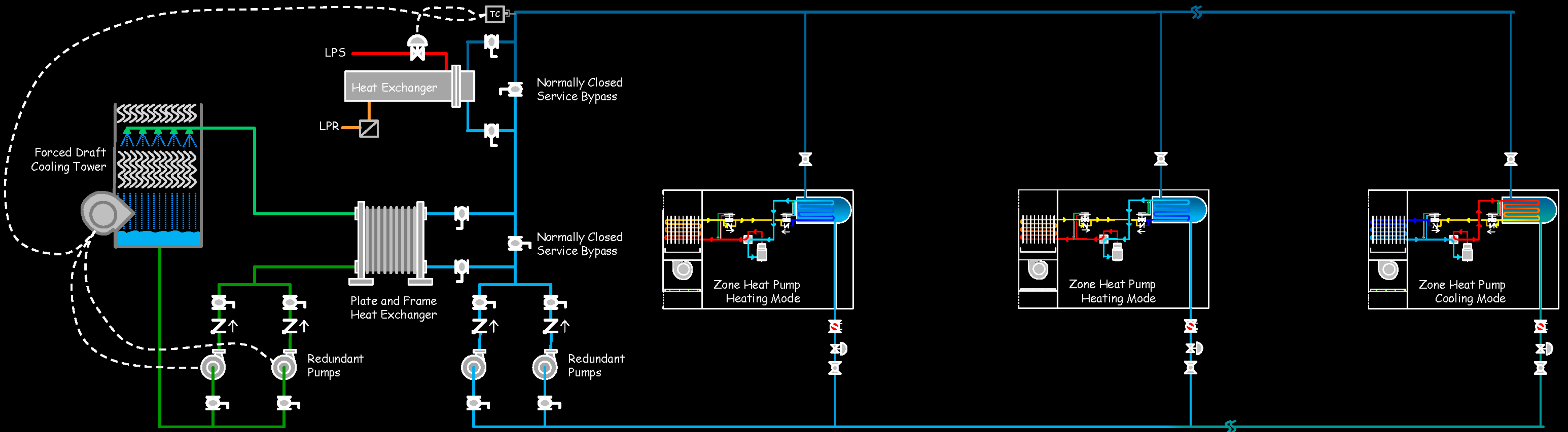
New Construction

- 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

Forced vs. Natural Response Testing



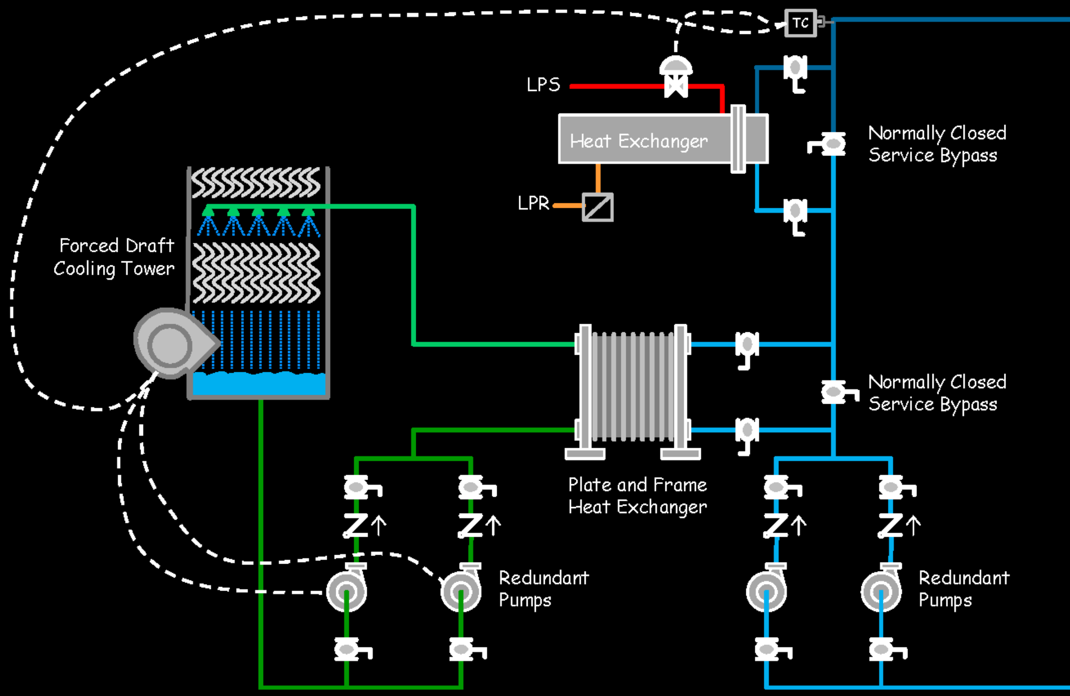
Water Source Heat Pump Loop
2022-11-16
DS

Forced vs. Natural Response Testing

Forced Response Testing

- With the system stable at a 70°F supply temperature, and
- No heat being added by the heat exchanger, and
- Some heat being rejected by the cooling tower fan operating at low speed

I override the supply temperature input and make the system "think" the supply temperature has gone up to 80°F



Water Source Heat Pump Loop
2022-11-16
DS

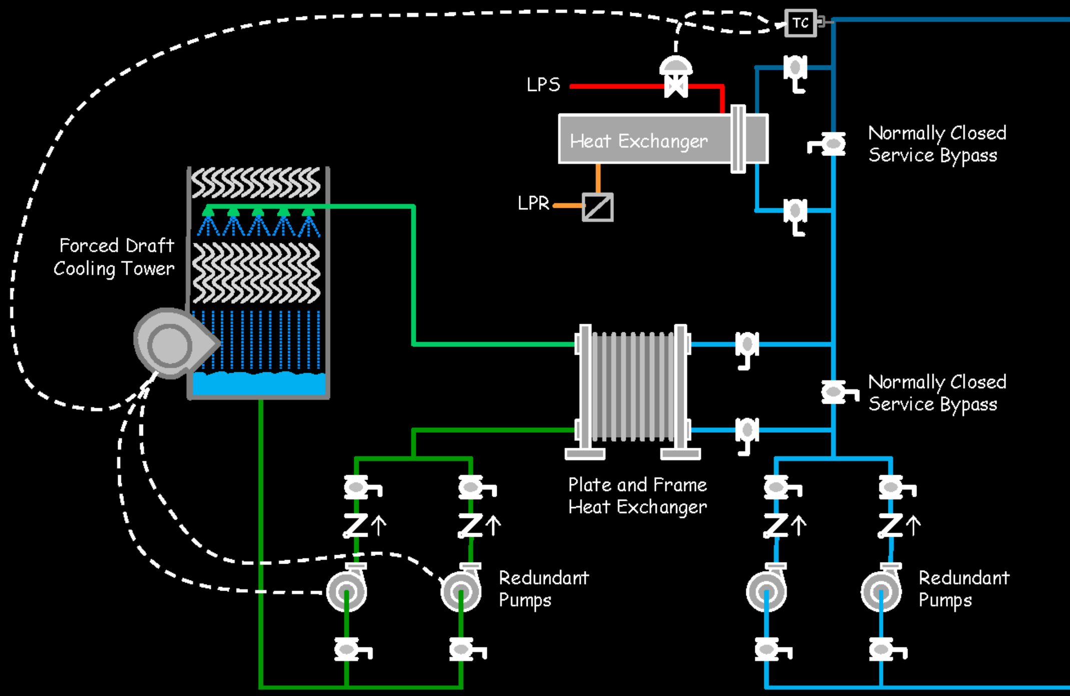
Forced vs. Natural Response Testing

Forced Response Testing

I Observe That:

- The heat exchanger valve remains closed
- The cooling tower fan speeds up to try to reject more heat and bring the temperature down to set point

I override the supply temperature input and make the system “think” the supply temperature has dropped up to 60°F (with a 70°F set point)



Water Source Heat Pump Loop

2022-11-16

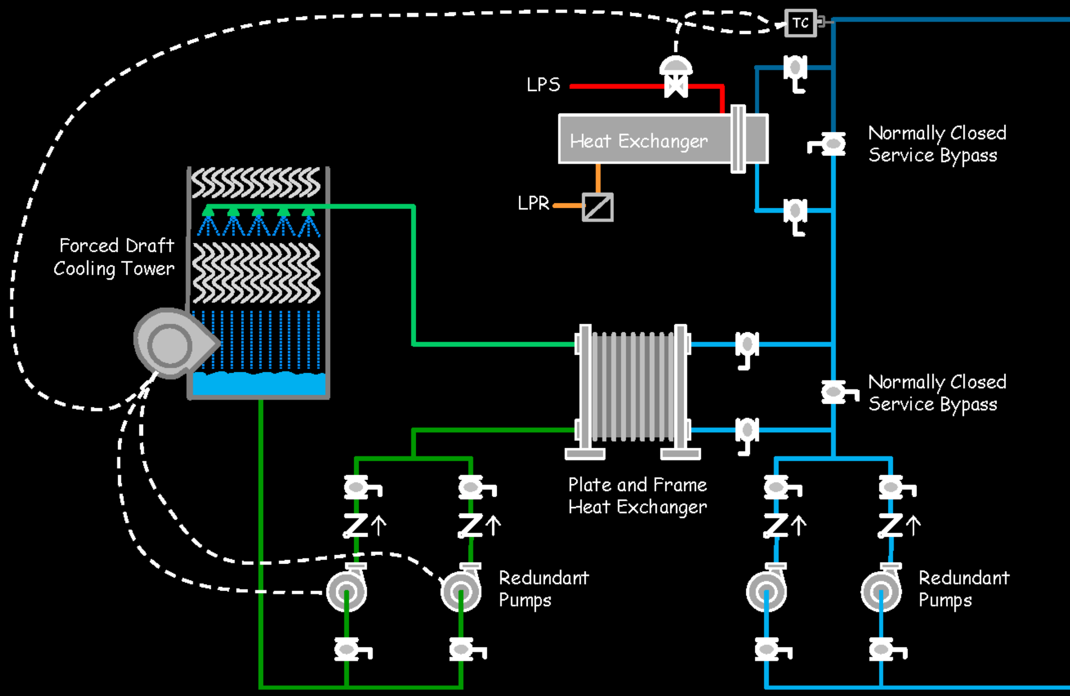
DS

Forced vs. Natural Response Testing

Forced Response Testing

I Observe That:

- The cooling tower fan speed is reduced, and then
- The fan is cycled off, and then
- The pumps are cycled off, and then
- The heat exchanger valve starts to modulate open to add heat to the system to bring it back up to set point

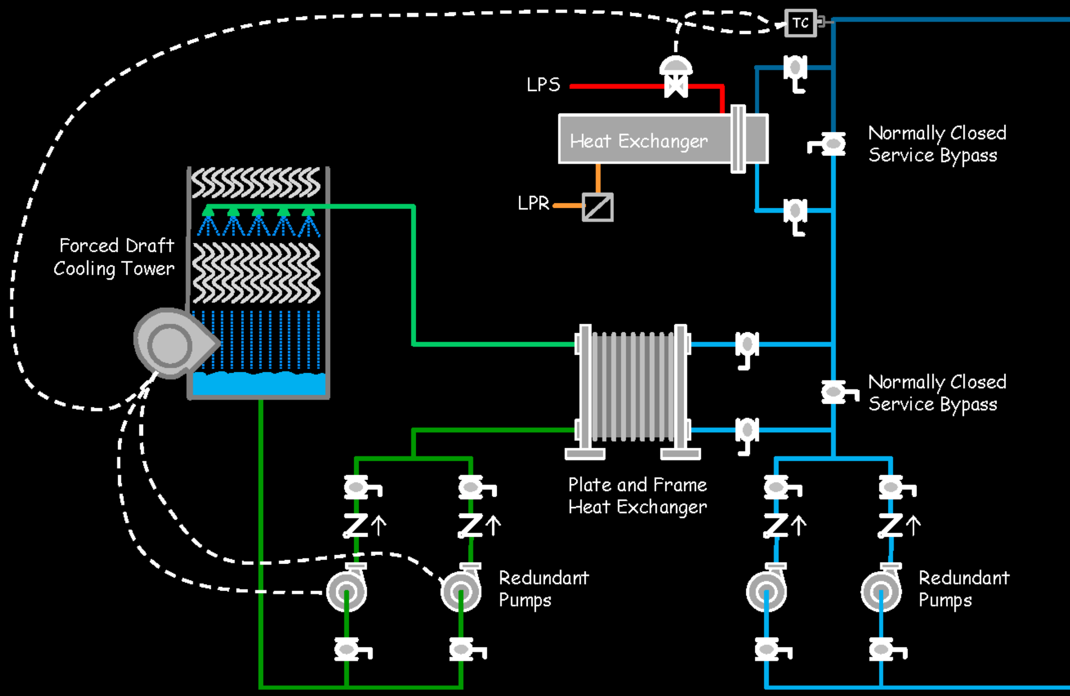


Water Source Heat Pump Loop
2022-11-16
DS

Forced vs. Natural Response Testing

Natural Response Testing

- I pull trend data from the system for a day when the outdoor air temperature swung from 53 – 98°F



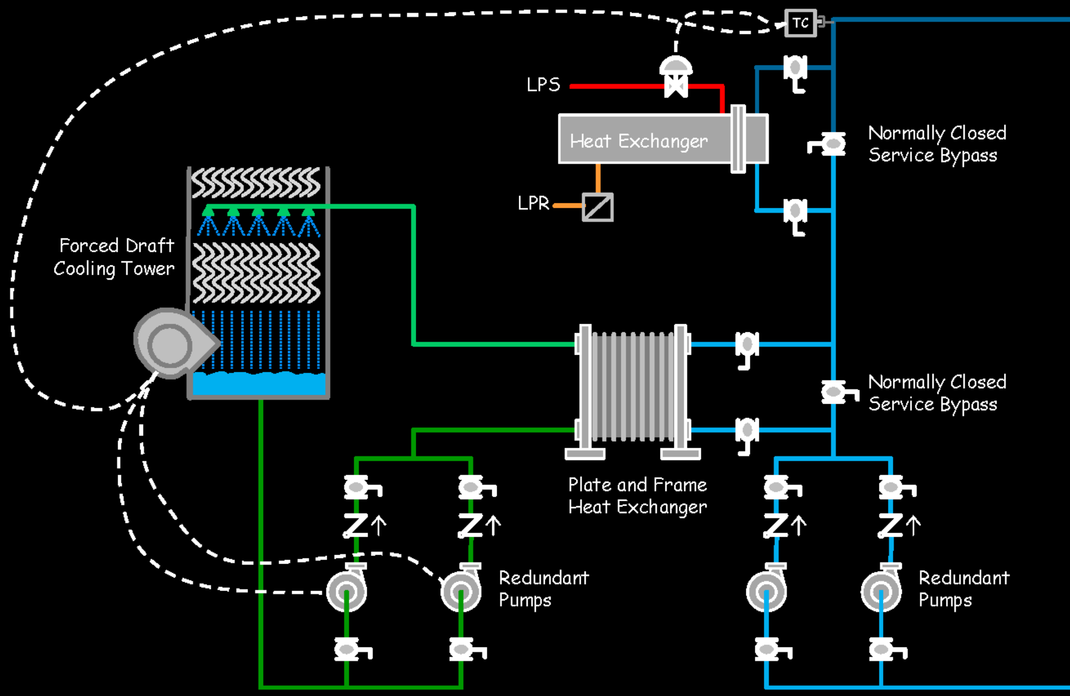
Water Source Heat Pump Loop
2022-11-16
DS

Forced vs. Natural Response Testing

Natural Response Testing

I Observe That

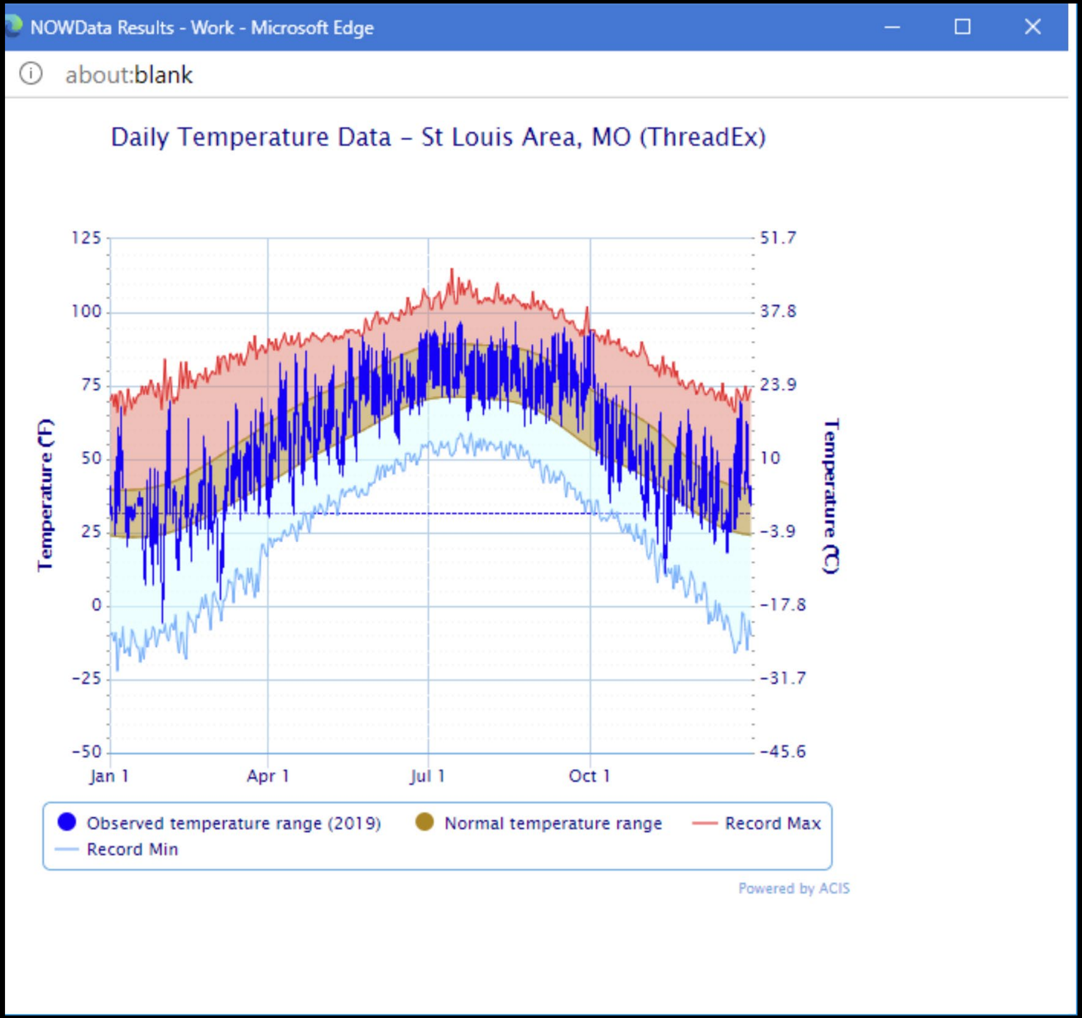
- The heat exchanger adds heat if the loop temperature drops below set point, and
- The cooling tower rejects heat when the loop temperature rises above set point, and
- The heat exchanger is never active when the cooling tower is active, but
- The loop temperature is very unstable when there is a small load on the heat exchanger and,
- The cooling tower fan short cycles when the heat rejection requirement is modest

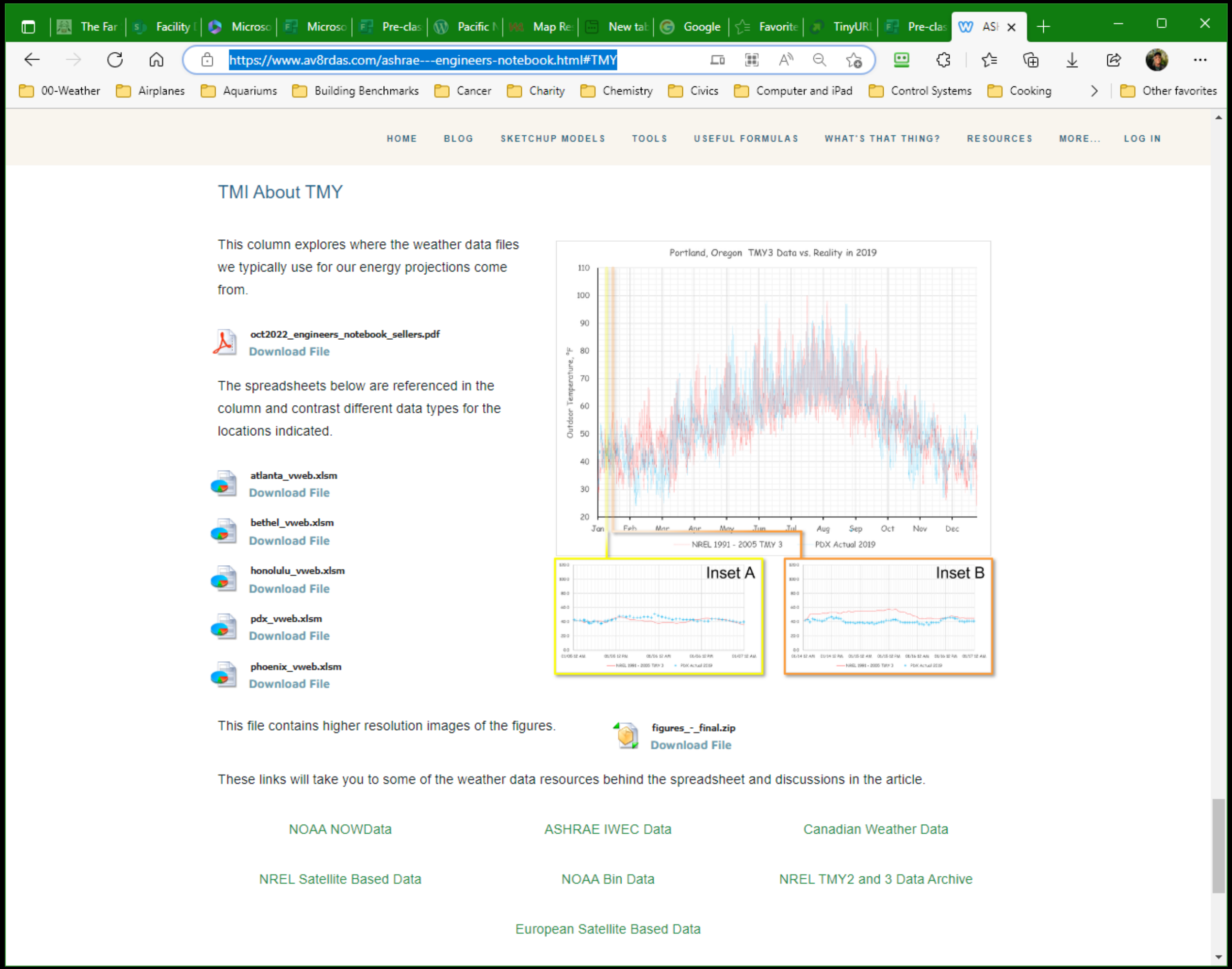


Water Source Heat Pump Loop
2022-11-16
DS

Finding the Day You Want to Observe

https://tinyurl.com/TMIAboutTMY





Functional Testing

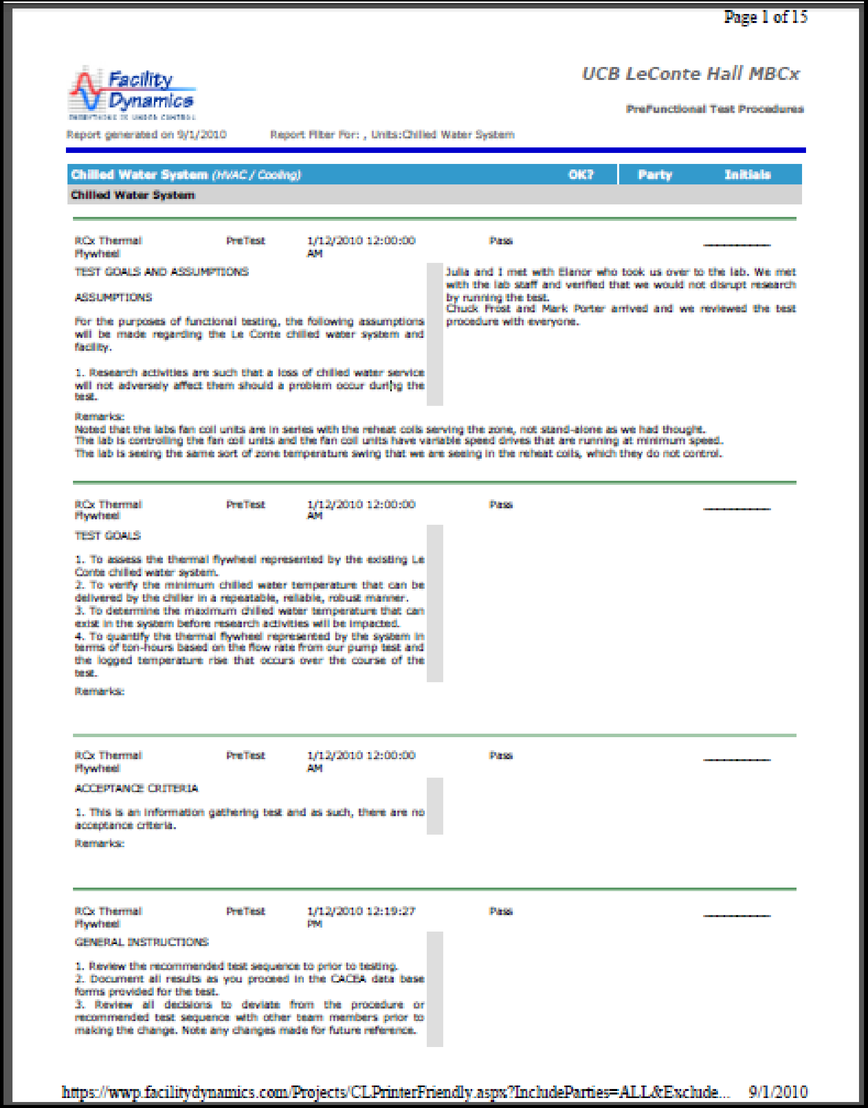
One of the ways we have a dialog with the building

How Do We Dialog with a Building?

We perform a functional test

Functional test components

- Statement of purpose
- Instructions for using the test form
- Equipment requirements
- Acceptance criteria
- Precautions
- Documentation
- Procedure
- Return to Normal and Follow-up
- https://tinyurl.com/CHWFlywheelTest



Page 1 of 15

Facility Dynamics

UCB LeConte Hall MBCx

PreFunctional Test Procedures

Report generated on 9/1/2010 Report Filter For: , Units:Chilled Water System

Chilled Water System *(HVAC / Cooling)*	OK?	Party	Initials
Chilled Water System			

RCx Thermal Flywheel | PreTest | 1/12/2010 12:00:00 AM | Pass | ___________

TEST GOALS AND ASSUMPTIONS

ASSUMPTIONS

For the purposes of functional testing, the following assumptions will be made regarding the Le Conte chilled water system and facility.

1. Research activities are such that a loss of chilled water service will not adversely affect them should a problem occur during the test.

Julia and I met with Elanor who took us over to the lab. We met with the lab staff and verified that we would not disrupt research by running the test.
Chuck Frost and Mark Porter arrived and we reviewed the test procedure with everyone.

Remarks:
Noted that the labs fan coil units are in series with the reheat coils serving the zone, not stand-alone as we had thought.
The lab is controlling the fan coil units and the fan coil units have variable speed drives that are running at minimum speed.
The lab is seeing the same sort of zone temperature swing that we are seeing in the reheat coils, which they do not control.

RCx Thermal Flywheel | PreTest | 1/12/2010 12:00:00 AM | Pass | ___________

TEST GOALS

1. To assess the thermal flywheel represented by the existing Le Conte chilled water system.
2. To verify the minimum chilled water temperature that can be delivered by the chiller in a repeatable, reliable, robust manner.
3. To determine the maximum chilled water temperature that can exist in the system before research activities will be impacted.
4. To quantify the thermal flywheel represented by the system in terms of ton-hours based on the flow rate from our pump test and the logged temperature rise that occurs over the course of the test.

Remarks:

RCx Thermal Flywheel | PreTest | 1/12/2010 12:00:00 AM | Pass | ___________

ACCEPTANCE CRITERIA

1. This is an information gathering test and as such, there are no acceptance criteria.

Remarks:

RCx Thermal Flywheel | PreTest | 1/12/2010 12:19:27 PM | Pass | ___________

GENERAL INSTRUCTIONS

1. Review the recommended test sequence to prior to testing.
2. Document all results as you proceed in the CACEA data base forms provided for the test.
3. Review all decisions to deviate from the procedure or recommended test sequence with other team members prior to making the change. Note any changes made for future reference.

https://wwp.facilitydynamics.com/Projects/CLPrinterFriendly.aspx?IncludeParties=ALL&Exclude... 9/1/2010

The Real Trick

Figuring out what to ask

Figuring Out What to Ask for New Construction Projects

General Goal - NCx

Validate the machinery and systems

1. Do the systems deliver?
2. Do the systems work well together?
3. Was the machine big enough?

Figuring Out What to Ask for Existing Building Projects

General Goal EBCx

Troubleshooting, Diagnostics, Data Gathering for Investigation and Analysis

1. Do the systems deliver?
2. Do the systems work well together?
3. Was the machine big enough?

Figuring Out What to Ask for New Construction Projects

General Goal EBCx

Troubleshooting, Diagnostics, Data Gathering for Investigation and Analysis

1. Why don’t the systems deliver?
2. Do the systems work well together?
3. Was the machine big enough?

Figuring Out What to Ask for New Construction Projects

General Goal EBCx

Troubleshooting, Diagnostics, Data Gathering for Investigation and Analysis

1. Why don't the systems deliver?
2. Why don't the systems work well together?
3. Was the machine big enough?

Figuring Out What to Ask for New Construction Projects

General Goal EBCx

Troubleshooting, Diagnostics, Data Gathering for Investigation and Analysis

1. Why don’t the systems deliver?
2. Why don’t the systems work well together?
3. How big does the machine need to be?

Figuring Out What to Ask for New Construction Projects

General Goal EBCx

Troubleshooting, Diagnostics, Data Gathering for Investigation and Analysis

1. Why don’t the systems deliver?
2. Why don’t the systems work well together?
3. How big does the machine need to be?
4. How much will I save if I make my targeted improvement?

Figuring Out What to Ask for New Construction Projects

General Goal EBCx

Troubleshooting, Diagnostics, Data Gathering for Investigation and Analysis

1. Why don't the systems deliver?
2. Why don't the systems work well together?
3. How big does the machine need to be?
4. How much will I save if I make my targeted improvement?

Resources

- The design documents
- Manufacturers literature
- The control system design narrative and logic diagrams

  This could be different from the information on the vendor control drawings!

- The Functional Testing Guide

  https://tinyurl.com/FTGBlogPost

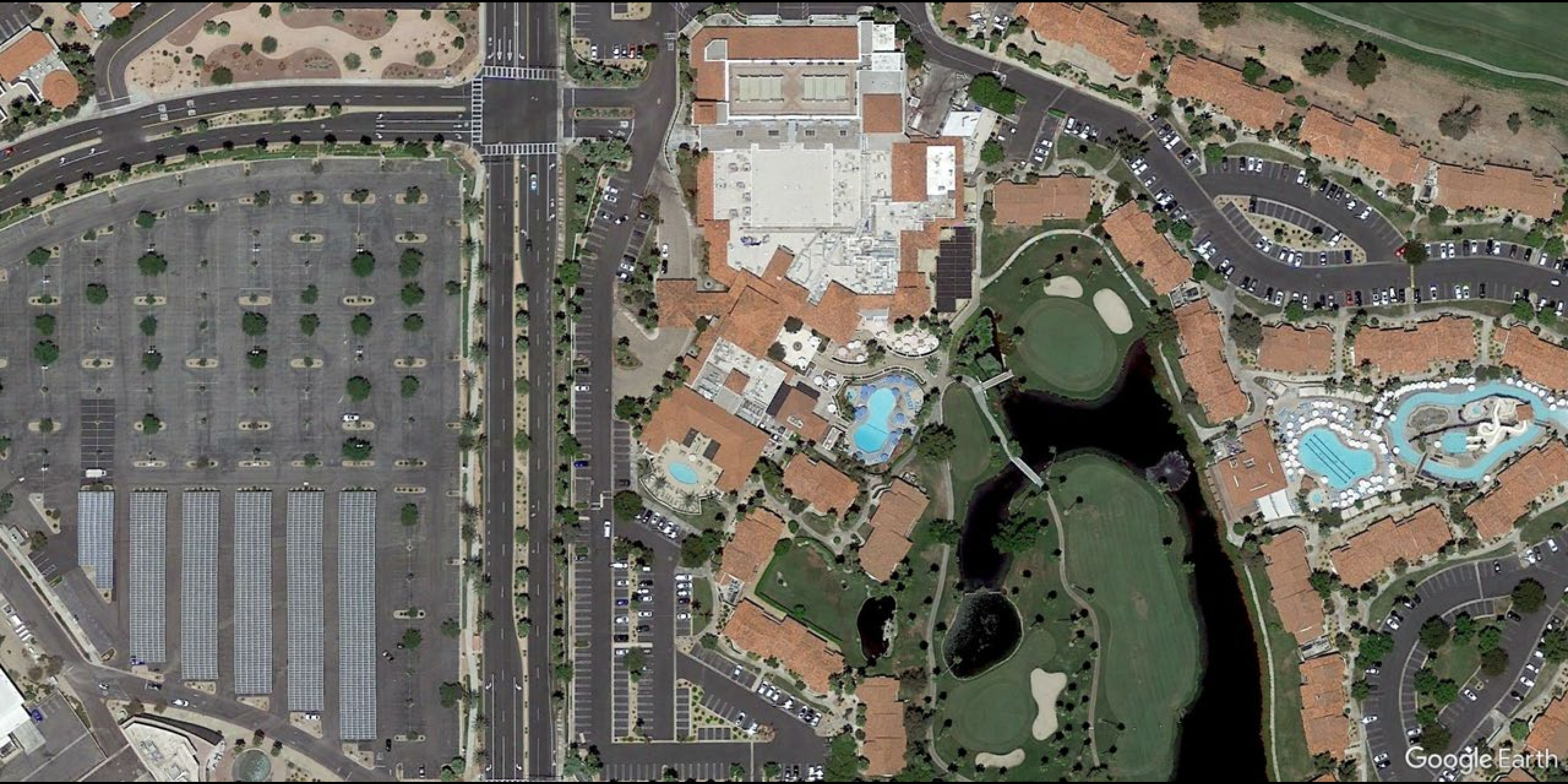
- Your knowledge and experience

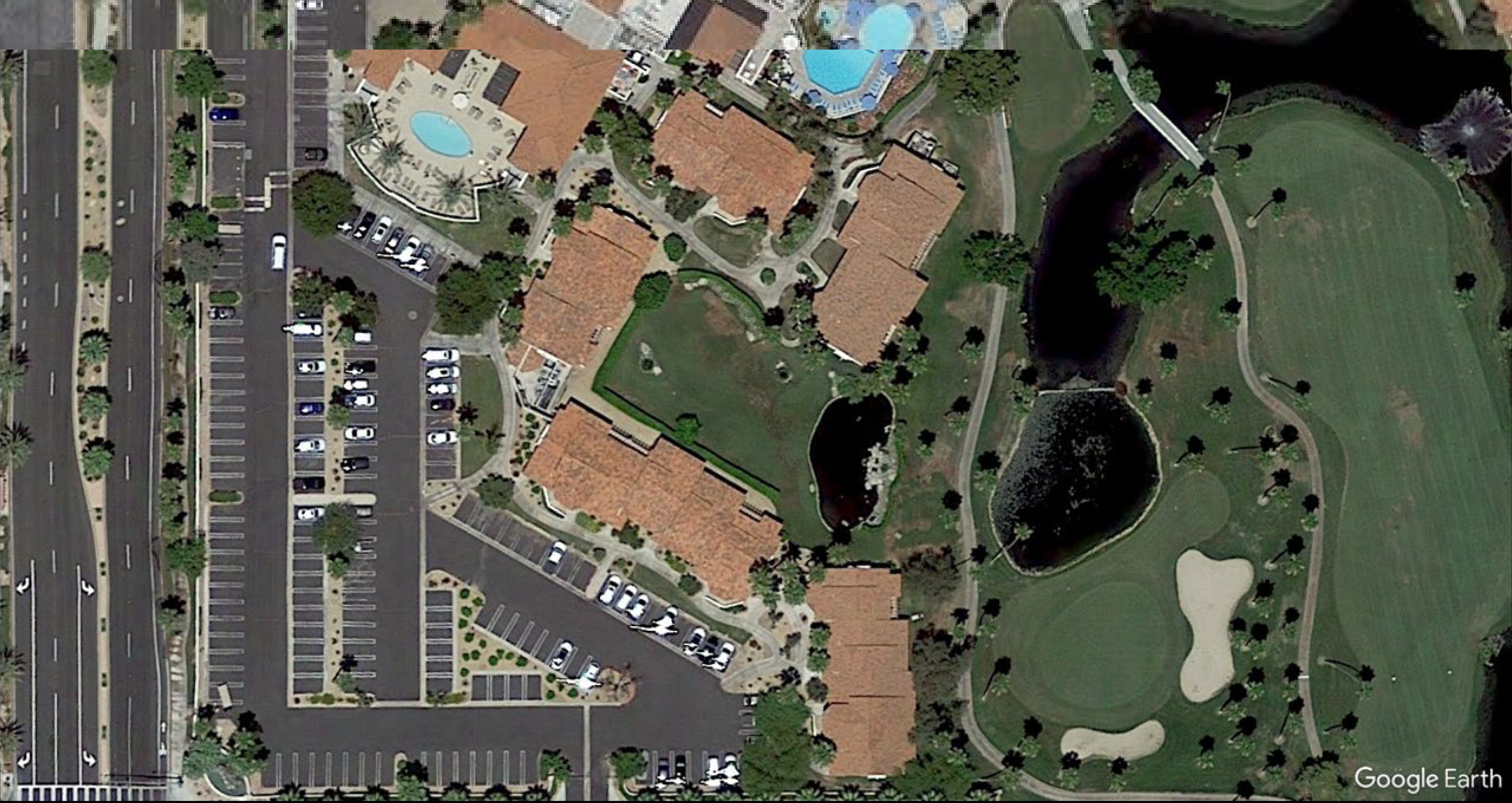
Gaining Some Experience

Focusing on an Existing System

A Hospitality Industry Campus Style Location

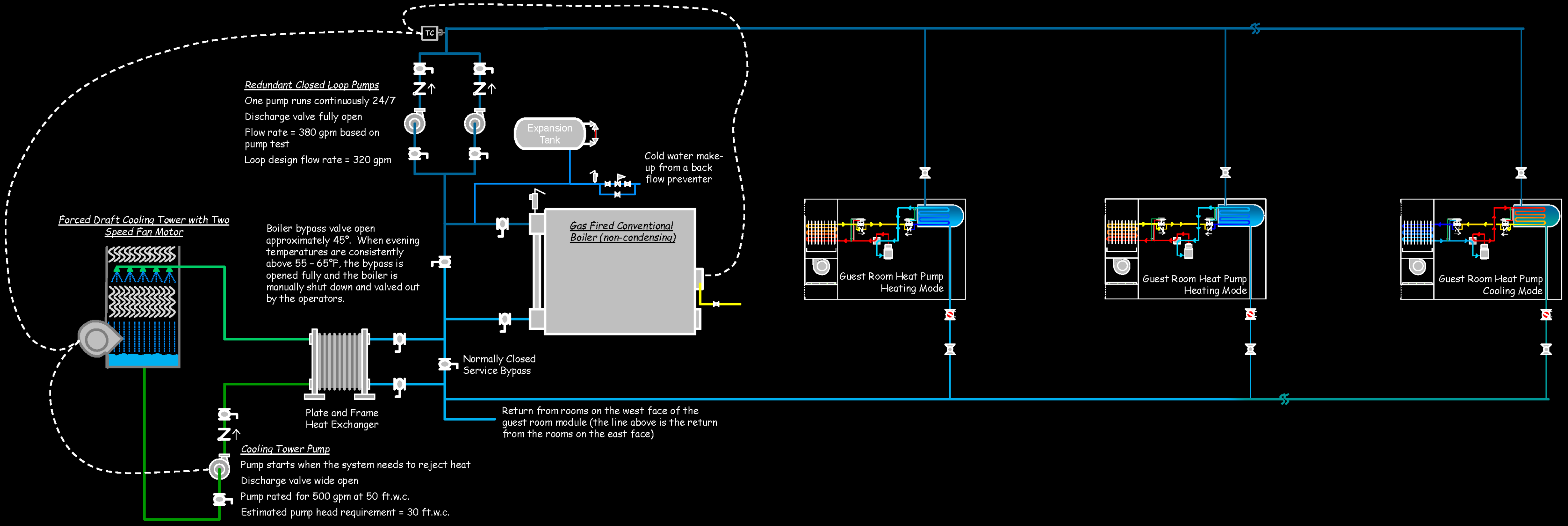
- Palm Springs, CA
- North is towards the top of the image
- Focusing on the guest room buildings


Google Earth

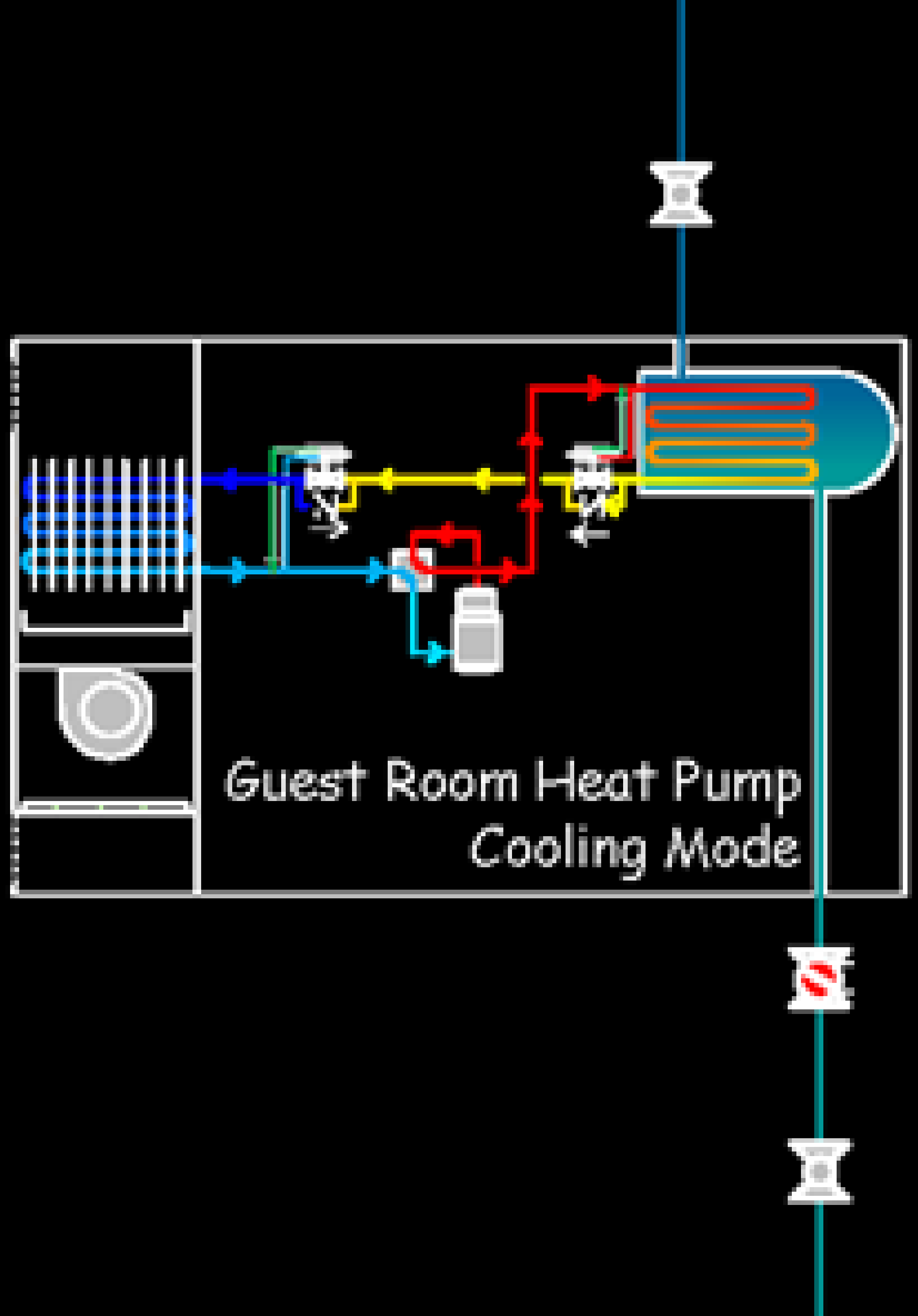

Google Earth

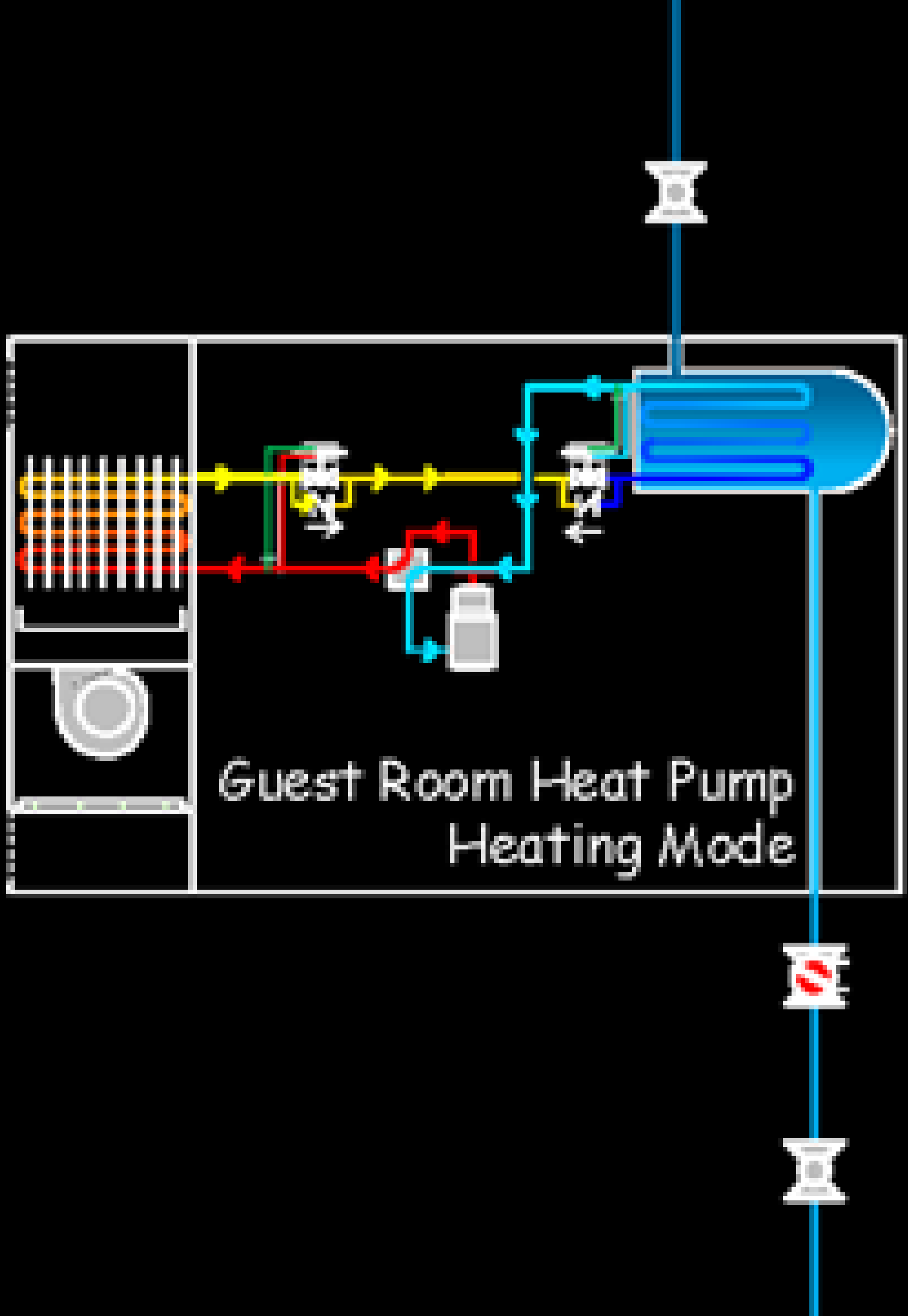


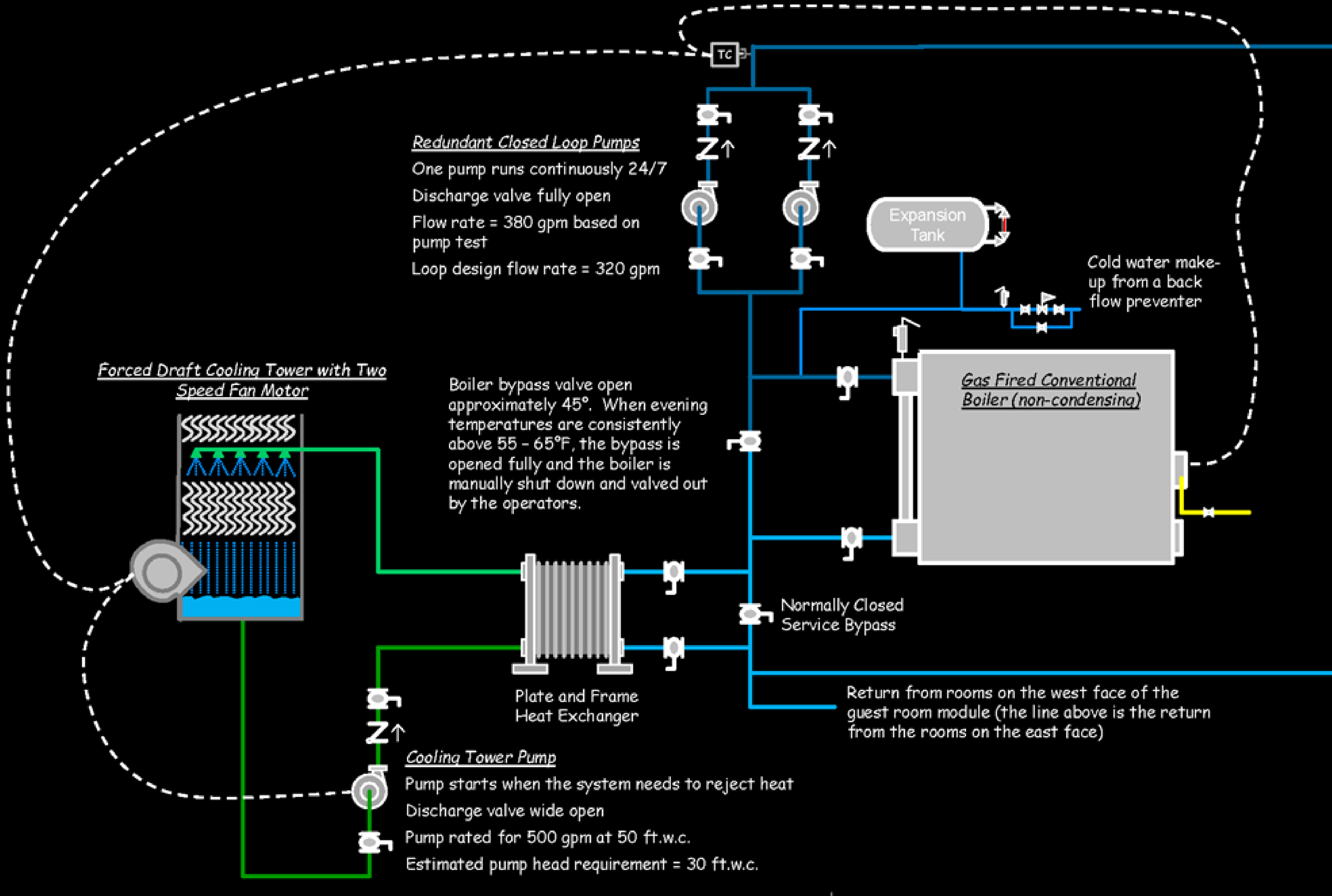

A Typical Guest Room Heat Pump Loop



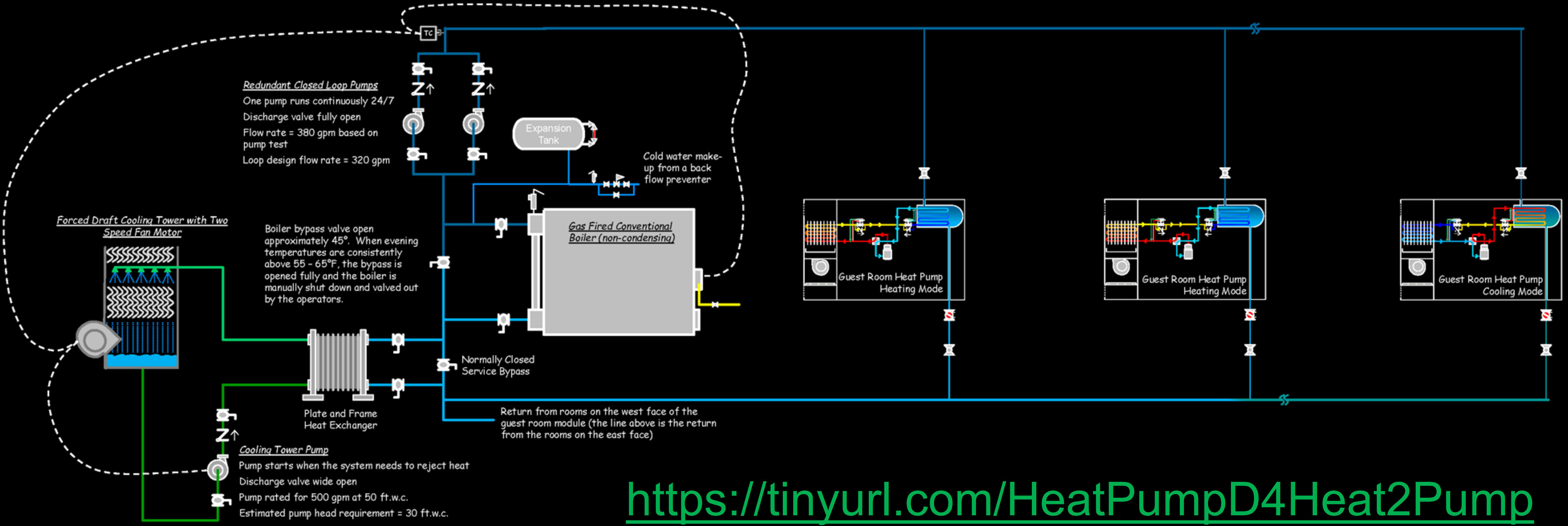
Water Source Heat Pump Loop
2022-11-16, DS


Guest Room Heat Pump
Cooling Mode


Guest Room Heat Pump
Heating Mode


TC
Redundant Closed Loop Pumps
One pump runs continuously 24/7
Discharge valve fully open
Flow rate = 380 gpm based on pump test
Loop design flow rate = 320 gpm
Expansion Tank
Cold water make-up from a back flow preventer
Forced Draft Cooling Tower with Two Speed Fan Motor
Boiler bypass valve open approximately 45°. When evening temperatures are consistently above 55 – 65°F, the bypass is opened fully and the boiler is manually shut down and valved out by the operators.
Gas Fired Conventional Boiler (non-condensing)
Normally Closed Service Bypass
Plate and Frame Heat Exchanger
Return from rooms on the west face of the guest room module (the line above is the return from the rooms on the east face)
Cooling Tower Pump
Pump starts when the system needs to reject heat
Discharge valve wide open
Pump rated for 500 gpm at 50 ft.w.c.
Estimated pump head requirement = 30 ft.w.c.

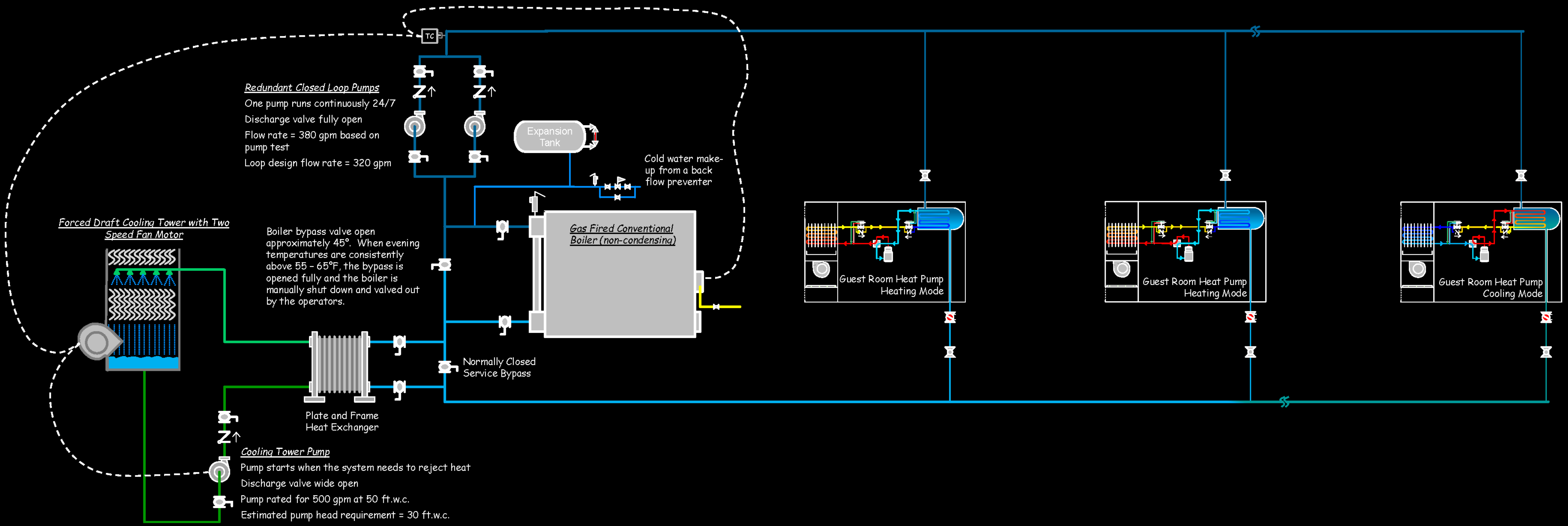
Some Questions For You



Water Source Heat Pump Loop
2022-11-16, DS

https://tinyurl.com/HeatPumpD4Heat2Pump


Thinking About Monitoring



Water Source Heat Pump Loop

2022-11-16, DS

Monitoring Plan Targets

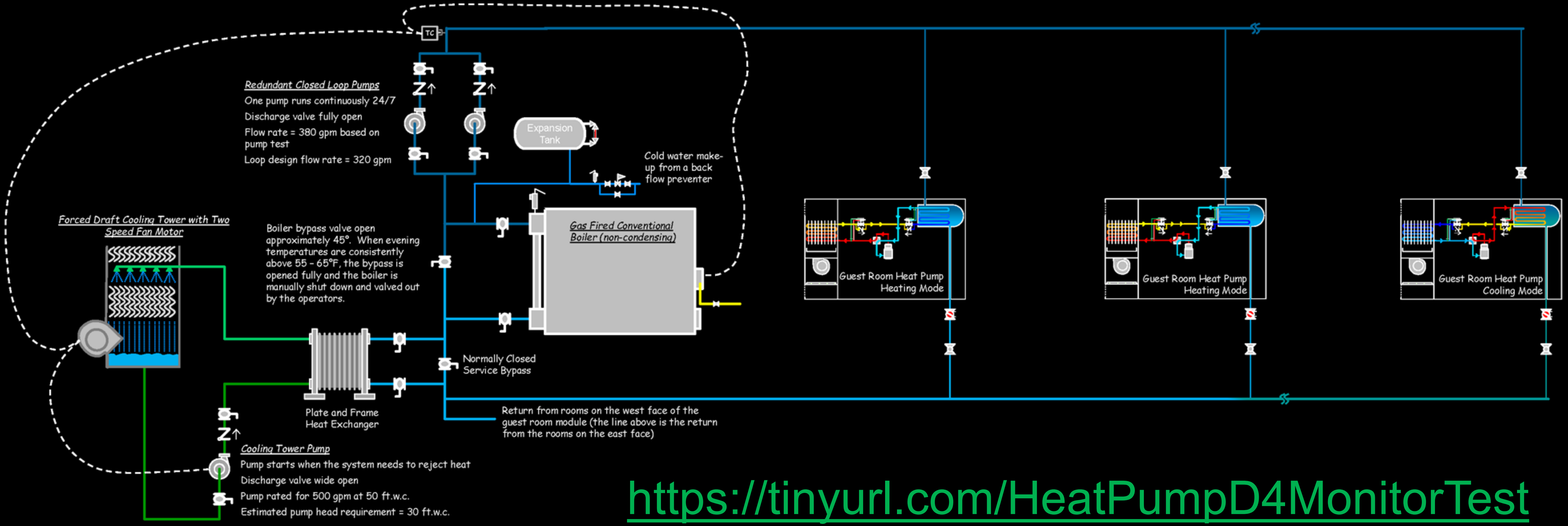
- Firm up (or not) opportunities identified during scoping
- Provide data
  - Support more detailed investigations
  - Diagnostics and trouble shooting
  - Calculations
    - Looking for common opportunities
    - Are schedules actually working?
    - Are VAV systems VAVing?
    - Are optimization strategies working?
- Support expansion of the findings list
- Support cost benefit assessments
- Support verification

Logger Serial Number (EMS indicates control system trend)	System	Point (use full point name for EMS Points)	Sensor	Sampling Time	Sensor Location	Logger Location	Link to Screenshots of deployed location of sensors and Logger / Link to Screenshot of Launch		Notes
10263770	Cooling Tower	Cell 1 Hot Basin Temperature	TMC50-HD	1 minute	Hot basin of cell 1	On magnet under the steel	Sensor 1	Overview	1. Put logger in a zip lock bag and then under something to protect it.
	Cooling Tower	Cell 2 Hot Basin Temperature	TMC50-HD	1 minute	Hot basin of cell 2		Sensor 2	Logger Location	
	Cooling Tower	Cell 1 Cold Basin Temperature	TMC50-HD	1 minute	Hot basin of cell 1		Sensor 3	Typical Basin Temperature Sensor	
	Cooling Tower	Cell 2 Cold Basin Temperature	TMC50-HD	1 minute	Hot basin of cell 1		Sensor 4		
							Logger	Screen shot of logger status at launch	
10263769	South Tower MCC	Cooling tower 1 fan amps	CTV-B (50 amp)	1 minute	CT 1 feed at MCC	At MCC	Sensor 1	Central Plant MCC	1. See general note 2.
	South Tower MCC	Cooling tower 2 fan amps	CTV-B (50 amp)	1 minute	CT 2 feed at MCC		Sensor 2		
	South Tower MCC	CW Pump 1 amps	CTV-B (50 amp)	1 minute	CW Pump 1 feed at MCC		Sensor 3		
	South Tower MCC	CW Pump 2 amps	CTV-B (50 amp)	1 minute	CW Pump 2 feed at MCC		Sensor 4		
							Logger	Screen shot of logger 10263769	
	South Tower CHW	Chiller 1 Amps	CTV-D (600 amp)	1 minute	Chiller 1 main switch		Sensor 1		1. David will ship down 600 amp CTs for you to use.
	South Tower CHW	Chiller 2 Amps	CTV-D (600 amp)	1 minute	Chiller 2 main switch		Sensor 2		
							Sensor 3		
							Sensor 4		
							Logger		
10263774	South Tower CHW	Chiller 1 EWT - Chilled Water	TMC20-HD	1 minute	Thermometer well	At chiller	Sensor 1	Logger Location	1. See general notes 1 and 3.
	South Tower CHW	Chiller 1 LWT - Chilled Water	TMC20-HD	1 minute	Thermometer well		Sensor 2	Sensors	
	South Tower CHW	Chiller 1 EWT - Condenser Water	TMC20-HD	1 minute	Thermometer well		Sensor 3	Sensor detail	
	South Tower CHW	Chiller 1 LWT - Condenser Water	TMC20-HD	1 minute	Thermometer well		Sensor 4		
							Logger	Logger 10263774 Launch	
10263767	South Tower CHW	Chiller 2 EWT - Chilled Water	TMC20-HD	1 minute	Thermometer well	At chiller	Sensor 1	Logger Location	1. See general notes 1 and 3.
	South Tower CHW	Chiller 2 LWT - Chilled Water	TMC20-HD	1 minute	Thermometer well		Sensor 2	Sensors	
	South Tower CHW	Chiller 2 EWT - Condenser Water	TMC20-HD	1 minute	Thermometer well		Sensor 3		
	South Tower CHW	Chiller 2 LWT - Condenser Water	TMC20-HD	1 minute	Thermometer well		Sensor 4		
							Logger	Screen shots with bad sensor and fix	
10263771	South Tower CHW	CHW Pump 1 Amps	CTV-D (200 amp)	1 minute	CT 1 feed at MCC	At MCC	Sensor 1	Central Plant MCC	1. See general note 2. 2. I have assumed a 20 amp CT will be big enough for the domestic water pumps.
	South Tower CHW	CHW Pump 2 Amps	CTV-D (200 amp)	1 minute	CT 2 feed at MCC		Sensor 2		
	South Tower DomWtr	Pump 1 Amps	CTV-A (20 amp)	2 seconds	DW Pump 1 feed in MCC		Sensor 3		
	South Woter DomWtr	Pump 2 Amps	CTV-A (20 amp)	2 seconds	DW Pump 2 feed in MCC		Sensor 4		
							Logger	Logger 10263771 deployment screenshot	
10359812 (Carlos's logger)	ST Eq. Rm. Conditions	ST Eq. Rm. Temperature	Internal	1 minute	On Top of DW Pump Panel	At DW Pumps	Sensor 1	Logger tied to conduit at Booster Pump	1. Borrow one of Carlos's loggers with an internal lighting sensor.
	ST Eq. Rm. Conditions	ST. Eq. Rm RH	Internal	1 minute	On Top of DW Pump Panel		Sensor 2		
	ST Eq. Rm. Conditions	ST Eq. Rm. Lighting Level	Internal	1 minute	On Top of DW Pump Panel		Sensor 3		
							Sensor 4		
							Logger	Screen shot of 10359812 launch	
10263768	NT Lobby DD Unit	Supply fan amps	CTV-D (50 amp)	1 minute	VFD incoming line	Tie-wrapped to supply fan VFD	Sensor 1	Fan amps sensor	1. See general notes 1 and 4.
	NT Lobby DD Unit	Fan Leaving Air Temperature	TMC20-HD	1 minute	Downstream of fan		Sensor 2	Fan discharge sensor	
	NT Lobby DD Unit	Cold Deck Temperature	TMC20-HD	1 minute	Downstream of coil		Sensor 3	Cold deck sensor	
	NT Lobby DD Unit	Hot Deck Temperature	TMC20-HD	1 minute	Downstream of coil		Sensor 4	Hot deck sensor	
							Logger	Screen shot of logger ant launch	
10264069	NT Lobby DD Unit	Return temperature	Internal	1 minute	In return duct	Tie-wrapped to duct support in the return duct	Sensor 1	Data logger - Initial deployment	1. Try to get the sensor into the system away from the door so that air leakage around the door does not influence the logger too much.
	NT Lobby DD Unit	Return RH	Internal	1 minute	In return duct		Sensor 2		
							Sensor 3		
							Sensor 4		
							Logger	Screen shot of logger ant launch Screen shot of logger re-deployment	

Monitoring Plan Resources

- Monitoring Plan Template (blank and a filled-out example)
- Monitoring Plan Blog Posts
- Data Logging Resources
- A Video
- All linked from this location
- https://tinyurl.com/MonitoringPlans

A Monitoring Question



Water Source Heat Pump Loop
2022-11-16, DS

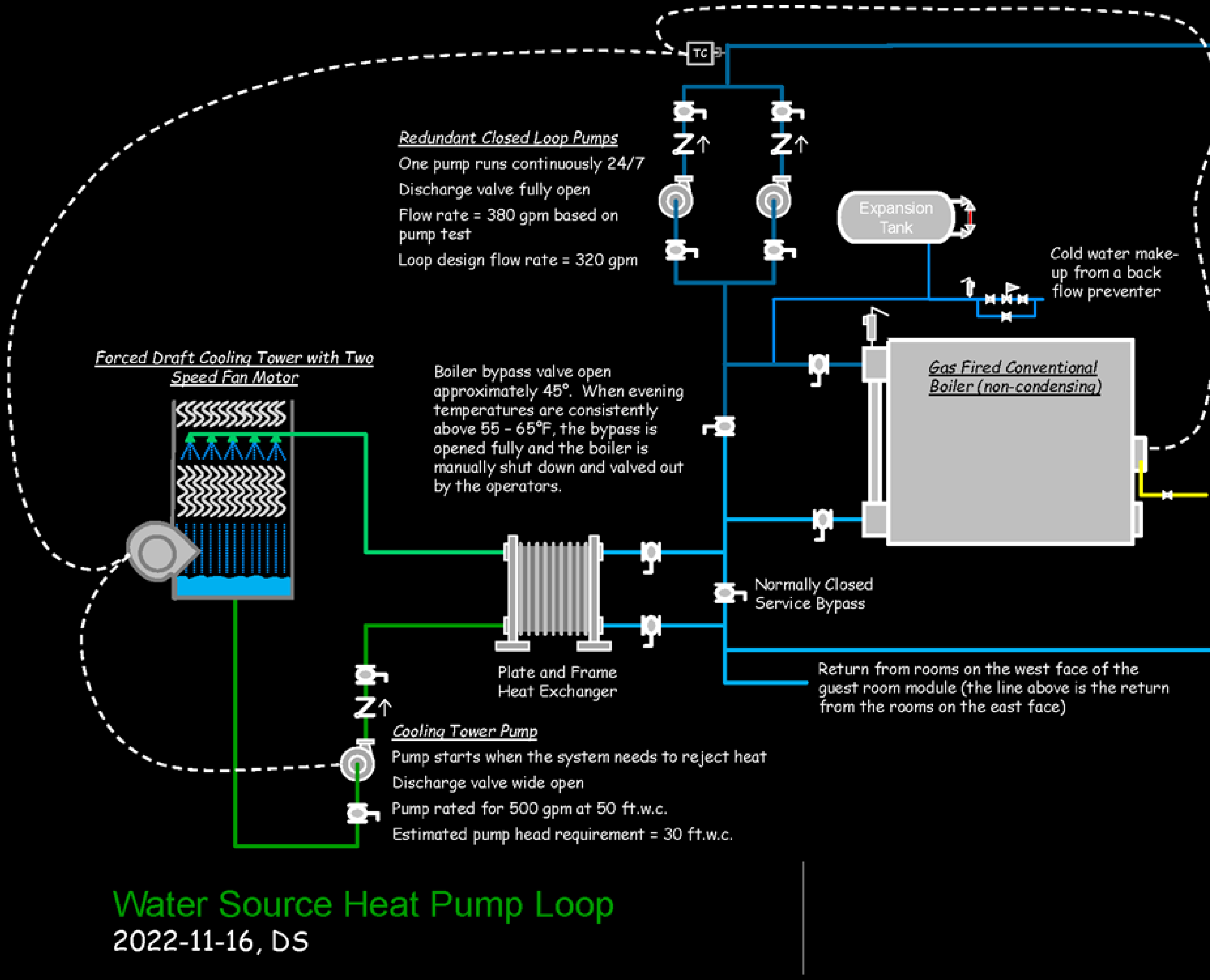
https://tinyurl.com/HeatPumpD4MonitorTest

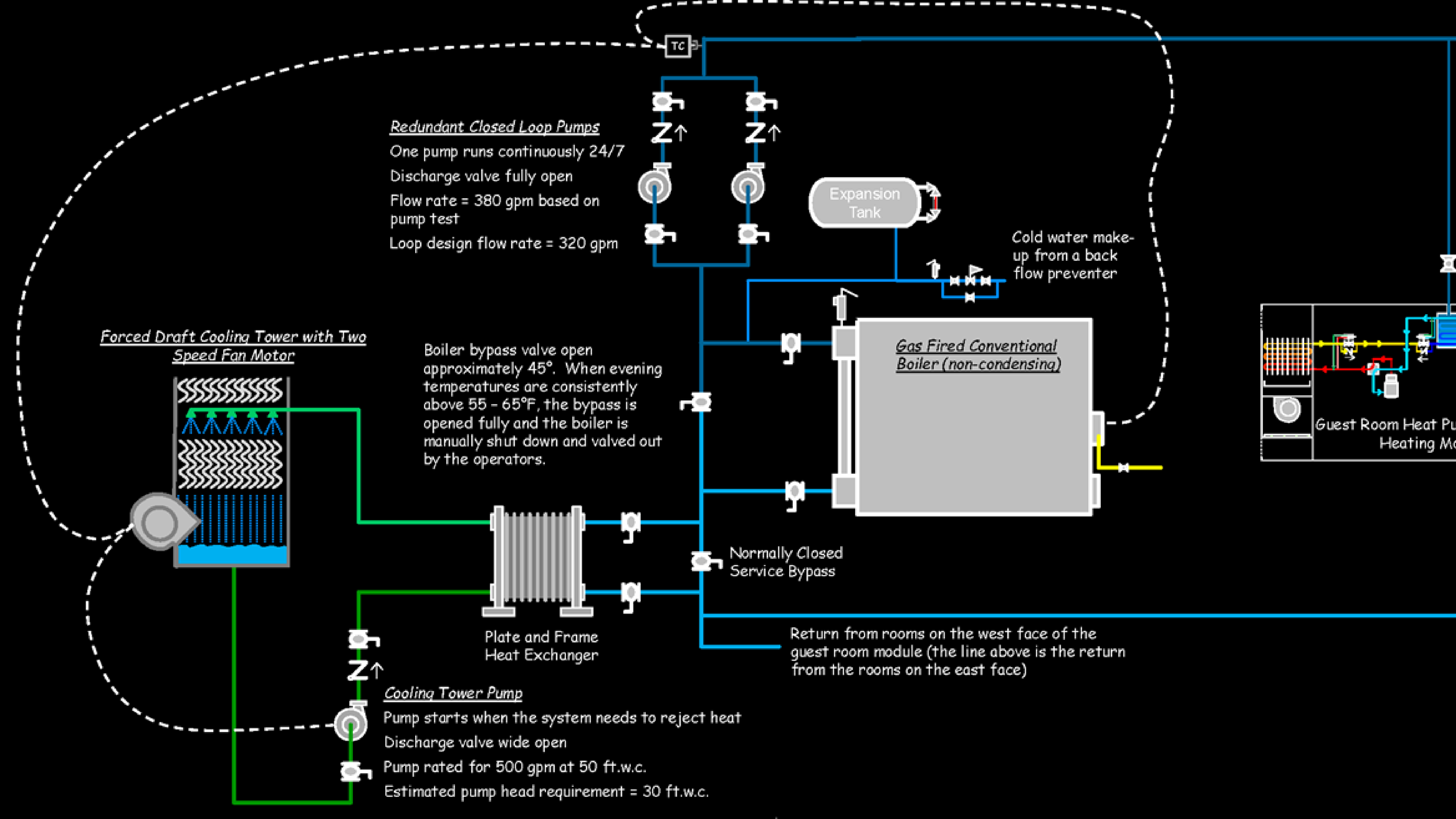
Adding Some Constraints

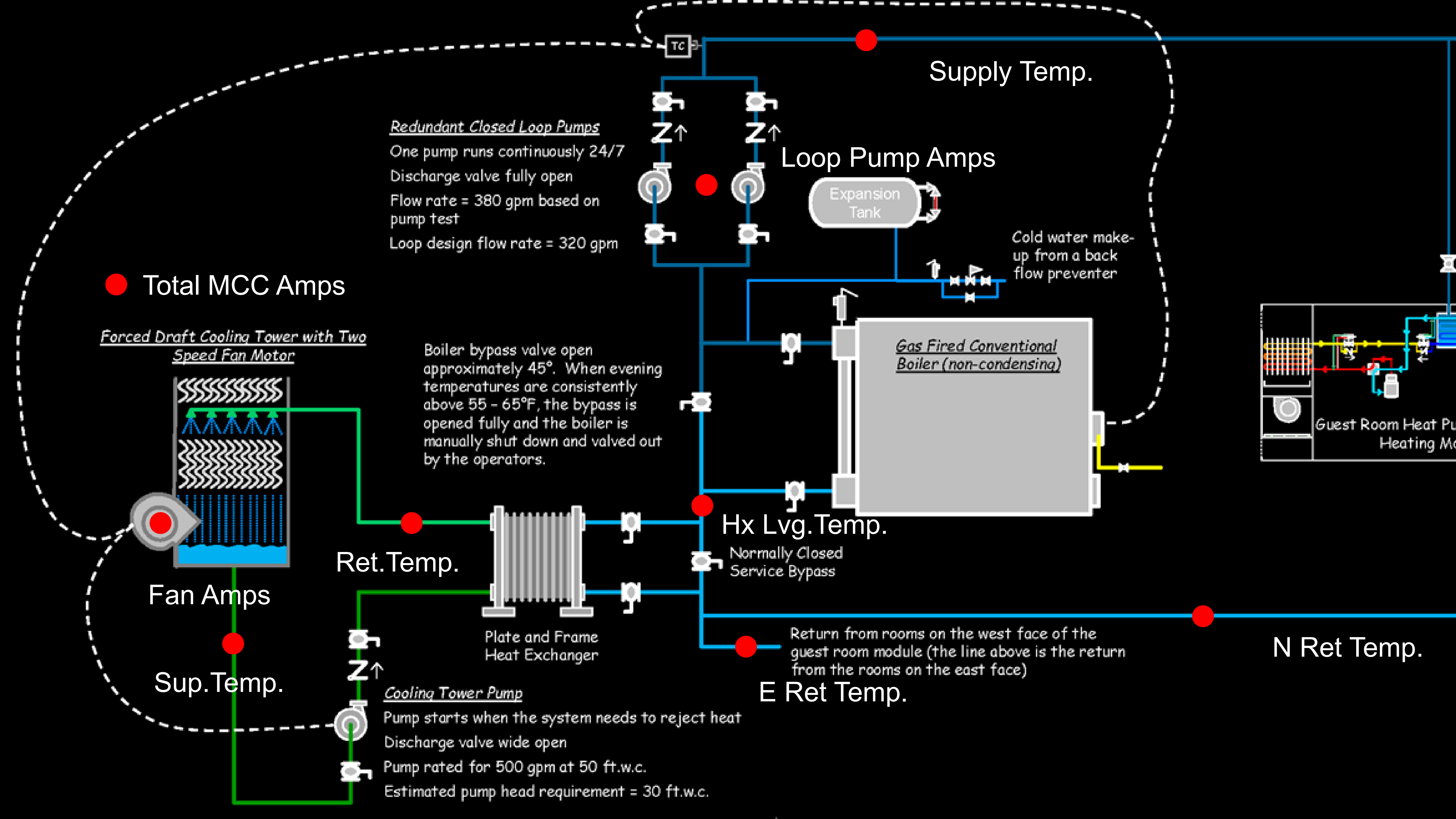
Your logger inventory

- 2 – four channel loggers
- 8 – temperature sensors
- 4 – CTs

What data points would you select to give you the most insight?




TC
Redundant Closed Loop Pumps
One pump runs continuously 24/7
Discharge valve fully open
Flow rate = 380 gpm based on pump test
Loop design flow rate = 320 gpm
Expansion Tank
Cold water make-up from a back flow preventer
Forced Draft Cooling Tower with Two Speed Fan Motor
Boiler bypass valve open approximately 45°. When evening temperatures are consistently above 55 – 65°F, the bypass is opened fully and the boiler is manually shut down and valved out by the operators.
Gas Fired Conventional Boiler (non-condensing)
Guest Room Heat Pu
Heating Mo
Normally Closed Service Bypass
Plate and Frame Heat Exchanger
Return from rooms on the west face of the guest room module (the line above is the return from the rooms on the east face)
Cooling Tower Pump
Pump starts when the system needs to reject heat
Discharge valve wide open
Pump rated for 500 gpm at 50 ft.w.c.
Estimated pump head requirement = 30 ft.w.c.



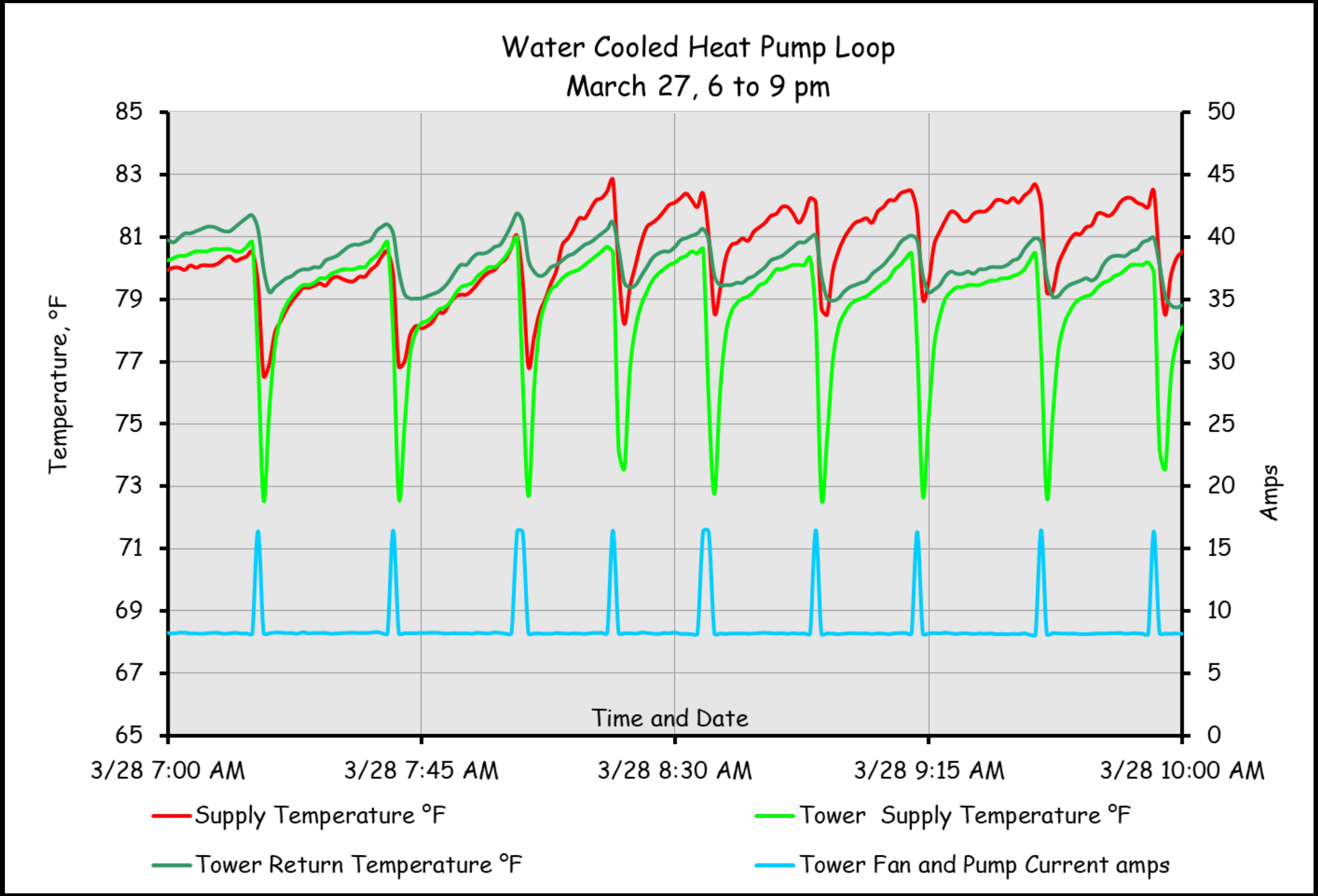
TC
Supply Temp.
Redundant Closed Loop Pumps
One pump runs continuously 24/7
Discharge valve fully open
Flow rate = 380 gpm based on pump test
Loop design flow rate = 320 gpm
Loop Pump Amps
Expansion Tank
Cold water make-up from a back flow preventer
Total MCC Amps
Forced Draft Cooling Tower with Two Speed Fan Motor
Boiler bypass valve open approximately 45°. When evening temperatures are consistently above 55 – 65°F, the bypass is opened fully and the boiler is manually shut down and valved out by the operators.
Gas Fired Conventional Boiler (non-condensing)
Guest Room Heat Pu
Heating Mo
Hx Lvg.Temp.
Normally Closed Service Bypass
Ret.Temp.
Fan Amps
Plate and Frame Heat Exchanger
Return from rooms on the west face of the guest room module (the line above is the return from the rooms on the east face)
N Ret Temp.
E Ret Temp.
Sup.Temp.
Cooling Tower Pump
Pump starts when the system needs to reject heat
Discharge valve wide open
Pump rated for 500 gpm at 50 ft.w.c.
Estimated pump head requirement = 30 ft.w.c.

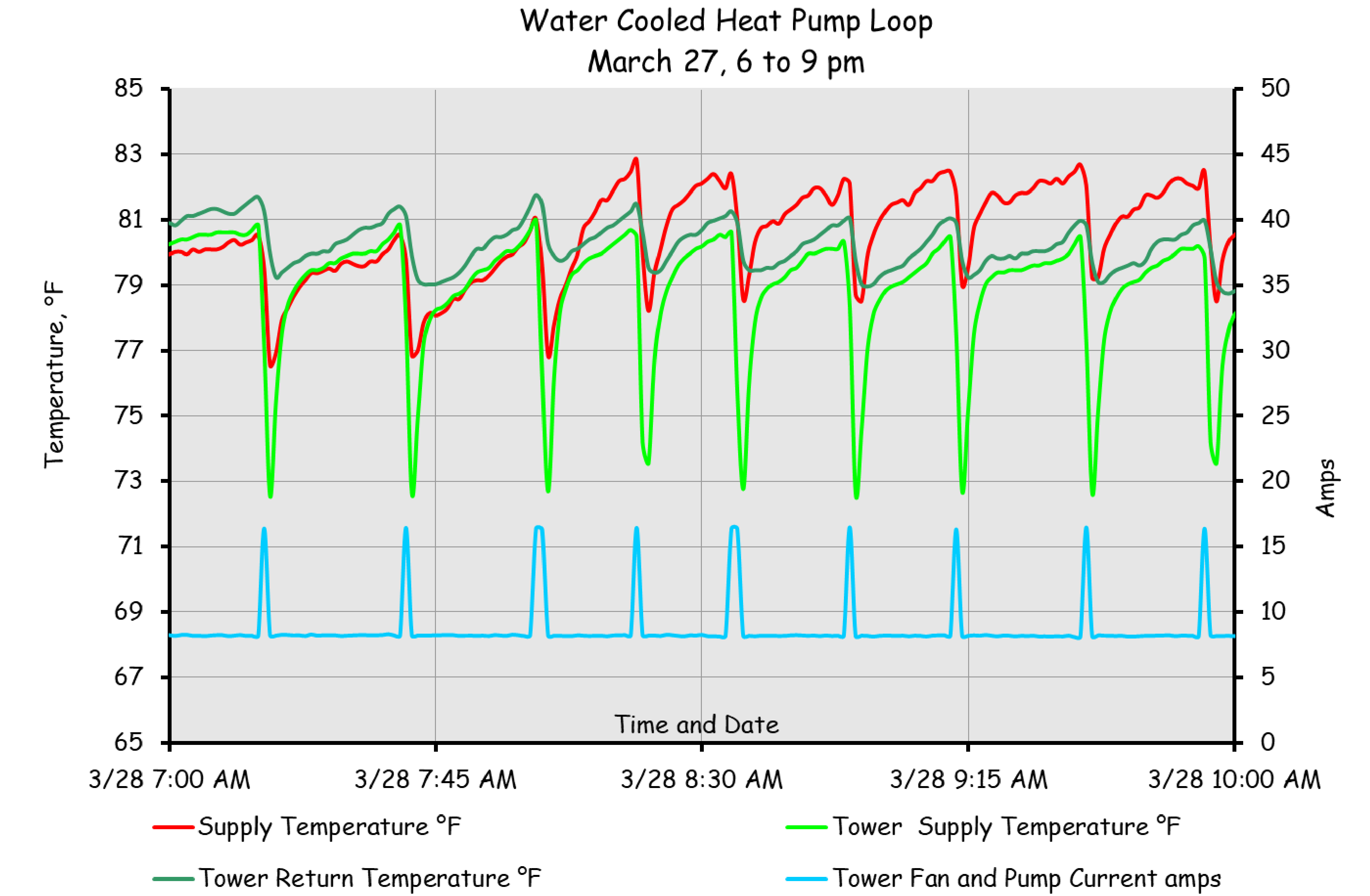
Let’s Look at Some Data

https://tinyurl.com/DataLoggingDecades

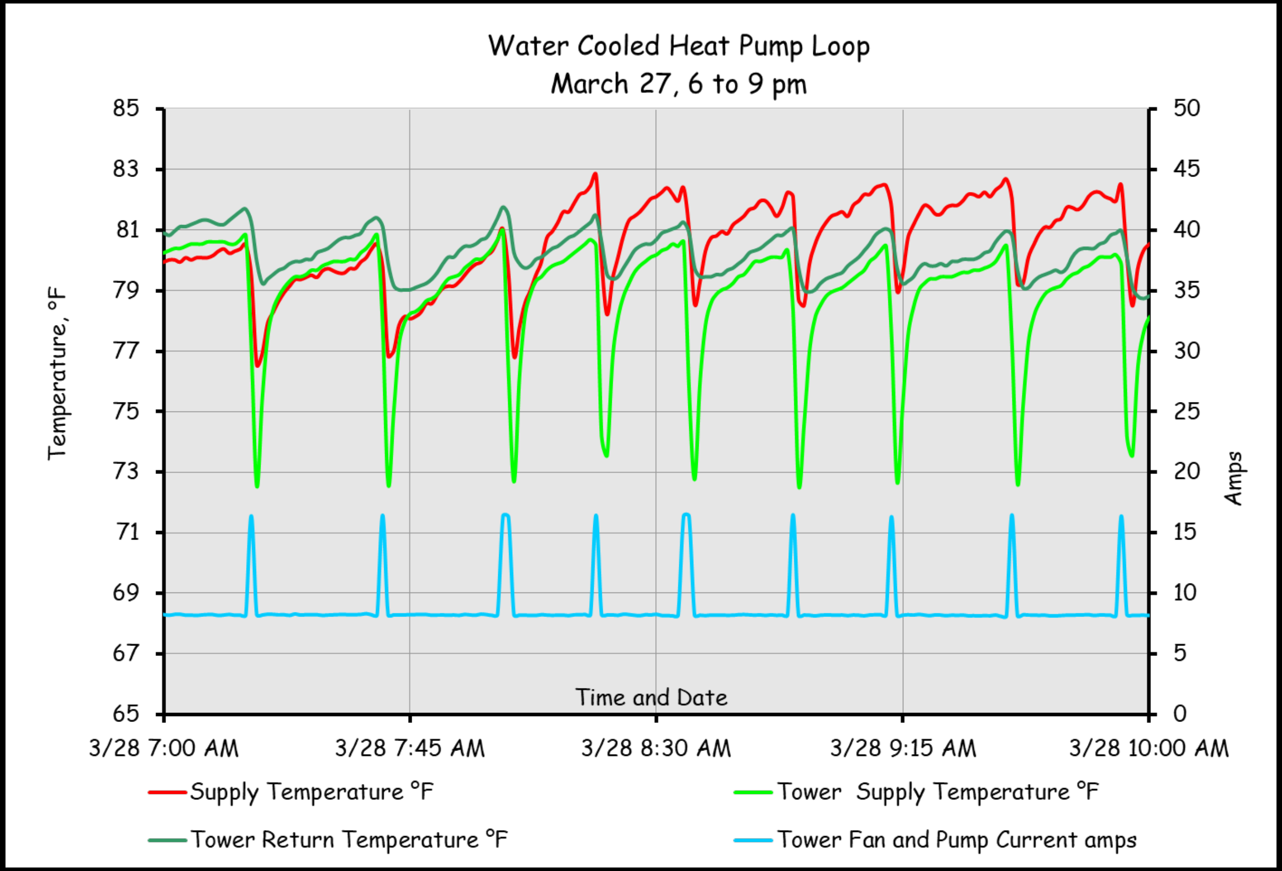

onset
CTV-D
onset
HOBO 4-channel analog logger
onset
StoP
onset
HOBO data node
temp
HOBO MX CO2 logger
onset
onset
esc
on/off
yes
next
no
alt
HOBO U-Shuttle
HOBO
RH
Temp
2 x External
onset

What You Might Learn



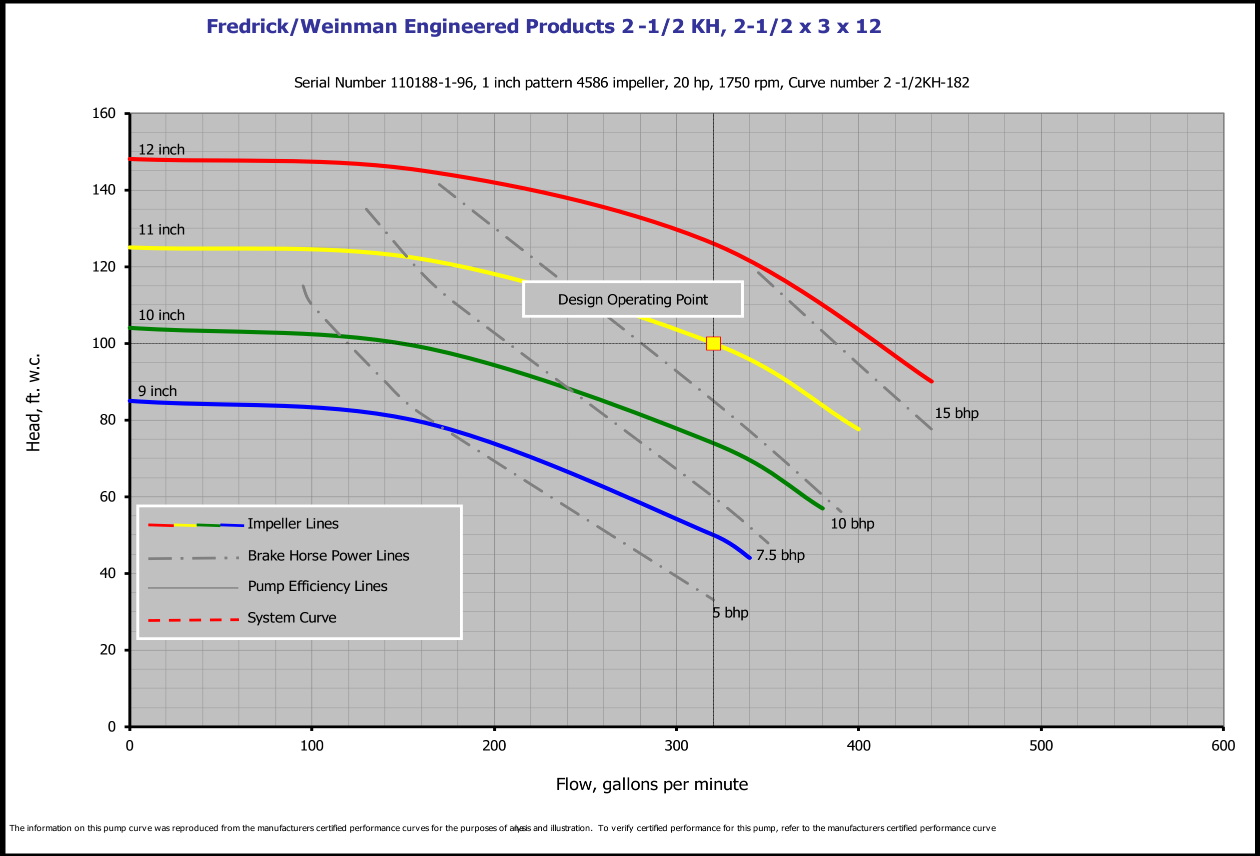

Water Cooled Heat Pump Loop
March 27, 6 to 9 pm
Temperature, °F
Amps
85
83
81
79
77
75
73
71
69
67
65
50
45
40
35
30
25
20
15
10
5
0
Time and Date
3/28 7:00 AM
3/28 7:45 AM
3/28 8:30 AM
3/28 9:15 AM
3/28 10:00 AM
Supply Temperature °F
Tower Supply Temperature °F
Tower Return Temperature °F
Tower Fan and Pump Current amps

What Did You Learn?



https://tinyurl.com/HeatPumpD4TempTrends

What You Might Learn From the Pump

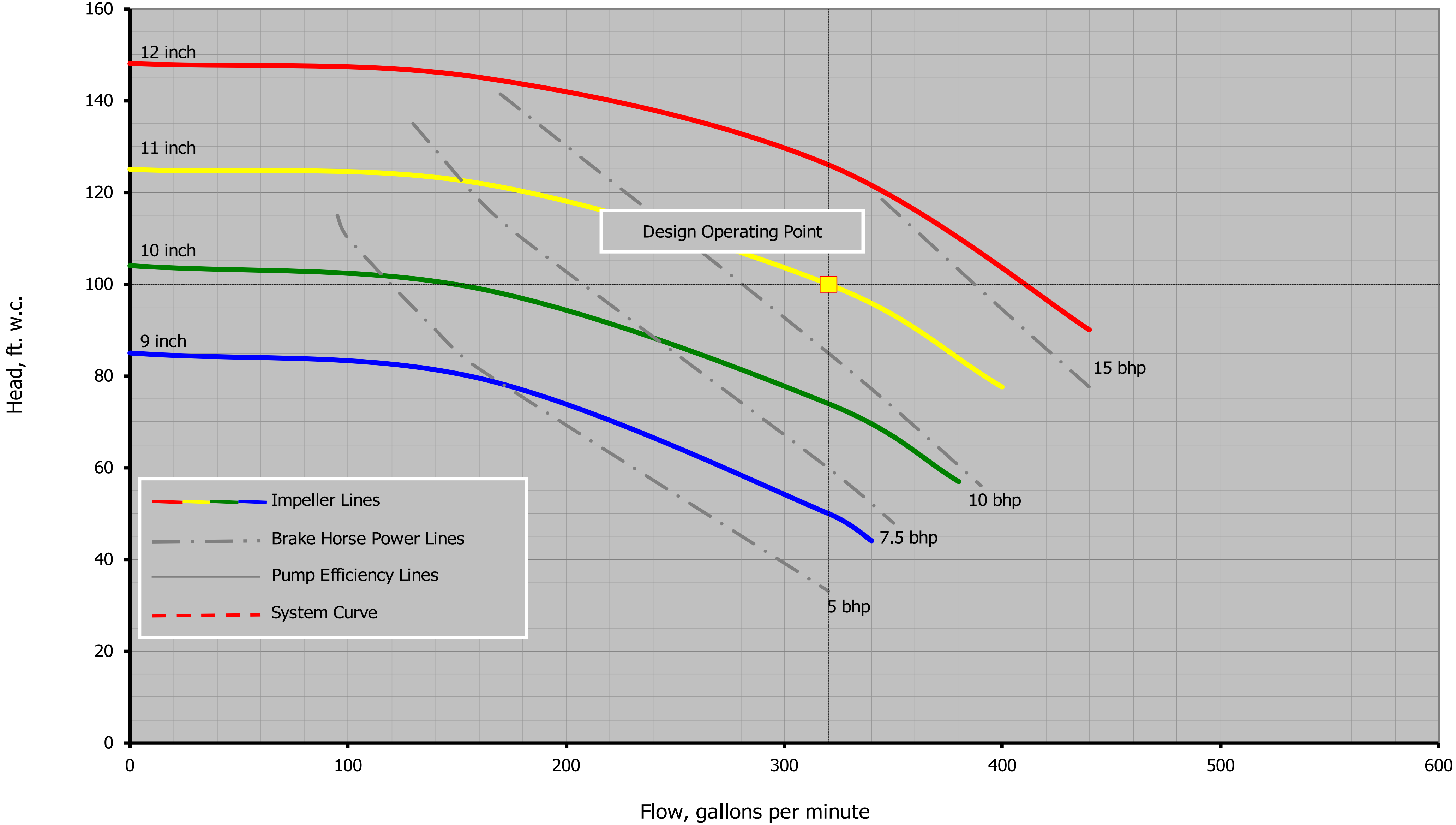


Design Condition

- 11 inch impeller
- Design Flow – 320 gpm
- Design Head – 100 ft.w.c.

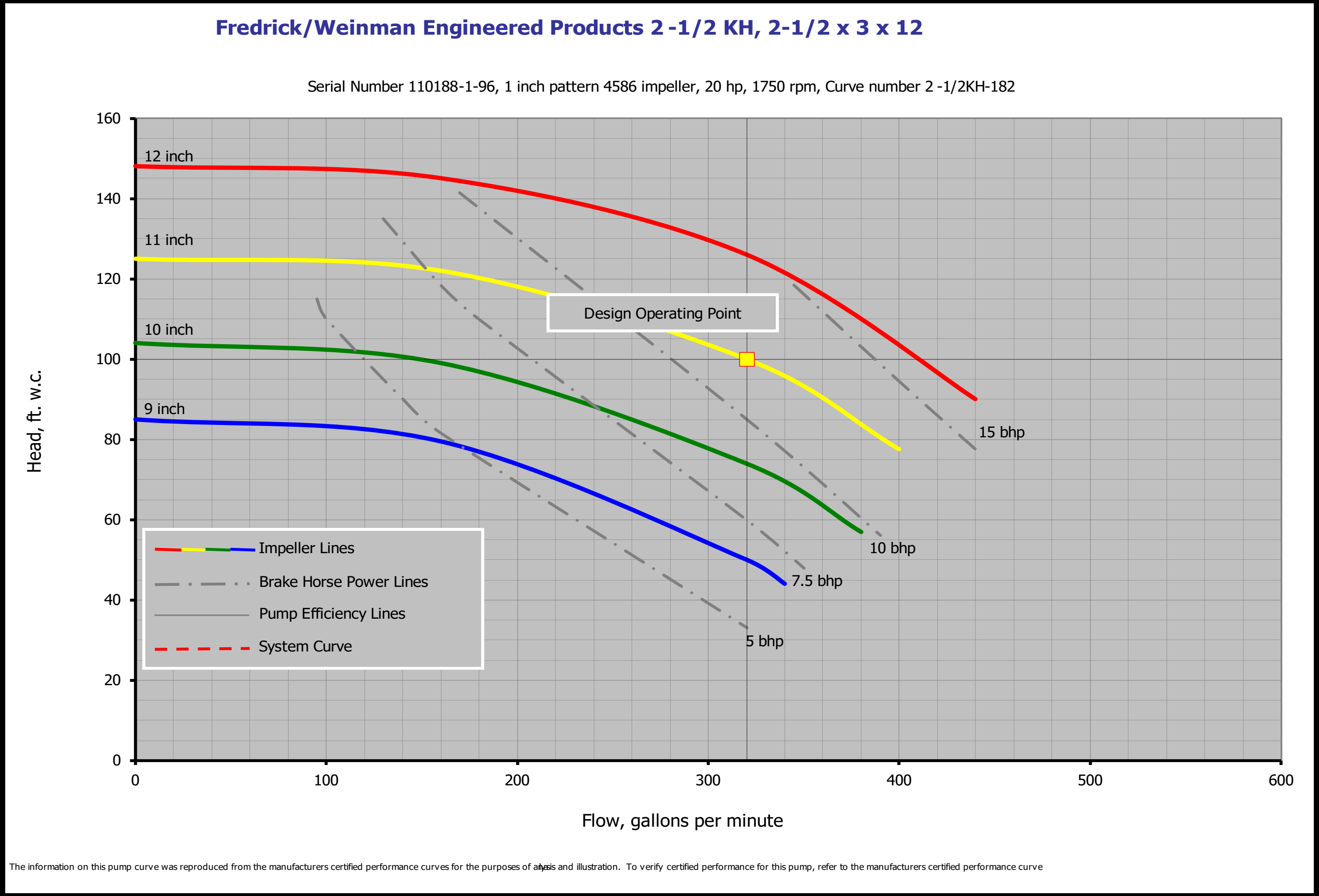
Fredrick/Weinman Engineered Products 2 -1/2 KH, 2-1/2 x 3 x 12

Serial Number 110188-1-96, 1 inch pattern 4586 impeller, 20 hp, 1750 rpm, Curve number 2 -1/2KH-182

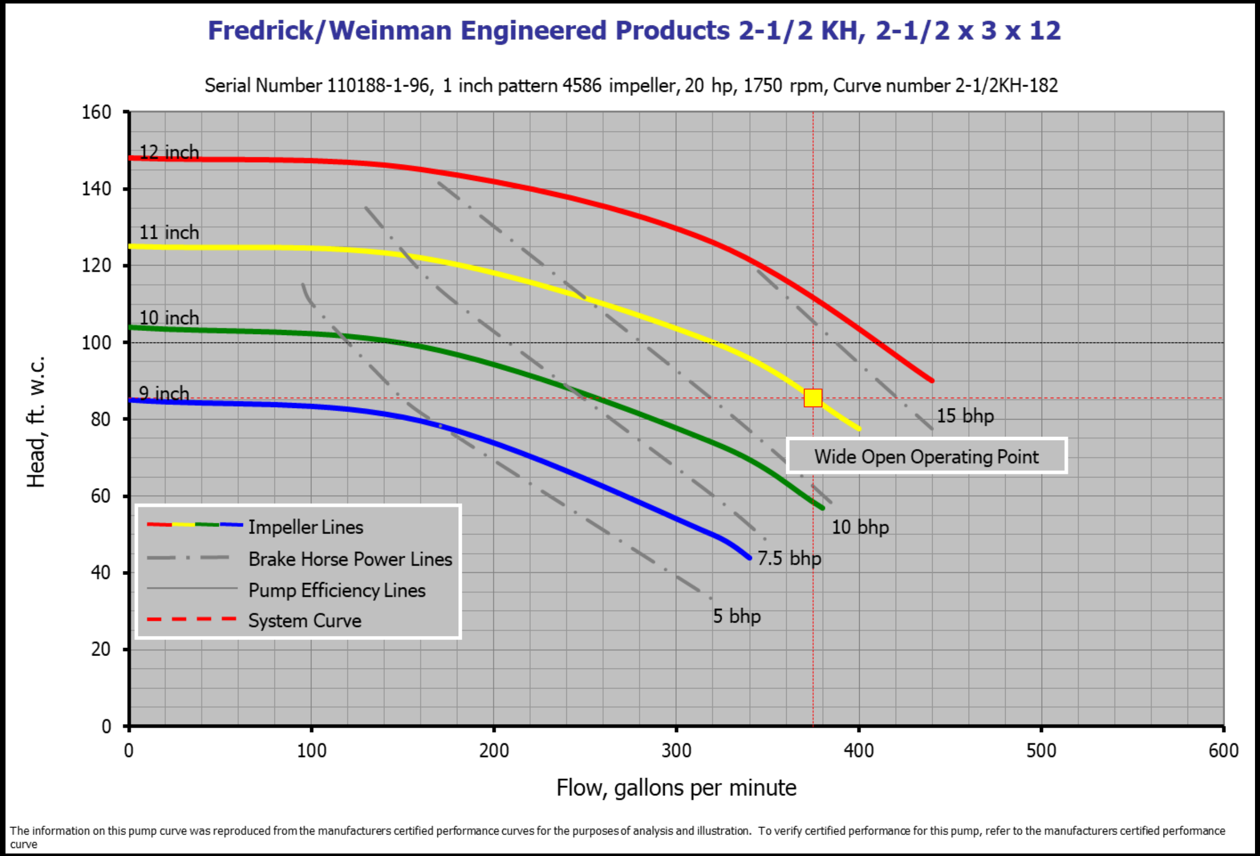


The information on this pump curve was reproduced from the manufacturers certified performance curves for the purposes of analysis and illustration. To verify certified performance for this pump, refer to the manufacturers certified performance curve

Does the Pump Head Seem Reasonable?



What You Might Learn From the Pump

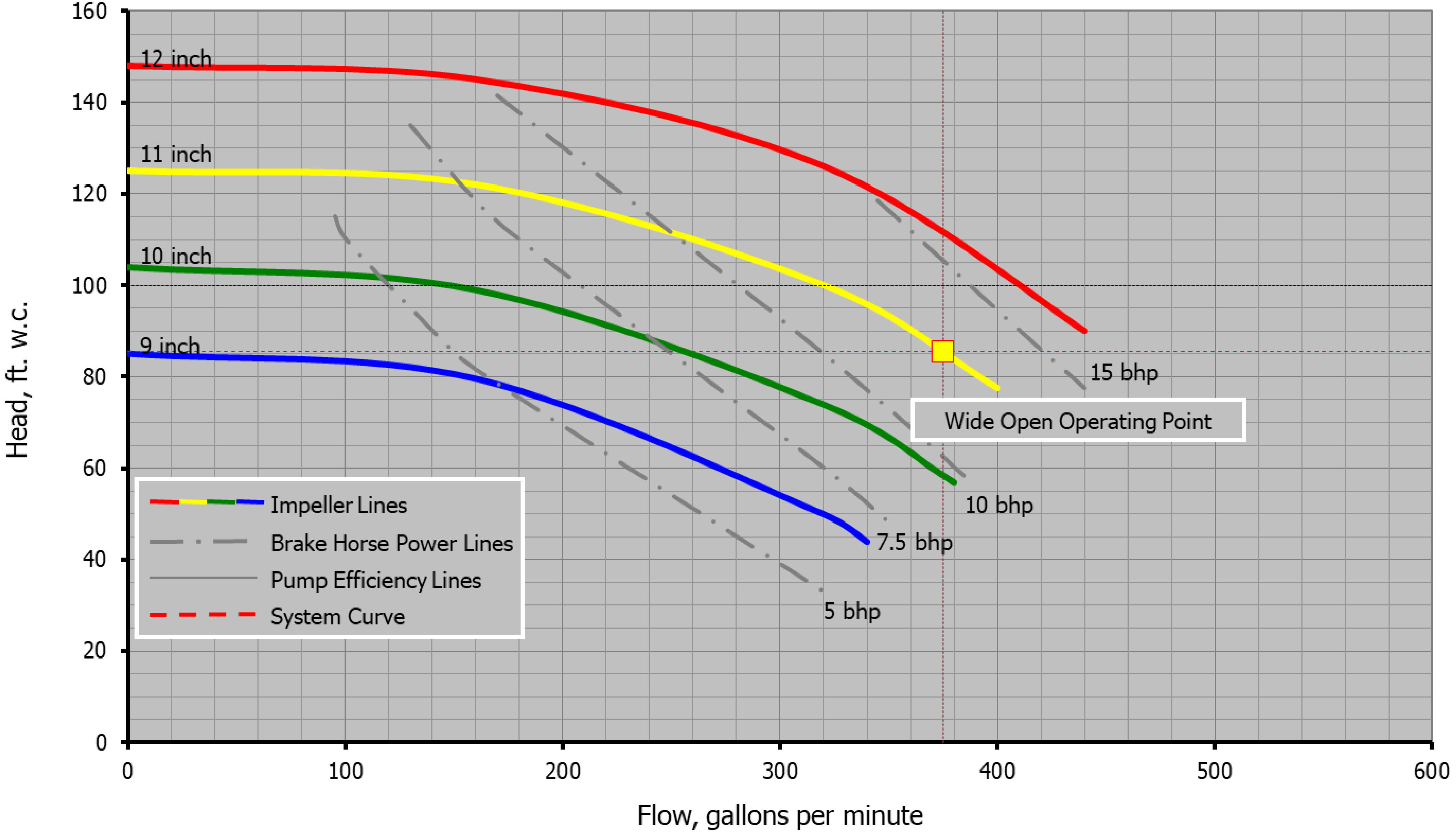


Pump Test Results

- 11 inch impeller
- Wide open head – 84 – 86 ft.w.c.
- Flow (from pump curve) – 375 - 380 gpm
- Design Flow – 320 gpm

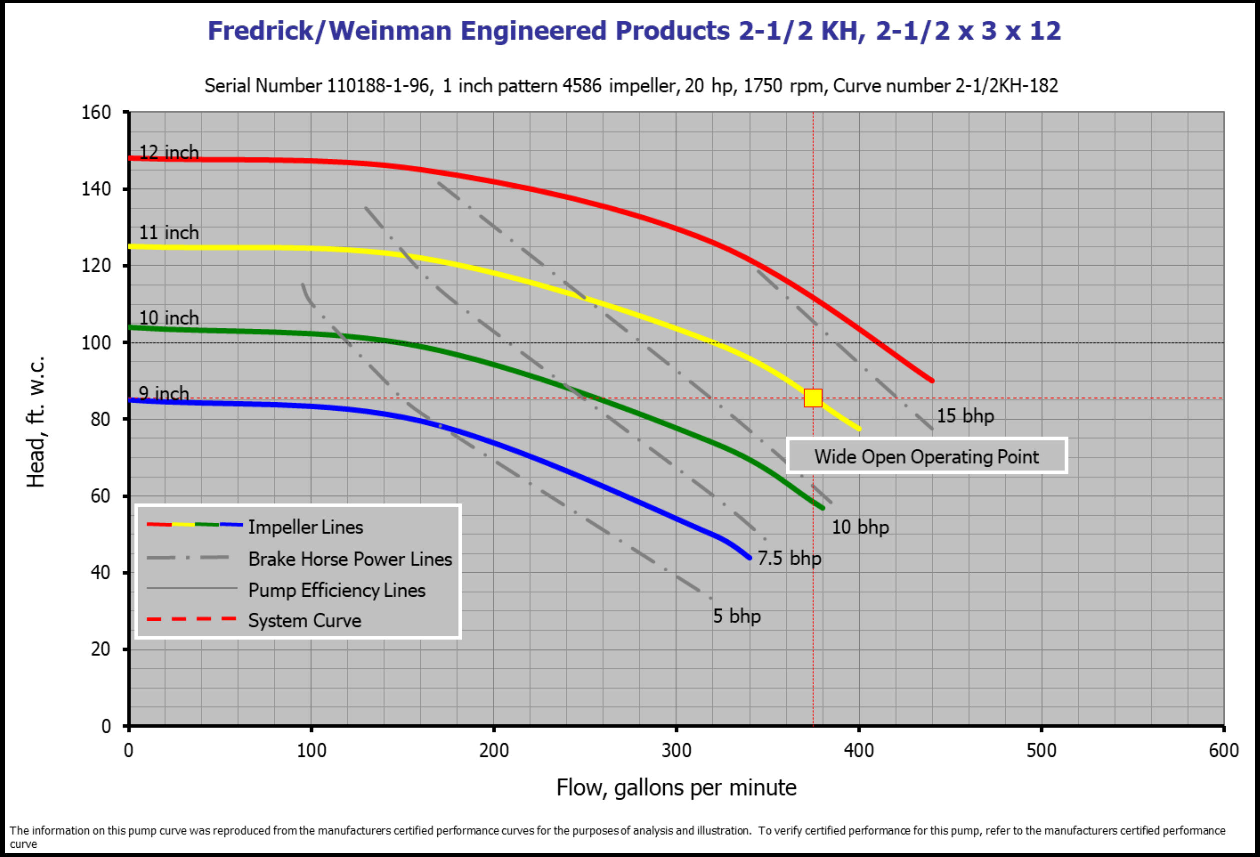
Fredrick/Weinman Engineered Products 2-1/2 KH, 2-1/2 x 3 x 12

Serial Number 110188-1-96, 1 inch pattern 4586 impeller, 20 hp, 1750 rpm, Curve number 2-1/2KH-182



What Did You Learn?

https://tinyurl.com/HeatPumpD4PumpTest



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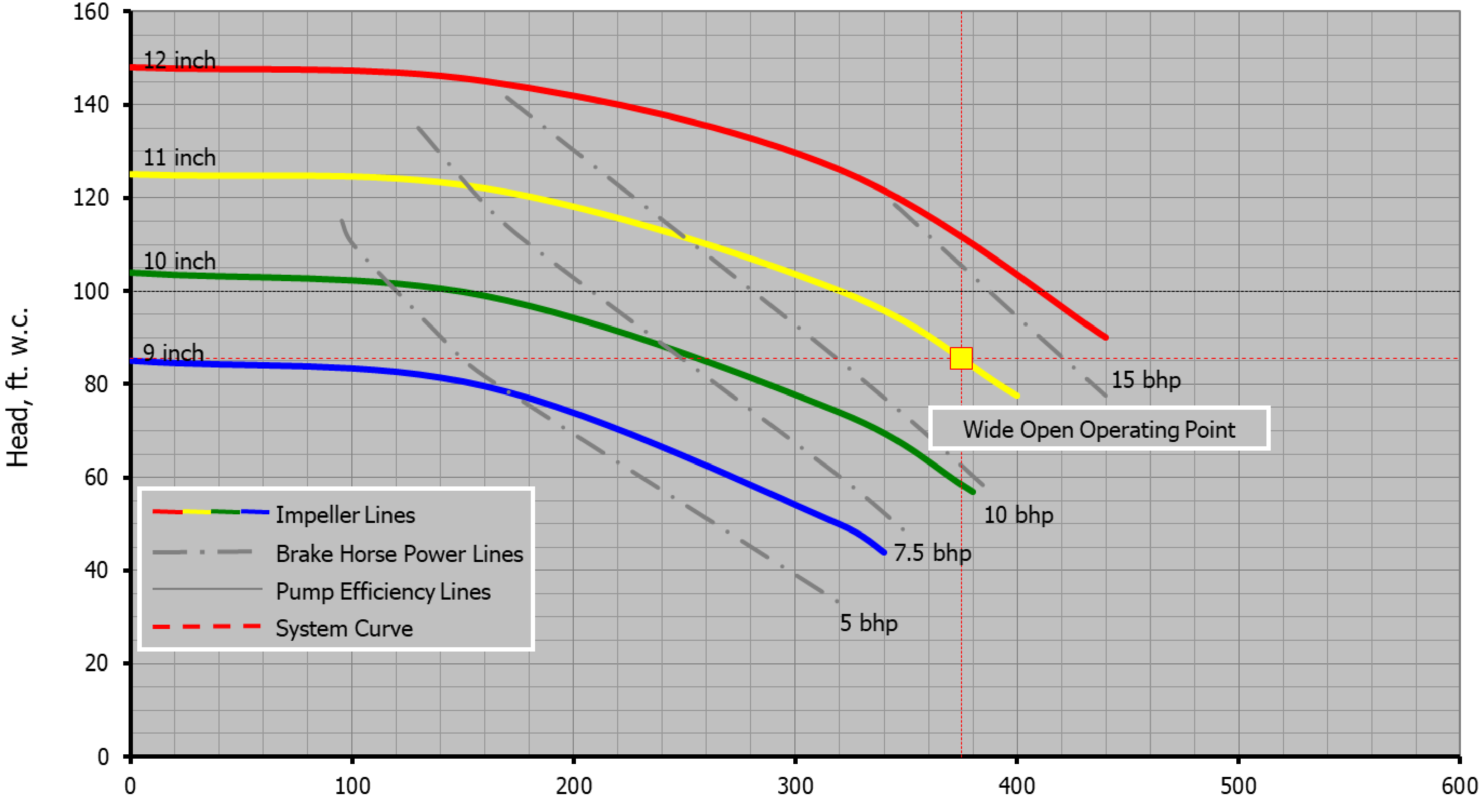

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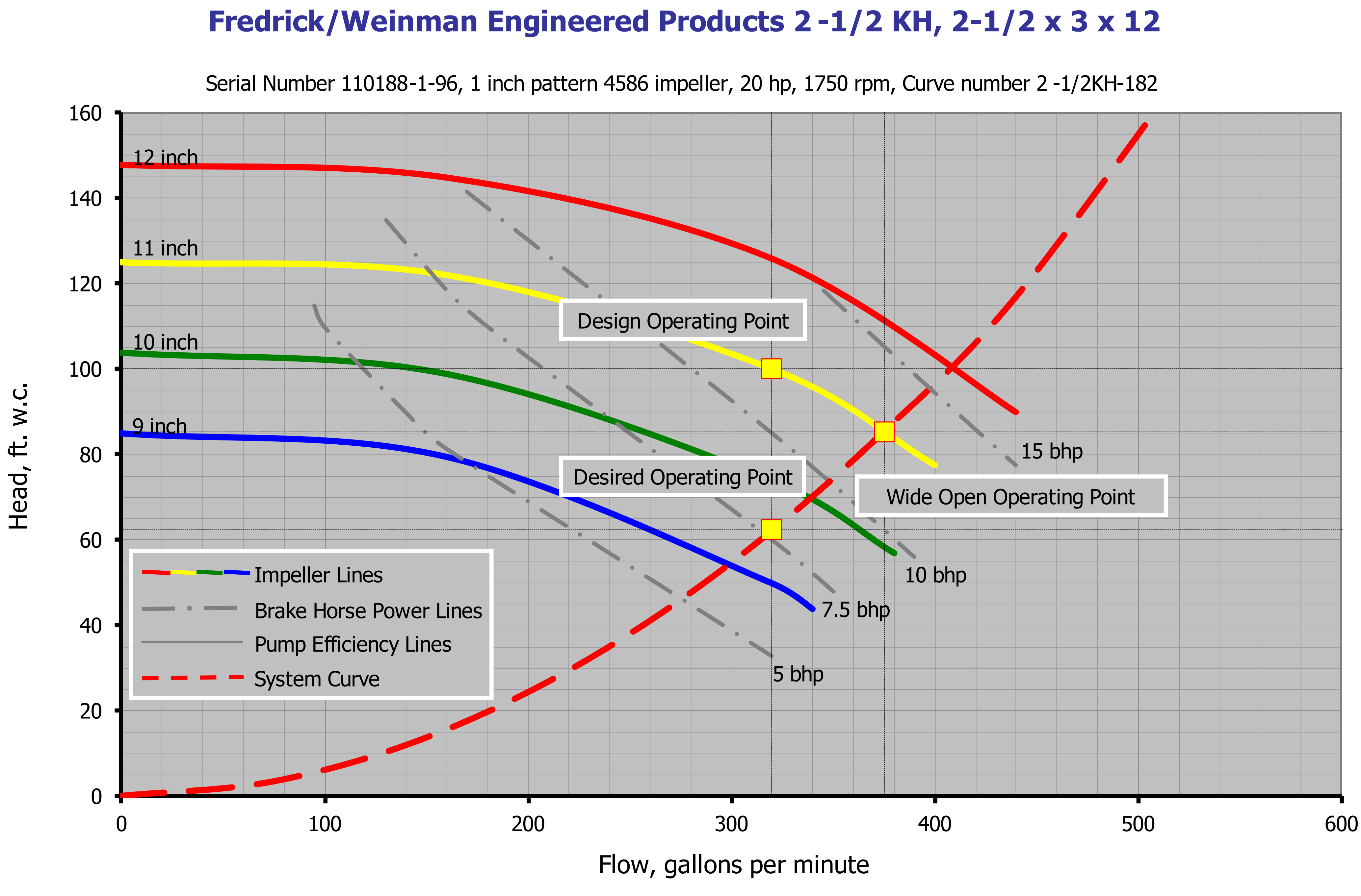
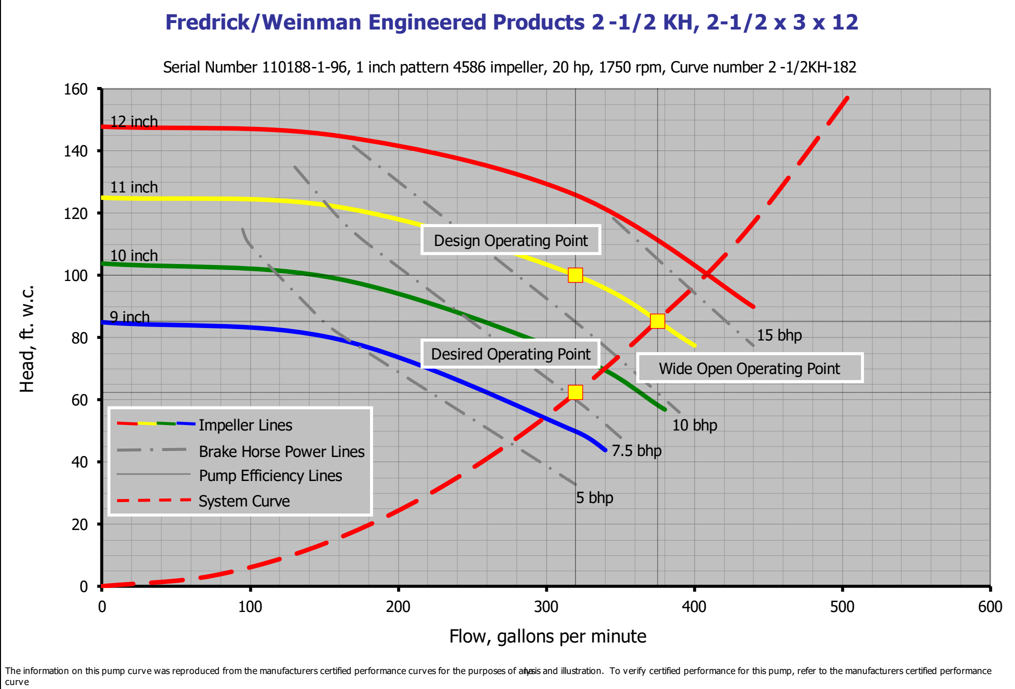
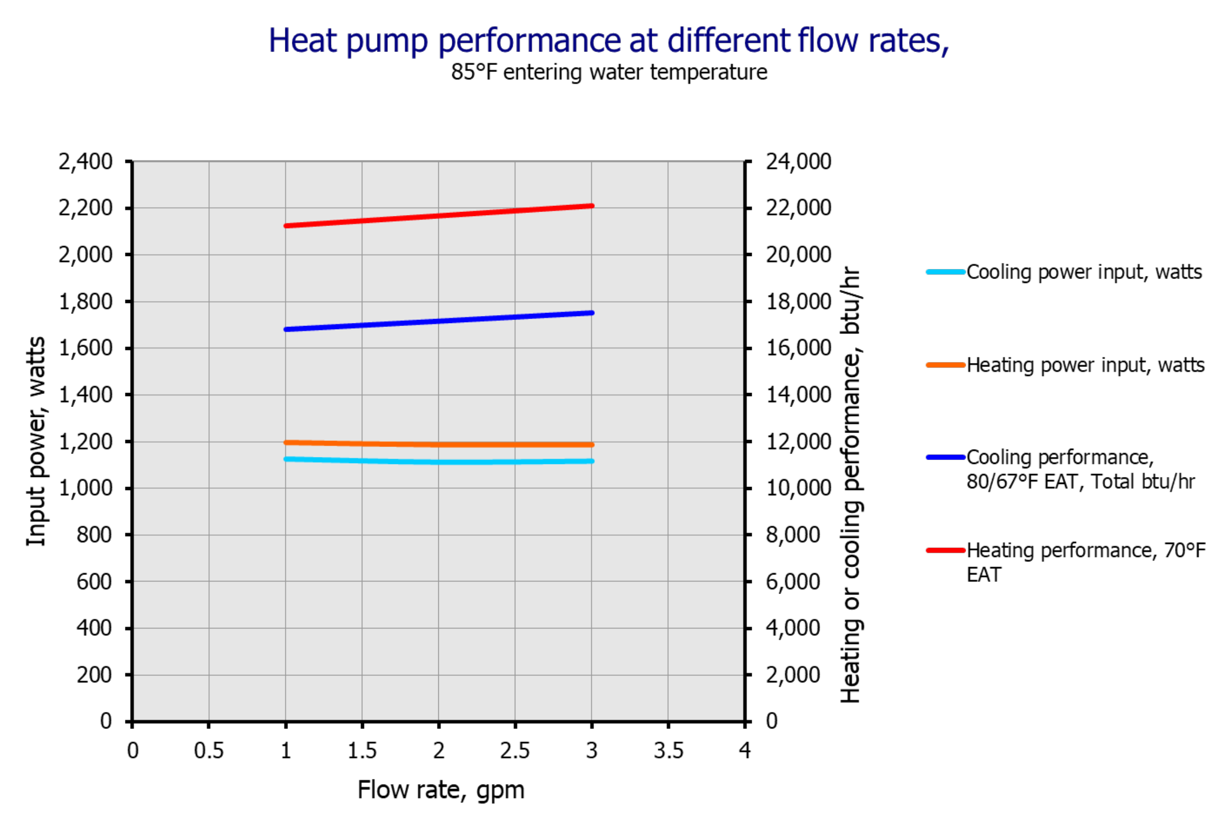


The information on this pump curve was reproduced from the manufacturers certified performance curves for the purposes of analysis and illustration. To verify certified performance for this pump, refer to the manufacturers certified performance curve

Considering Heat Pump Interactions

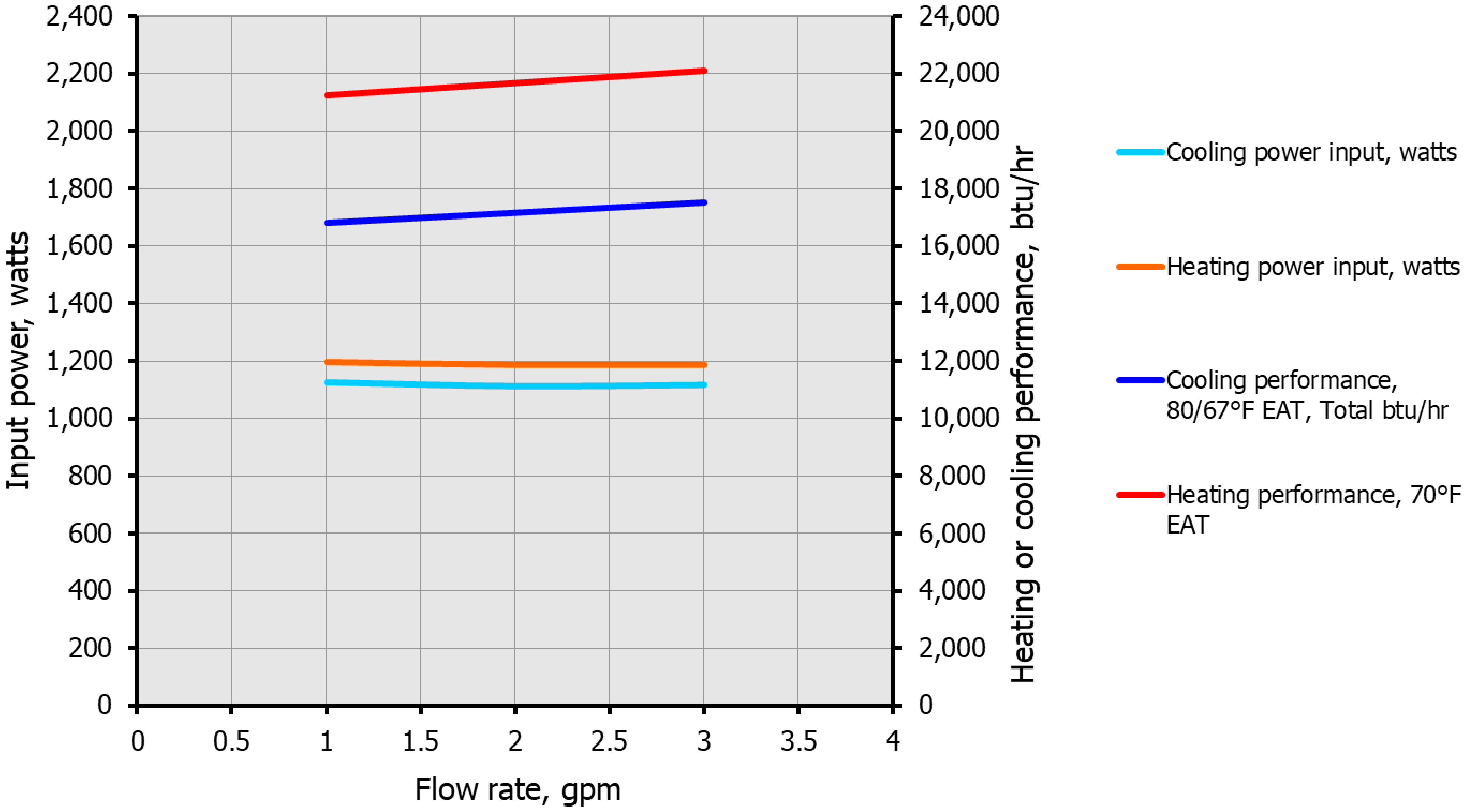
Heat pump performance can be impacted by the flows and temperatures in the system



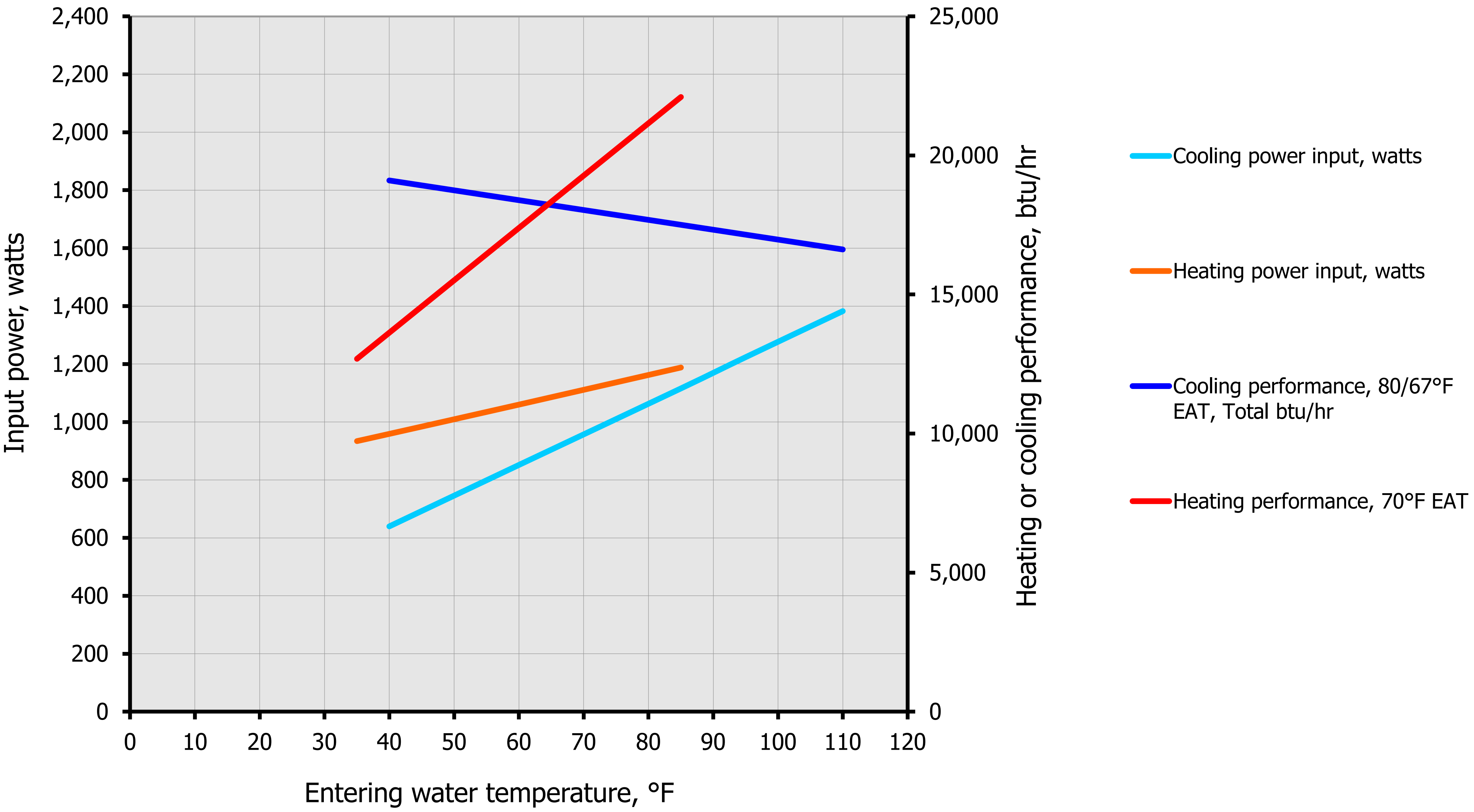


Heat pump performance at different flow rates,

85°F entering water temperature



Heat pump performand at different entering water temperatures, 3 gpm flow rate



Bottom Lines

Findings Summary Table		$0.10	per kWh	$0.78	per therm					
Item	Finding	Annual Electricity Savings		Annual Gas Savings		Total Annual Savings	Implementation Costs	Simple Payback	Recommended (Yes/No)	Note Reference
		kWh	$	Therms	$	$	$	Years		
Guest Housing Heat Pump Loops										
1	GHL4 - Potential to vary loop flow rate	41,540	$4,154	0	$0	$4,154	$22,704	5.5	Yes	Note 2
2	GHL2 - Cycle cooling tower pump as 1st stage	0	$0	0	$0	$0	$0	0.0	N/A	Note 1
3	GHL8 - Bypassing Flow around Heat Exchang	0	$0	0	$0	$0	$0	0.0	No	
4	GHL5 - Trim Cooling Tower Pump	40,396	$4,040	0	$0	$4,040	$9,000	2.2	Yes	
5	GHL1, GHL3 - Optimize closed loop	277,192	$27,719	48,094	$37,513	$65,232	$140,199	2.1	Yes	
Total for Guest Housing Heat Pump Loops		**359,127**	**$35,913**	**48,094**	**37,513**	**$73,426**	**$171,903**	**2.3**		
Notes	1. This finding has already been implemented by the operating staff									
	2 The simple payback for this finding could be as low as 4 years. The energy savings is a conservative estimate.									
	3 Further investigation is needed to estimate beneifts and cost for this measure.									
	4 Energy savings possible is a conservative estimate. The actual savings could be double from the amount listed									

Bottom Lines

Note that none of the savings opportunities are directly related to the heat pumps!

Findings Summary Table — $0.10 per kWh, $0.78 per therm

Item	Finding	Annual Electricity Savings		Annual Gas Savings		Total Annual Savings	Implementation Costs	Simple Payback	Recommended (Yes/No)	Note Reference
		kWh	$	Therms	$	$	$	Years		
Guest Housing Heat Pump Loops										
1	GHL4 - Potential to vary loop flow rate	41,540	$4,154	0	$0	$4,154	$22,704	5.5	Yes	Note 2
2	GHL2 - Cycle cooling tower pump as 1st stag	0	$0	0	$0	$0	$0	0.0	N/A	Note 1
3	GHL8 - Bypassing Flow around Heat Exchang	0	$0	0	$0	$0	$0	0.0	No	
4	GHL5 - Trim Cooling Tower Pump	40,396	$4,040	0	$0	$4,040	$9,000	2.2	Yes	
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Total for Guest Housing Heat Pump Loops		**359,127**	**$35,913**	**48,094**	**37,513**	**$73,426**	**$171,903**	**2.3**		

Notes
1. This finding has already been implemented by the operating staff
2. The simple payback for this finding could be as low as 4 years. The energy savings is a conservative estimate.
3. Further investigation is needed to estimate beneifts and cost for this measure.
4. Energy savings possible is a conservative estimate. The actual savings could be double from the amount listed

VRF Systems (Again)

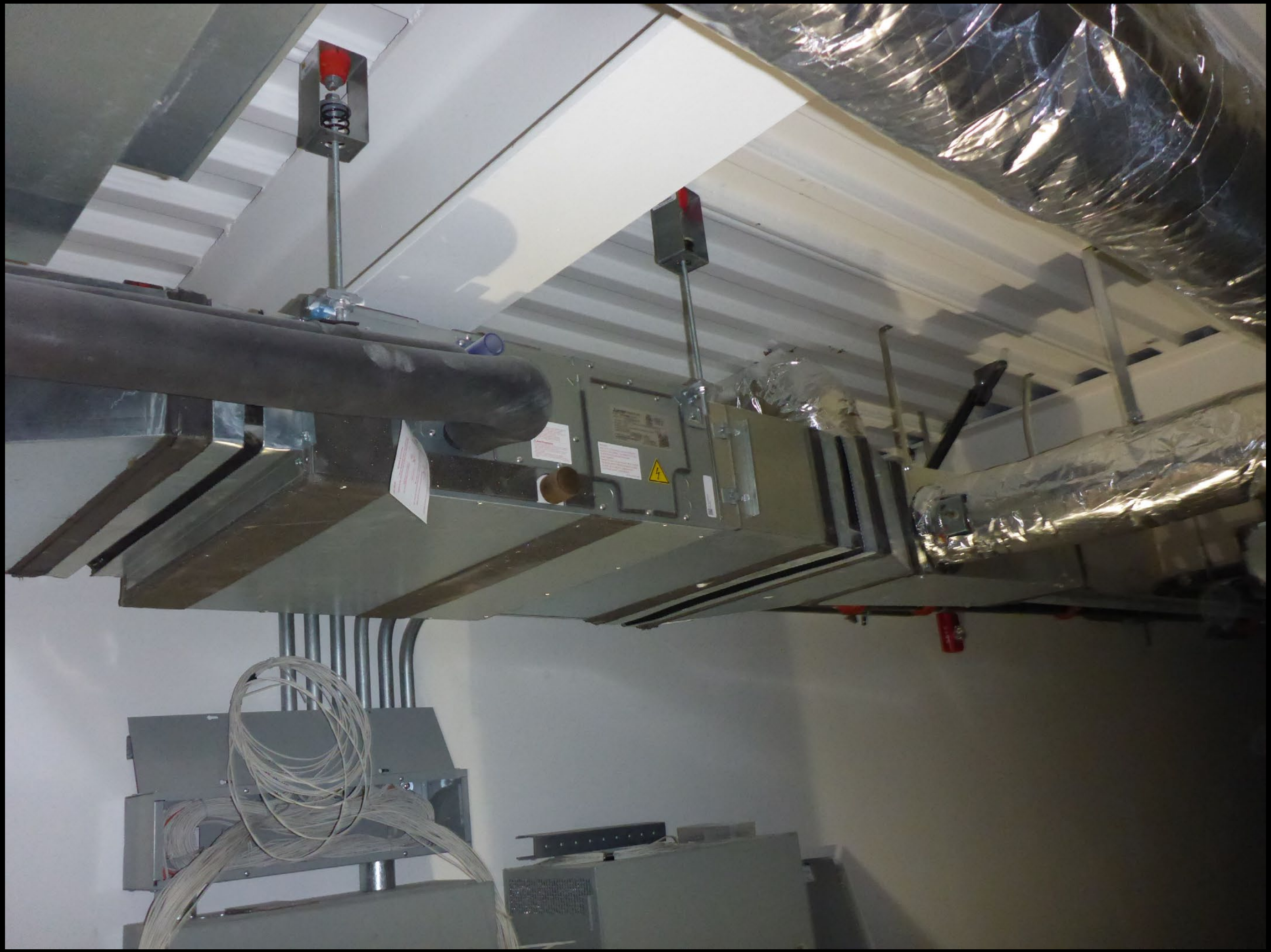
Variable Refrigerant Flow Systems (VRF)

- Complex!
- Move heat by using refrigerant instead of using water

https://tinyurl.com/VRFAnnimation

Variable Refrigerant Flow Systems

- Key components
  - Indoor unit



Variable Refrigerant Flow Systems

- Key components
  - Indoor unit

Variable Refrigerant Flow Systems

- Key components
  - Indoor unit
  - Outdoor unit

Variable Refrigerant Flow Systems

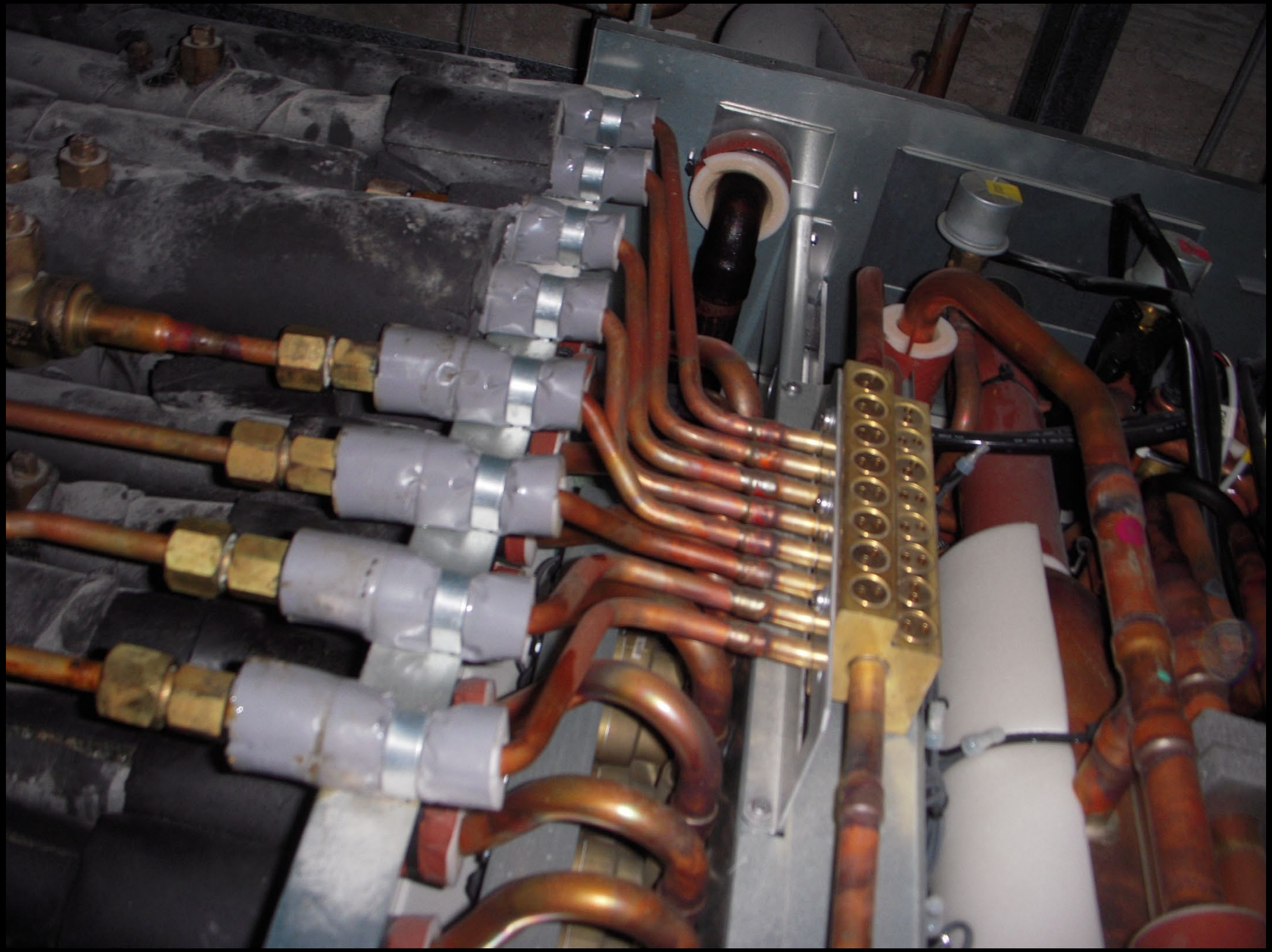
- Key components
  - Indoor unit
  - Outdoor unit
  - Branch Controller

Variable Refrigerant Flow Systems

- Key components
  - Indoor unit
  - Outdoor unit
  - Branch Controller

Variable Refrigerant Flow Systems

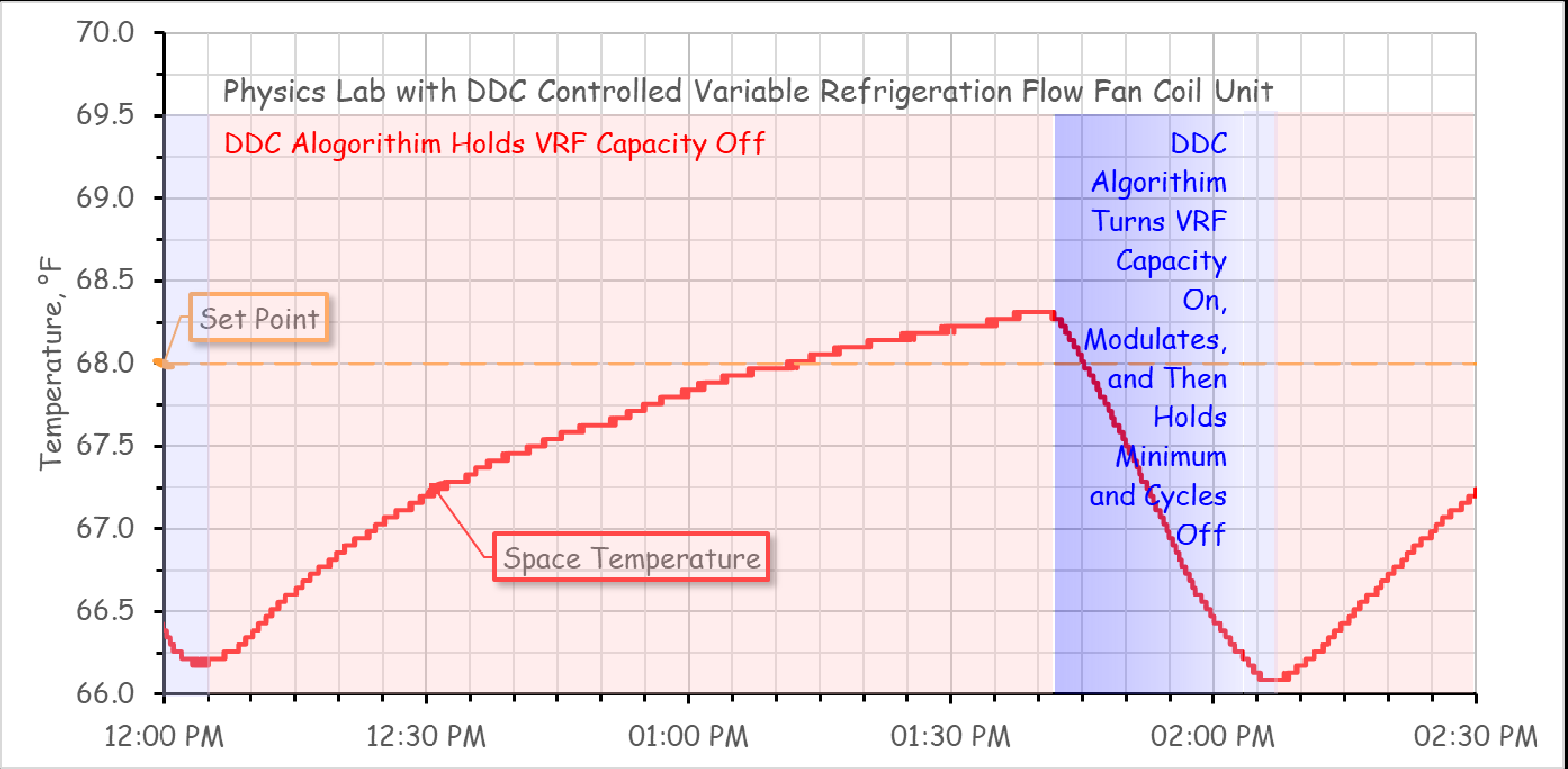
- Key components
  - Indoor unit
  - Outdoor unit
  - Branch Controller



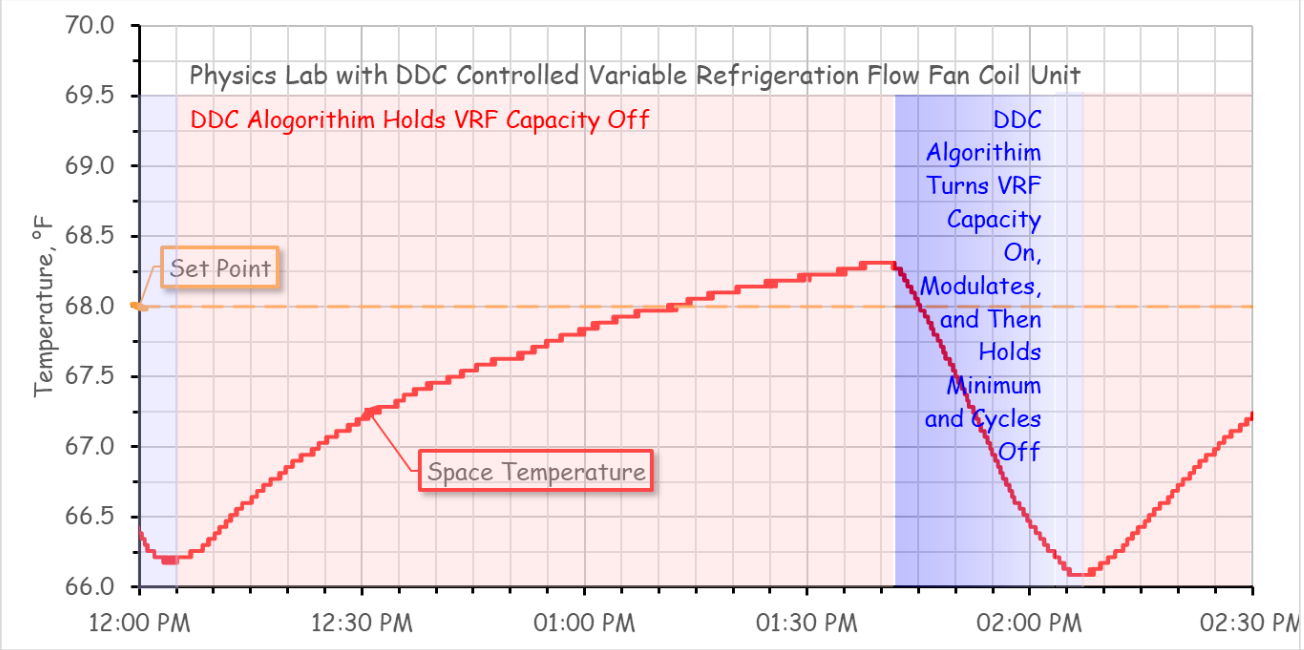
Variable Refrigerant Flow Systems

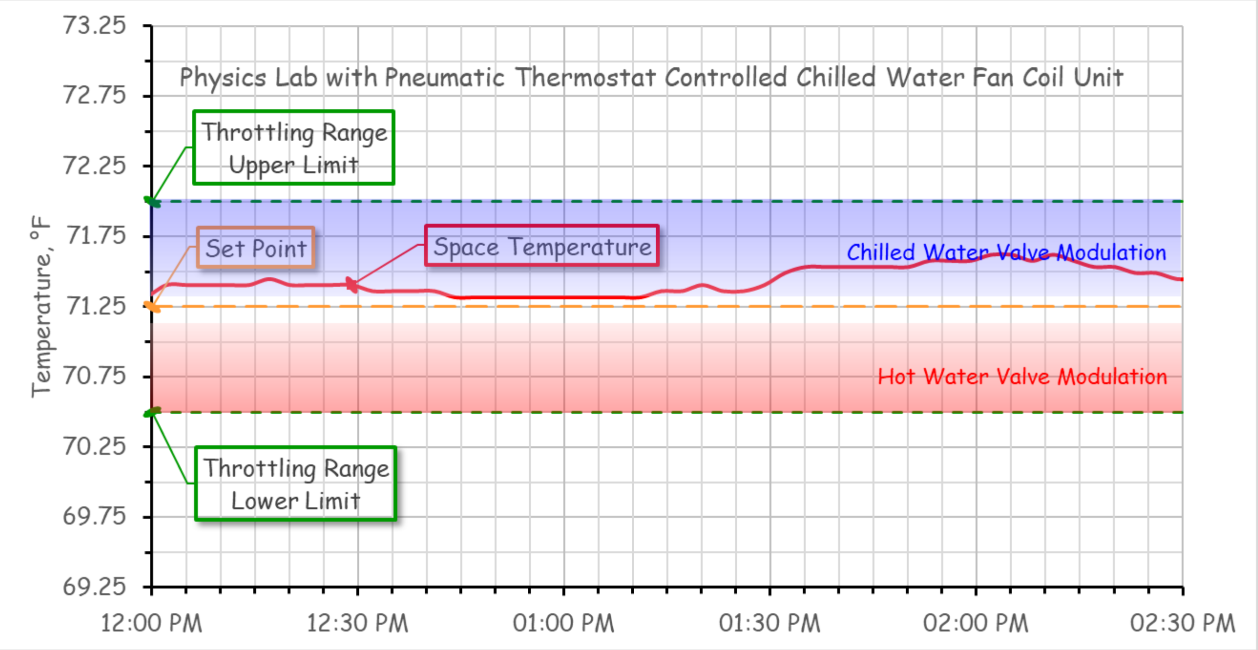
- Key components
  - Indoor unit
  - Outdoor unit
  - Branch Controller
  - Control System
    - Proprietary
    - Limited BACnet integration options
    - Maintenance tool is highly desirable option

Turn-Down Limitations



Turn-Down Limitations





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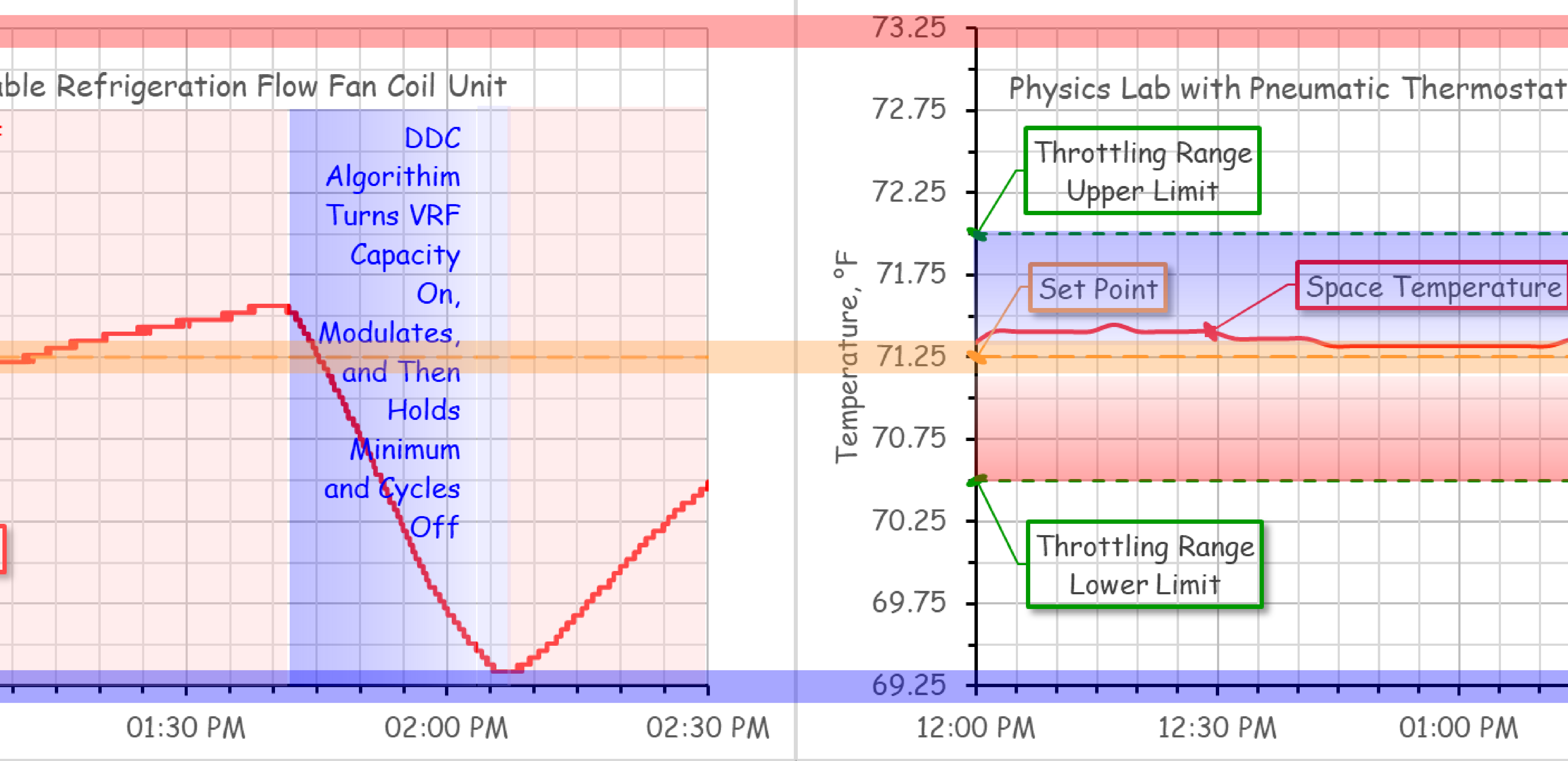

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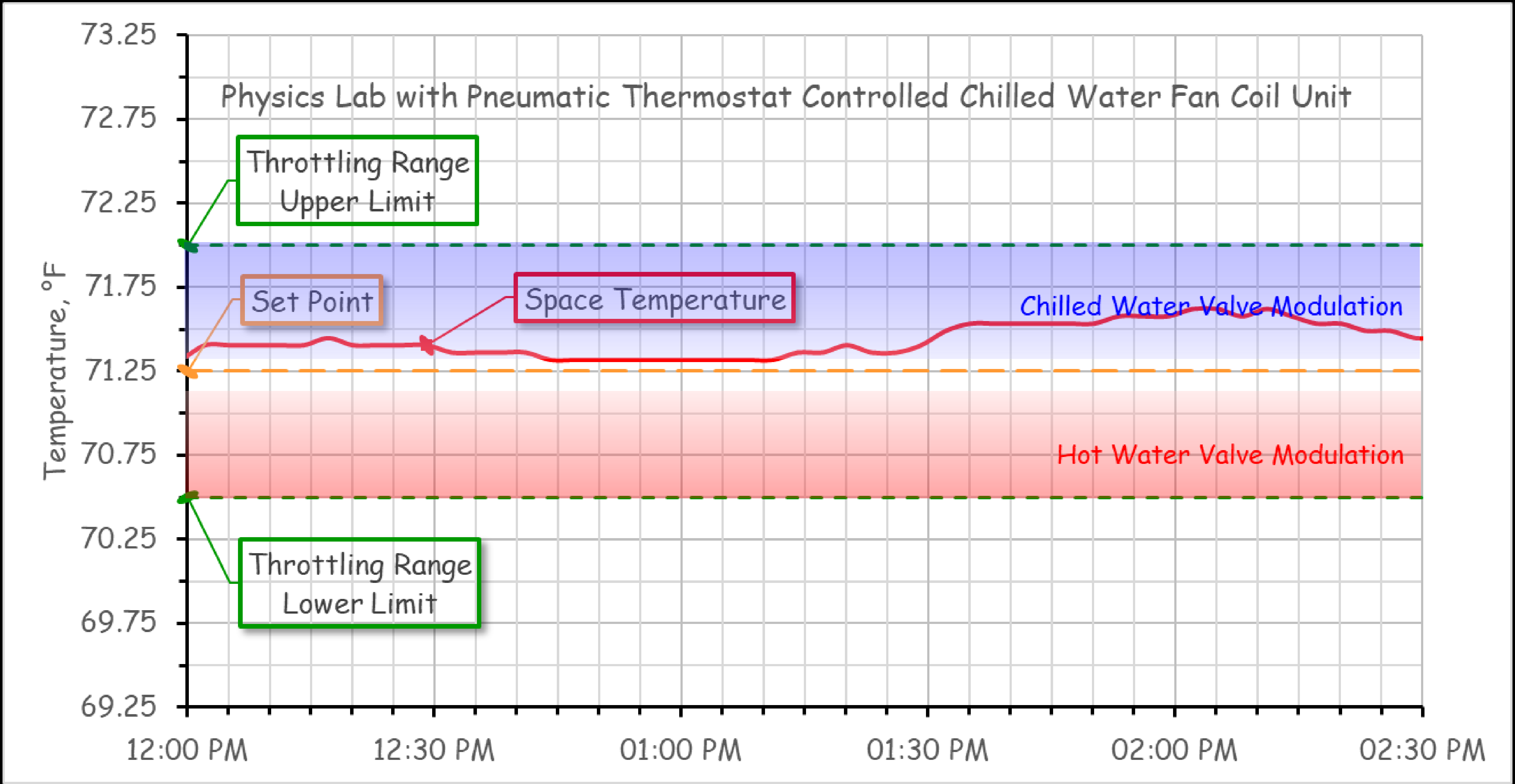
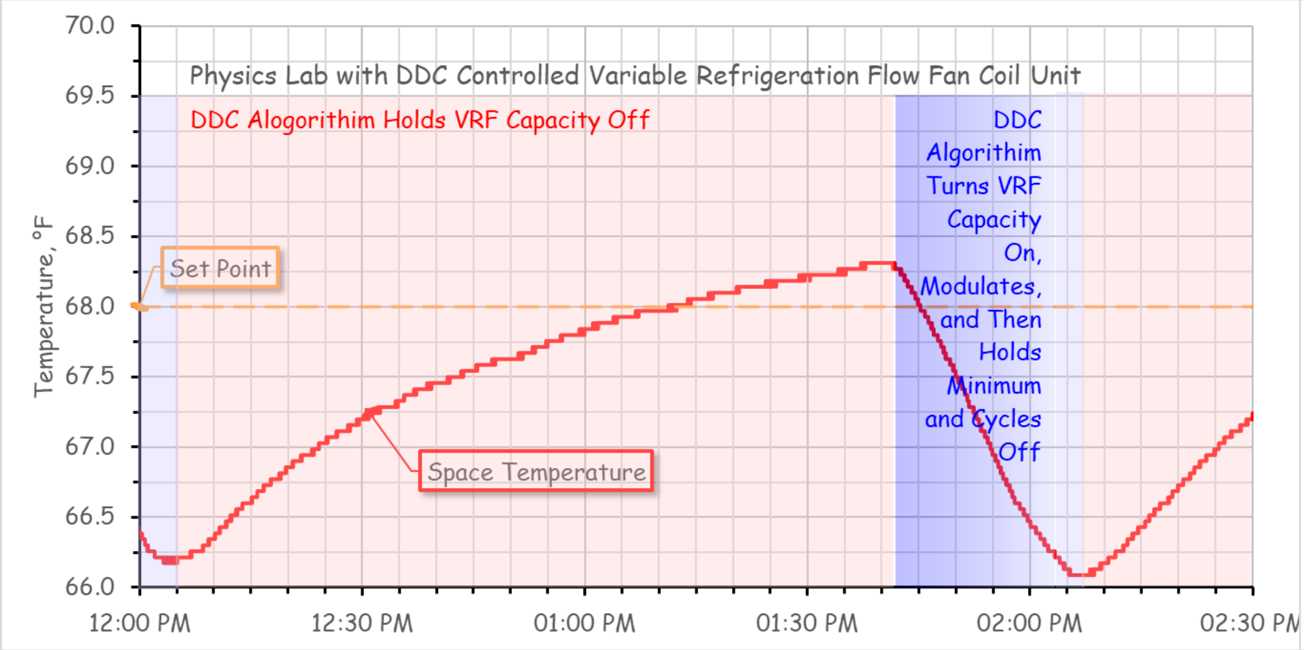
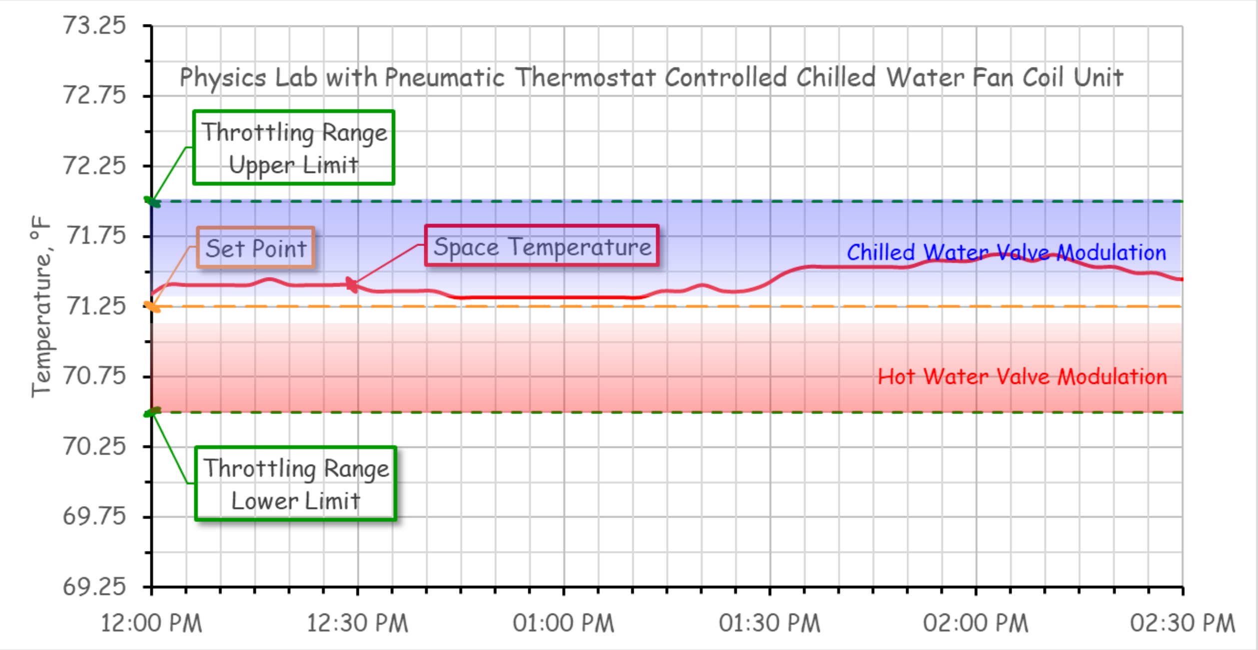
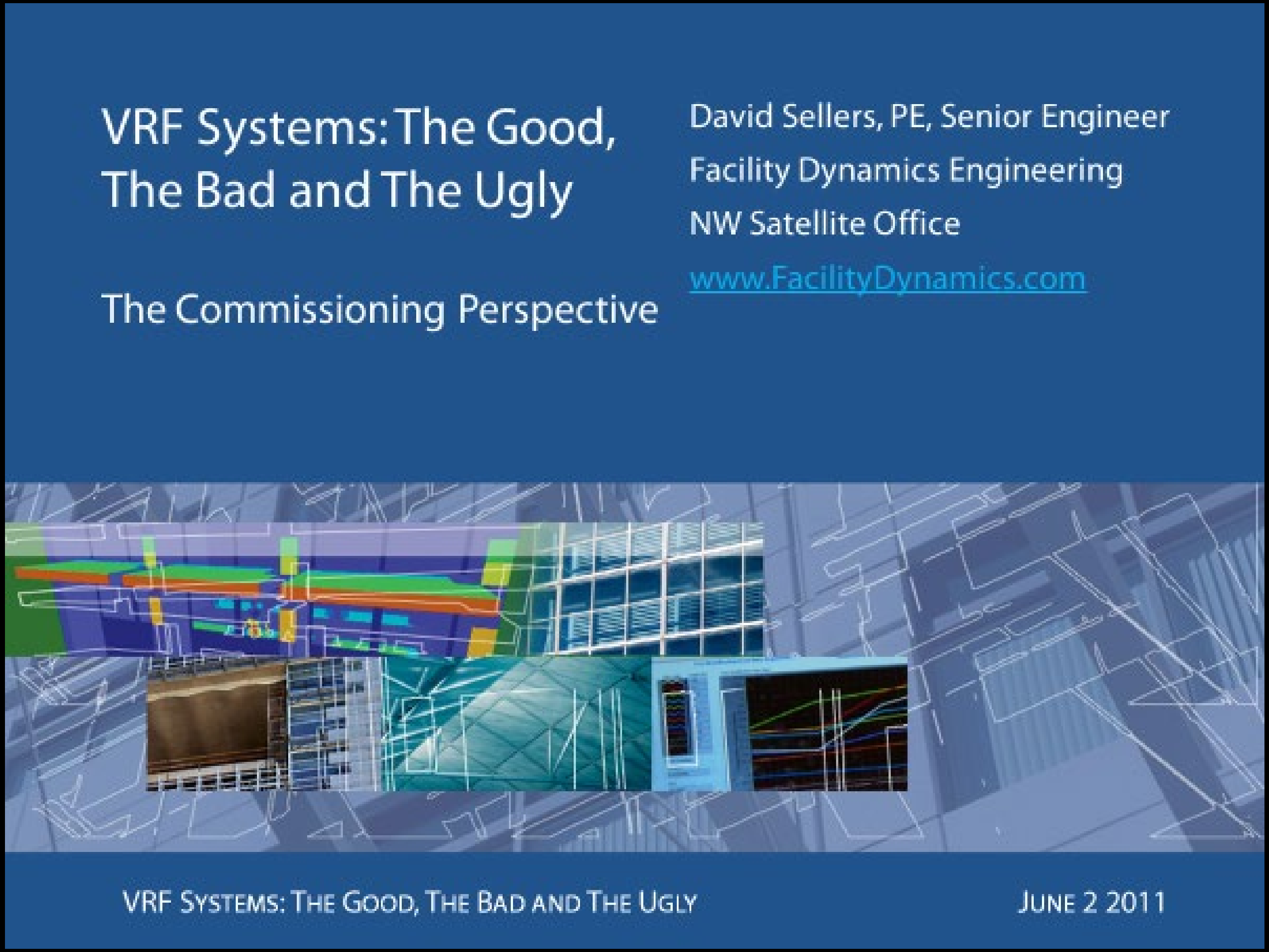


Turn-Down Limitations





VRF Systems



https://tinyurl.com/VRFMemo

VRF Systems

Taking a closer look at the details

Variable Flow Refrigeration (VRF) Systems Sequence of Operation

Overview

The VRF systems associated with this project operate using a proprietary digital control system that manages the interactions of the indoor units serving the occupied zones with the branch controllers and outdoor units serving the system.

The system is served by:

- Two OutDoor Units (ODU) that can serve as conventional condensers to reject heat to the ambient environment or near-conventional heat pumps to extract heat from the ambient environment, and
- Three Branch Controllers (BC) to manage and direct the flow of refrigerant between
- Twenty-five InDoor Units (IDUs) with contain coils that function as evaporators for a cooling cycle and condensers for a heating cycle.

Note that the ODUs are two different sizes and that each ODU contains two compressors. The ODUs are "twinned" which generally means they are piped in parallel and will operate as a unit with the Mitsubishi controllers using one as the master unit and the other as the slave unit, staging the compressors based on the operating mode and requirements of the system to optimize performance and efficiency.

This system configuration will allow:

1. Refrigerant to be sent to the outdoor units operating as conventional condensing units to reject heat if there is a net cooling requirement on the system, or
2. Refrigerant to be sent to the outdoor units operating as heat pumps to capture heat from the outdoors if there is a net heating requirement on the system, or
3. Refrigerant to be redirected from zone to zone for the purposes of heat recovery.

The system diagrams/operating diagrams used in the following section can be viewed as a narrated animation by downloading the Mitsubishi City Multi Refrigerant Flow Animation Application at www.mylinkdrive.com.

Full Cooling

This operating mode is virtually identical to a conventional direct expansion/vapor compression refrigeration process and is illustrated in Figure 1.

In this mode, refrigerant is evaporated in the coils in all zones to cool them. The heat is then rejected in the coils at the ODU which causes the refrigerant to condense.

In this operating mode the air leaving the ODU fan will be warmer than the ambient temperature. This condition is used by the control system as an indication that the ODU is in the cooling mode.

Full Heating

This operating mode is virtually identical to a conventional direct expansion/vapor compression process applied in a heat pump and is illustrated in Figure 2, although the coils in the condenser can see a liquid vapor mix entering them whereas heat pumps often receive only liquid refrigerant and the outdoor coil.

In this mode, refrigerant is condensed in the coils in all zones to heat them. Then, the refrigerant is evaporated in the coils at the ODU, which causes it to pick up heat from the ambient environment for use in heating the indoor zones.

In this operating mode the air leaving the ODU fan will be cooler than the ambient temperature. This condition is used by the control system as an indication that the ODU is in the heating mode.

Heat Recovery

There are three general operating states associated with the VRF system performing heat recovery.

Balanced System

This operating mode is illustrated in Figure 3.

In this operating mode, energy is transferred from the zones that require cooling to the zones that require heating with no heat being rejected or picked up at the coils in the ODU. This is the lowest energy state for the system because no ODU fan operation is require and because the refrigerant moving through the system does double duty by first passing through the coils where cooling is required and picking up energy and then moving to the coils where heating is required and giving that energy back up.

In this operating mode, the compressor operates but the ODU fan does not operate. The control system uses this as an indication that the system is in a balanced state.

More Zones in Heating than Cooling

This operating mode is illustrated in Figure 4.

This operating mode allows the VRF system to concurrently provide heating and cooling with the energy extracted from the zones needing cooling providing energy to the zones that need heat. But because more heat is required than is being recovered from the zones with a cooling load, the ODU coils are configured to recover heat from the ambient environment and the ODU operates as a heat pump.

As was the case for the full heating mode, the ODU coil receives a mix of liquid and gaseous refrigerant, and the air leaving the ODU fan is cooler than the ambient air. The control system uses the cooler air leaving the ODU fan in combination with a mixed operating state of the VRF InDoor Unit (IDU) zones (some in heating and some in cooling) as an indication that the system is in this operating state.

More Zones in Cooling than Heating

This operating mode is illustrated in Figure 5.

This operating mode is similar to the operating mode discussed in the preceding paragraph in that it allows the VRF system to concurrently provide heating and cooling with the energy extracted from the zones needing cooling providing energy to the zones that need heat. But because the heat that needs to be rejected by the zones in cooling exceeds the amount of heat required by the zones in heating, the ODU coils receive hot gas and the ODF fan operates to .

As was the case for the full heating mode, the ODU coil receives a mix of liquid and gaseous refrigerant, and the air leaving the ODU fan is cooler than the ambient air. The control system uses the cooler air leaving the ODU fan in combination with a mixed operating state of the VRF InDoor Unit (IDU) zones (some in heating and some in cooling) as an indication that the system is in this operating state.

Proprietary Digital Control System

The various elements in the VRF system are managed by a stand-alone proprietary digital control system that is capable of providing all of the functionality necessary to operate the system, perform diagnostics, schedule equipment, and track energy consumption including providing web-based access to these features from a central location. However, since the City of Seattle is a sole source Siemens site, the Mitsubishi control system will be integrated with the Siemens control system using BACnet as well as dedicated physical points that are hardwired into the Siemens control system.

The two primary control elements of the Mitsubishi Control network are the Network Manager and the IDU Remote Controllers.

Network Manager

The Mitsubishi AE-200 controller functions as the network manager for the Mitsubishi control system. It shall be furnished and programmed by the Mitsubishi installing contractor and will be mounted by the Mechanical Instrumentation contractor in an enclosure furnished by the Mechanical Instrumentation contractor.

The Mechanical Instrumentation contractor shall also furnish and install all wiring, raceways and accessories require for a complete wiring system and shall make final terminations to the Mitsubishi equipment in coordination with the Mitsubishi Installing Contractor.

Commissioning shall be performed in conjunction with the Commissioning Provider, the Mitsubishi installing contractor and the Mechanical Instrumentation contractor with support from the design and construction team as required by the contract documents.

The AE-200 provides the following functions for this project.

- Master control functions for the network
- Operation and monitoring of the VRF equipment in the facility
- BACnet functions as required to integrate with the Siemens system
- Web browser access to allow a user with proper credentials to access the system via a web browser for monitoring, operation, energy management, and maintenance functions.

(Continued on sheet MI.8.03-2)

Figure 4 - A VRF System with a Net Heating Requirement on the System

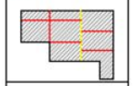
Figure 1 - A VRF System Operating in the Full Cooling Mode

Figure 2 - A VRF System Operating in Full Heating Mode

Figure 3 - A VRF System Operating in a Balanced State

Figure 5 - A VRF System with a Net Cooling Requirement on the System

KEY PLAN



SHEET TITLE
VRF System Sequence of Operation Part 1

SHEET NUMBER
MI.8.03-1

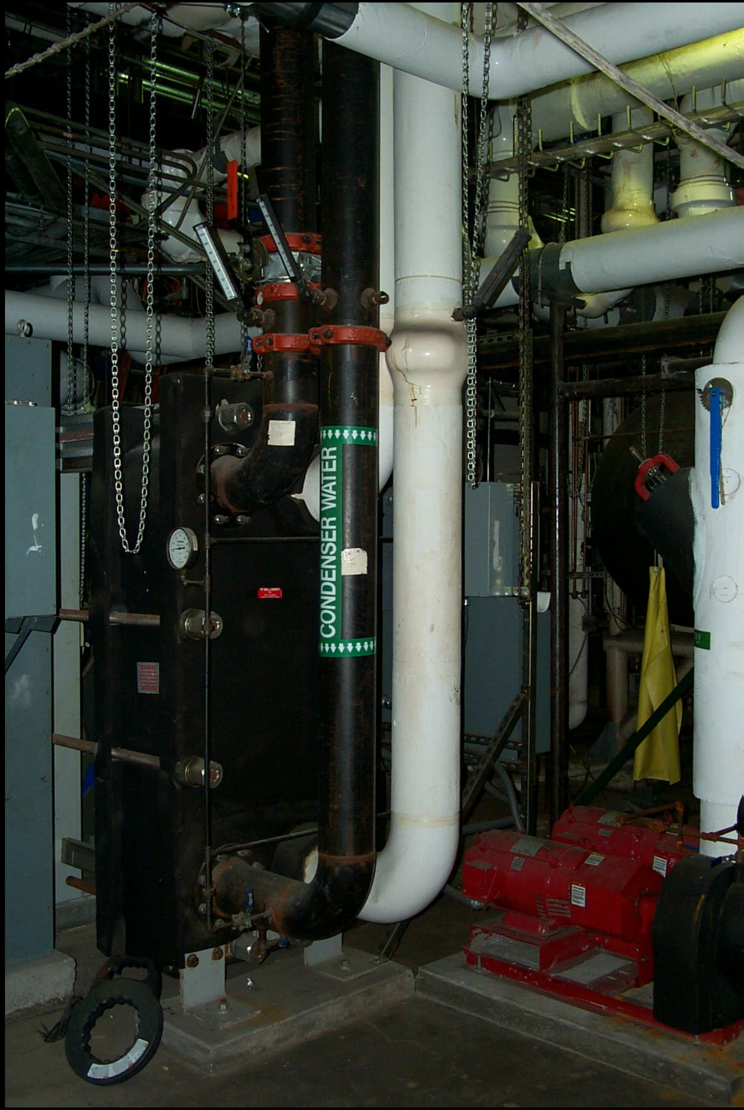
The Power of Ongoing Cx

(With Heat Pumps)

The Power of Ongoing Cx

Another Question

https://tinyurl.com/HeatPumpD4CentralPlant



Central Plant Applications

Opening the door to recovering energy we have been tossing away all of these years

Thank You

Together, Building
a Better California

Break Time

We will be back at ??:?? ?m Pacific Time

Together, Building a Better California