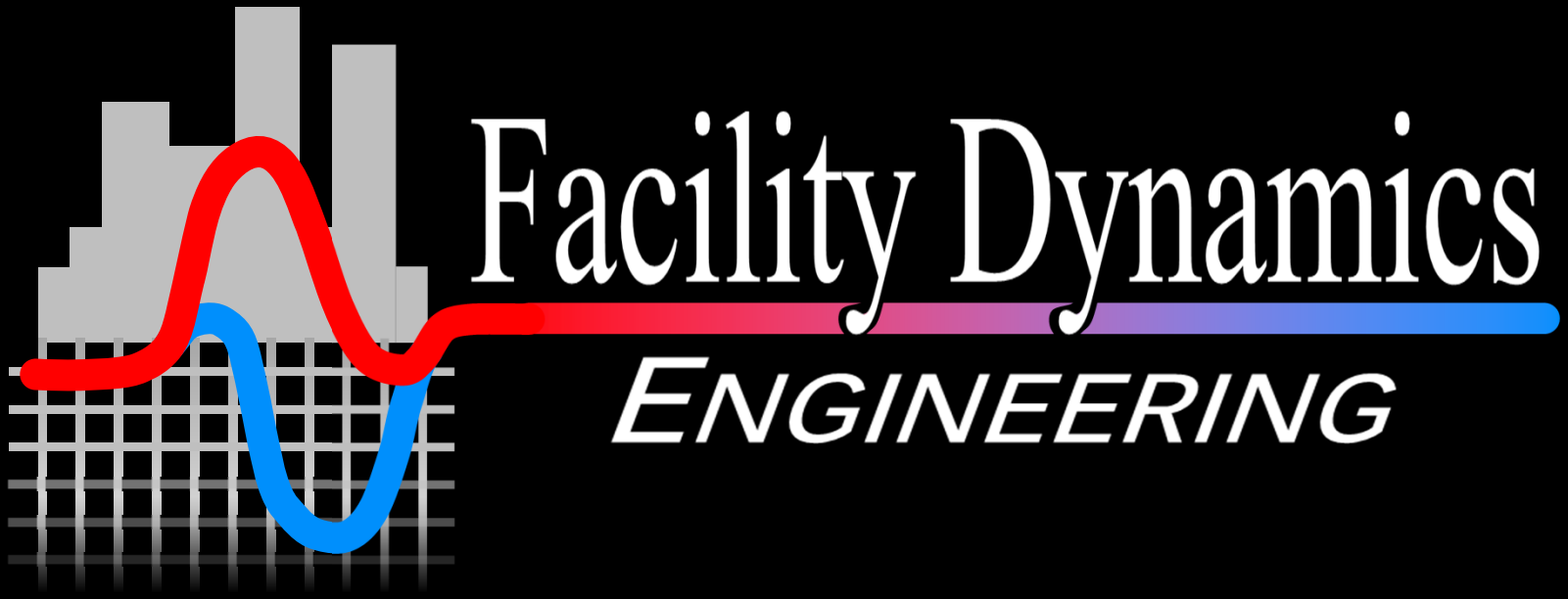


Introduction to the Controlled Systems

Load Dynamics

Presented By:

David Sellers; Facility Dynamics Engineering

Senior Engineer

NAVFAC

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

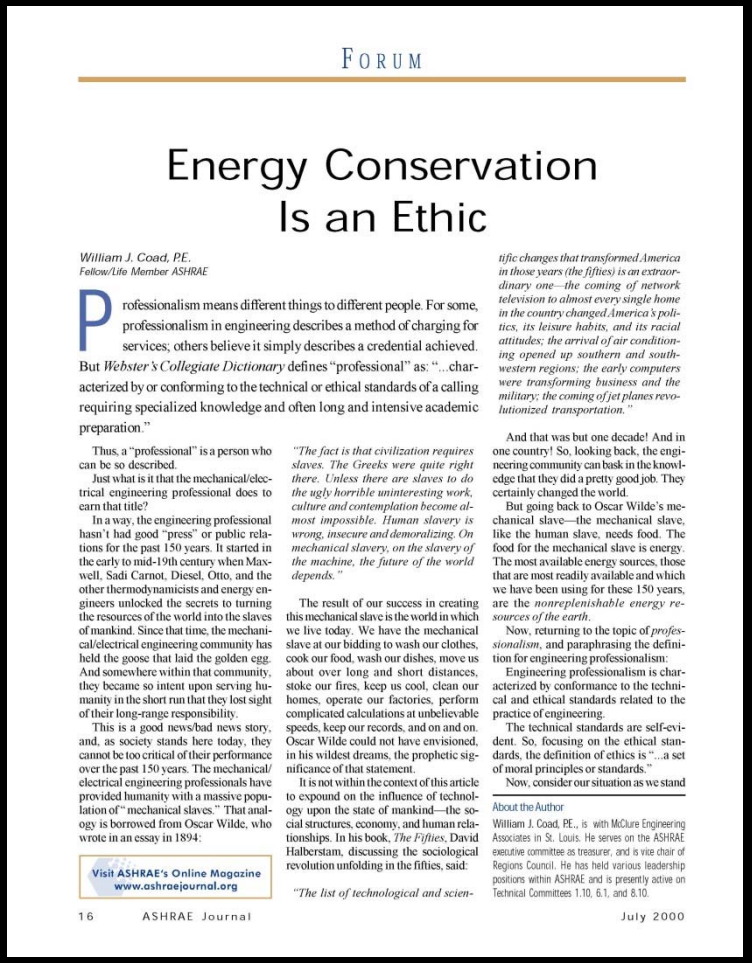
1976

- 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



FORUM

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 crash my first 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 blow up my first duct
- 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
  - HVAC system owner
  - Process exhaust system owner
  - Central chilled water plant system co-owner
  - DDC system co-owner
  - Fire protection system owner

A Bit About Me

1999 - 2005

- Semiconductor industry downturn continues
  - 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
  - Leadership role for FDE's Not-For-Profit division

What We Will Cover in This Module

Part 1

- The dynamic, interactive, nature of the loads served by HVAC systems and the challenges we face when we try to integrate them with a control system
- This is important enough that I will probably bring this up at least once ~~each day~~

Part 2

- An overview of common components in HVAC systems and a bit about their physics and performance dynamics and how those factors might relate to the design of the control system

Some Resources

The location for things I hand out or use in class

http://www.av8rdas.com/navfac.html/#NAVFAC_SE

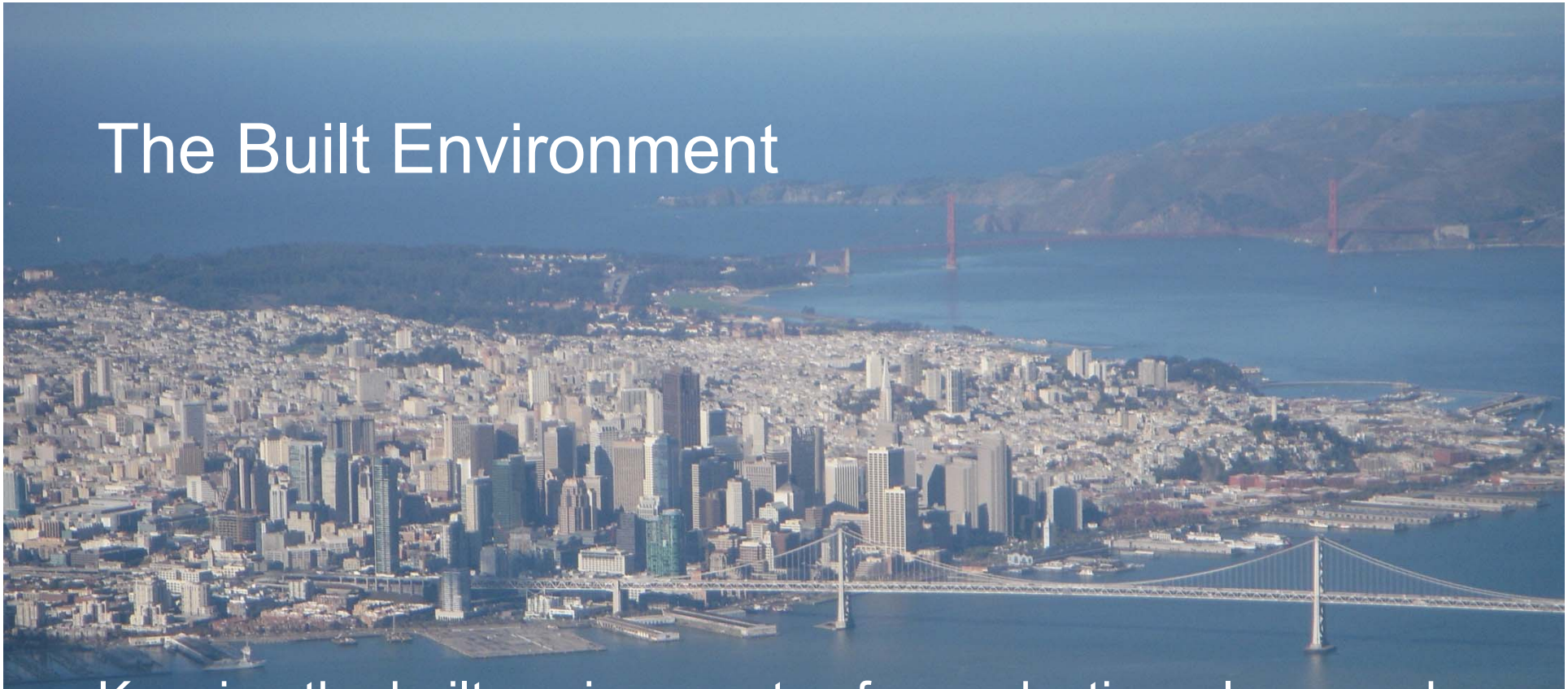
The location of my blog

www.Av8rDAS.Wordpress.com

The location of our commissioning resources web page

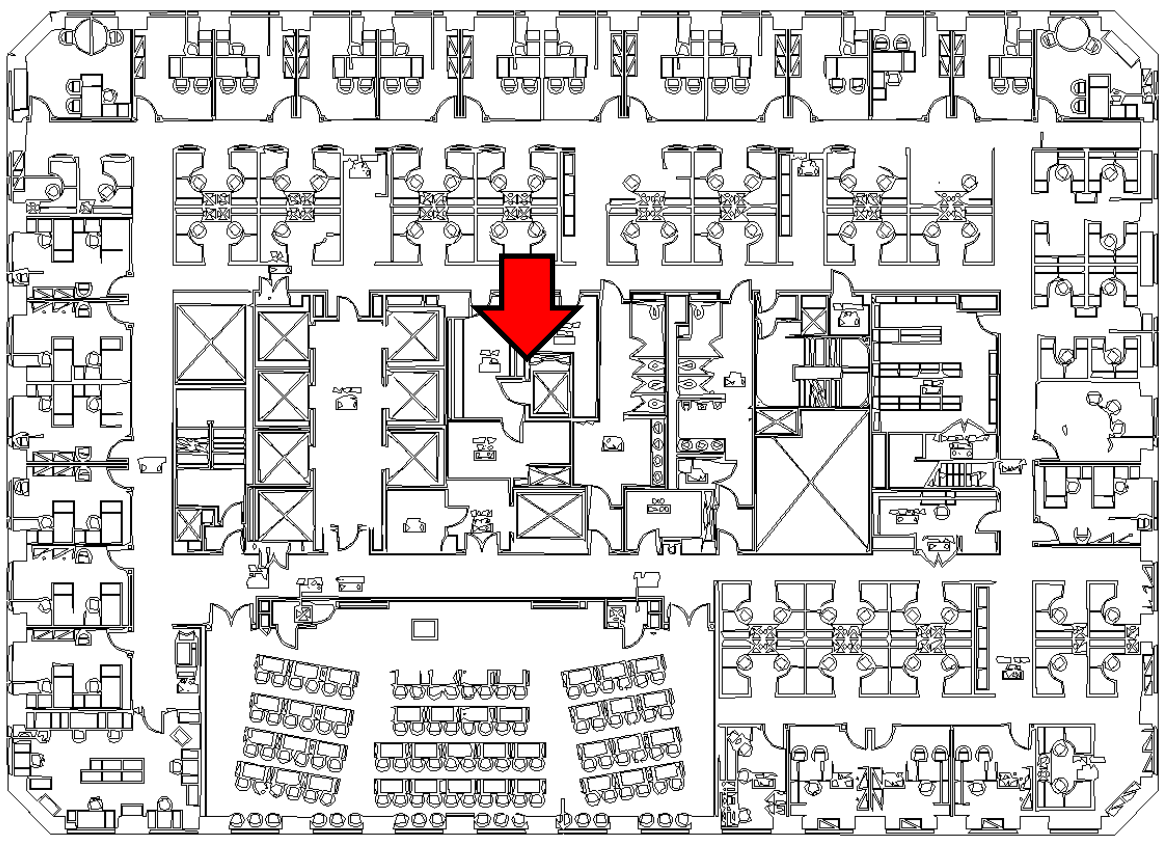
http://www.av8rdas.com/

The Built Environment



Keeping the built environment safe, productive, clean, and comfortable is a fundamental goal of HVAC systems and their controls

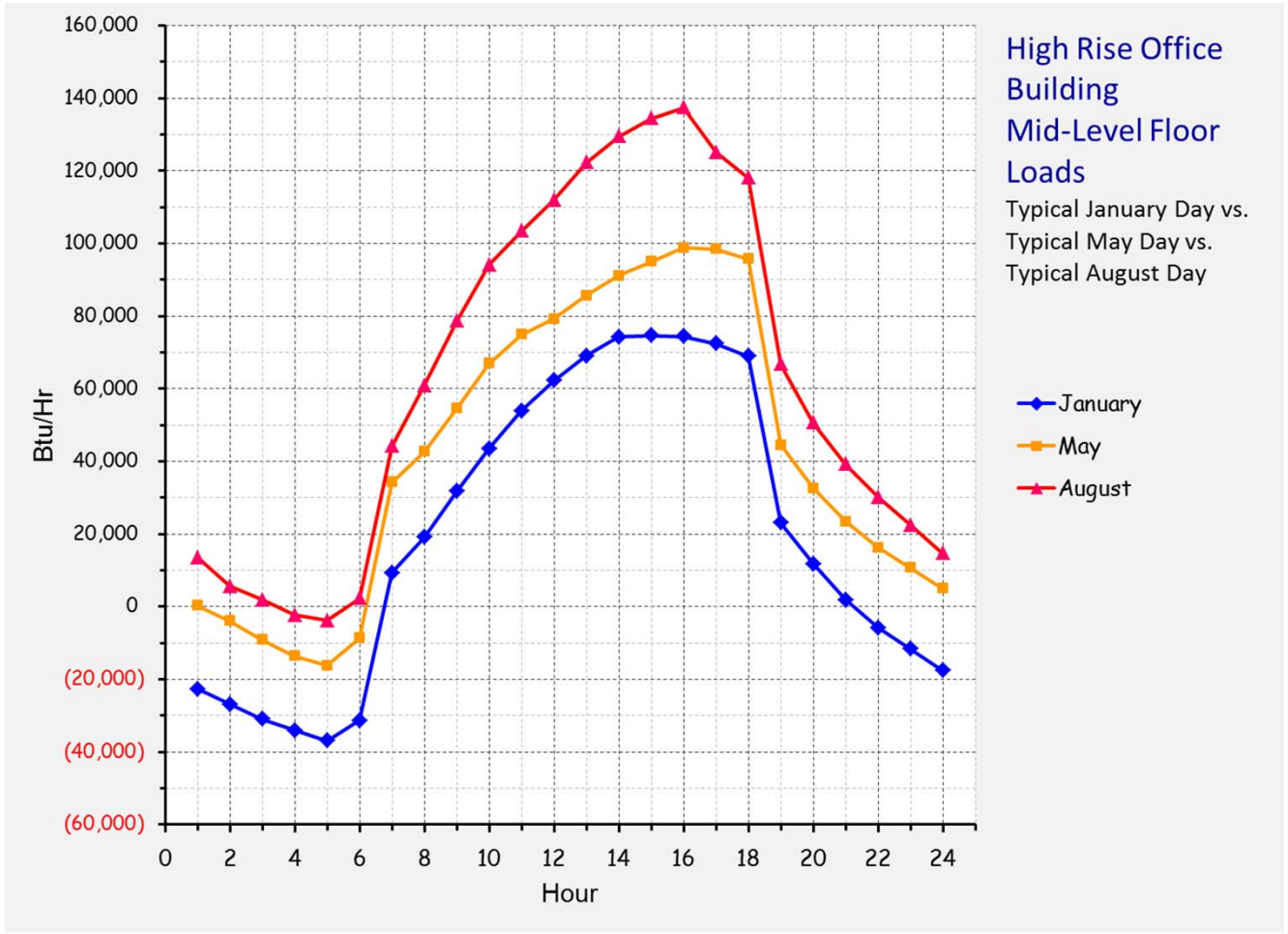
- Ventilation systems control contaminants by introducing filtered, conditioned outdoor air
- Heating and cooling systems track the loads to control comfort



uctive, clean, and
AC systems and

- Ventilation systems control contaminants by introducing filtered, conditioned outdoor air
- Heating and cooling systems track the loads to control comfort

The Loads can be Very Dynamic



The Cooling Requirements Vary with Time of Day and Time of Year

Load Dynamics

A Research Experiment by the FDE NW Research Lab

Dr. Riley Sellers; PhD CTK *LBNL CTPSC* *

Hobbes Sellers; Post Doc *Applied Chaos Theory*

* Doctorate of Philosophy - Canine Treat Kinetics - Lower Buchanan National Labs, Canine Treat Preservation Systems Center

Outside = Inside

A Research Experiment by the FDE NW Research Lab

The Experiment

- Use an environmental test chamber to assess the thermal response characteristics of different envelope configurations

Environmental Test Chamber

Outside = Inside

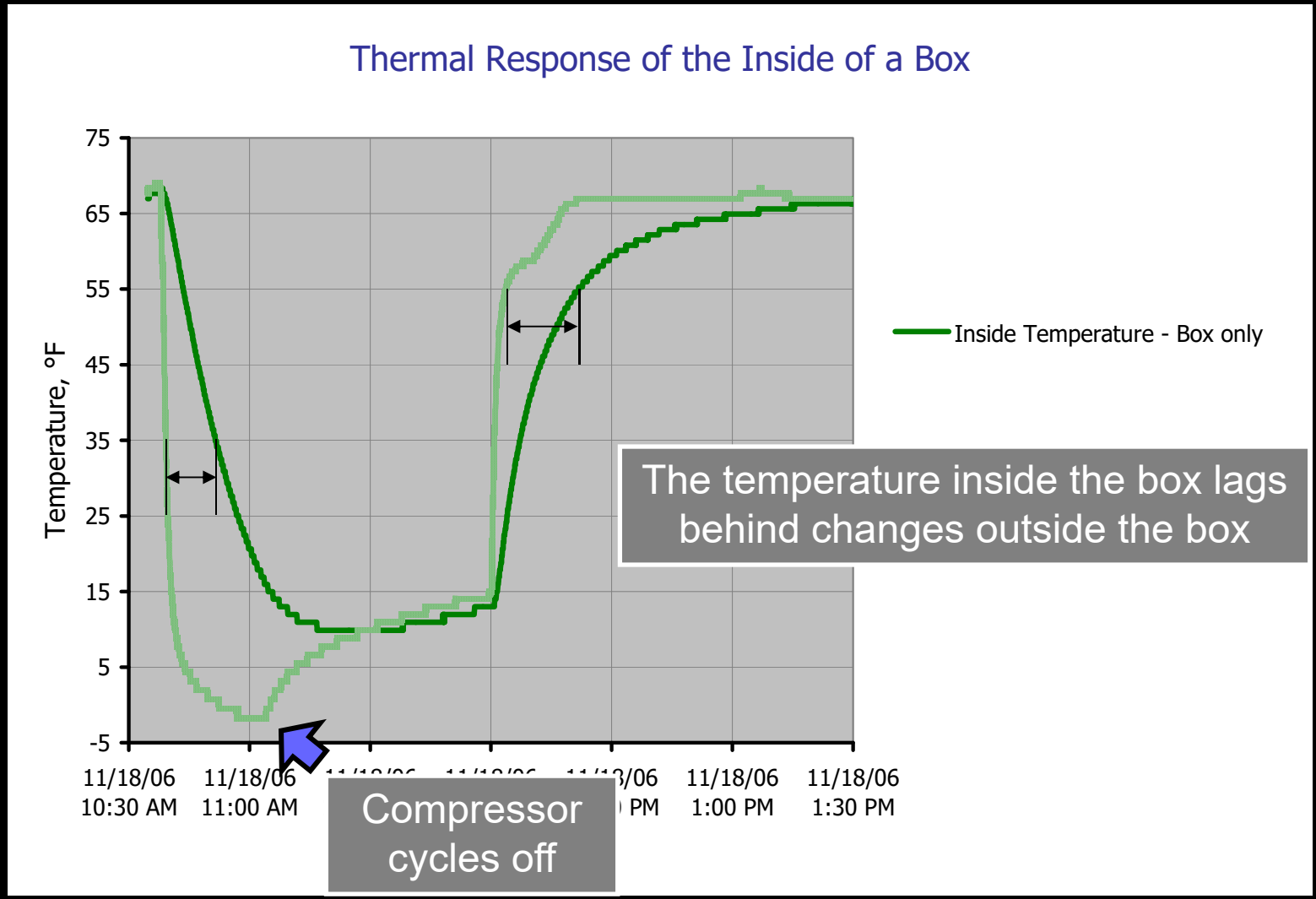
A Research Experiment by the FDE NW Research Lab

Envelope Configuration 1

- Cardboard box, no insulation

Envelope Configuration 1

Test Results – Envelope Configuration 1



Outside = Inside

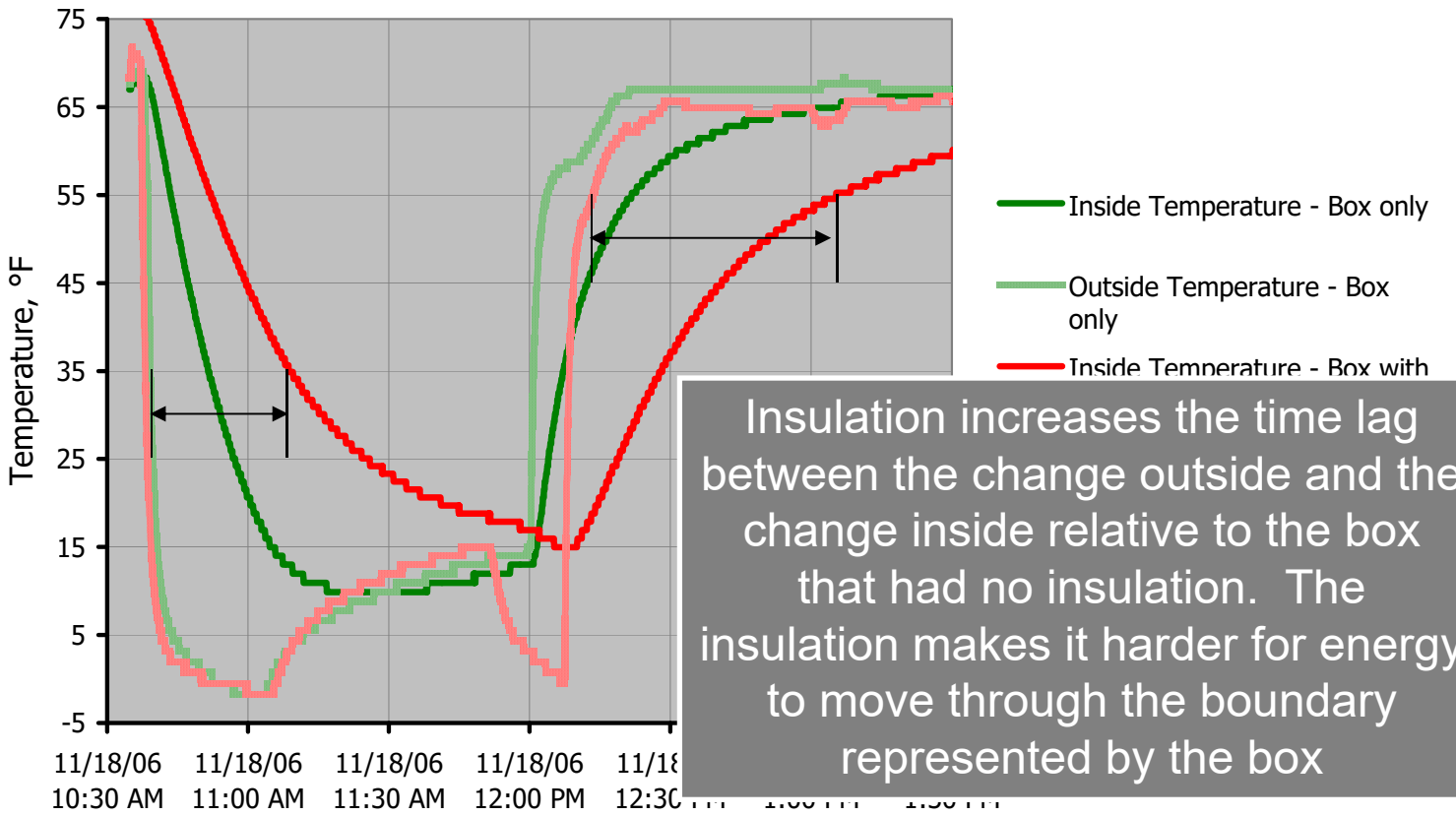
A Research Experiment by the FDE NW Research Lab

Envelope Configuration 2

- Cardboard box, insulated

Envelope Configuration 2

Test Results – Envelope Configuration 2



Insulation increases the time lag between the change outside and the change inside relative to the box that had no insulation. The insulation makes it harder for energy to move through the boundary represented by the box

Outside = Inside

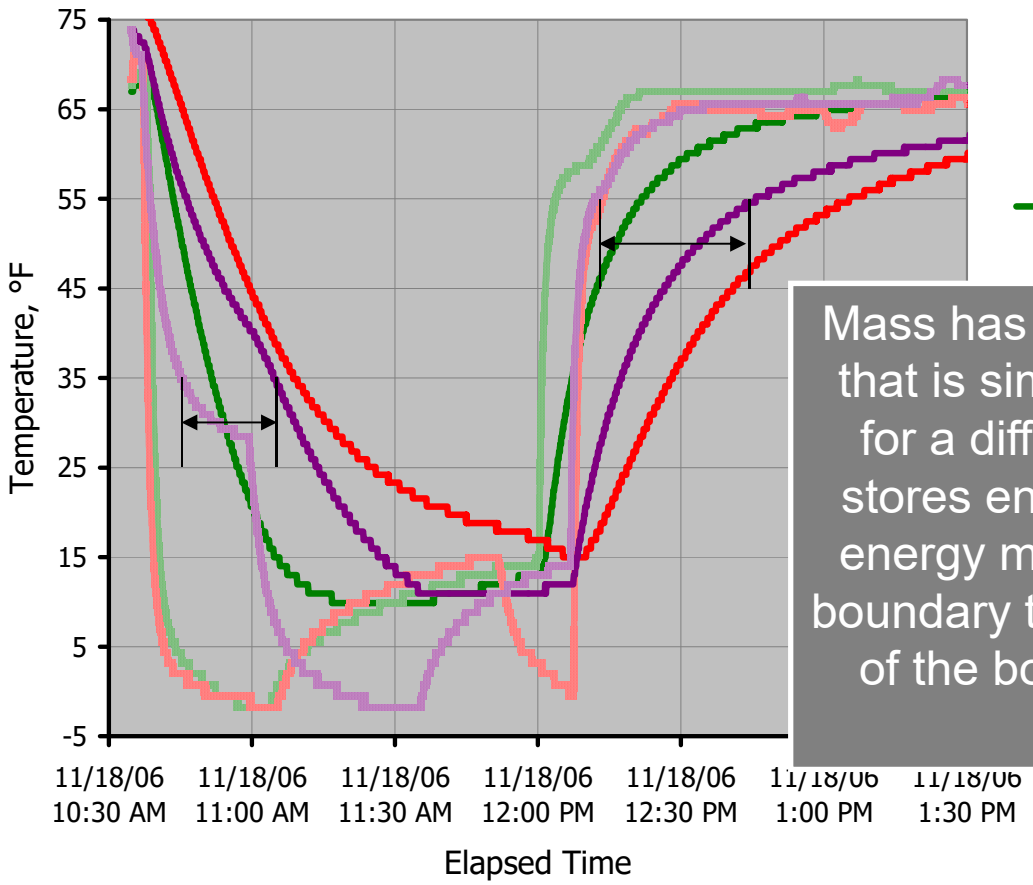
A Research Experiment by the FDE NW Research Lab

Envelope Configuration 3

- Cardboard box with rocks, no insulation

Envelope Configuration 3

Test Results – Envelope Configuration 3



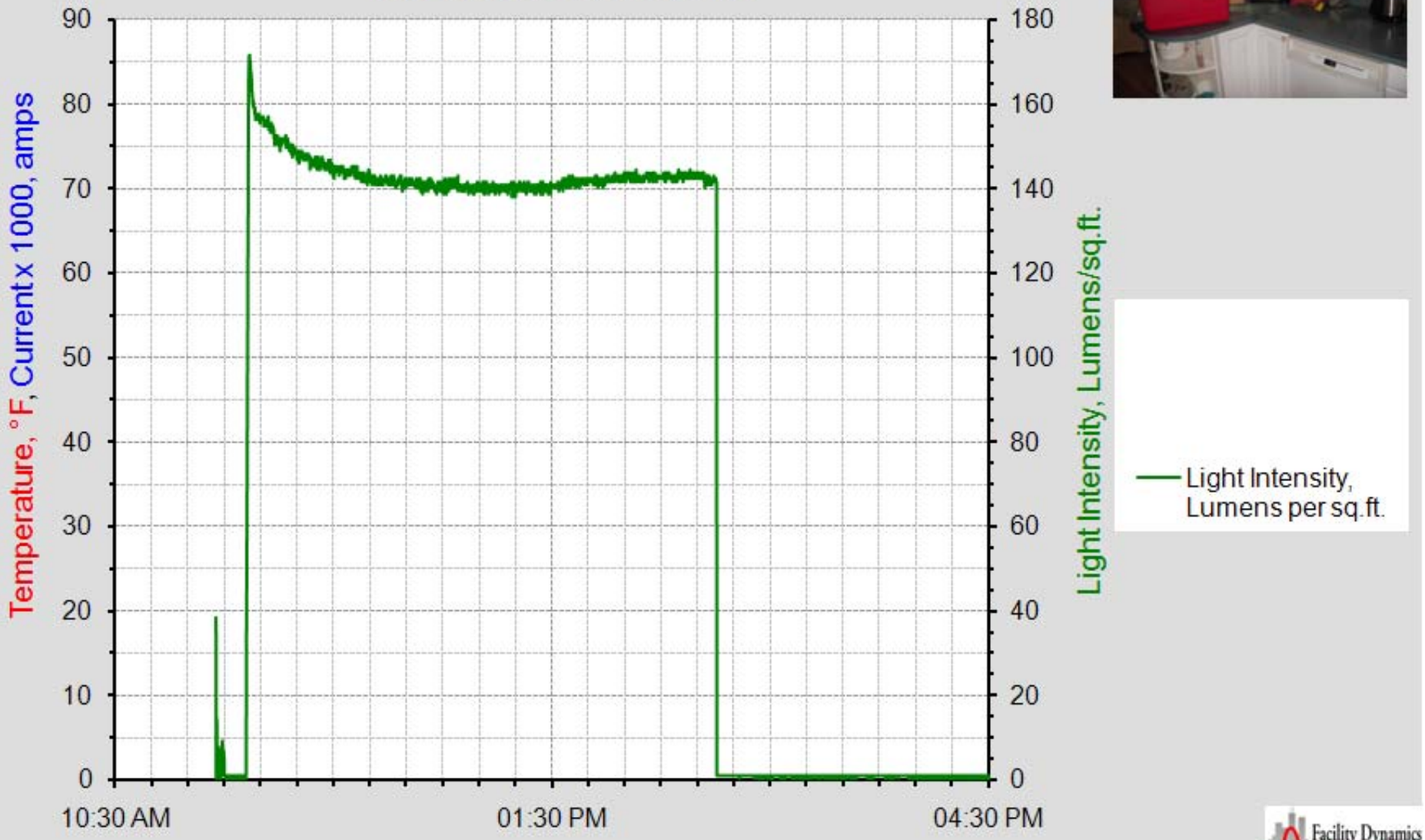
Mass has an impact on the time lag that is similar to the insulation, but for a different reason. The mass stores energy, which means more energy must move across the box boundary to change the temperature of the box, all other things being equal

Internal Gains Have Lags Too


onset
HOBO

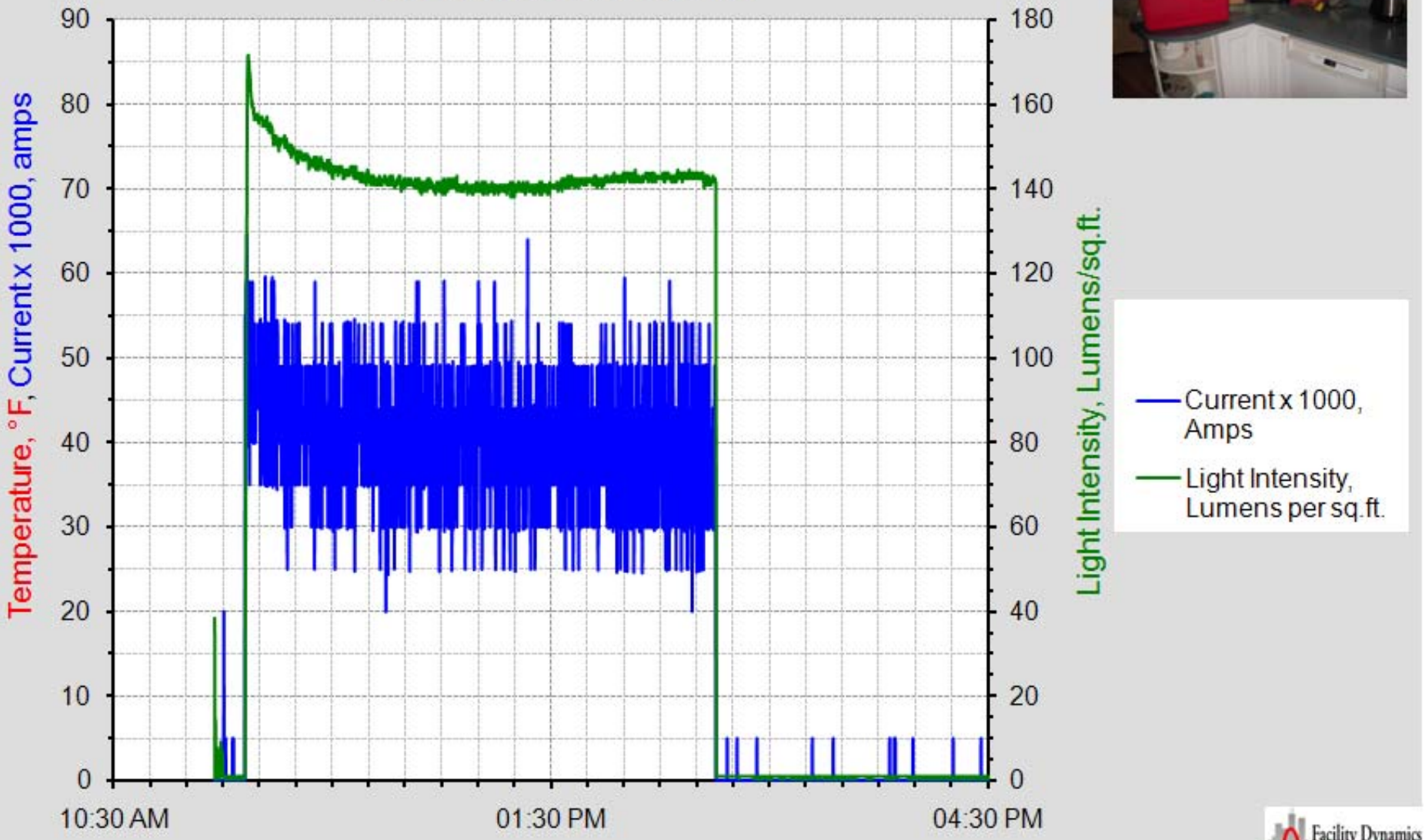
Temperature Inside an Insulated Enclosure

With and Without a Light On



Temperature Inside an Insulated Enclosure

With and Without a Light On

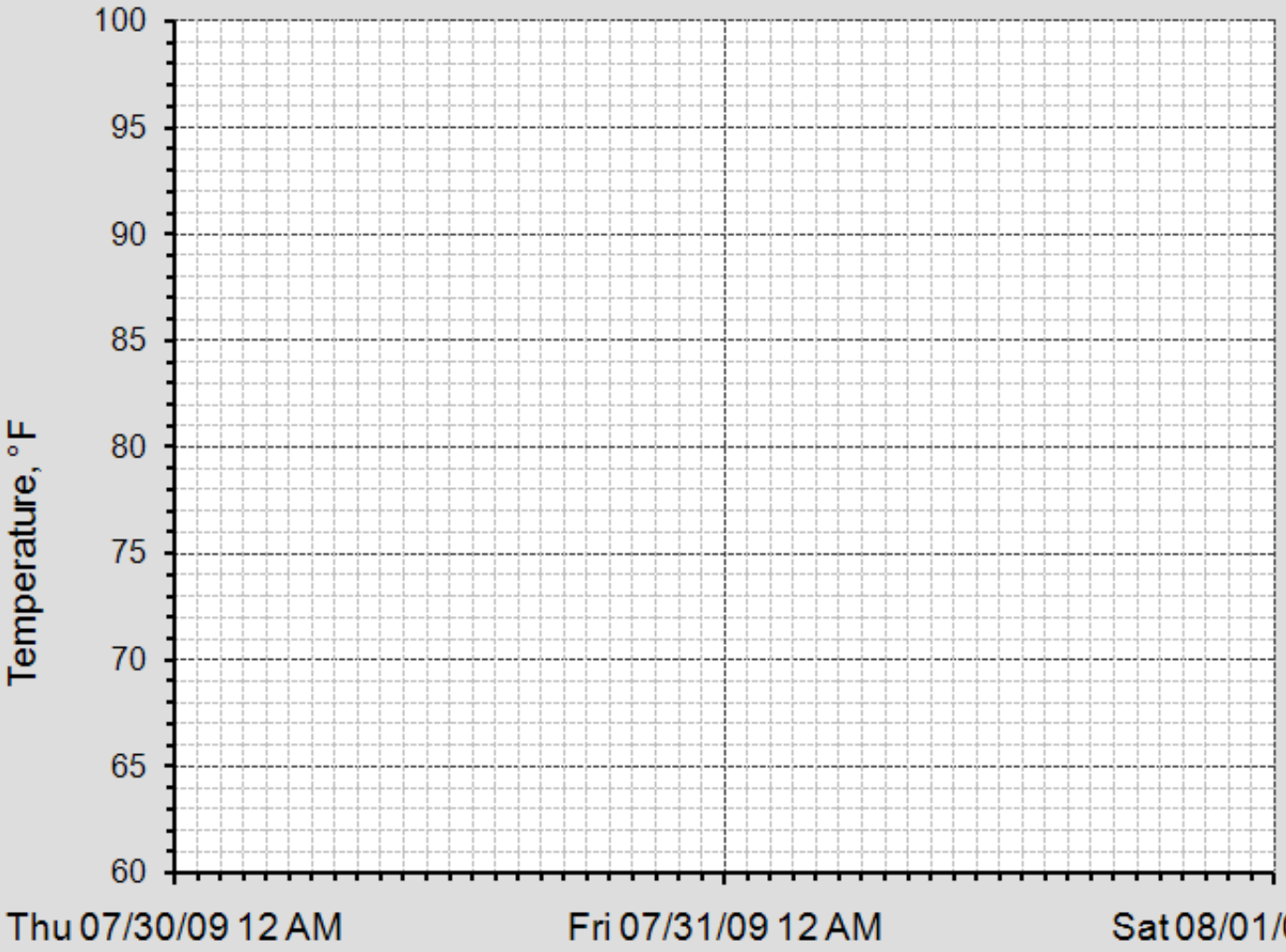


Even though power is consumed and light is produced instantaneously when the light is turned on, the temperature rise associated with the energy consumption lags the power consumption and light production

Everything Interacts with Everything, Even in a Simple Building

8560 North Buchanan, Portland, OR Summer Thermal Response

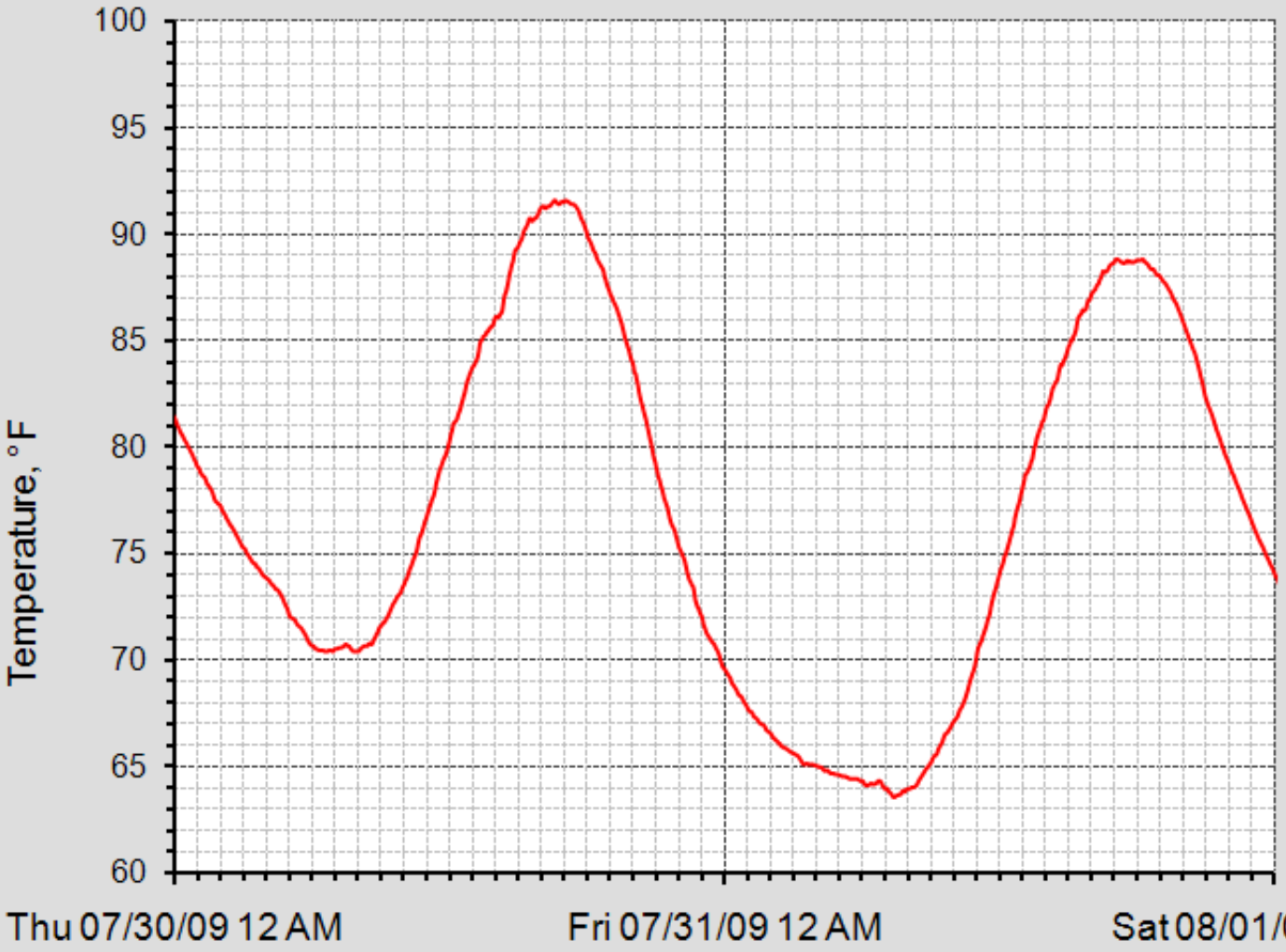
Portand 0.4% Cooling Design Condition - 90/67 °Ft_{db}/t_{wb}, 22°F Daily Range



Single story, light frame construction
Poured concrete basement
No air conditioning
Doors and windows open
Ceiling fans operating

8560 North Buchanan, Portland, OR Summer Thermal Response

Portand 0.4% Cooling Design Condition - 90/67 °Ft_{db}/t_{wb}, 22°F Daily Range

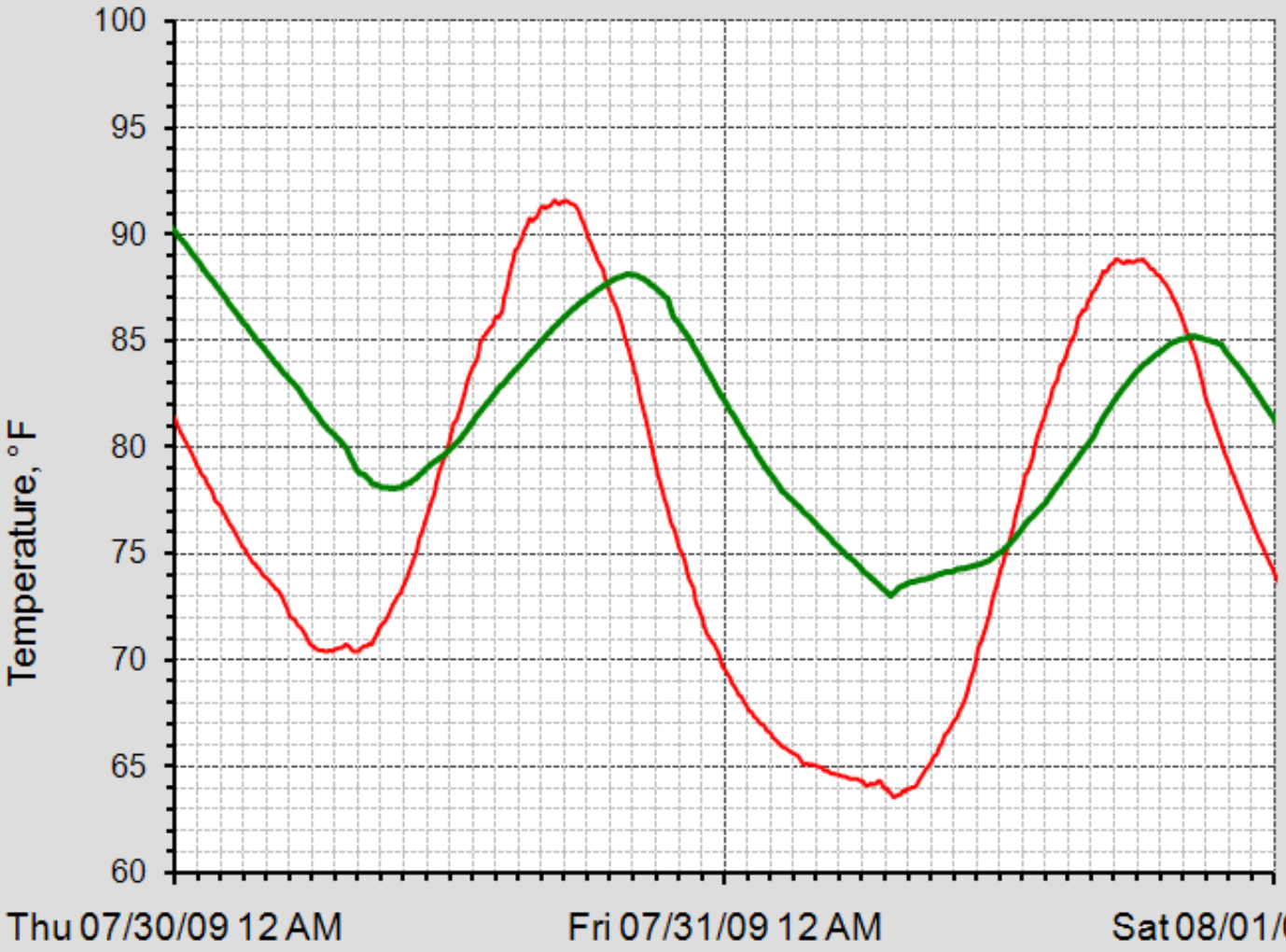


Single story, light frame construction
Poured concrete basement
No air conditioning
Doors and windows open
Ceiling fans operating

Outdoor Temp.; North Side

8560 North Buchanan, Portland, OR Summer Thermal Response

Portand 0.4% Cooling Design Condition - 90/67 °Ft_{db}/t_{wb}, 22°F Daily Range



Single story, light frame construction
Poured concrete basement
No air conditioning
Doors and windows open
Ceiling fans operating

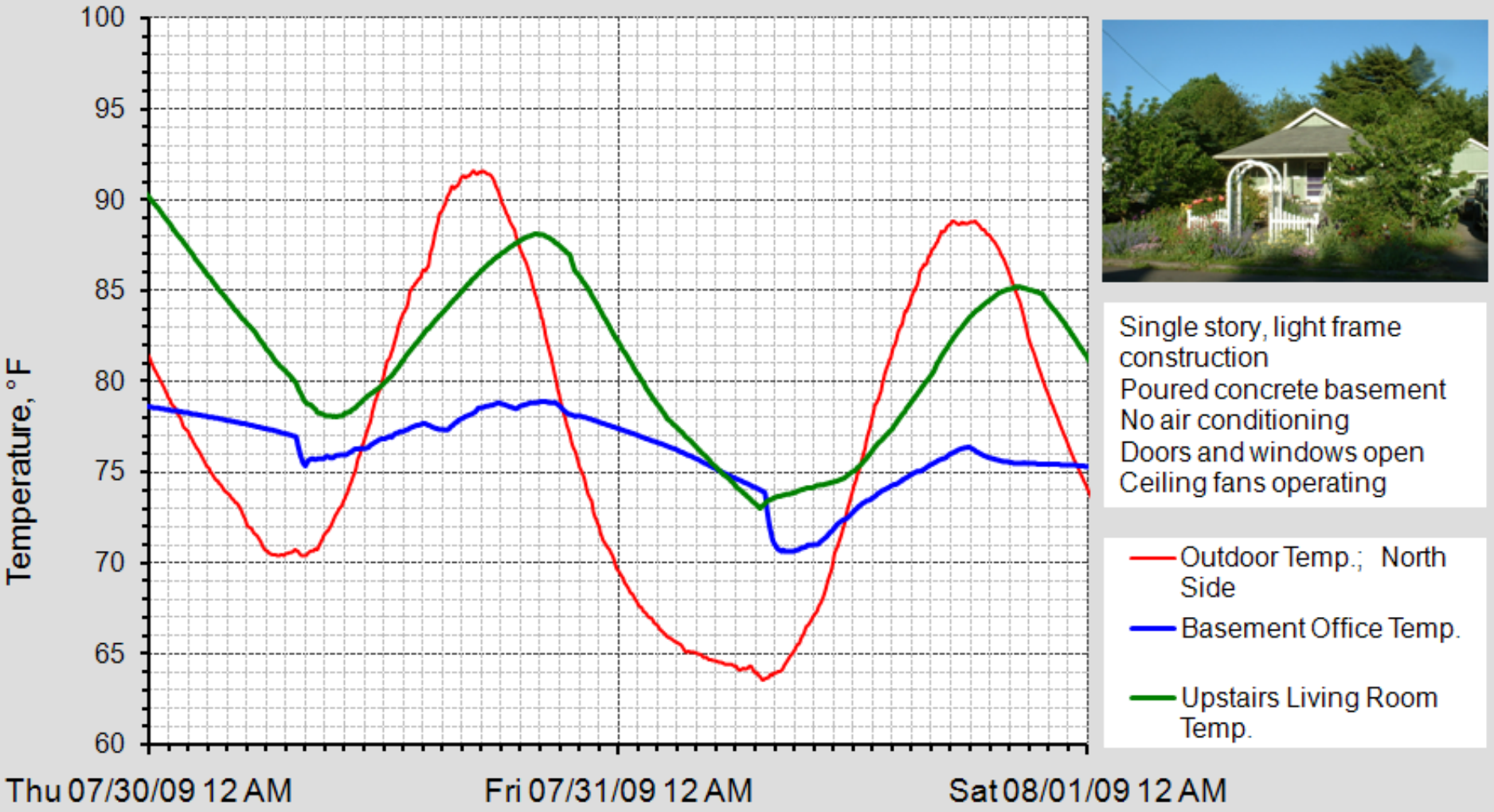
Outdoor Temp.; North Side

Upstairs Living Room Temp.

Facility Dynamics Engineering

8560 North Buchanan, Portland, OR Summer Thermal Response

Portand 0.4% Cooling Design Condition - 90/67 °Ft_{db}/t_{wb}, 22°F Daily Range



Single story, light frame construction
Poured concrete basement
No air conditioning
Doors and windows open
Ceiling fans operating

Outdoor Temp.; North Side

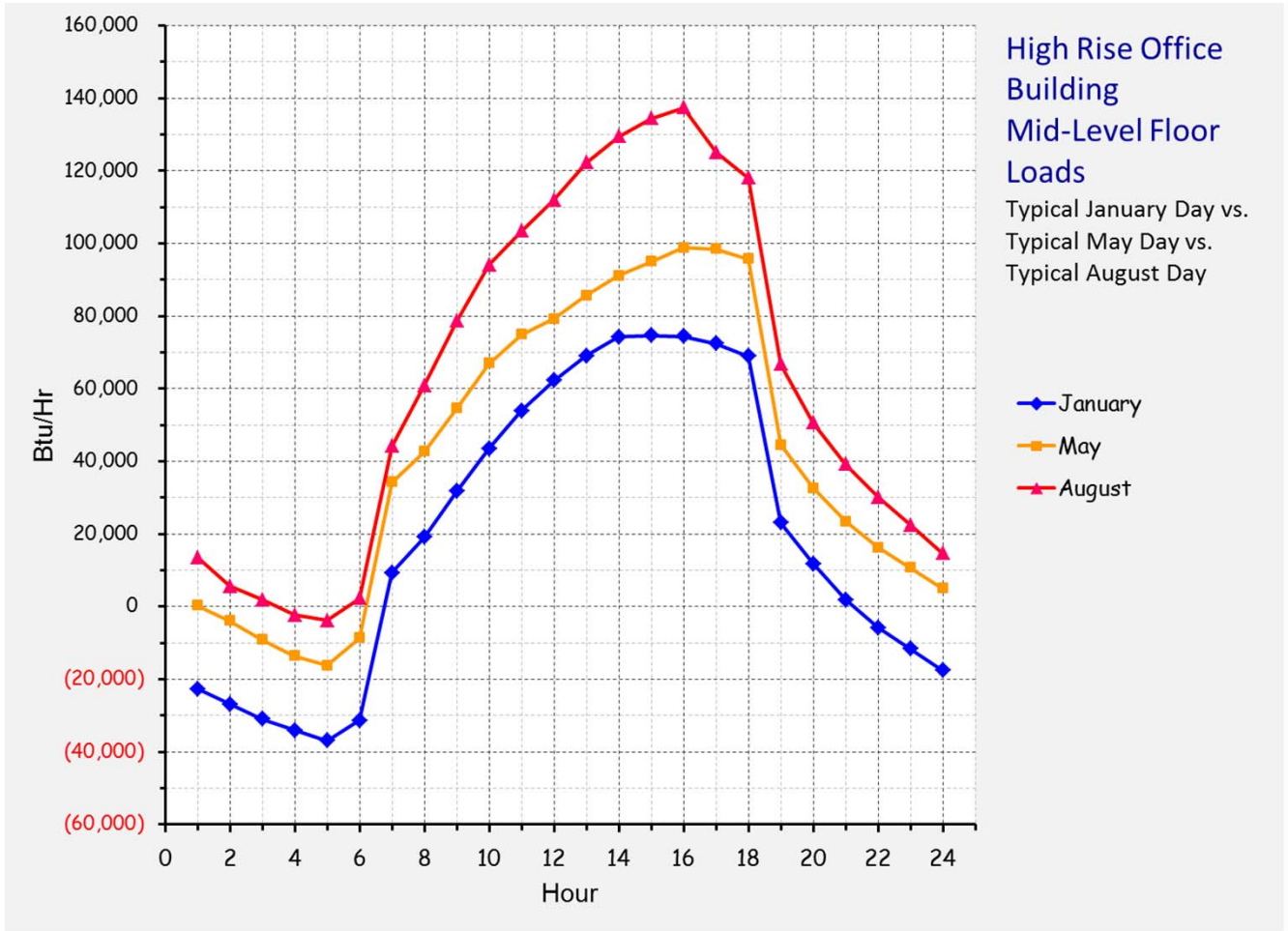
Basement Office Temp.

Upstairs Living Room Temp.

Facility Dynamics Engineering

Cool the Building with Cool Outdoor Air

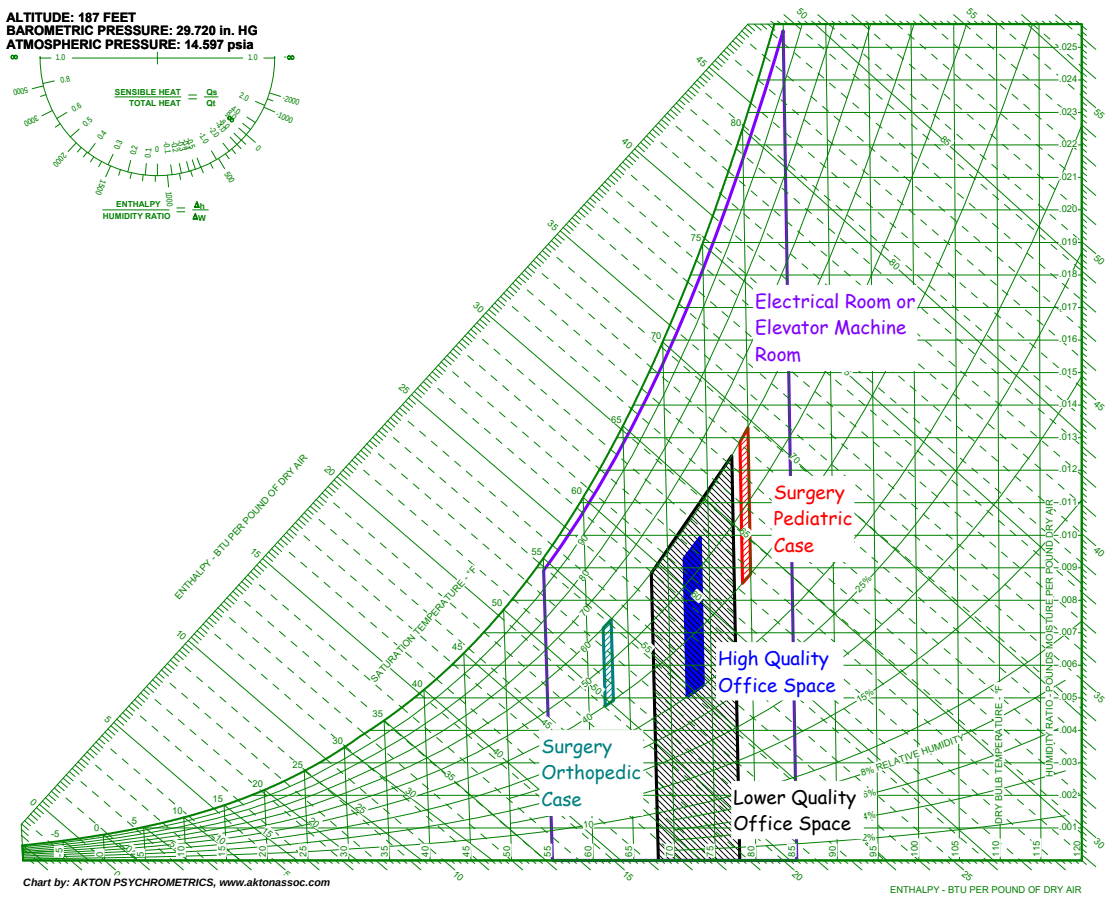
Simple in Concept; Challenging in Reality



The Cooling Requirements Vary with Time of Day and Time of Year

Cool the Building with Cool Outdoor Air

Simple in Concept; Challenging in Reality

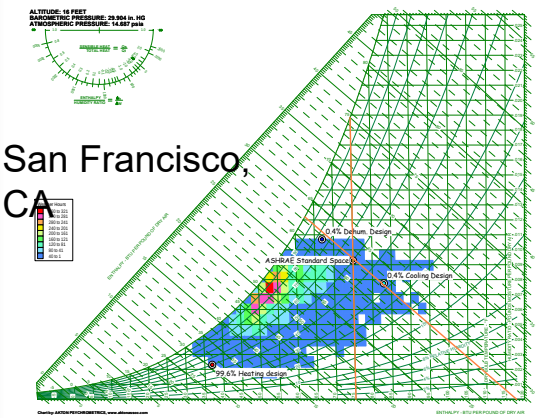


The Suitability of Outdoor Air for Cooling Varies with the Application

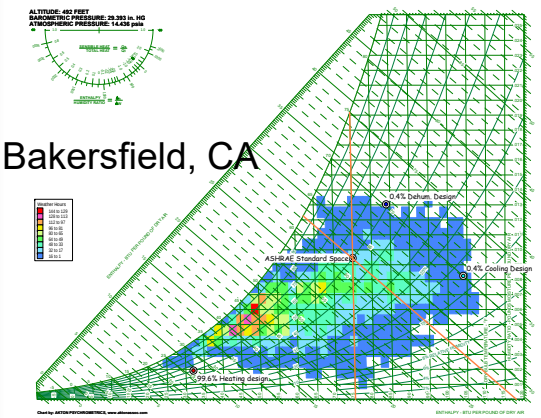
Cool the Building with Cool Outdoor Air

Simple in Concept; Challenging in Reality

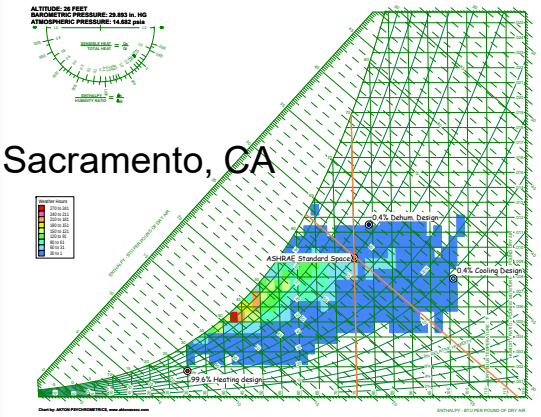
San Francisco, CA



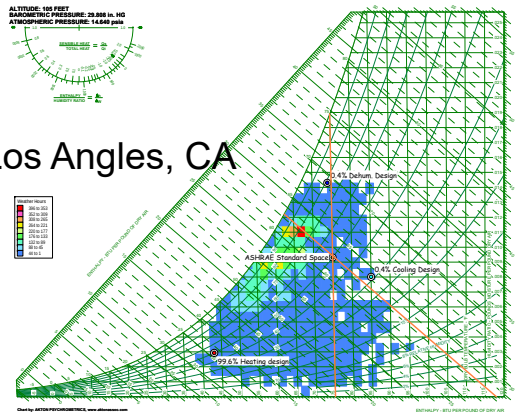
Bakersfield, CA



Sacramento, CA



Los Angles, CA

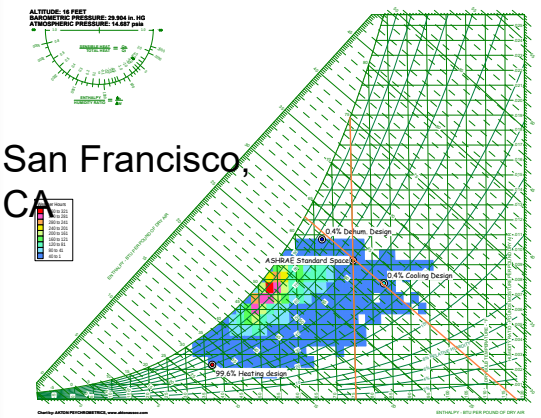


The Cooling Requirements Vary with Location as Does the Suitability of Outdoor Air for Cooling

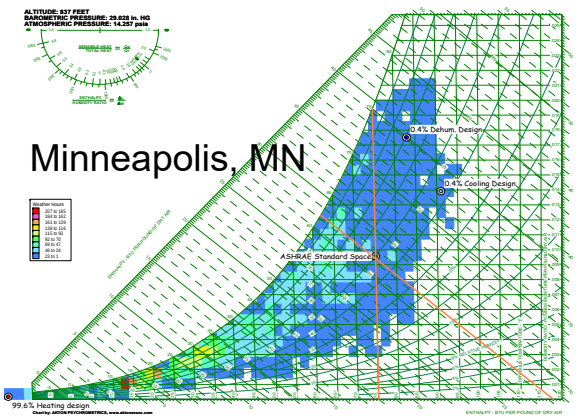
Cool the Building with Cool Outdoor Air

Simple in Concept; Challenging in Reality

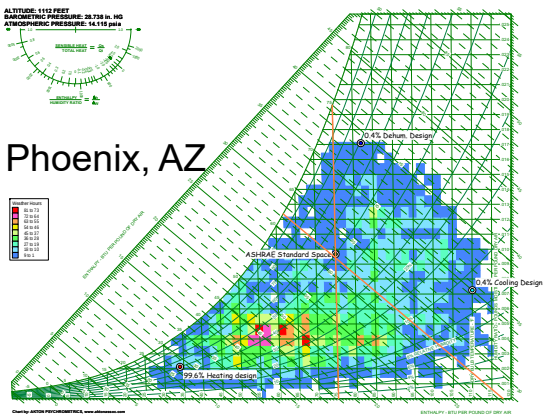
San Francisco, CA



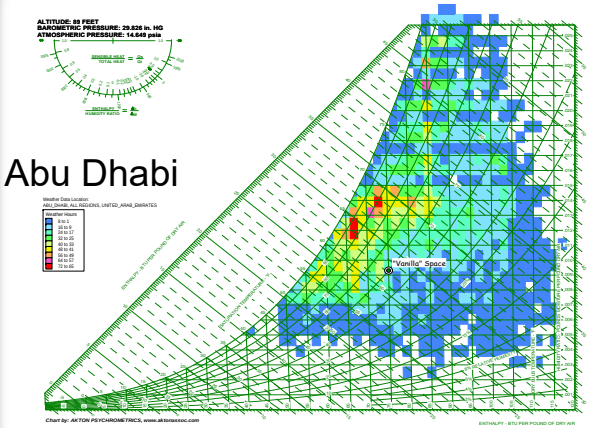
Minneapolis, MN



Phoenix, AZ



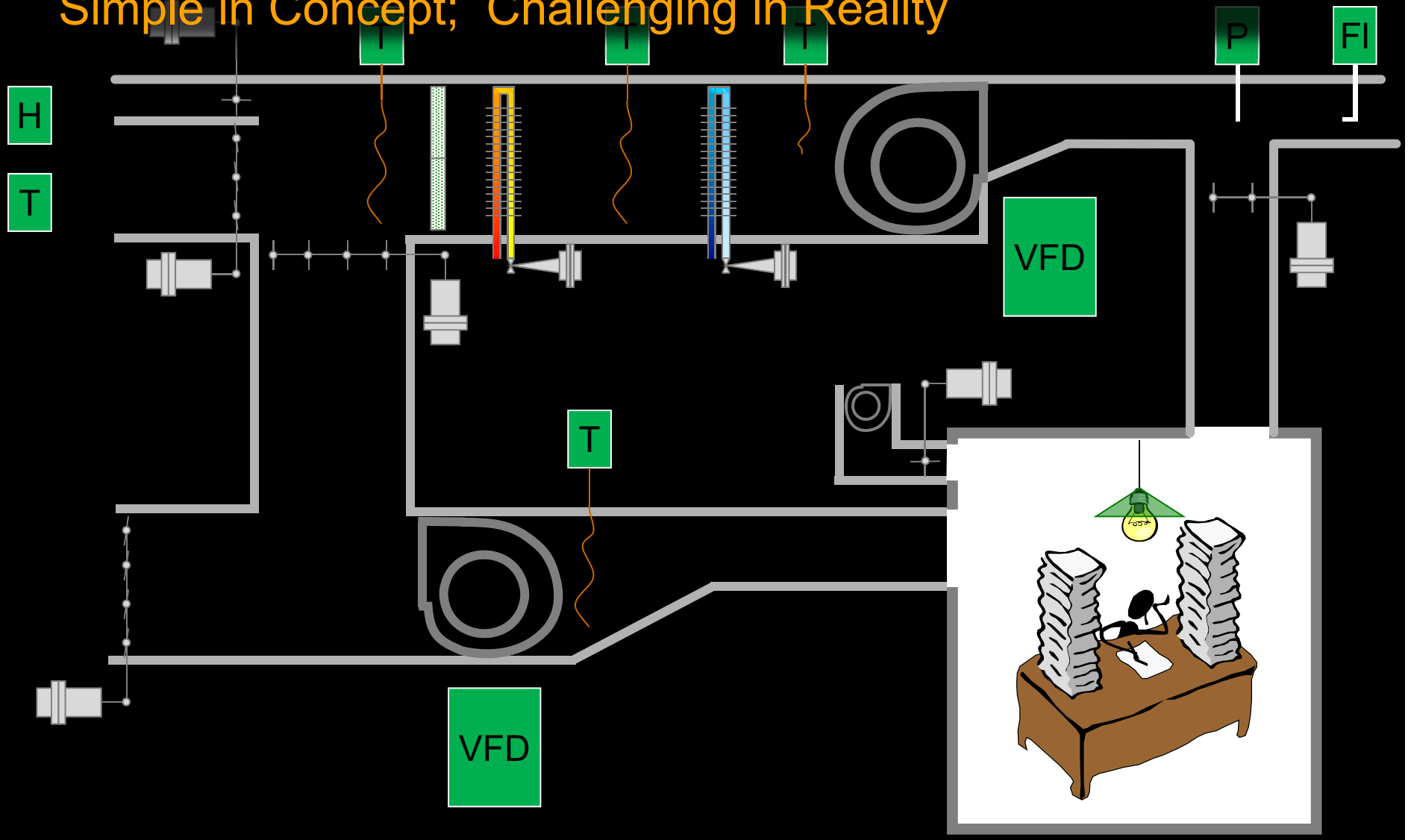
Abu Dhabi

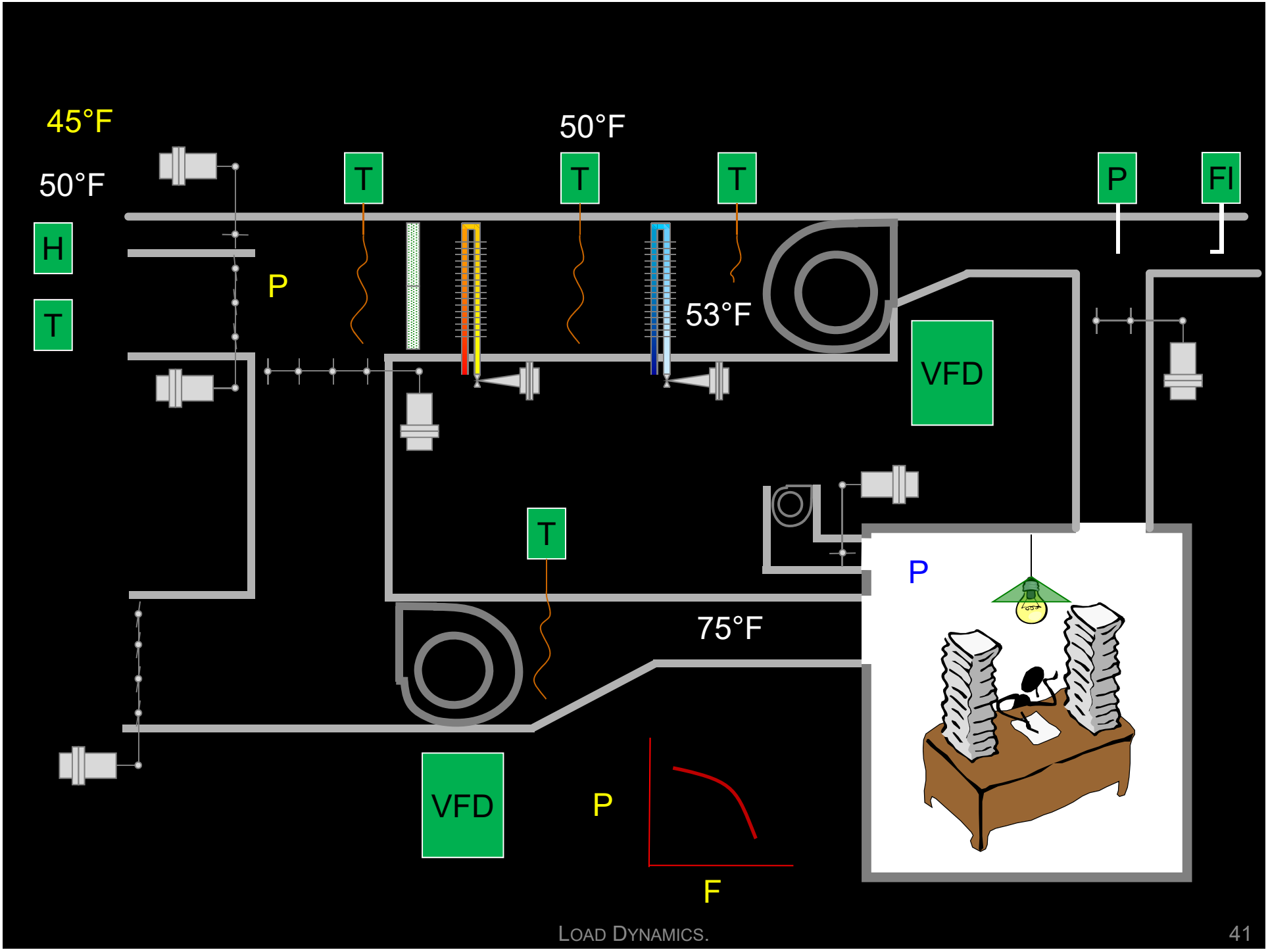


The Cooling Requirements Vary with Location as Does the Suitability of Outdoor Air for Cooling

Cool the Building with Cool Outdoor Air

Simple in Concept; Challenging in Reality

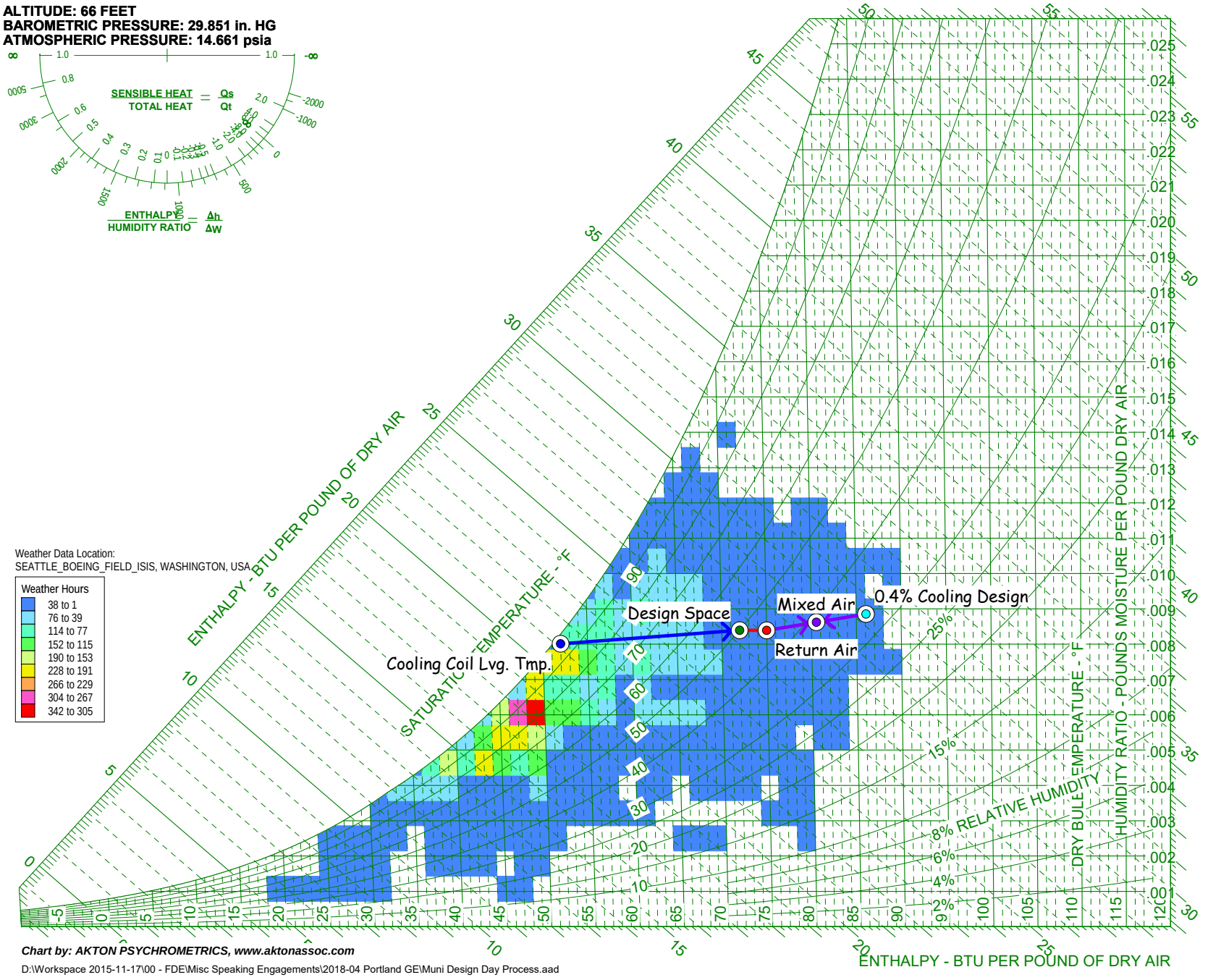



45°F
50°F
50°F
T
T
T
P
FI
H
T
P
53°F
VFD
T
P
75°F
VFD
P
F

Aside from those things, it should not be too hard to get a control system to work

The Load Profile

The design day vs. reality


ALTITUDE: 66 FEET
BAROMETRIC PRESSURE: 29.851 in. HG
ATMOSPHERIC PRESSURE: 14.661 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / Δw
Weather Data Location:
SEATTLE_BOEING_FIELD_ISIS, WASHINGTON, USA
Weather Hours
38 to 1
76 to 39
114 to 77
152 to 115
190 to 153
228 to 191
266 to 229
304 to 267
342 to 305
Design Space
Mixed Air
0.4% Cooling Design
Return Air
Cooling Coil Lvg. Tmp.
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
8% RELATIVE HUMIDITY
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
D:\Workspace 2015-11-17\00 - FDE\Misc Speaking Engagements\2018-04 Portland GE\Muni Design Day Process.aad

Load profile drivers

1. The state of the air

$$v = \frac{1}{x_a}\left[\left|\frac{RT}{p}\right| \bullet \frac{1}{a} \bullet \left(x_a^{\,2} A_{aa} + 2x_a x_w A_{aw} - X_a^{\,3} A_{www} p\right)\beta\right]$$

$$h = \left[x_a h_a^{\circ} + \left(0.62198 x_w h_w^{\circ}\right)\beta - \left(x_a^{\,2} B_{aa} + 2x_a x_w B_{aw} + x_w^{\,2} B_{aw} + x_w^{\,2} B_{ww}\right) \bullet p\alpha - \frac{1}{2} x_w^{\,3} B_{www} p^2 \alpha\right] \frac{1}{x_a} + \bar{h_a} W \bar{h_w}$$

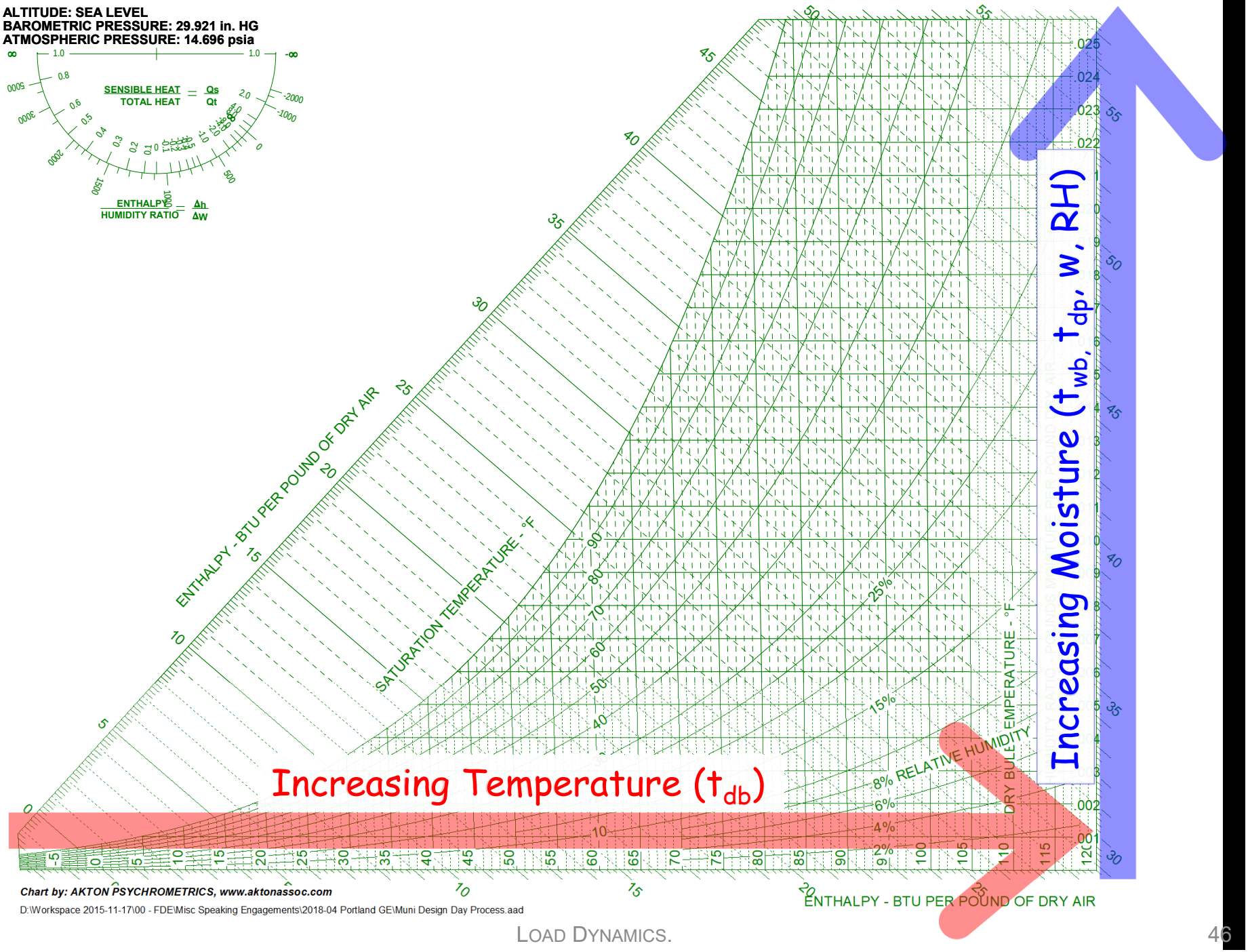
2. The nature of the process occurring at the load

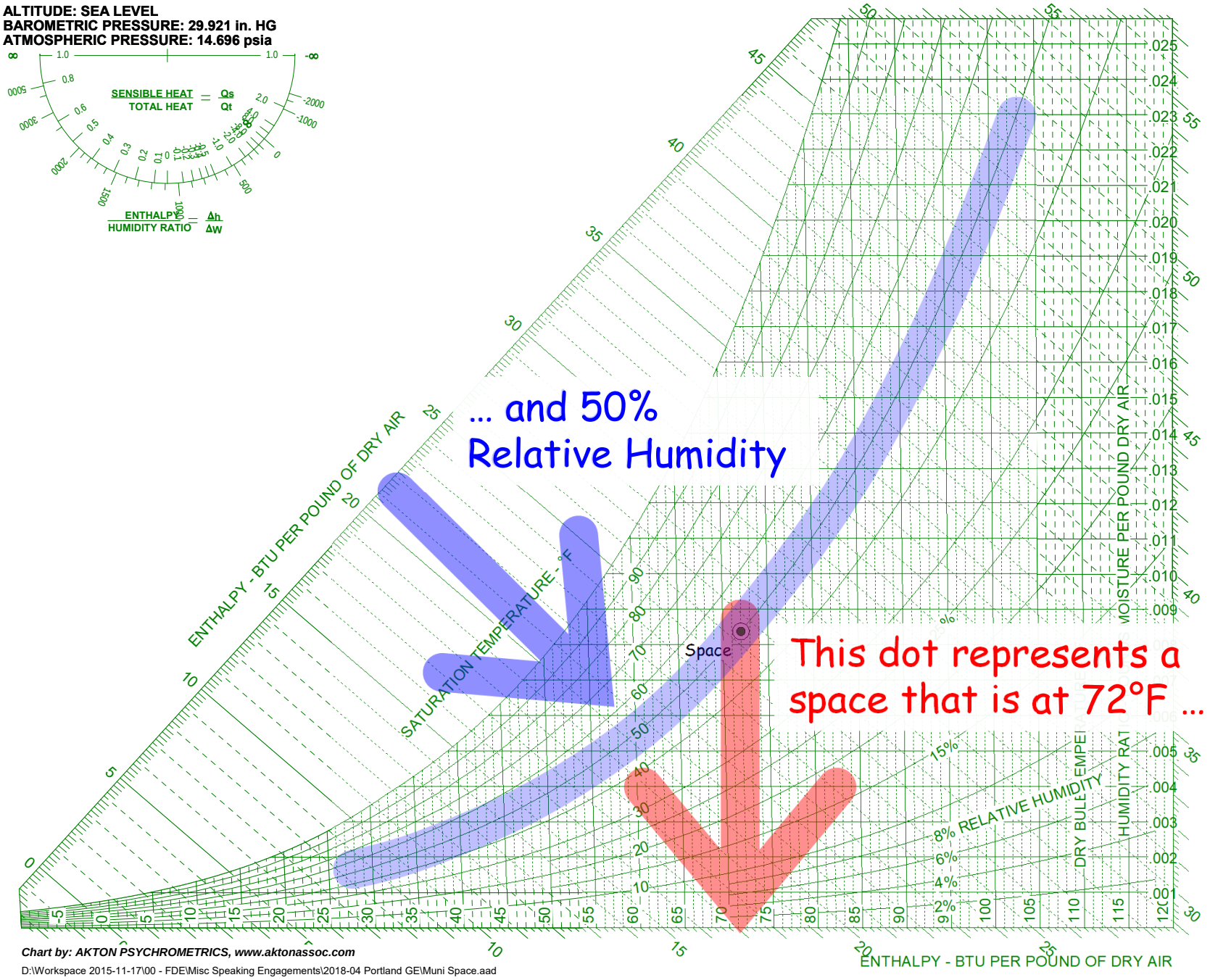
$$\bar{Q} + \sum_1 \left[\dot{m} \times \left(u_1 + \frac{p_1 v_1}{J} + \frac{z_1}{J} + \frac{V_1^2}{2gJ}\right)\right] = \frac{\bar{W}}{J} + \sum_2 \left[\dot{m} \times \left(u_2 + \frac{p_2 v_2}{J} + \frac{z_2}{J} + \frac{V_2^2}{2gJ}\right)\right]$$

3. The process design target

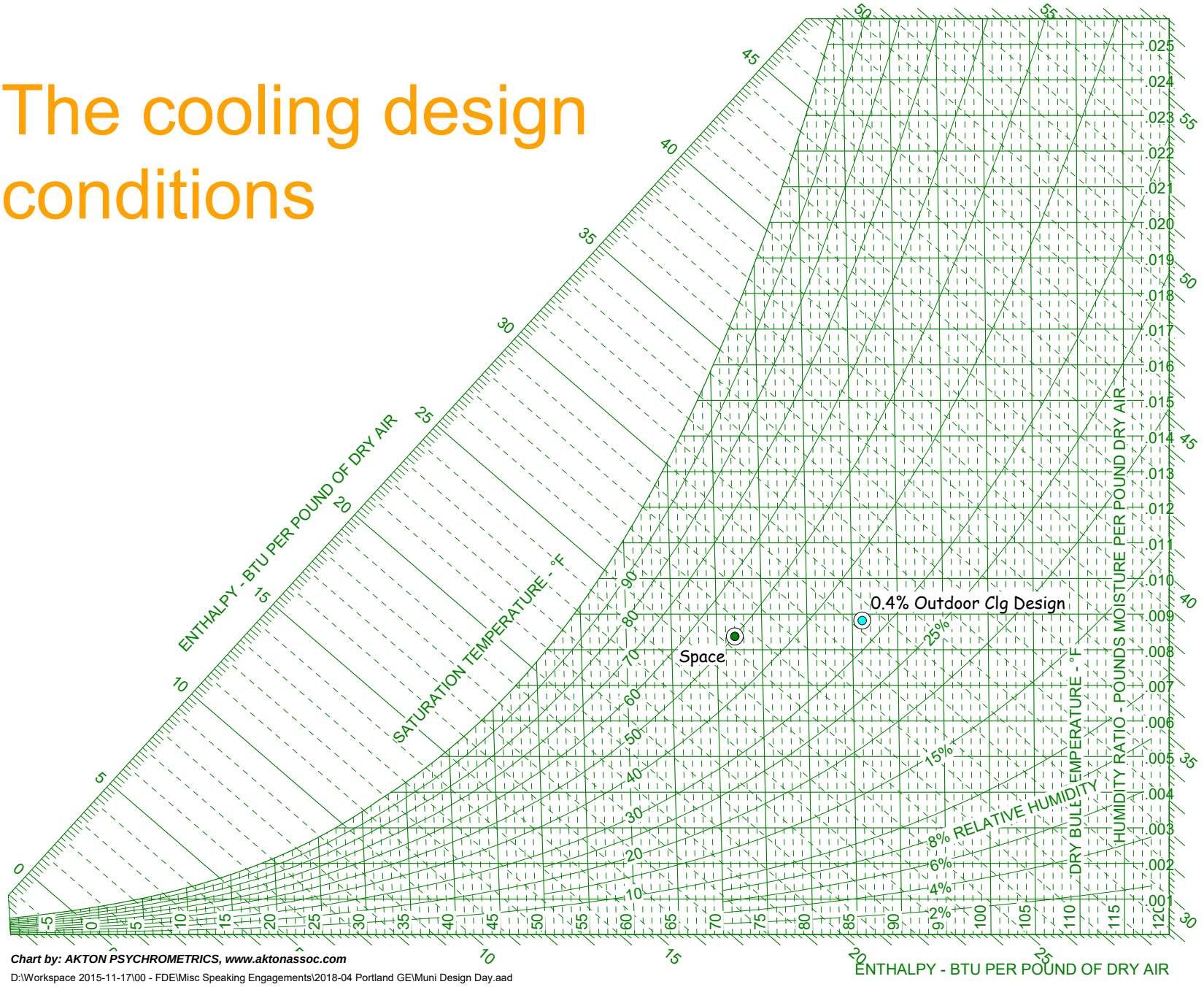
$t_{db} = 72.000°\text{F}$, $t_{wb} = 60.064°\text{F}$, $t_{dp} = 52.370°\text{F}$, $h = 26.435$ Btu/lb$_m$,

$w = 58.73$ grains$_{H_2O}$/lb$_{m_{DA}}$, RH $= 50.000$, $\upsilon = 13.611$ ft^3/lb$_m$, $\rho = .0741$ lb$_m$/ft^3

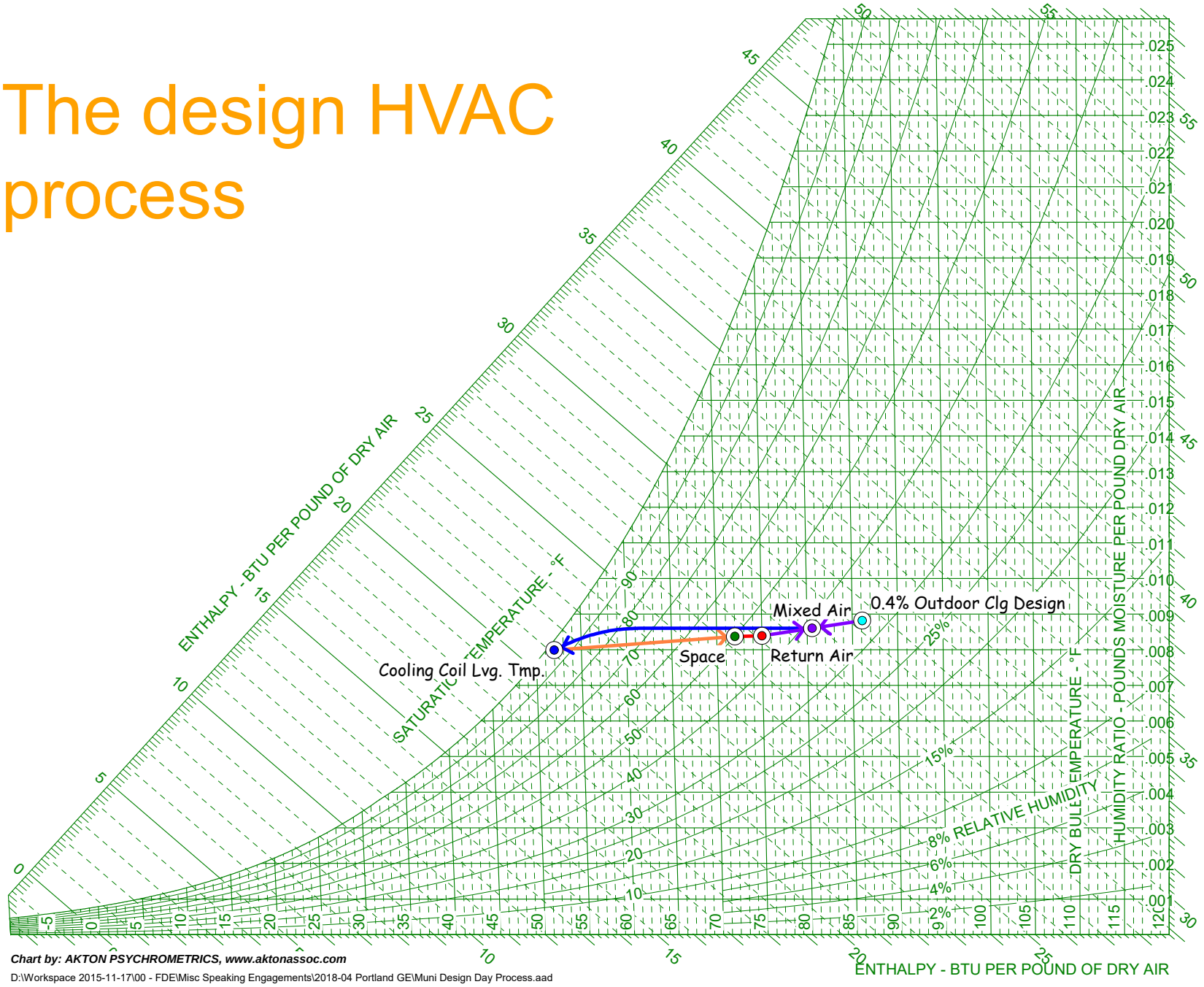

ALTITUDE: SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ATMOSPHERIC PRESSURE: 14.696 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / Δw
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
DRY BULB TEMPERATURE - °F
ENTHALPY - BTU PER POUND OF DRY AIR
Increasing Temperature (t_{db})
Increasing Moisture (t_{wb}, t_{dp}, w, RH)
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
D:\Workspace 2015-11-17\00 - FDE\Misc Speaking Engagements\2018-04 Portland GE\Muni Design Day Process.aad


ALTITUDE: SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ATMOSPHERIC PRESSURE: 14.696 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / Δw
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
MOISTURE PER POUND DRY AIR
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO
8% RELATIVE HUMIDITY
Space
… and 50% Relative Humidity
This dot represents a space that is at 72°F …
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
D:\Workspace 2015-11-17\00 - FDE\Misc Speaking Engagements\2018-04 Portland GE\Muni Space.aad

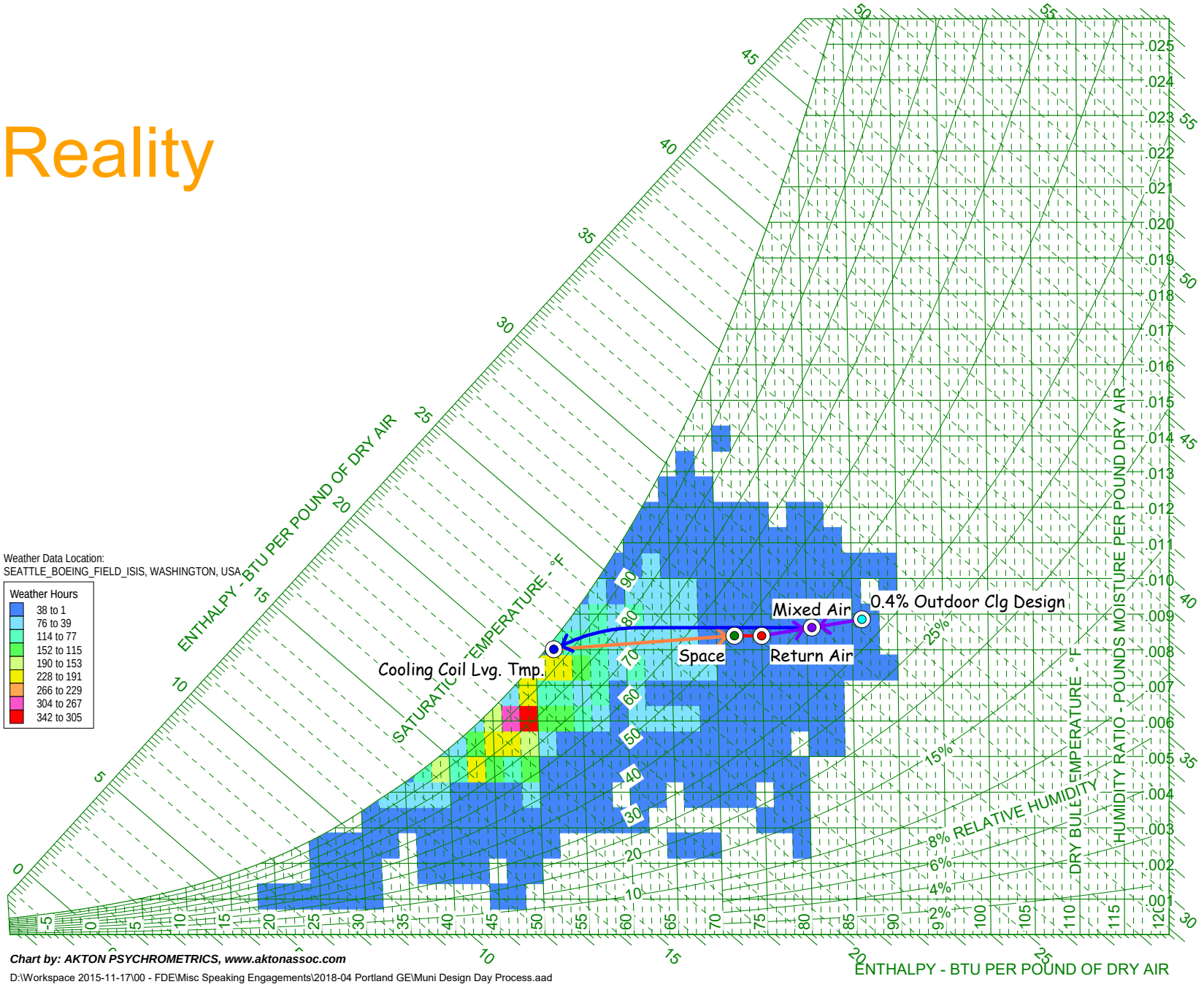
The cooling design conditions



The design HVAC process



Reality


Weather Data Location:
SEATTLE_BOEING_FIELD_ISIS, WASHINGTON, USA
Weather Hours
38 to 1
76 to 39
114 to 77
152 to 115
190 to 153
228 to 191
266 to 229
304 to 267
342 to 305
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
Mixed Air
0.4% Outdoor Clg Design
Space
Return Air
Cooling Coil Lvg. Tmp.
8% RELATIVE HUMIDITY
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
D:\Workspace 2015-11-17\00 - FDE\Misc Speaking Engagements\2018-04 Portland GE\Muni Design Day Process.aad

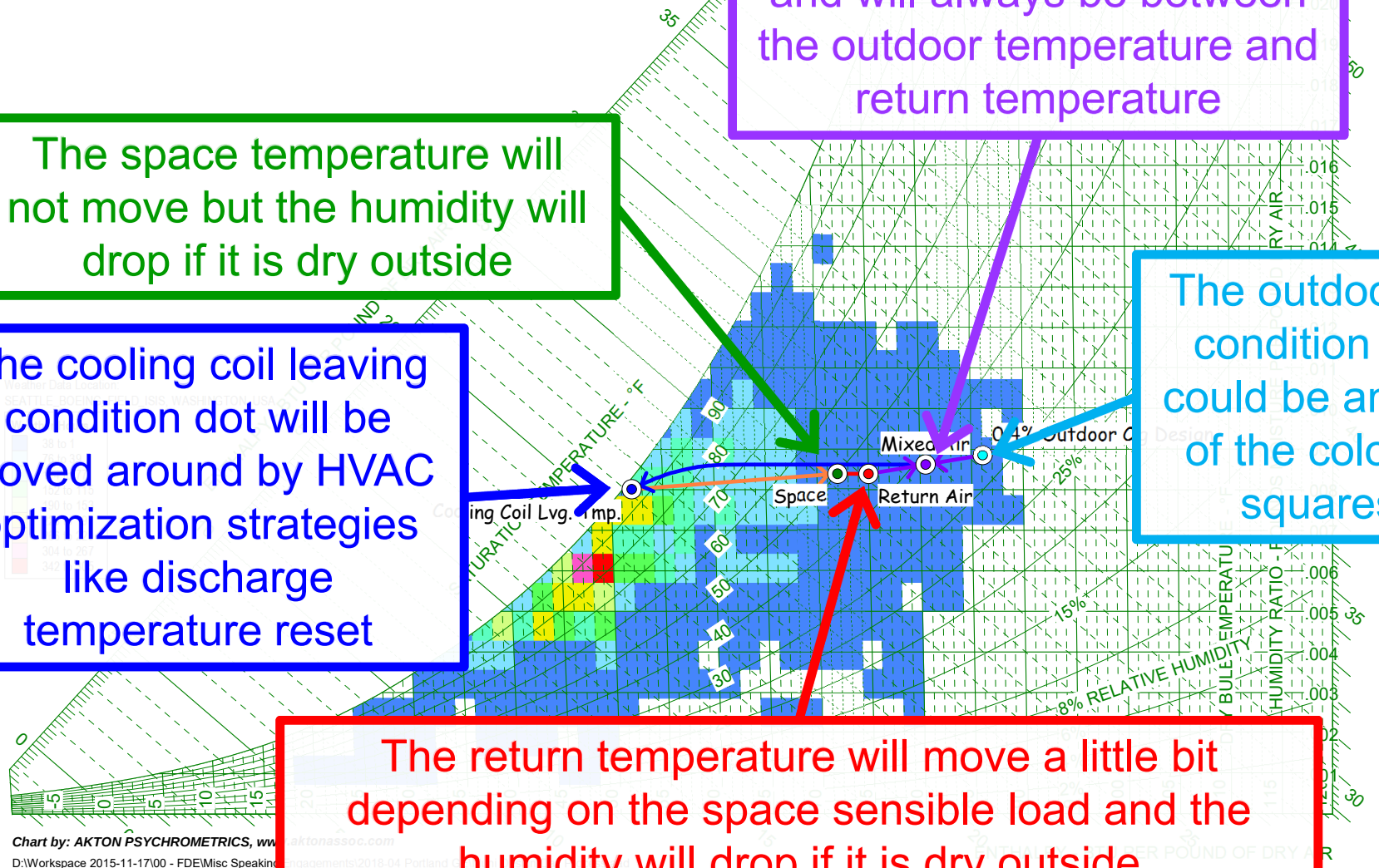
Reality

The mixed air temperature will be moved around by the economizer control process and ventilation requirements and will always be between the outdoor temperature and return temperature

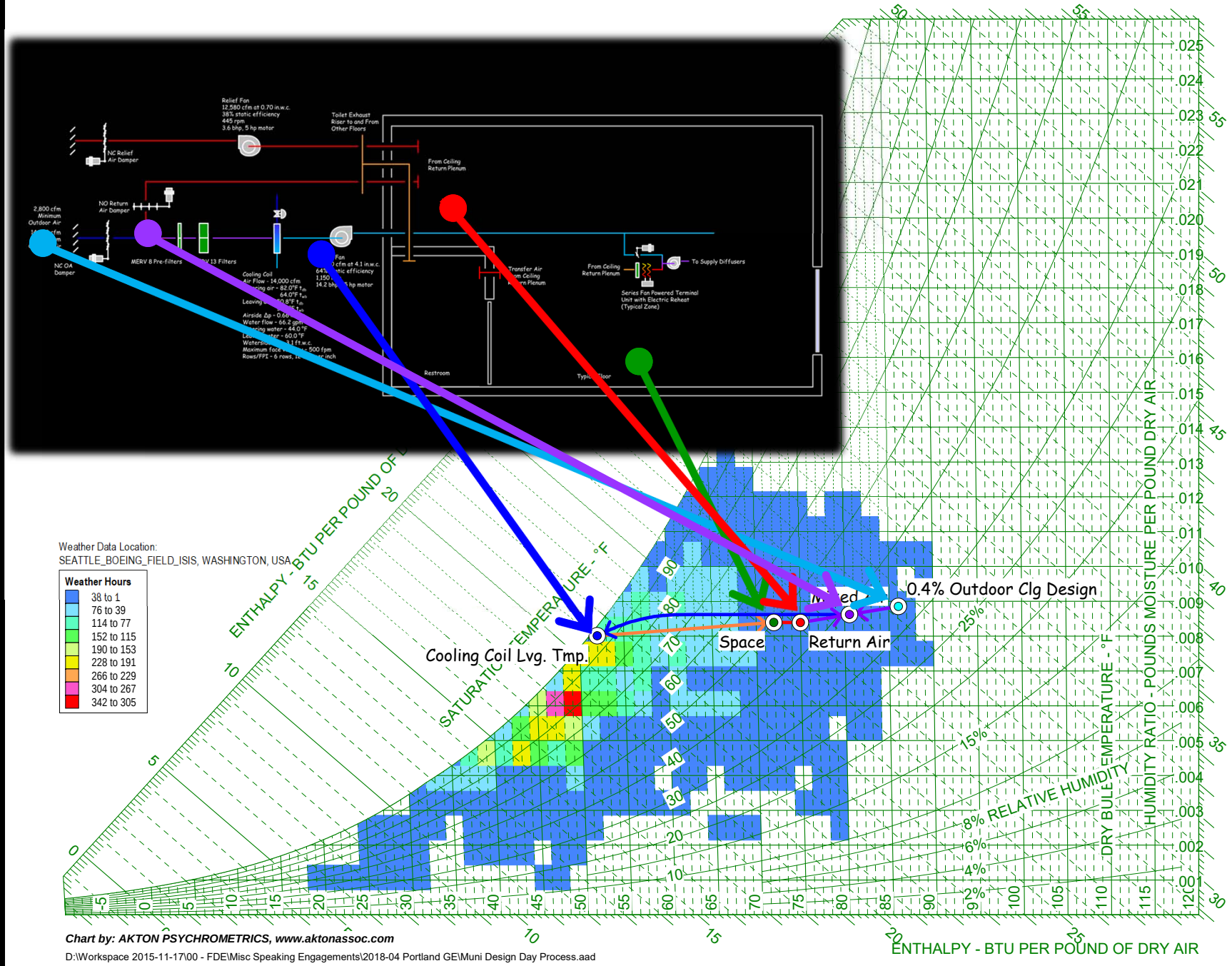
The space temperature will not move but the humidity will drop if it is dry outside

The cooling coil leaving condition dot will be moved around by HVAC optimization strategies like discharge temperature reset

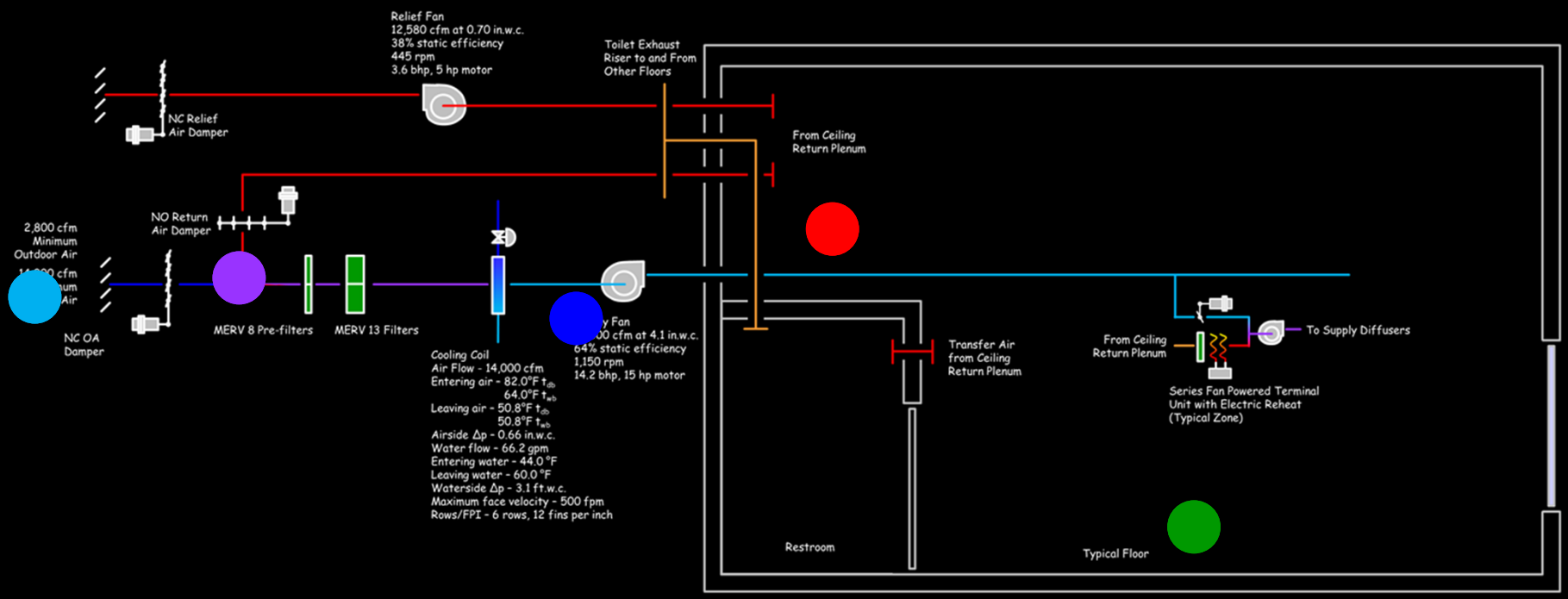
The outdoor air condition dot could be an any of the colored squares



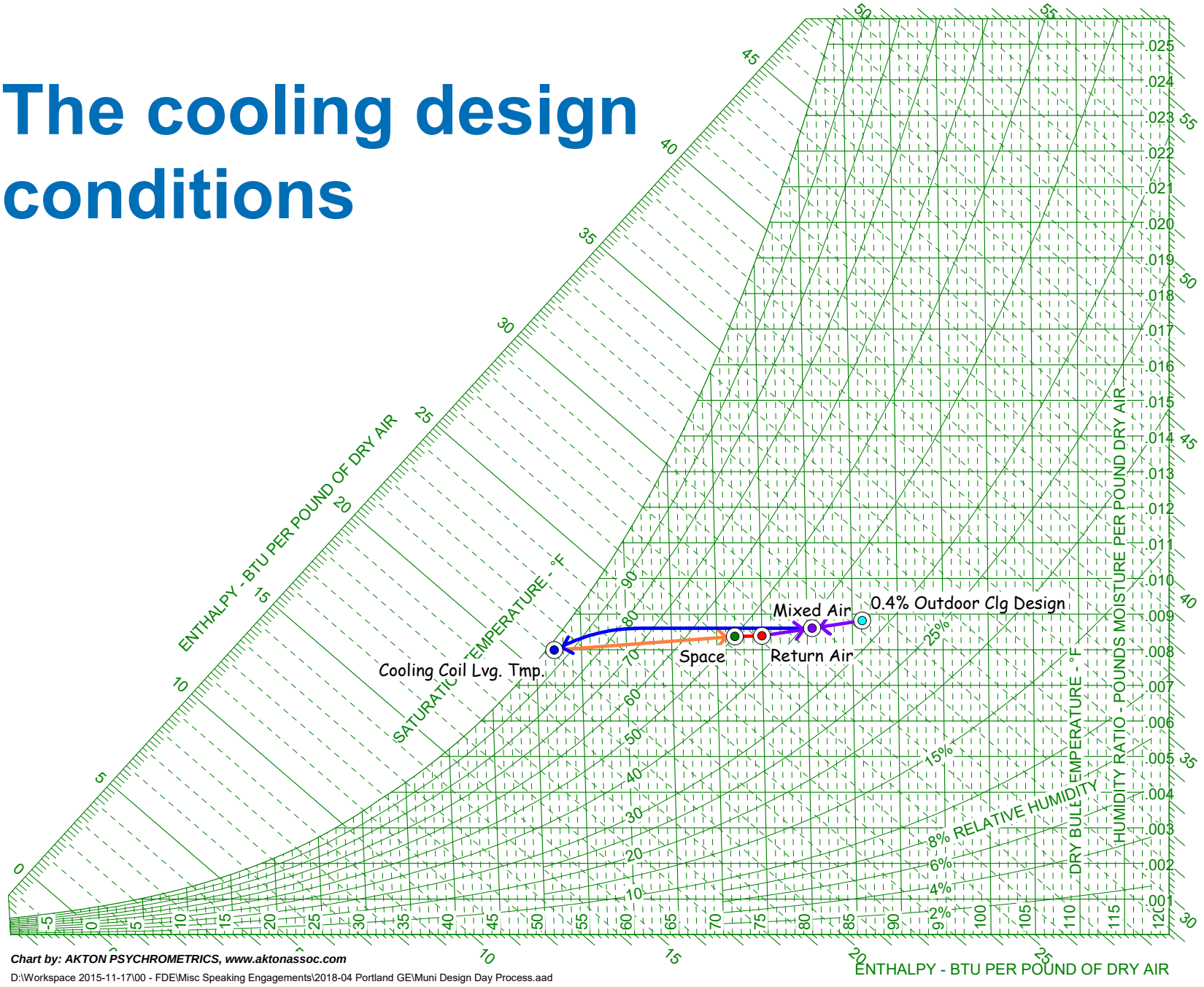
The return temperature will move a little bit depending on the space sensible load and the humidity will drop if it is dry outside

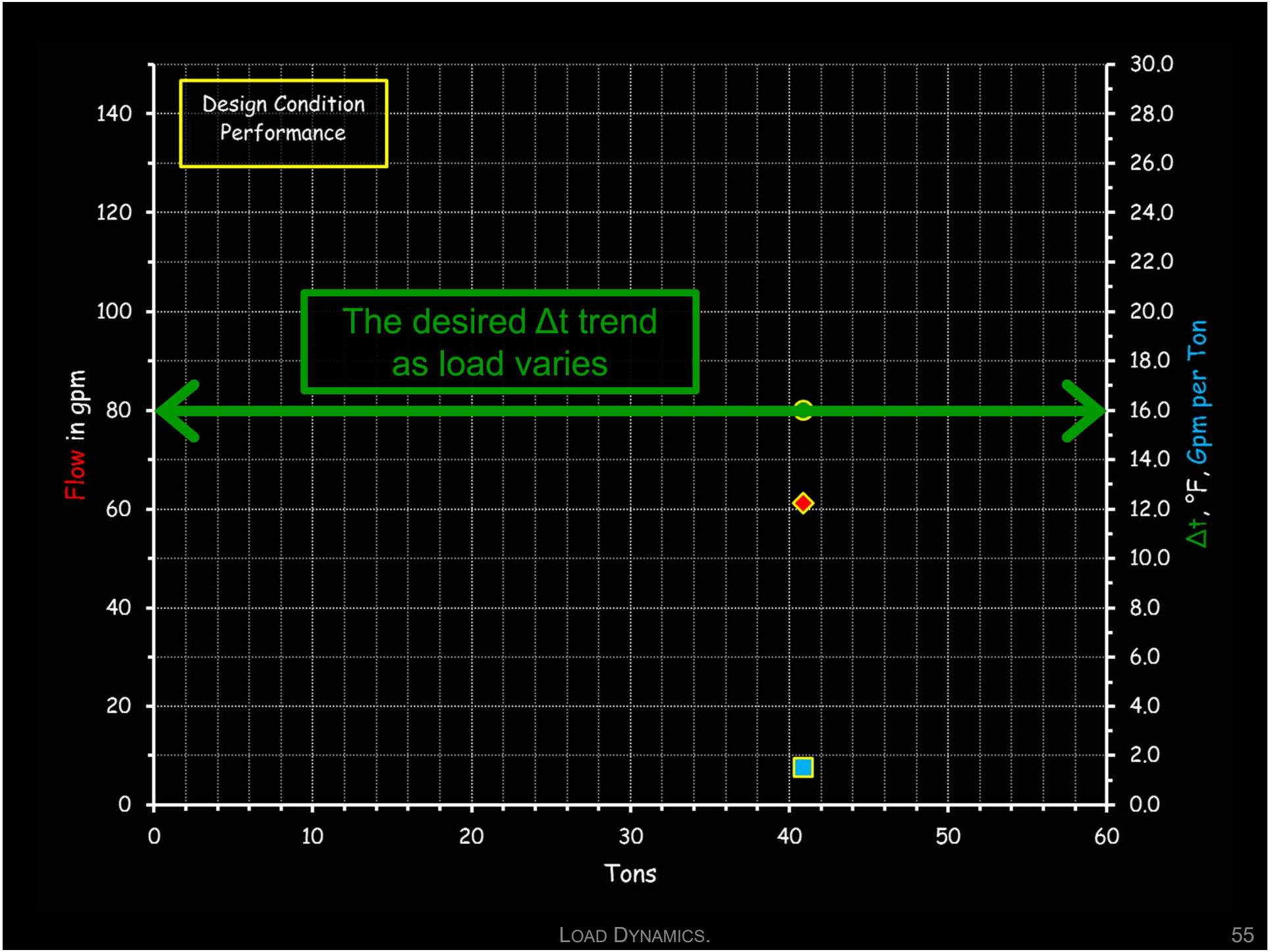

Relief Fan
12,580 cfm at 0.70 in.w.c.
38% static efficiency
445 rpm
3.6 bhp, 5 hp motor
Toilet Exhaust
Riser to and From
Other Floors
NC Relief
Air Damper
From Ceiling
Return Plenum
NO Return
Air Damper
2,800 cfm
Minimum
Outdoor Air
NC OA
Damper
MERV 8 Pre-filters
Cooling Coil
Air Flow - 14,000 cfm
Airside Δp - 0.6
Water flow - 66.2 gpm
Maximum face
Rows/FPI - 6 rows,
Restroom
From Ceiling
Return Plenum
To Supply Diffusers
Series Fan Powered Terminal
Unit with Electric Reheat
(Typical Zone)
Weather Data Location:
SEATTLE_BOEING_FIELD_ISIS, WASHINGTON, USA
Weather Hours
38 to 1
76 to 39
114 to 77
152 to 115
190 to 153
228 to 191
266 to 229
304 to 267
342 to 305
Cooling Coil Lvg. Tmp.
Space
Return Air
0.4% Outdoor Clg Design
ENTHALPY - BTU PER POUND OF DRY AIR
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
DRY BULB TEMPERATURE - °F
SATURATION TEMPERATURE - °F
8% RELATIVE HUMIDITY
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
D:\Workspace 2015-11-17\00 - FDE\Misc Speaking Engagements\2018-04 Portland GE\Muni Design Day Process.aad

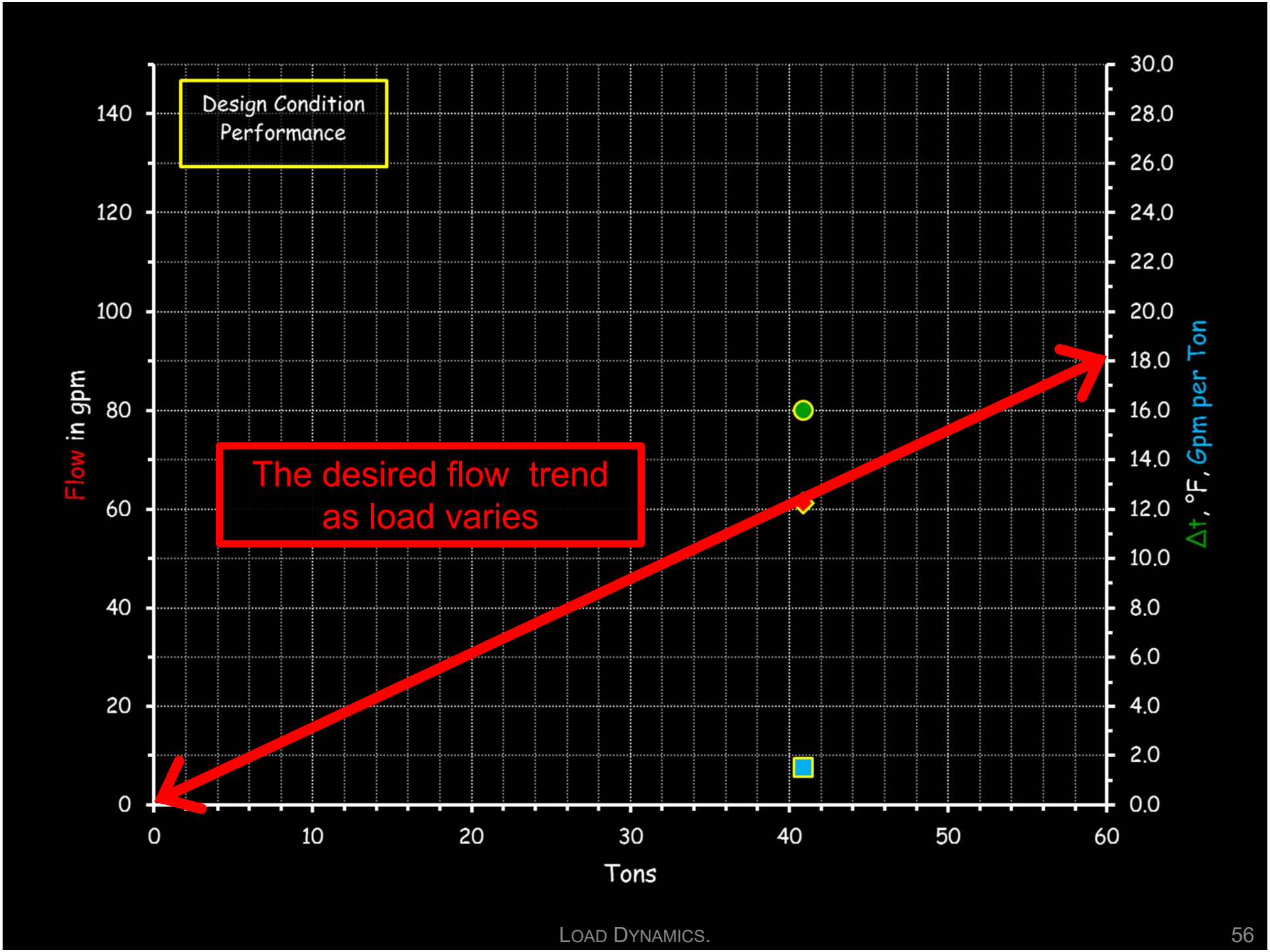
The mixed air condition is the cooling coil entering condition

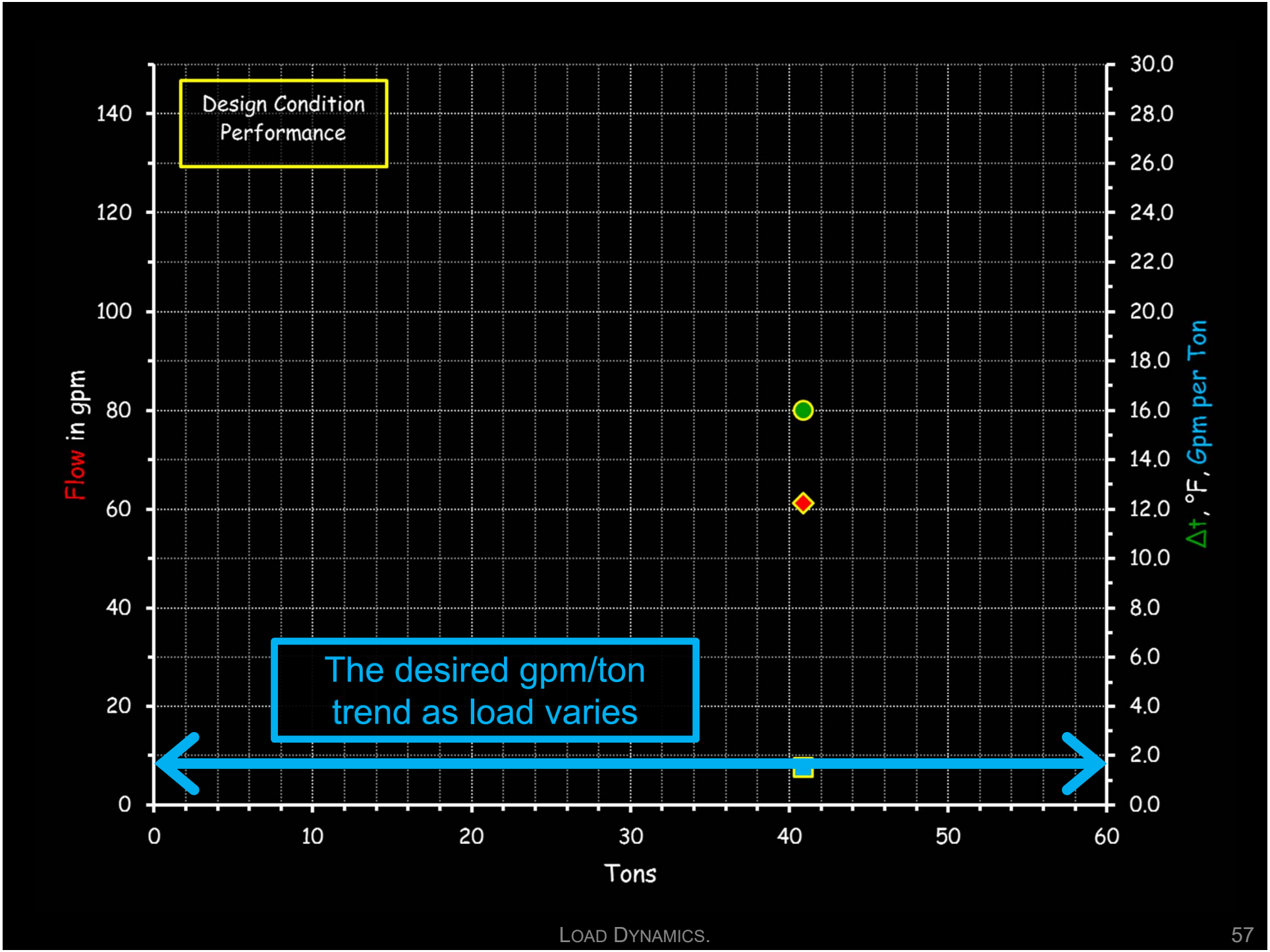


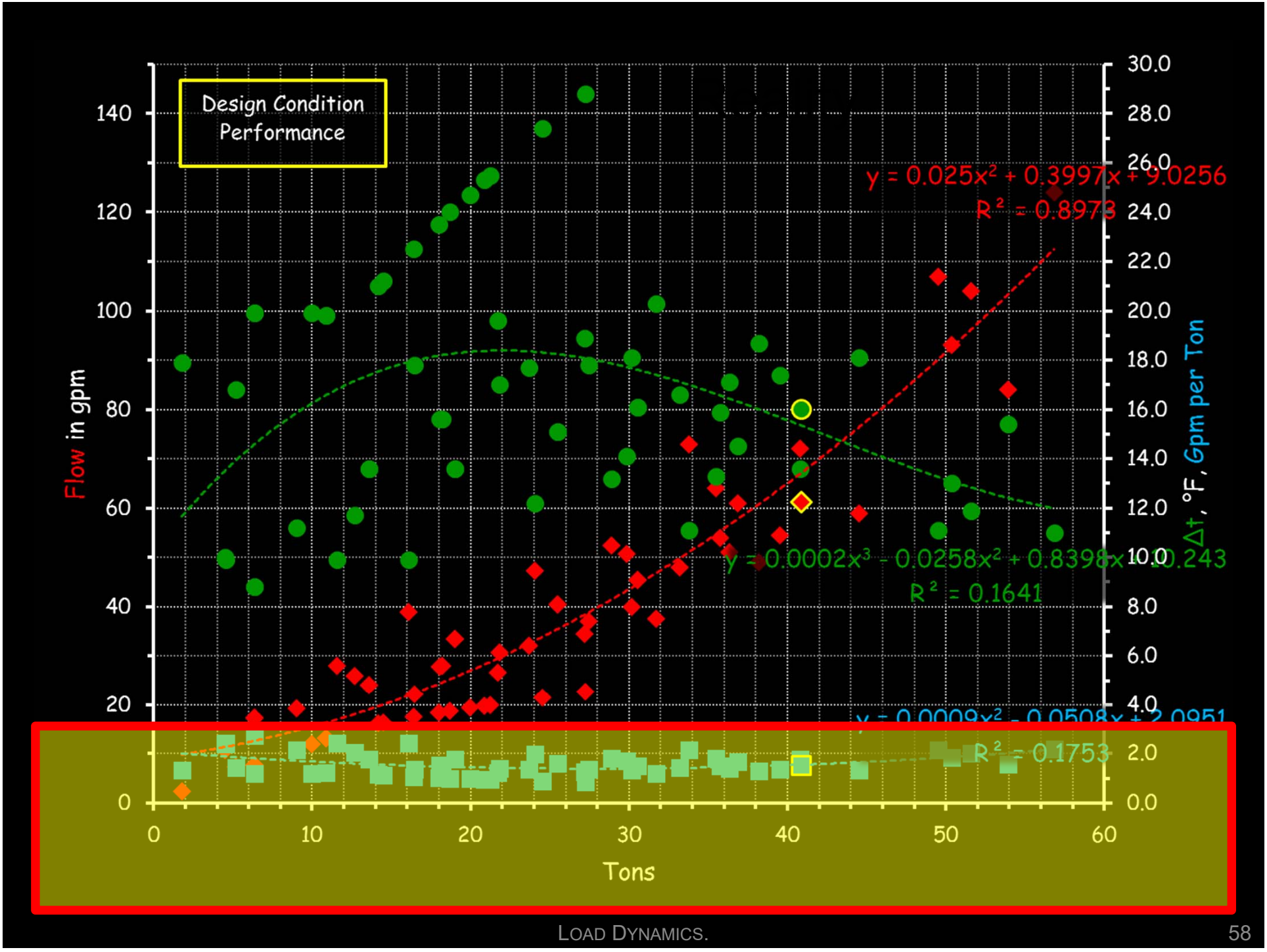
The cooling design conditions

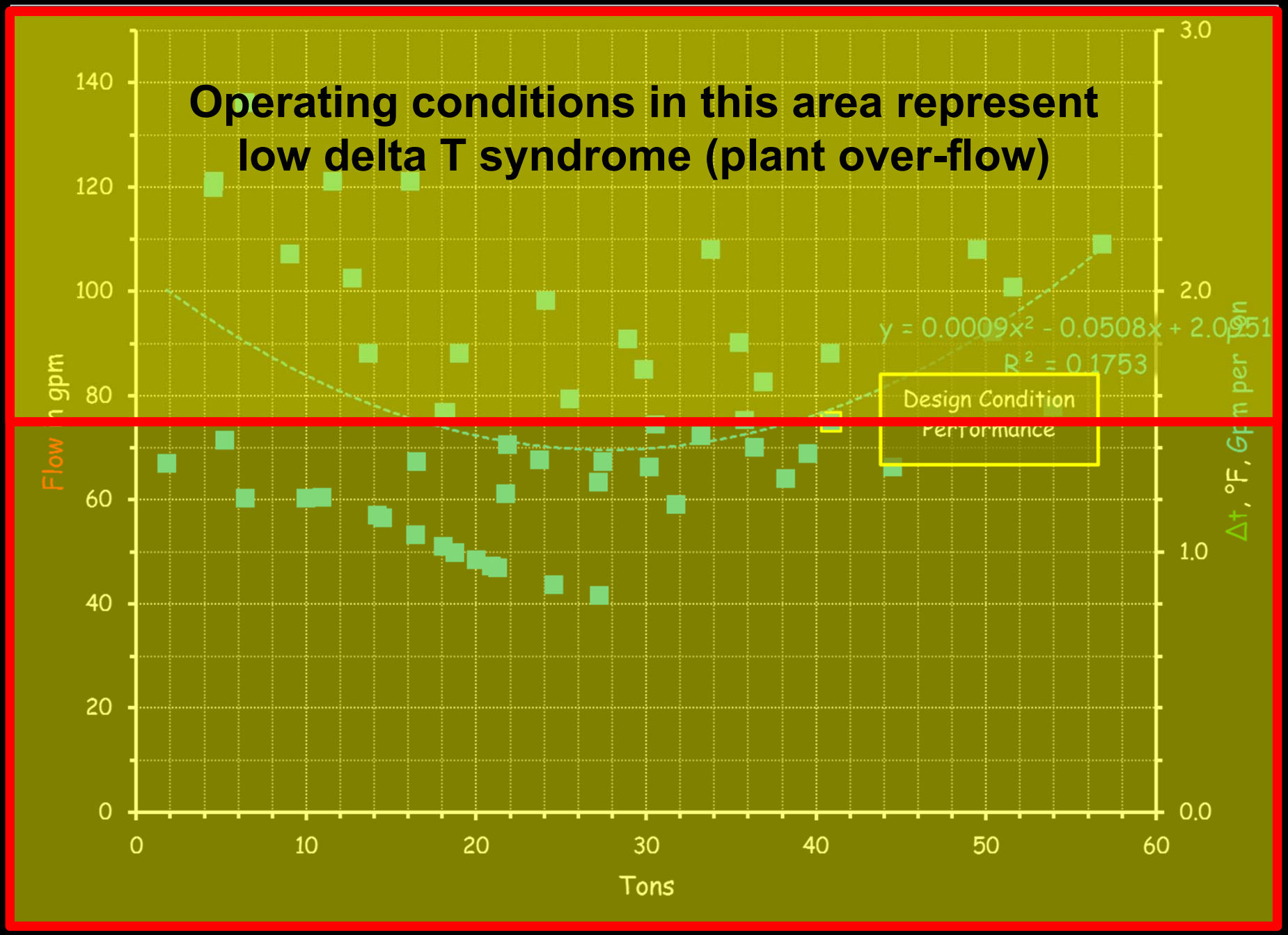



Design Condition
Performance
The desired Δt trend
as load varies
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
0
10
20
30
40
50
60


Design Condition
Performance
The desired flow trend
as load varies
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
0
10
20
30
40
50
60

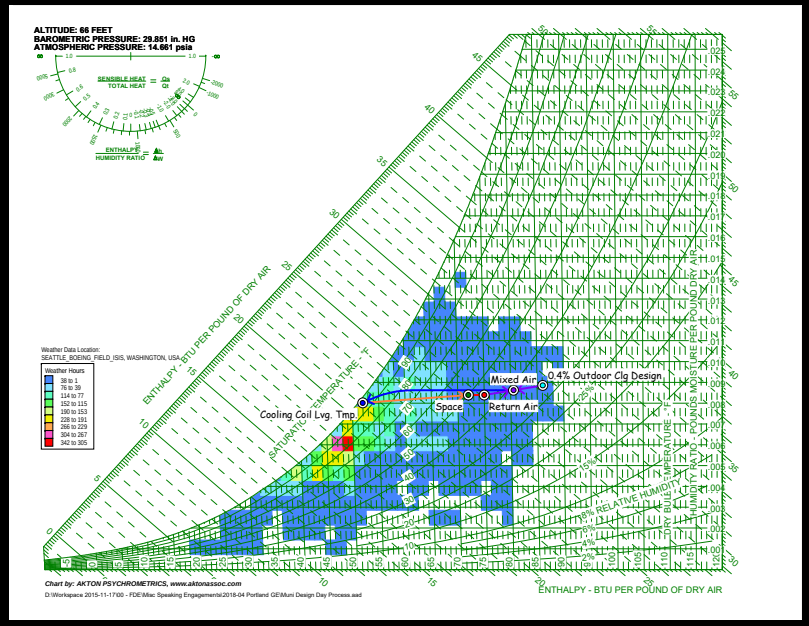

Design Condition
Performance
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
0
10
20
30
40
50
60
The desired gpm/ton
trend as load varies

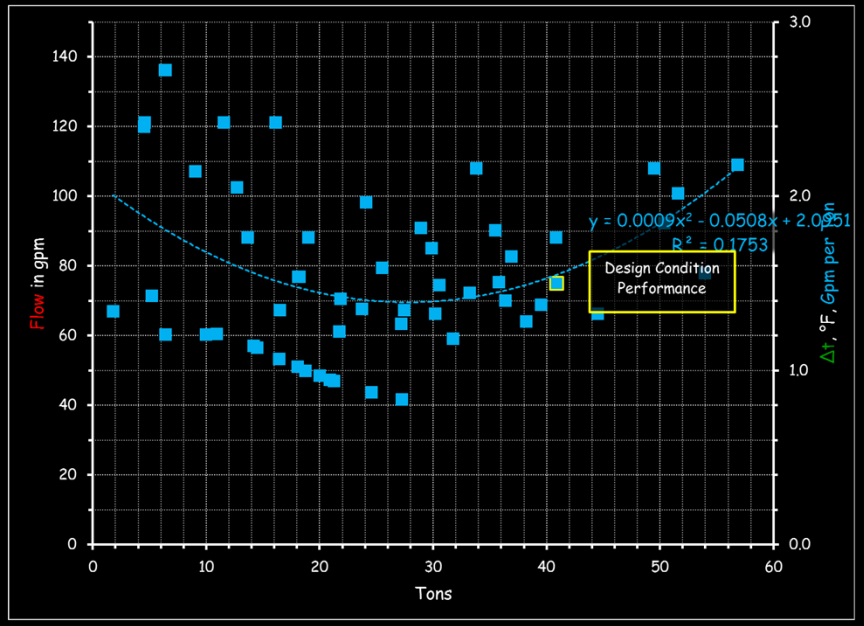

Design Condition
Performance
Flow in gpm
Δt, °F, Gpm per Ton
Tons
y = 0.025x² + 0.3997x + 9.0256
R² = 0.8973
y = 0.0002x³ - 0.0258x² + 0.8398x + 0.243
R² = 0.1641
R² = 0.1753
140
120
100
80
60
40
20
0
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
10
20
30
40
50
60


Operating conditions in this area represent low delta T syndrome (plant over-flow)
Design Condition
Performance
y = 0.0009x² - 0.0508x + 2.0251
R² = 0.1753
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
1.0
2.0
3.0
0
10
20
30
40
50
60

Load profiles and performance vary with climate

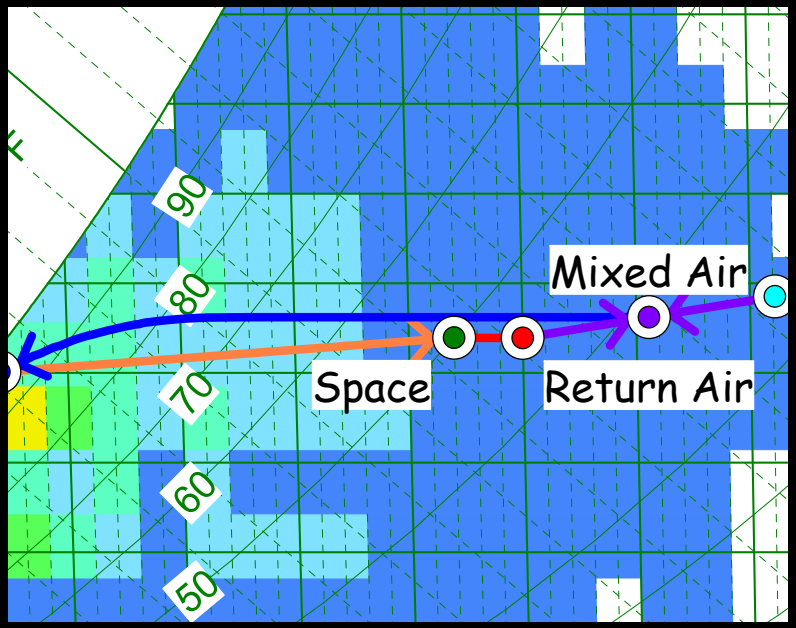
The seasonal and daily load profile seen by our building systems will vary a lot due to the nature of the climate and the performance characteristics of the equipment dealing with the climate.





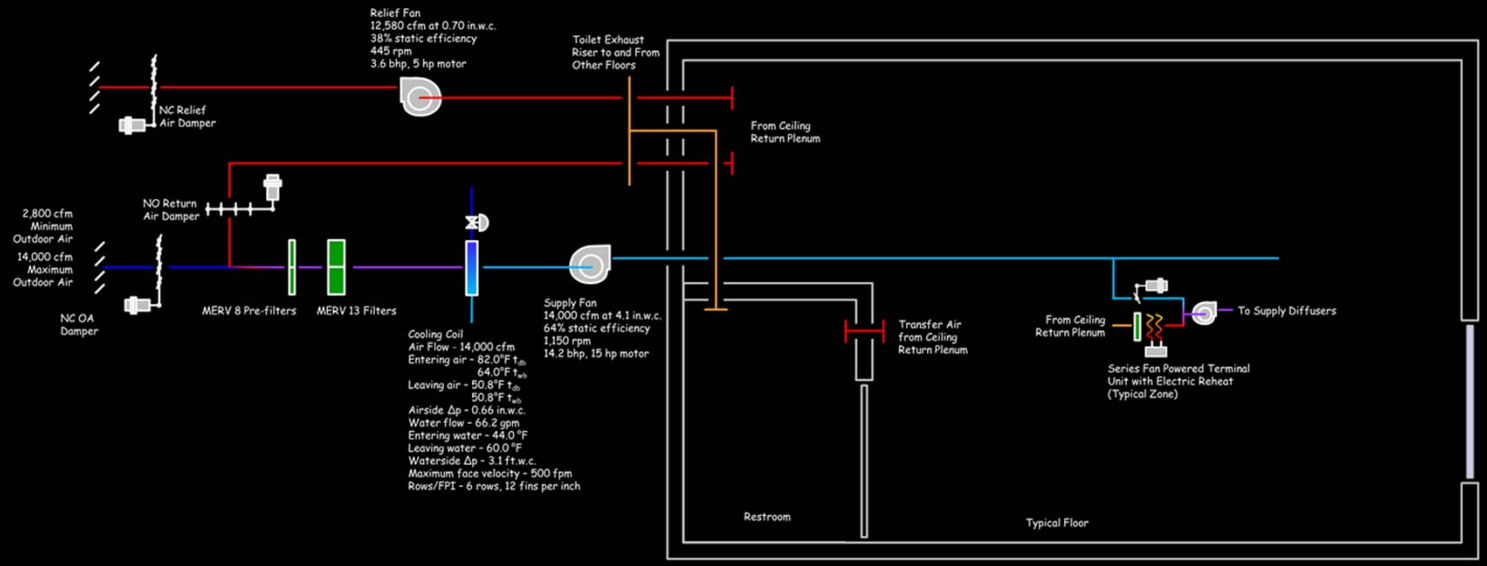
Load profiles and performance vary with climate

But the built environment served by our building systems needs to remain clean, safe, comfortable and productive, no matter what.



Equipment performance must follow load profile

Selecting, controlling and tuning the systems to follow the seasonal and daily load profile is a very important part of the over-all design, commissioning and operation process



The control system's crucial role

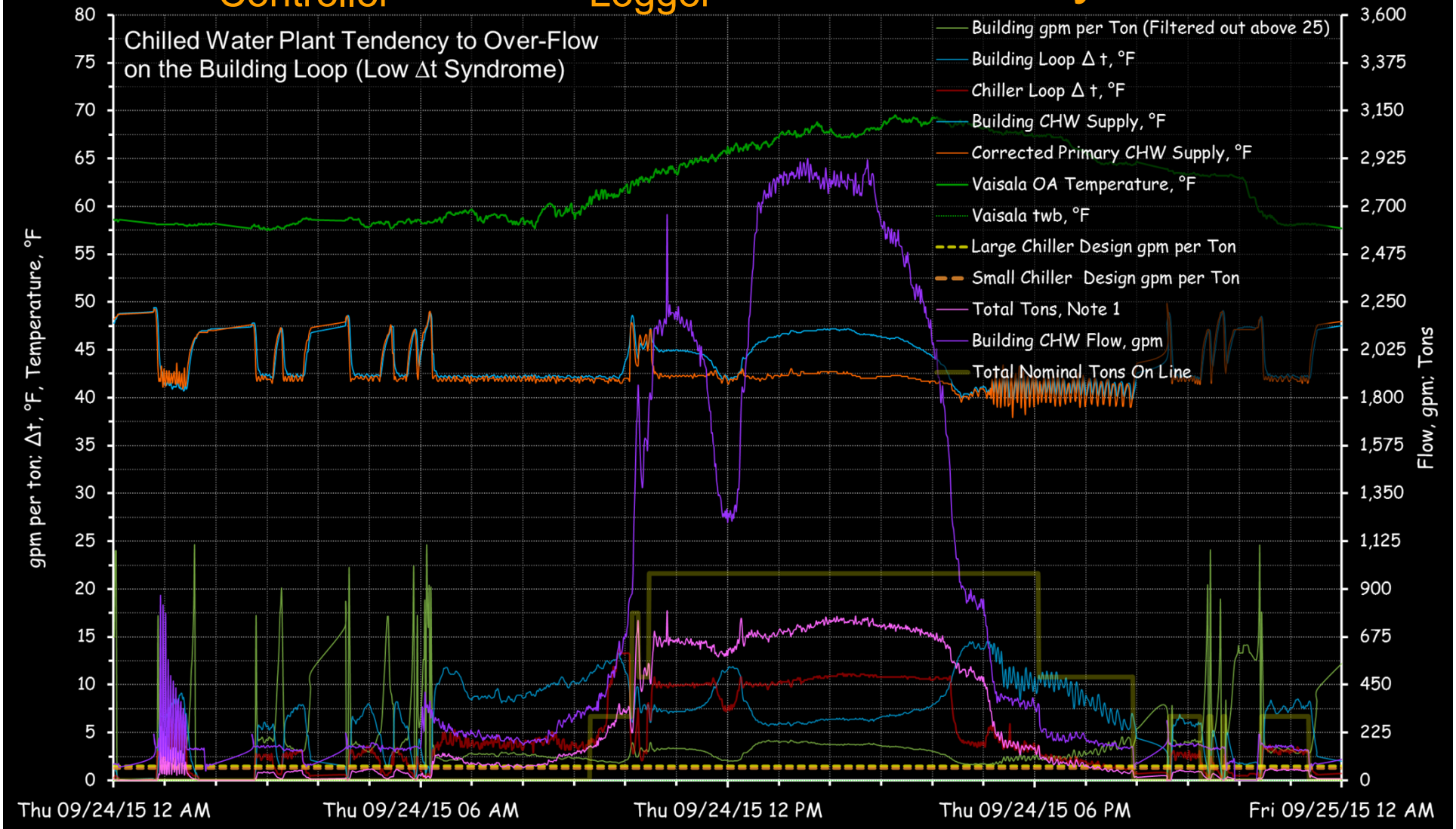
- Ensures systems perform as intended
- Manages system dynamics associated with load profile variations
- Supports functional testing
- Supports data logging and trending
- Supports persistence
- Informs future decisions

Data loggers

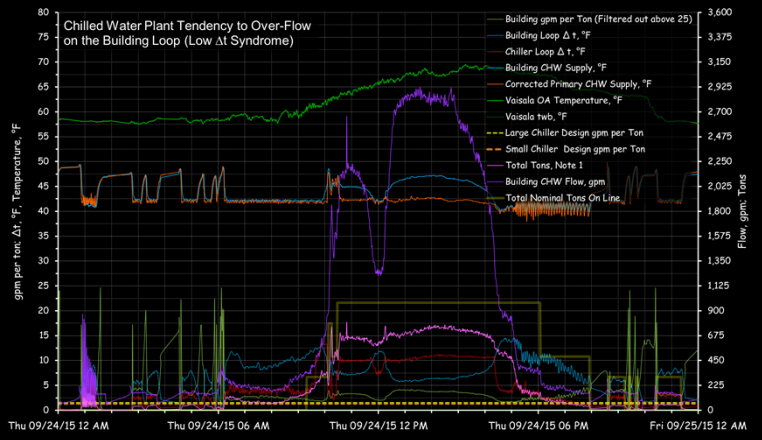
Data loggers supplement the control systems trending capabilities

- Potential for faster sampling rates
- Pick up data where points are missing in the control system

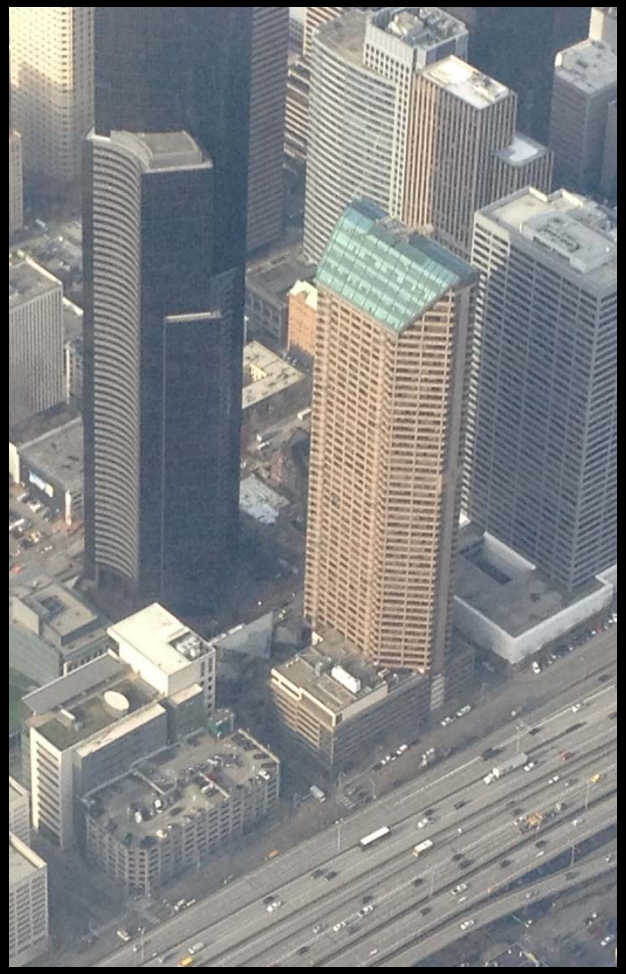
$Data_{Controller}$ + $Data_{Logger}$ = Trend Analysis



Trend analysis + Testing = A building dialog



Example of a load profile dialog



FADE IN:

EXT. EARLY – MORNING

- Cx provider with tool kit enters building and is greeted by the operating staff and a project manager

PROJECT ENGINEER (To Operating Team)

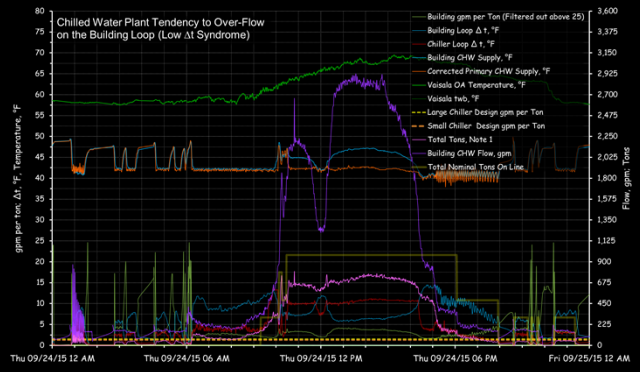
- *Our Cx provider has an idea about how to size the chillers for our new plant and would like to see what we have currently*

CHIEF ENGINEER

- Sure, let's head up and take a look around

FADE TO CHILLER PLANT:

Pump Identification →	P14-3 Stand-Alone (Discharge Full Open)			P14-3 Full Open (Pumping through CH-3)		
Service Area	Primary CHW through Chiller 2			Primary CHW through Chiller 2		
Physical Location of Unit	14th Floor Mechanical Room			14th Floor Mechanical Room		
Pump Information:	**Design**	**Submitted/TAB**	**Actual**	**Design**	**Submitted/TAB**	**Actual**
Manufacturer:			Paco			Paco
Model #:			29-60151859001			29-60151859001
Serial #:						
Part / Catalog #:			KP 6015, 6x8x12			KP 6015, 6x8x12
Nameplate GPM:			1,460.0			1,460.0
Actual Flow (GPM)			1,650.0			1,520.0
Nameplate Head (Ft):			50.0			50.0
Differential Pressure (Feet Hd)			50.6			54.5
Nameplate HP:			25.0			25.0
BHP:			24.5			23.8
Nameplate RPM:			1,150			1,150
Actual RPM:			1,181			1,181
Listed Impeller Diameter:			11.9			11.9
Actual Diameter (Tested):			12.1			12.1
Manual Control Information:						
Control Type:	Manual Isolation Valve			Manual Isolation Valve		
Manufacturer:						
Model:						
Device Adjustment Position:			100%			100%
Differential Pressure (Feet Hd)						
Control Information						
Controlled Medium:	Not Applicable			Not Applicable		
Control Type:						
Setpoint (BAS / Local Controller / FDE Measured):						
Final Controlled Device Position (Hz/%Open, etc.):						
Motor Data: Nameplate / Operational						
Manufacturer:	GE			GE		
HP / Efficiency / kW:	25.0	93.6%	Not Listed	25.0	93.6%	Not Listed
BHP Calc'd Meas'd Values / BHP VFD kW / VFD kW	23.6	Not Applicable	Not Applicable	23.5	Not Applicable	Not Applicable
Nameplate RPM / Measured	1,180	1,181		1,180	1,181	
Nameplate Volts:		460			460	
Voltage (VFD Display)	481	483	476	480	482	477
Nameplate Amperage:		30.4			30.4	
Amperage (VFD Display)	29.8	28.2	30.3	29.9	28.0	29.9
SFA:	Not Listed			Not Listed		
SF:	1.15			1.15		
Frame:	324T			324T		
Notes:						



CX PROVIDER

Then I bet the building knows how big the chillers need to be.

We just need to ask it the right questions.

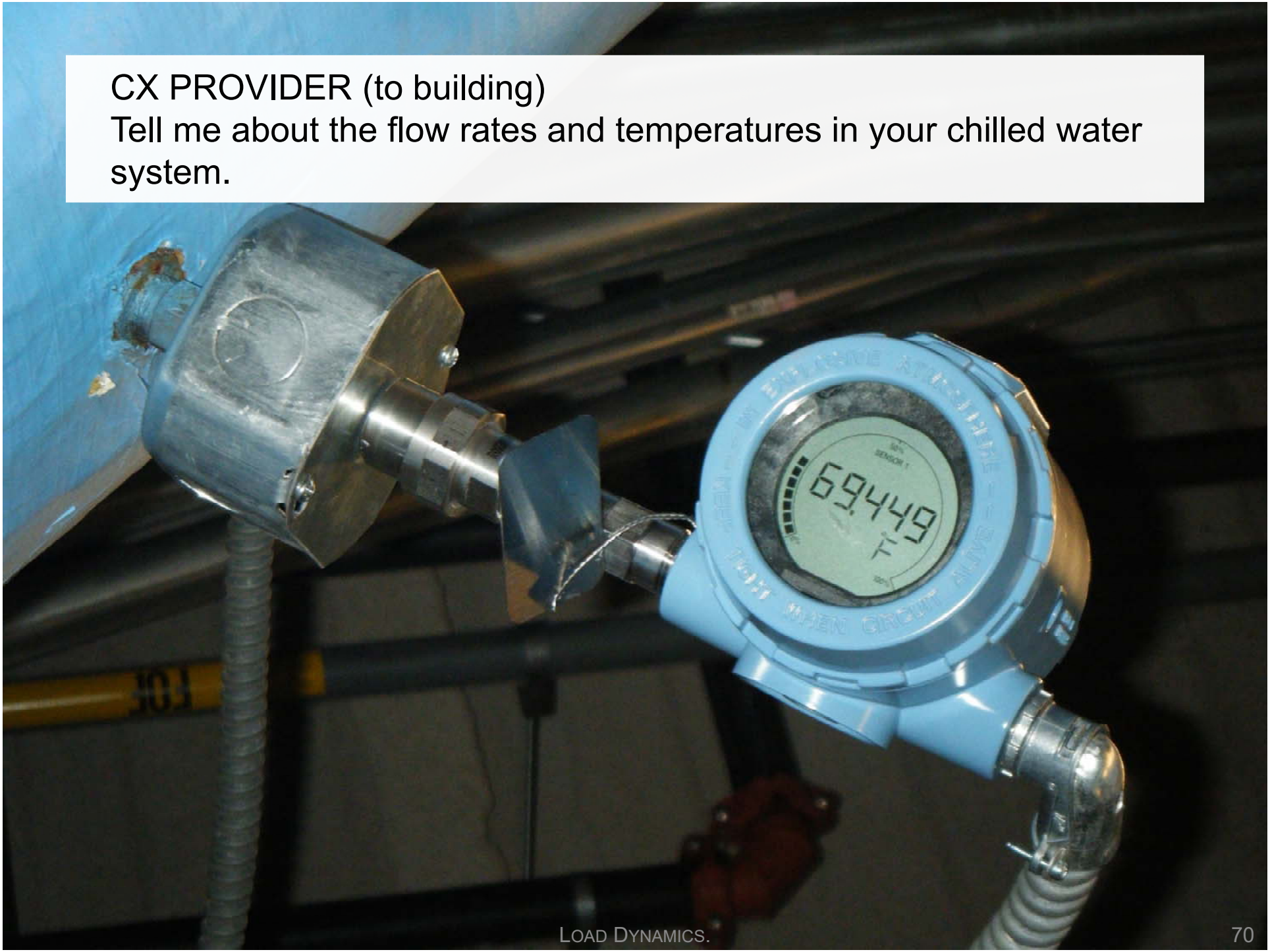
CHIEF ENGINEER

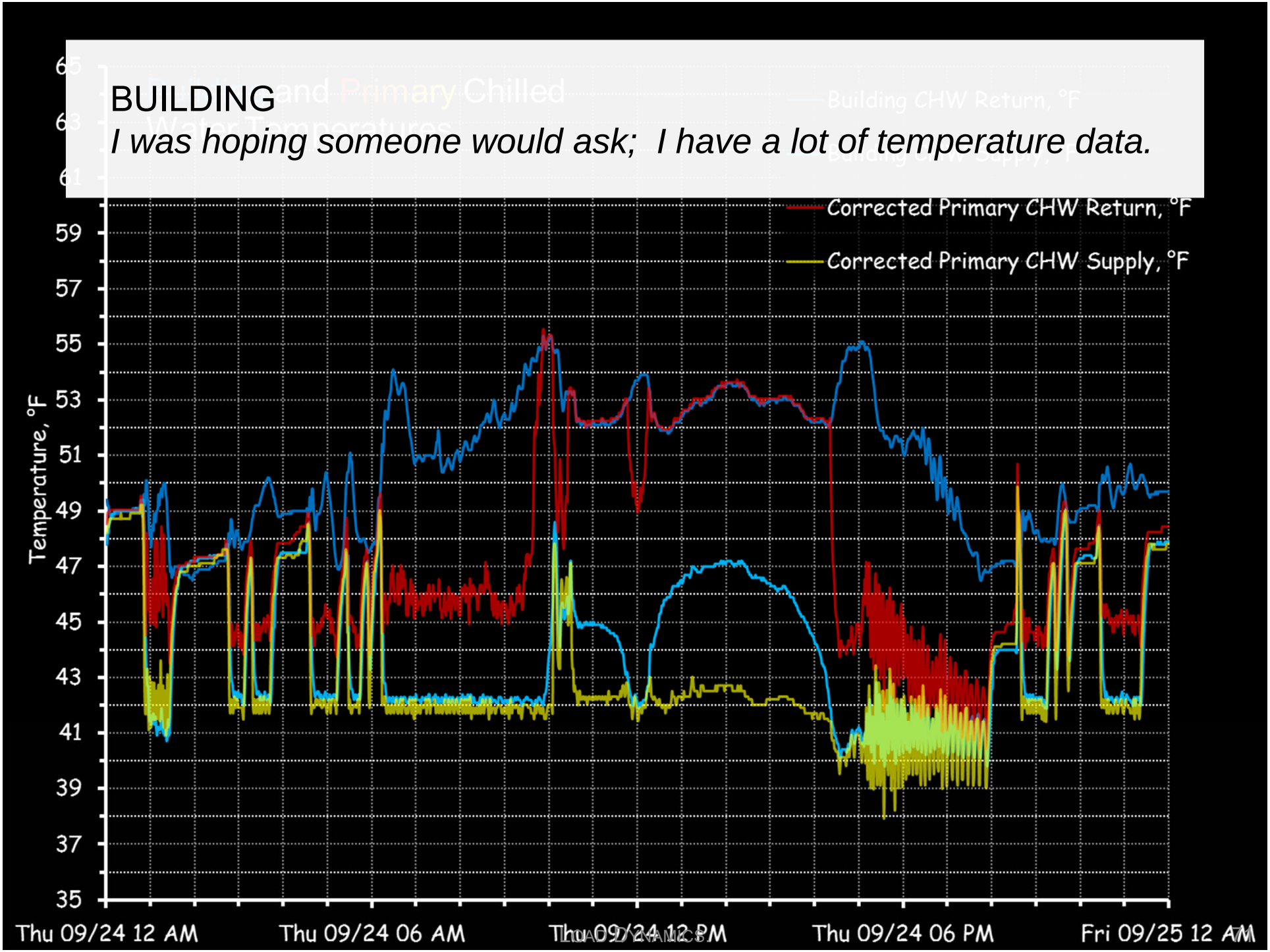
How will we do that?

CX PROVIDER

With functional testing, trending, and data logging.

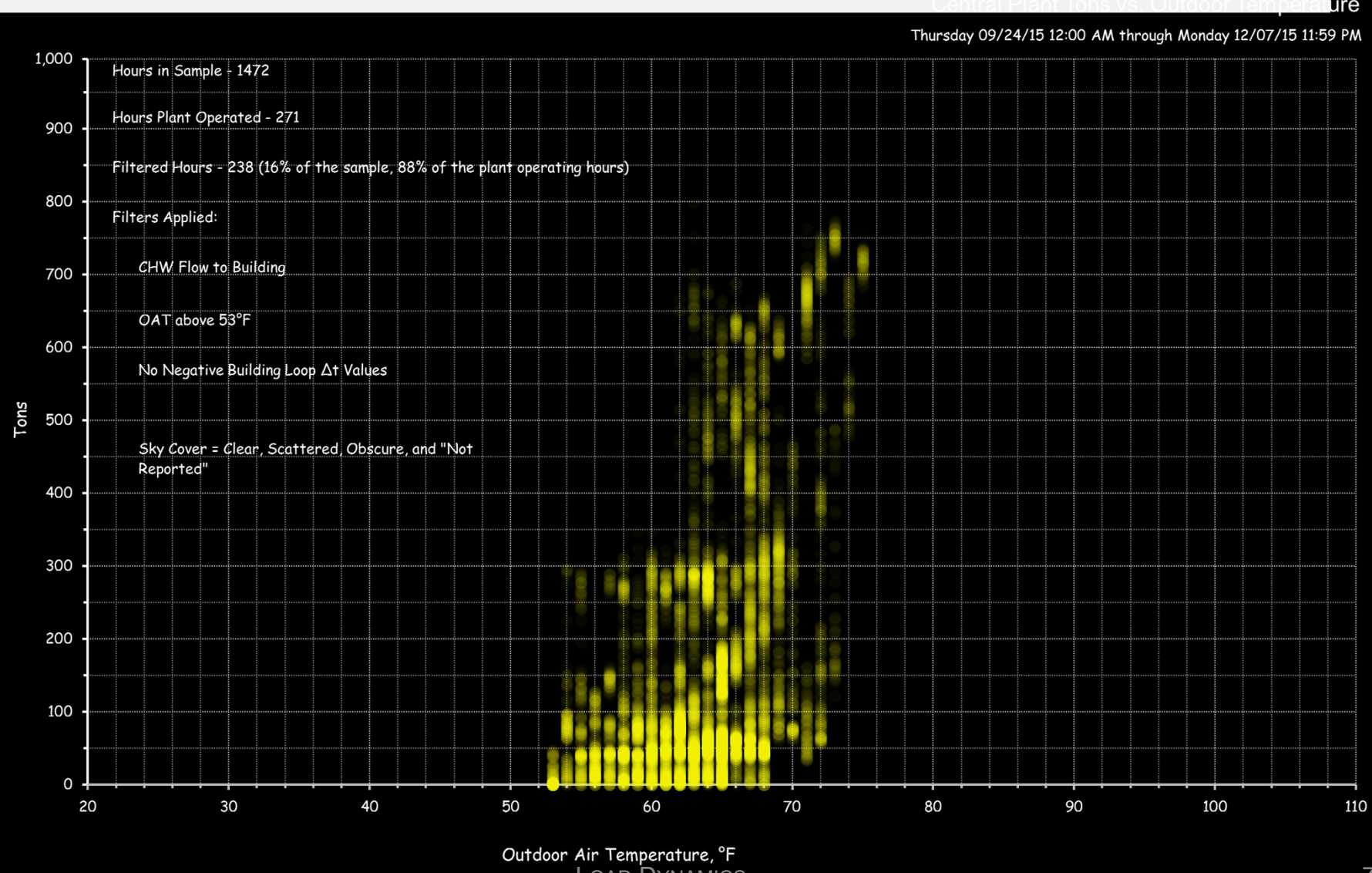
CX PROVIDER (to building)
Tell me about the flow rates and temperatures in your chilled water system.




BUILDING
I was hoping someone would ask; I have a lot of temperature data.
Corrected Primary CHW Return, °F
Corrected Primary CHW Supply, °F
Temperature, °F
65
63
61
59
57
55
53
51
49
47
45
43
41
39
37
35
Thu 09/24 12 AM
Thu 09/24 06 AM
Thu 09/24 12 PM
Thu 09/24 06 PM
Fri 09/25 12 AM

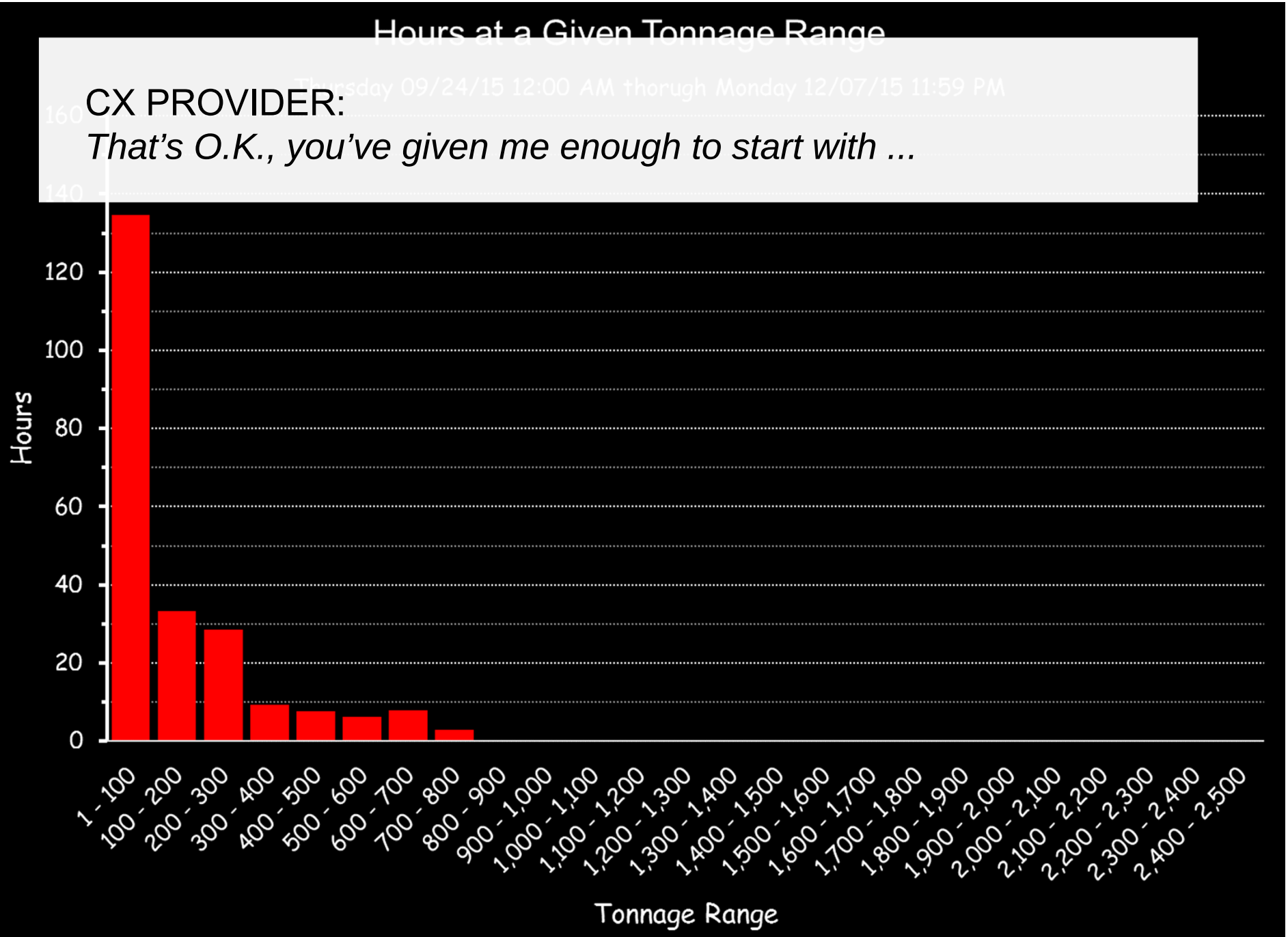
BUILDING:

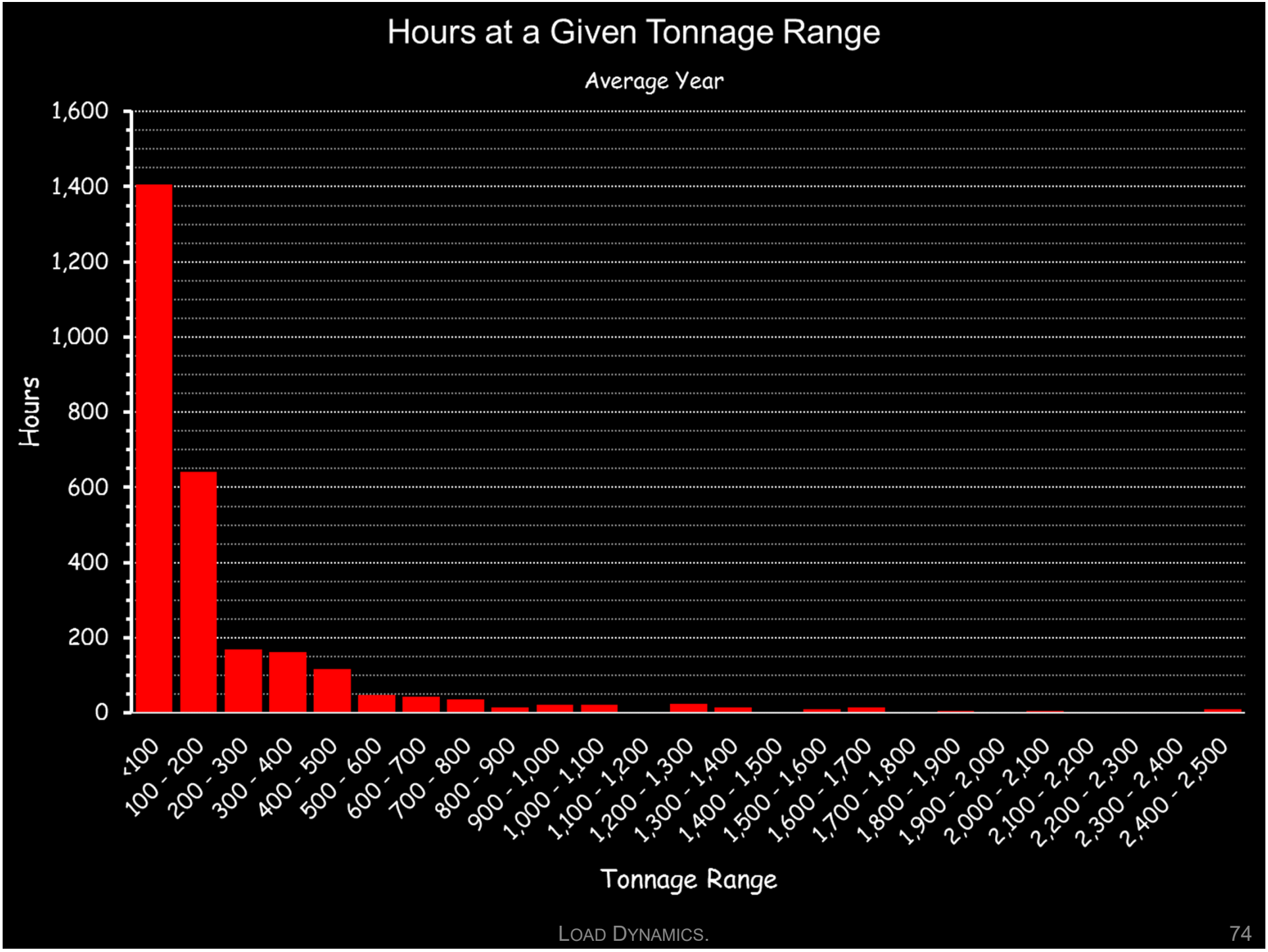
But I am afraid I only have a couple of months of flow and tonnage data. My flow meter was broken for a while.



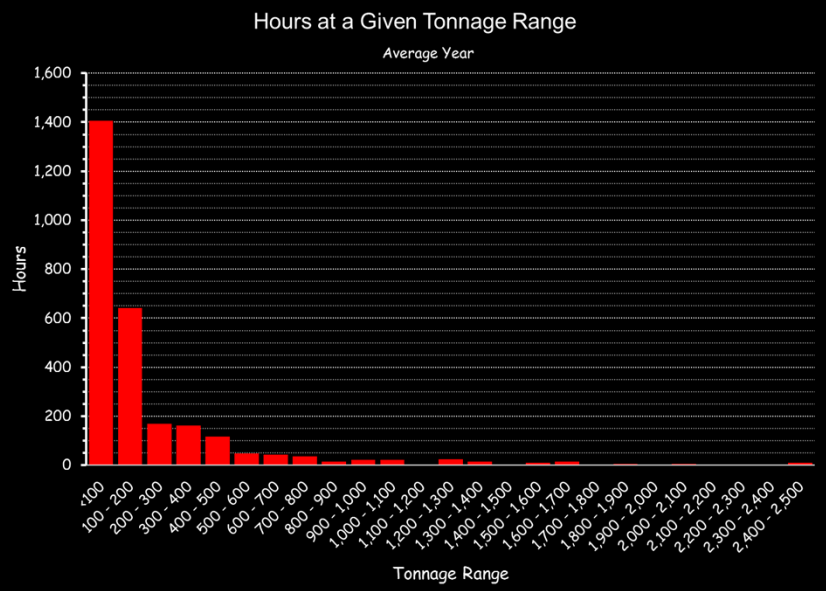
CX PROVIDER:

That's O.K., you've given me enough to start with ...




Hours at a Given Tonnage Range
Average Year
1,600
1,400
1,200
1,000
800
600
400
200
0
Hours
<100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1,000
1,000 - 1,100
1,100 - 1,200
1,200 - 1,300
1,300 - 1,400
1,400 - 1,500
1,500 - 1,600
1,600 - 1,700
1,700 - 1,800
1,800 - 1,900
1,900 - 2,000
2,000 - 2,100
2,100 - 2,200
2,200 - 2,300
2,300 - 2,400
2,400 - 2,500
Tonnage Range

The design evolves and is reviewd



FADE OUT:

FADE IN TIME PASSING MUSIC

FADE IN CX PROVIDER DOING DESIGN REVIEW ON THE NEW CENTRAL PLANT DESIGN

BUILDING:

I'm happy to see the design team paid attention to my suggestion about equipment sizes and turn down requirements.

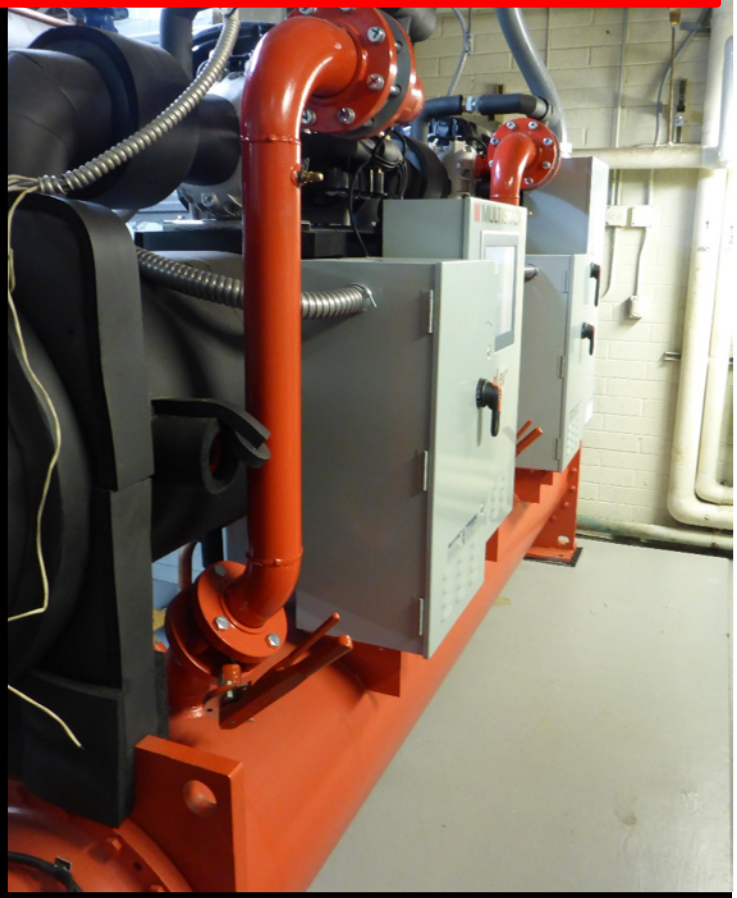
KW/TON		0.554	0.470	0.470

LOCATION		MECH RM	MECH RM	MECH RM
SERVES		CLG WATER	CLG WATER	CLG WATER
CAPACITY	TONS	300.0	1000.0	1,000.0
	KW/TON	0.554	0.470	0.470
	COP			
COMPRESSOR	TYPE	CNTFGL	CNTFGL	CNTFGL
	QUANTITY: NO	2	3	3
EVAPORATOR	FLOW: GPM	450	1,500	1,500
	EWT: F	59	59	59
	LWT: F	43	43	43
	PD: FT HD	11	18	18
	FOULING FACTOR	0.00010	0.00010	0.00010
CONDENSER	FLOW: GPM	850	2,800	2,800
	EWT: F	86	86	86
	LWT: F	76	76	76
	PD: FT HD	15	16	16
	FOULING FACTOR	0.00025	0.00025	0.00025
REFRIGERANT	TYPE	R-134A	R-134A	R-134A
	CHARGE: LBS	895	2851	2851
ELECTRICAL	VOLT/PHASE	460/3	460/3	460/3
	TOTAL KW	163.3	470.4	470.4
	MCA	261	518 [3]	518 [3]
	MOP	350	724 [3]	724 [3]
	SCCR: AMPS	100,000	100,000	100,000
OPER WEIGHT	WEIGHT: LBS	10,000	35,000	35,000
BASIS OF DESIGN	MANUFACTURER	SMARDT	SMARDT	SMARDT
	MODEL	WA095.2H	WV400.3U	WV400.3U
	NOTES	[1, 2, 4, 6]	[1, 2, 4, 6]	[1, 2, 4, 6]

PROVIDE ALL CHILLERS FROM ONE MANUFACTURER.

NOTES:

1. SINGLE POINT CONNECTION, REFER TO ELECTRICAL DRAWINGS.
2. MAGNETIC BEARING, OIL-LESS COMPRESSORS.
3. RATINGS PER COMPRESSOR.
4. PROVIDE ONE SPARE COMPRESSOR FOR EACH SIZE USED IN THE NOMINAL 300 TON AND 1000 TON CHILLERS. DELIVER AT END OF WARRANTY PERIOD – ALTERNATE BID ITEM.
5. PROVIDE 5 YEAR WARRANTY – ALTERNATE BID ITEM.
6. PROVIDE MARINE BOXES AT ENDS WITH PIPING CONNECTIONS (300 LB PRESSURE CLASS ON EVAPORATOR) AND HINGED ACCESS AT ALL ENDS.



BUILDING:

I think I will need to run some pumps and cooling towers when I run those new chillers. Will that impact how you would sequence them?

PUMPS - HYDRONIC

MARK		P14-1	P14-2	P14-3	P14-4	P14-5	P14-6
LOCATION		MECH RM	MECH RM	MECH RM	MECH RM	MECH RM	MECH RM
SERVES		CHILLED WTR	CHILLED WTR	CHILLED WTR	COND WTR	COND WTR	COND WTR
CAPACITY	FLOW: GPM	500	1,500	1,500	900	3,500	3,500
	TDH: FT	120	160	160	60	60	60
	EFFICIENCY: %	75	79	79	67	74	74
TYPE	DESCRIPTION	VIL	VIL	VIL	VIL	VIL	VIL
	MOTOR RPM	1,800	1,800	1,800	1,800	1,800	1,800
	MAX BHP	27.00	87.00	87.00	21.00	70.00	70.00
	SUCT CONN: IN	6	8	8	8	12	12
	DISCH CONN: IN	6	8	8	8	12	12
	IMP DIA: IN	11.20	13.26	13.26	8.34	10.00	10.00
ELECTRICAL	VOLT/PHASE	460/3	460/3	460/3	460/3	460/3	460/3
	MOTOR HP	40	100	100	25	75	75
	SCCR: AMPS	35,000	65,000	65,000	14,000	35,000	35,000
OPER WEIGHT	WEIGHT: LBS	1,050	2,150	2,150	950	2,600	2,600
BASIS OF DESIGN	MANUFACTURER	PACO	PACO	PACO	PACO	PACO	PACO
	MODEL	VLS 6x6x11.5	VLS 8X8X15	VLS 8X8X15	VLS 6x6x11.5	VLS 12x12x13	VLS 12x12x13
	NOTES	[1, 2, 3, 4]	[1, 2, 3, 4]	[1, 2, 3, 4]	[1, 2, 3, 4]	[1, 2, 3, 4]	[1, 2, 3, 4]

PROVIDE ALL PUMPS FROM ONE MANUFACTURER.

NOTES:

1. REFER TO ELECTRICAL DRAWINGS FOR DISCONNECT SWITCH.
2. PROVIDE WITH VARIABLE FREQUENCY DRIVE AND SUCTION DIFFUSER.
3. MOUNT PUMP ON SPRING ISOLATED CONCRETE INERTIA BASE; OPER WEIGHT DOES NOT INCLUDE INERTIA BASE.
4. PROVIDE ALL PUMPS WITH SUCTION DIFFUSERS; 300 LB PRESSURE CLASS ON CHILLED WATER PUMPS.

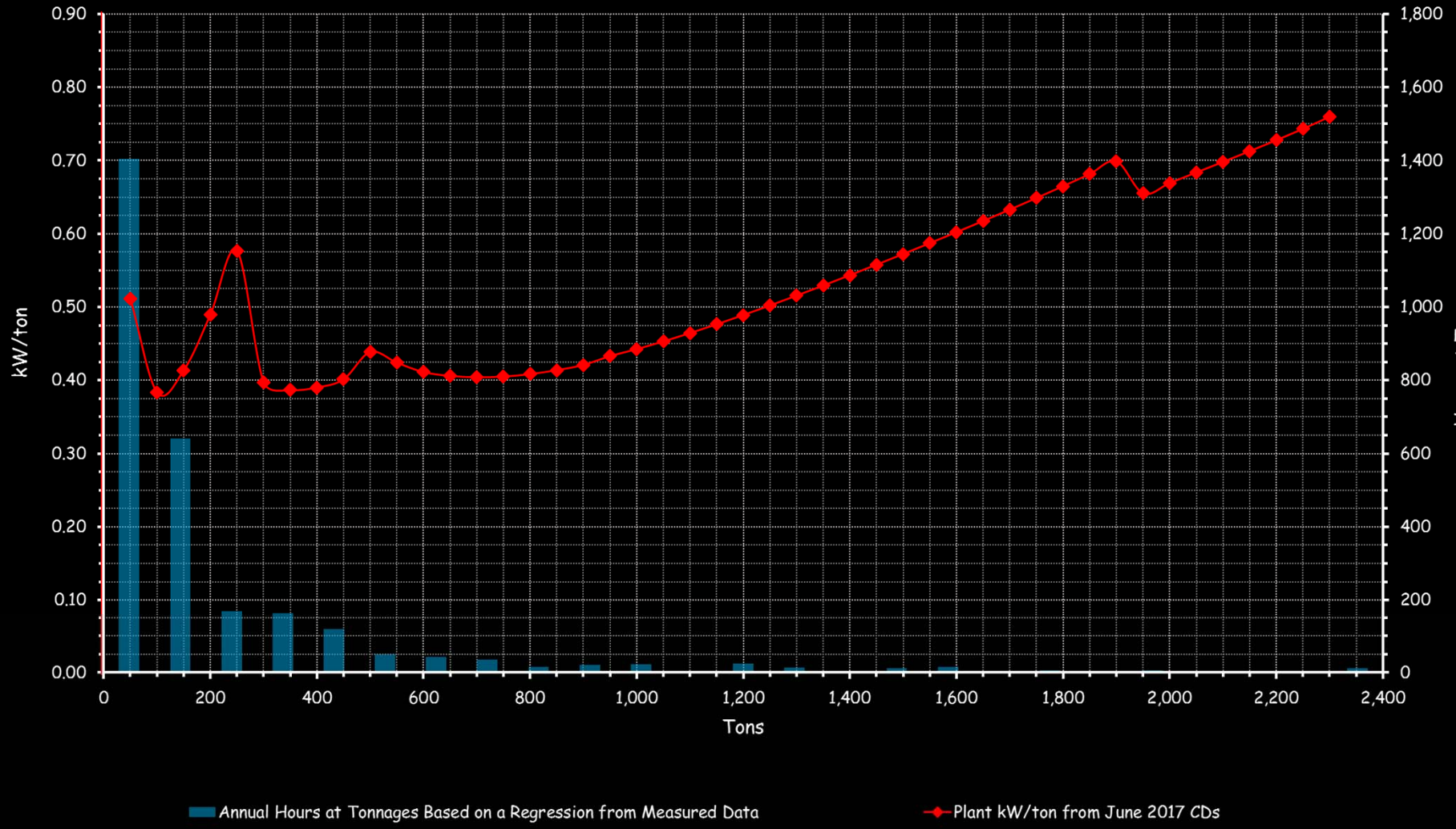
COOLING TOWERS

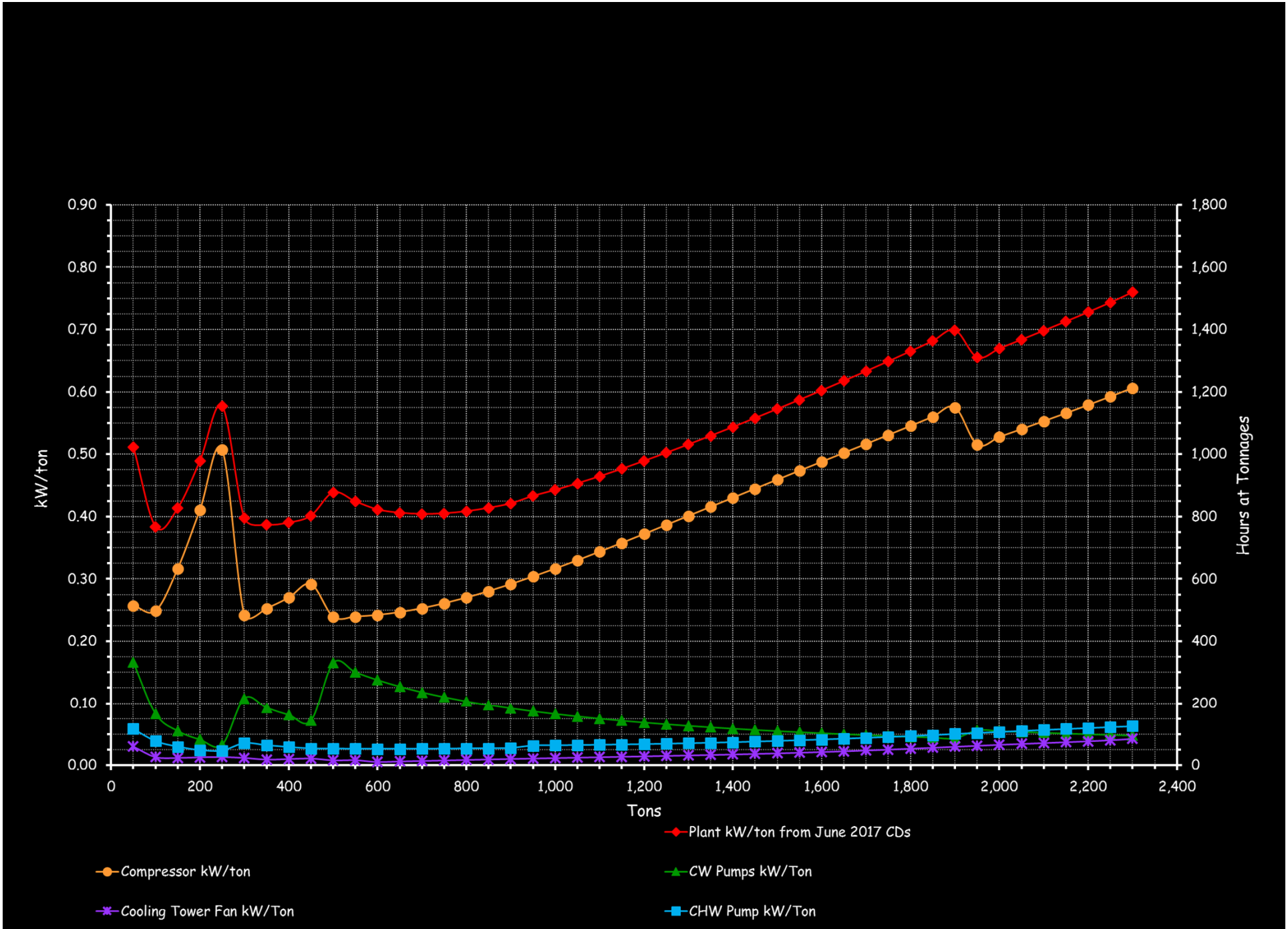
MARK		CT-1A	CT-1B
LOCATION		ROOF	ROOF
SERVES		CHILLERS	CHILLERS
TYPE	AIRFLOW CONFIG	IND DRAFT	IND DRAFT
	DISCHARGE	VERTICAL	VERTICAL
	CELLS	2	2
CAPACITY [1]	HEAT REJ: TONS	1,185	1,185
	FLOW: GPM	3,450	3,450
	AMBIENT WB: F	66	66
	EWT: F	86	86
	LWT: F	76	76
	PD: FT HD	12	12
FAN	TYPE	SILENT PROP	SILENT PROP
	FANS: NO	2	2
	AIRFLOW: CFM	268,800	268,800
	ESP: IN WG	–	–
	TOTAL MOTOR HP	60	60
	PONY MOTOR HP	–	–
	VOLT/PHASE	460/3	460/3
BASIN HEATER	HEATERS	–	–
	CAPACITY: KW	–	–
	VOLT/PHASE	460/3	460/3
ELECTRICAL	SCCR: AMPS	14,000	14,000
OPER WEIGHT	WEIGHT: LBS	43,780	43,780
BASIS OF DESIGN	MANUFACTURER	EVAPCO	EVAPCO
	MODEL	UT-224-418	UT-224-418
	NOTES	[2-7]	[2-7]

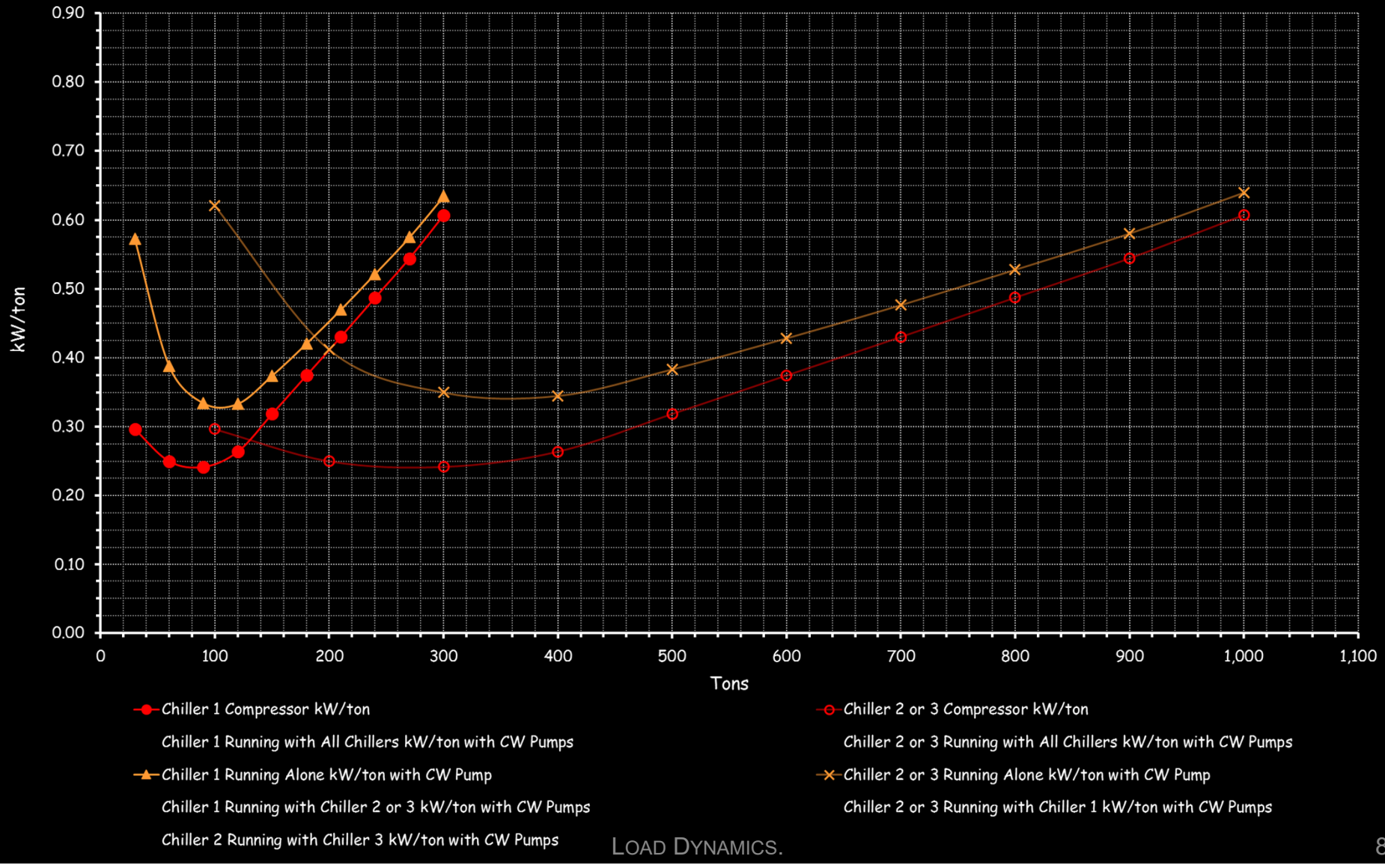
PROVIDE ALL COOLING TOWERS FROM ONE MANUFACTURER.

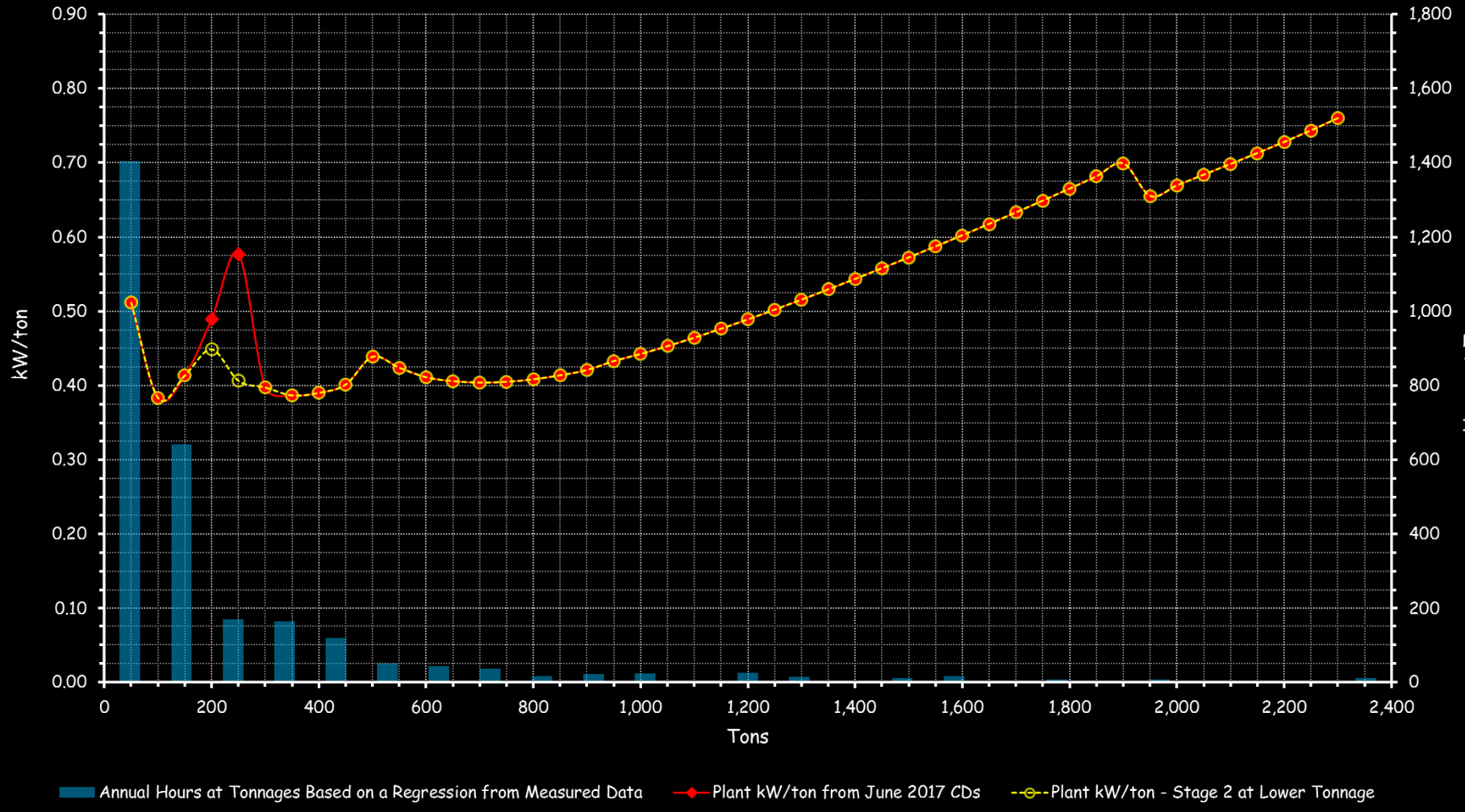
NOTES:

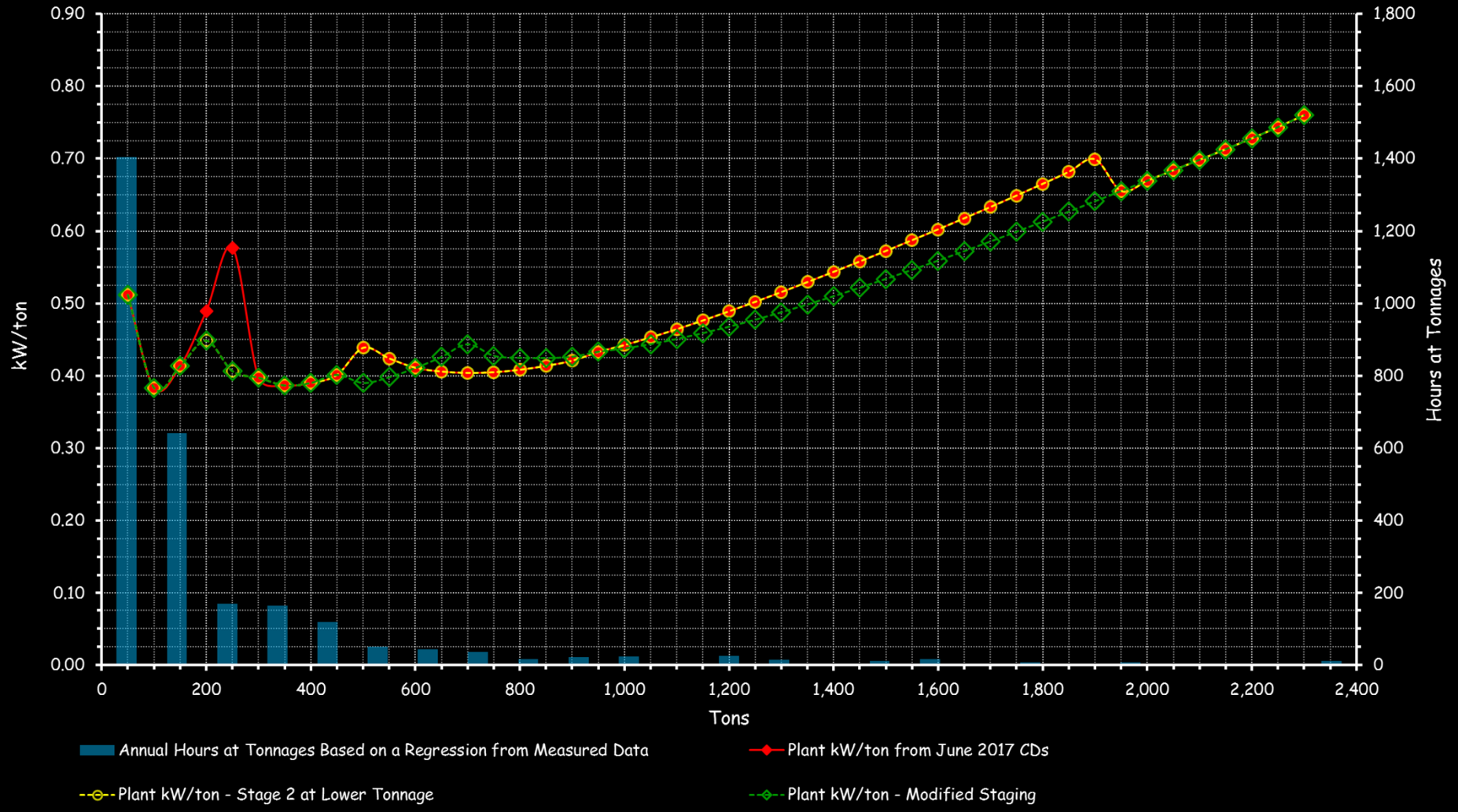
1. CAPACITIES BASED ON WATER.
2. REFER TO ELECTRICAL DRAWINGS FOR MOTOR STARTER AND DISCONNECT SWITCH.
3. PROVIDE WITH VIBRATION CUTOUT SWITCH.
4. PROVIDE WITH VARIABLE SPEED DRIVE AND FAN MOTORS.
5. PROVIDE WITH VORTEX ELIMINATOR AND BOTTOM PIPING CONNECTIONS.
6. PROVIDE STAINLESS STEEL PAN AND SUMP SWEEP PIPING/NOZZLES.
7. PROVIDE WITH REMOVABLE MOTOR LIFTING DAVIT PER 2-CELL TOWER, AND LIFTING DAVIT MOUNTING CHANNEL ON EACH TOWER CELL.


0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
kW/ton
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Hours at Tonnages
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
Tons
Annual Hours at Tonnages Based on a Regression from Measured Data
Plant kW/ton from June 2017 CDs


0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
kW/ton
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Hours at Tonnages
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
Tons
Plant kW/ton from June 2017 CDs
Compressor kW/ton
CW Pumps kW/Ton
Cooling Tower Fan kW/Ton
CHW Pump kW/Ton


0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
kW/ton
0
100
200
300
400
500
600
700
800
900
1,000
1,100
Tons
Chiller 1 Compressor kW/ton
Chiller 1 Running with All Chillers kW/ton with CW Pumps
Chiller 1 Running Alone kW/ton with CW Pump
Chiller 1 Running with Chiller 2 or 3 kW/ton with CW Pumps
Chiller 2 Running with Chiller 3 kW/ton with CW Pumps
Chiller 2 or 3 Compressor kW/ton
Chiller 2 or 3 Running with All Chillers kW/ton with CW Pumps
Chiller 2 or 3 Running Alone kW/ton with CW Pump
Chiller 2 or 3 Running with Chiller 1 kW/ton with CW Pumps


0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
kW/ton
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Hours at Tonnages
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
Tons
Annual Hours at Tonnages Based on a Regression from Measured Data
Plant kW/ton from June 2017 CDs
Plant kW/ton - Stage 2 at Lower Tonnage


0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
kW/ton
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Hours at Tonnages
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
Tons
Annual Hours at Tonnages Based on a Regression from Measured Data
Plant kW/ton from June 2017 CDs
Plant kW/ton - Stage 2 at Lower Tonnage
Plant kW/ton - Modified Staging

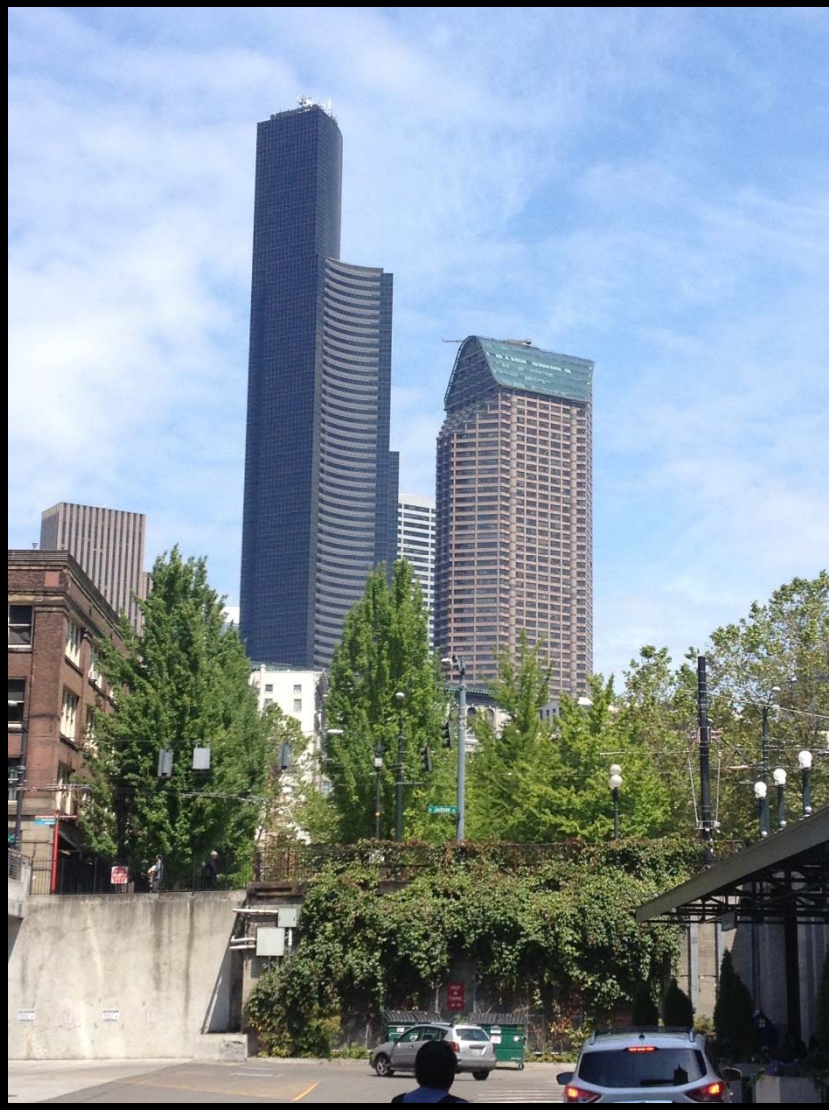
Bottom line

Com·mis·sion

kəˈmiSHən/Submit

Verb; Gerund or present participle: Commissioning

1. A process during which buildings are mentoring us about design



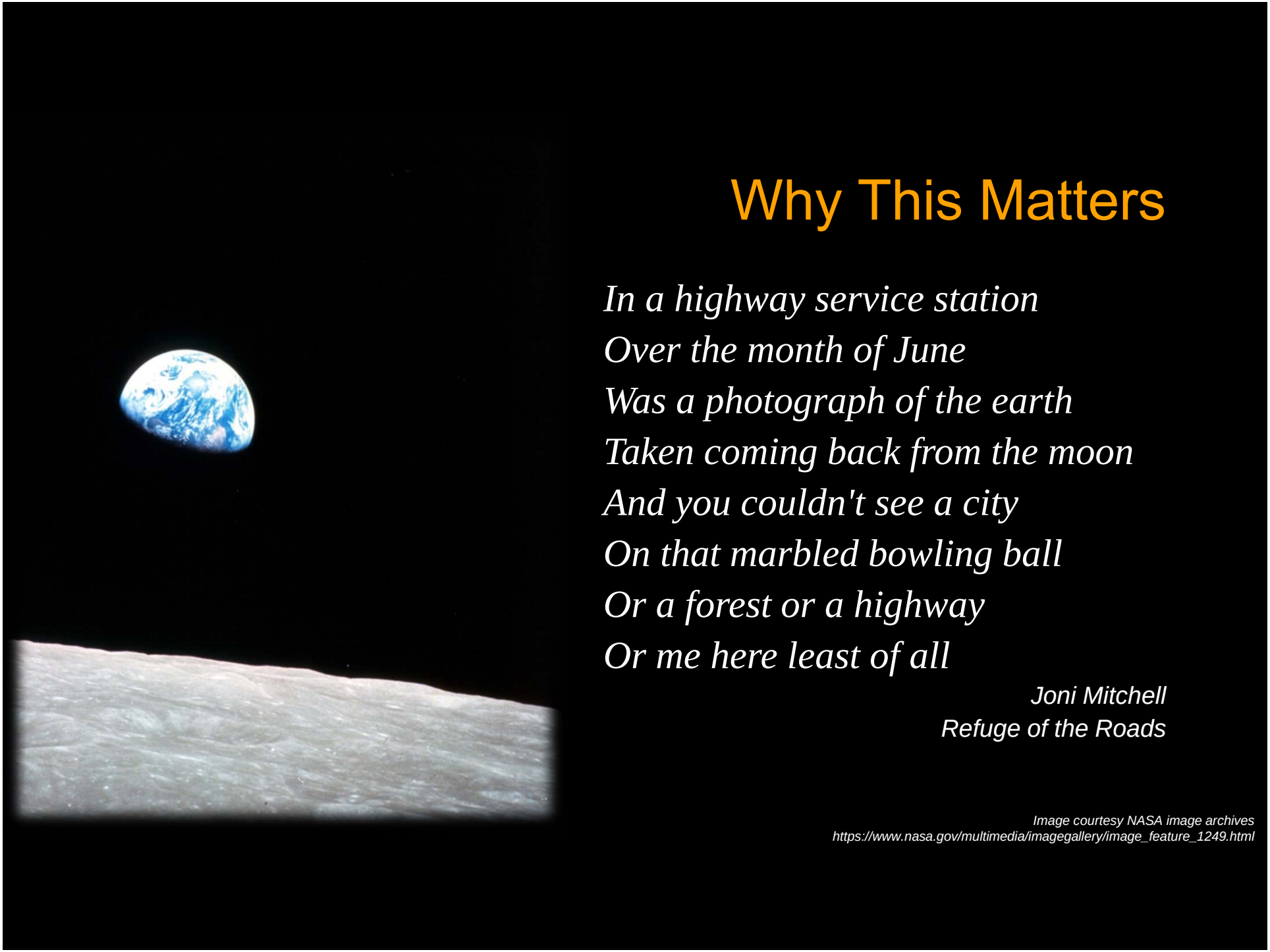
Empower your team

Why This Matters

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



Why This Matters

In a highway service station
Over the month of June
Was a photograph of the earth
Taken coming back from the moon
And you couldn't see a city
On that marbled bowling ball
Or a forest or a highway
Or me here least of all

Joni Mitchell
Refuge of the Roads

Image courtesy NASA image archives
https://www.nasa.gov/multimedia/imagegallery/image_feature_1249.html

Why This Matters

Interviewer:

What is your strongest memory of Apollo 11?

Michael Collins; Command Module Pilot, Apollo 11

Looking back at Earth from a great distance.

I really believe that if the political leaders of the world could see their planet from a distance of 100,000 miles their outlook could be fundamentally changed.

The earth must become as it appears: blue and white, not capitalist or Communist; blue and white, not rich or poor; blue and white, not envious or envied.

Small, shiny, serene, blue and white, FRAGILE.

Image courtesy NASA Image Archives; https://www.hq.nasa.gov/office/pao/History/ap11ann/kippsphotos/6550.jpg

Why This Matters

Interviewer:

That was 40 years ago. Would it look the same today?

Michael Collins; Command Module Pilot, Apollo 11

… It's certainly not serene, but definitely fragile, and growing more so. When we flew to the moon, our population was 3 billion; today it has more than doubled and is headed for 8 billion…

… The loss of habitat, the trashing of oceans, the accumulation of waste products - this is no way to treat a planet.

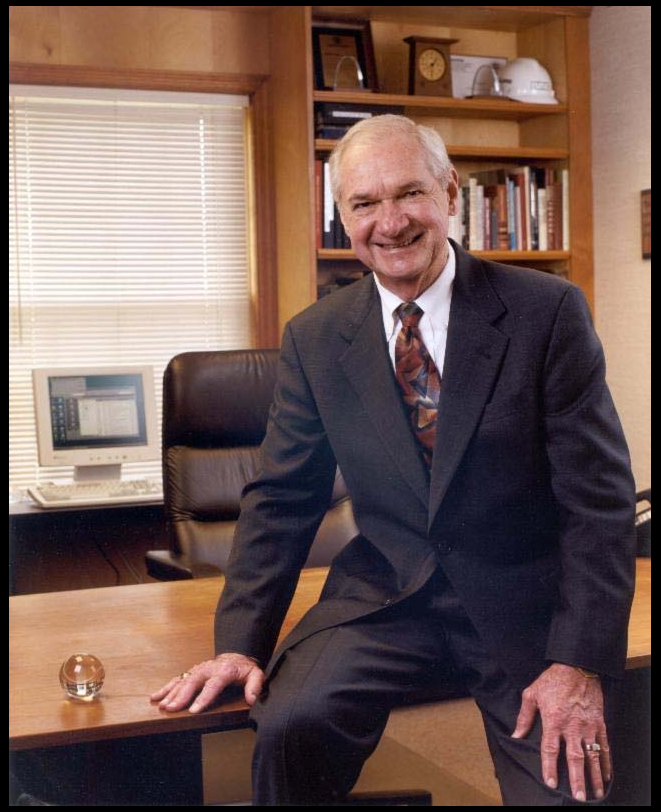
Image courtesy NASA/OSIRIS-REx team and the University of Arizona


We don’t inherit the world from our ancestors,
we borrow it from our children
Unknown

Bill Coad's thoughts on the topic

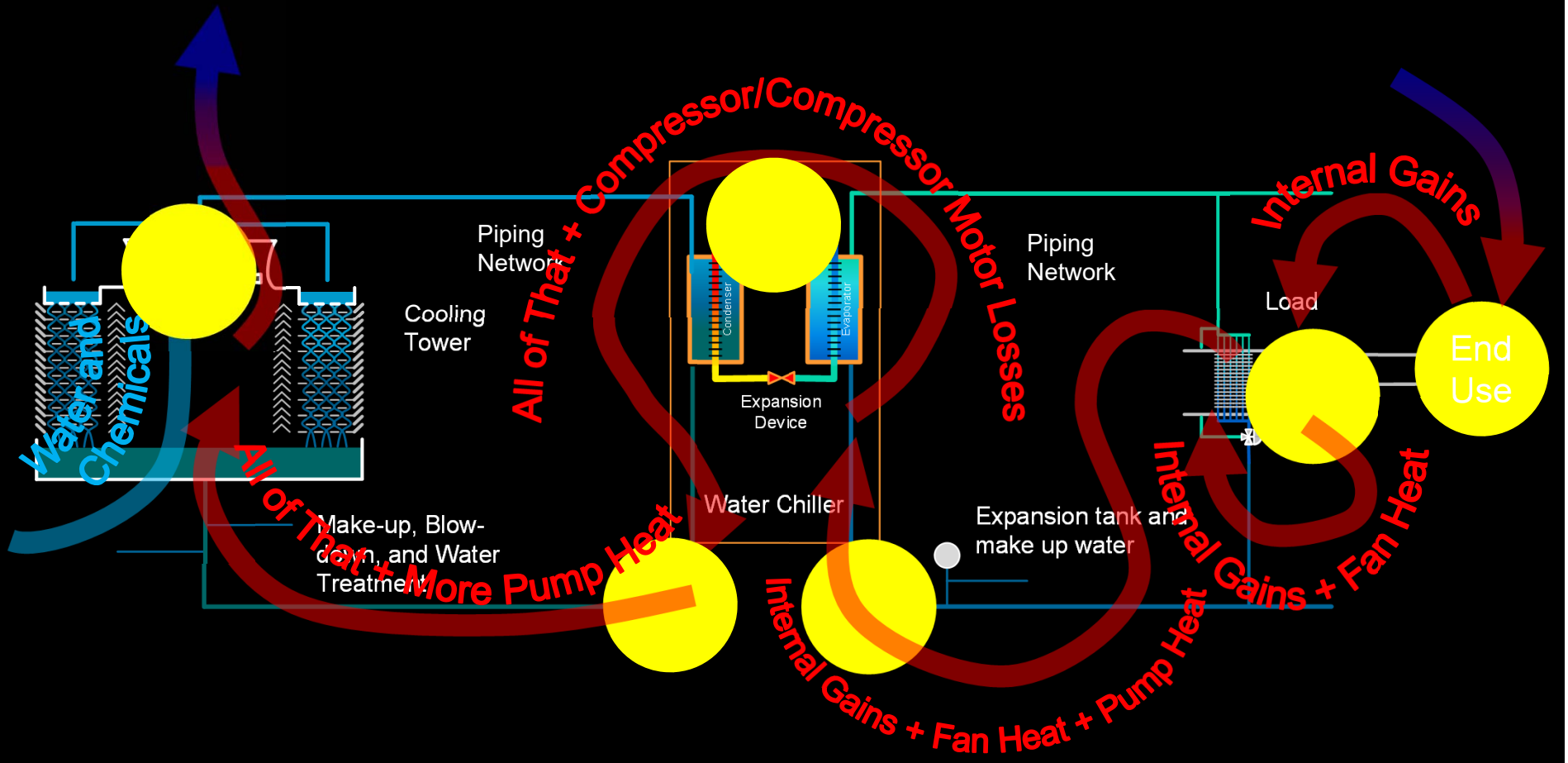
"… that is to practice our profession with an emphasis upon our responsibility to protect the long-range interests of the society we serve and, specifically, to incorporate the ethics of energy conservation and environmental preservation in everything we do."

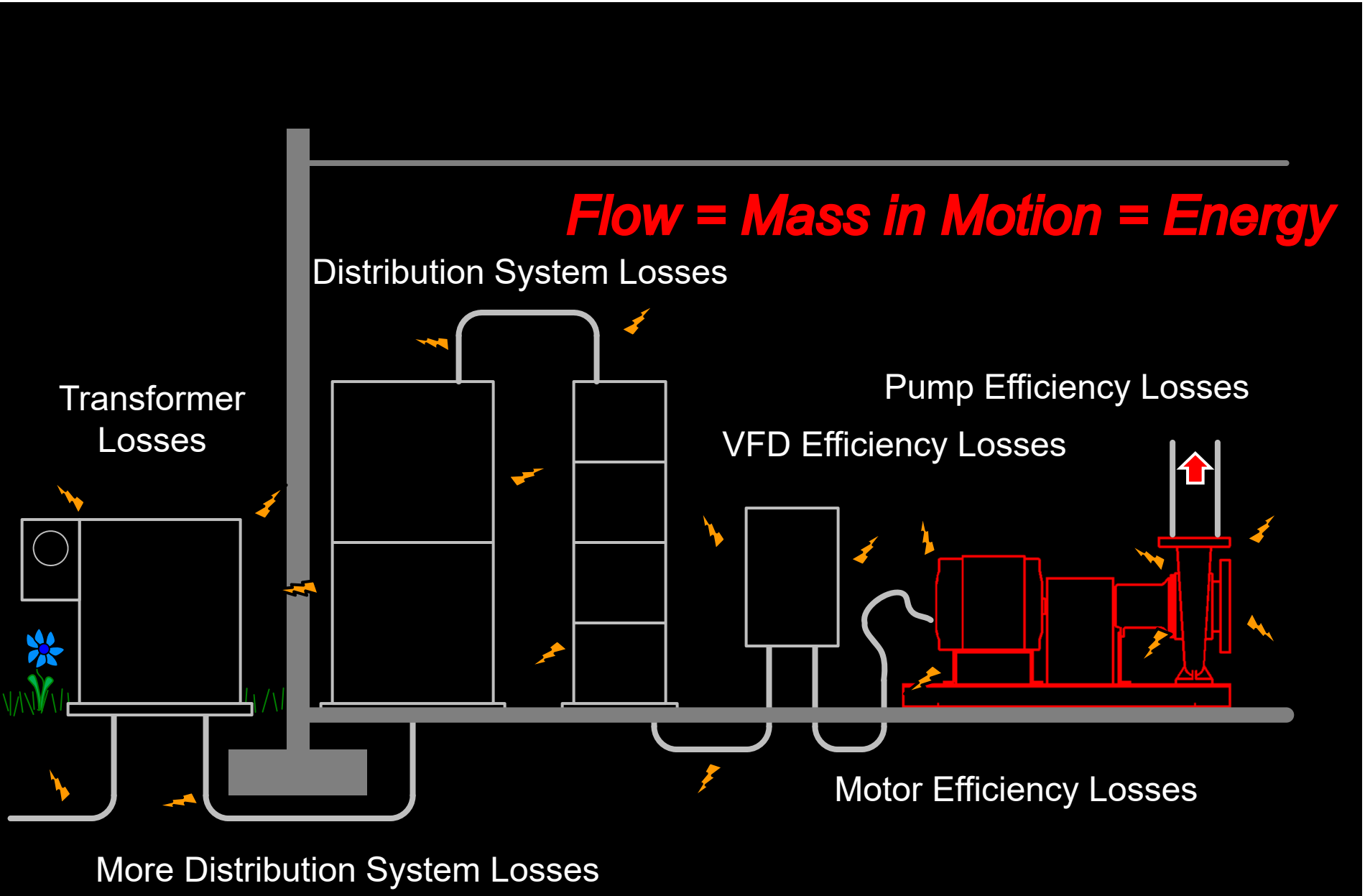
Energy Conservation is an Ethic
ASHRAE Journal, vol. 42, no. 7, p. 16-21



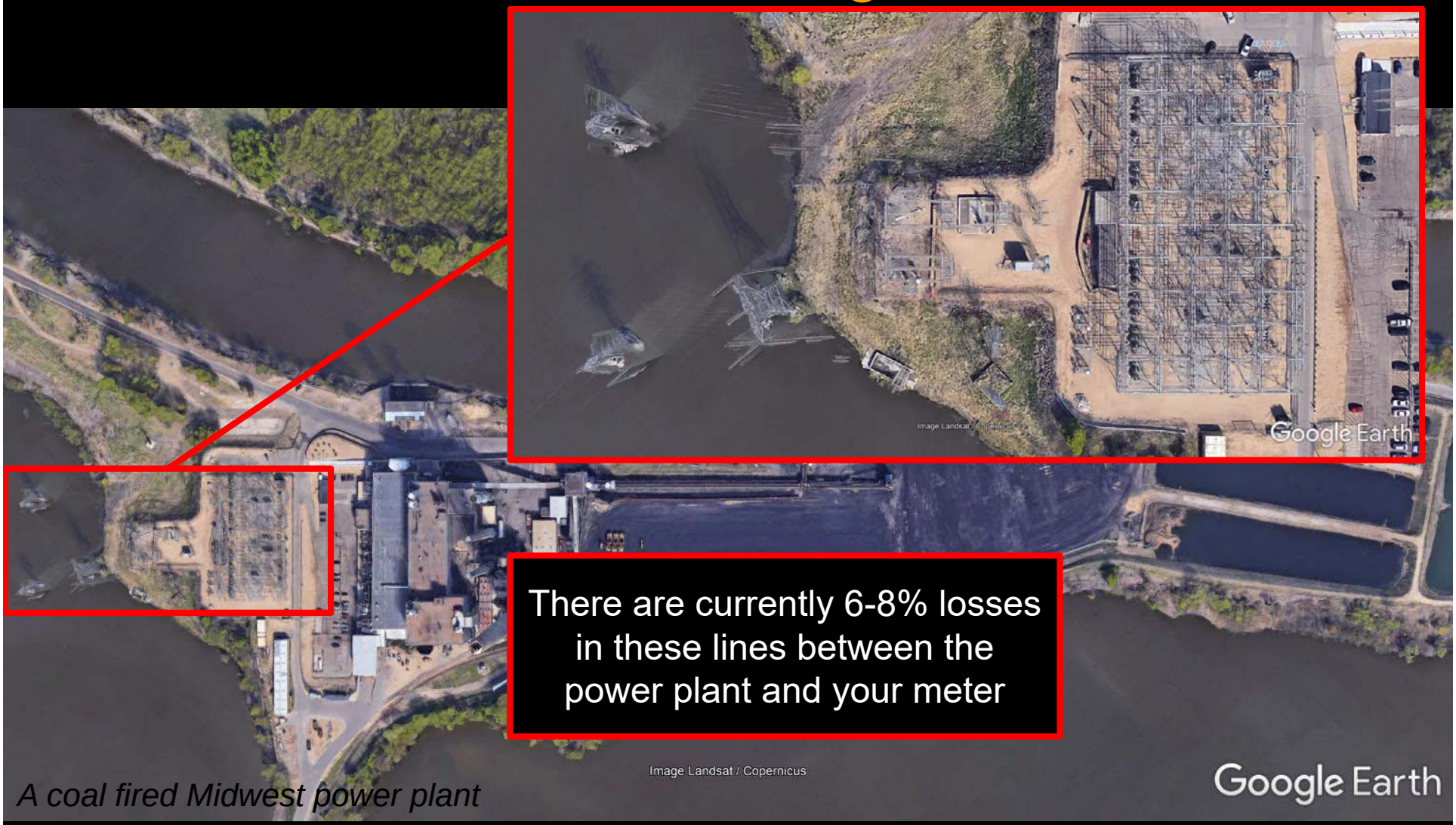
PDF available at http://www.av8rdas.com/bill-coads-writings.html

Applying the commissioning tool set can have ripple effects




Flow = Mass in Motion = Energy
Distribution System Losses
Transformer Losses
Pump Efficiency Losses
VFD Efficiency Losses
Motor Efficiency Losses
More Distribution System Losses

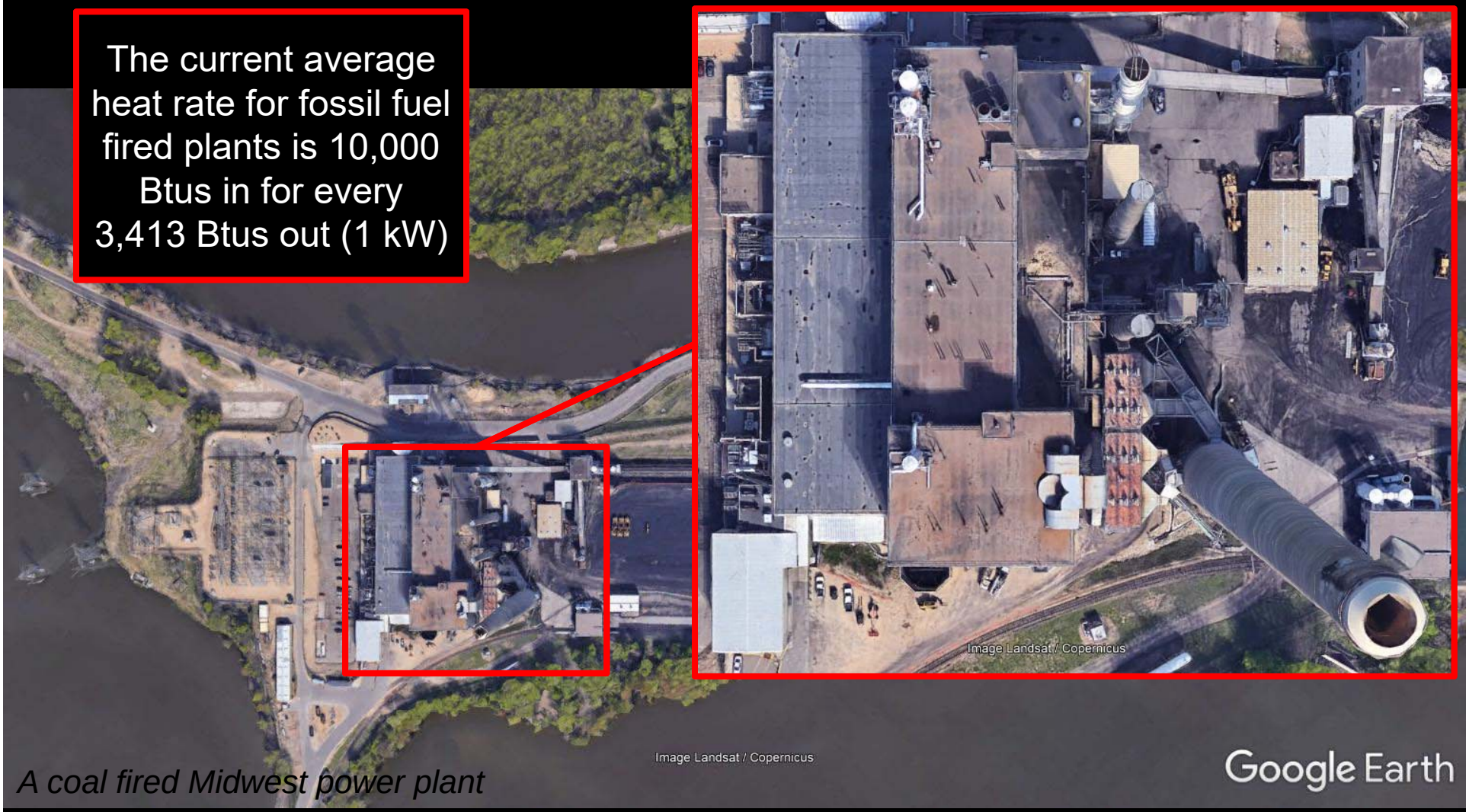
Transmission losses are significant



A coal fired Midwest power plant

Conversion losses are significant

The current average heat rate for fossil fuel fired plants is 10,000 Btus in for every 3,413 Btus out (1 kW)



A coal fired Midwest power plant

Physical principles will prevail

Conservation of mass and energy says that all of the mass in this pile of coal other than the fly ash will end up in the atmosphere

A coal fired Midwest power plant

Bottom line

Generating power consumes finite resources and impacts the environment

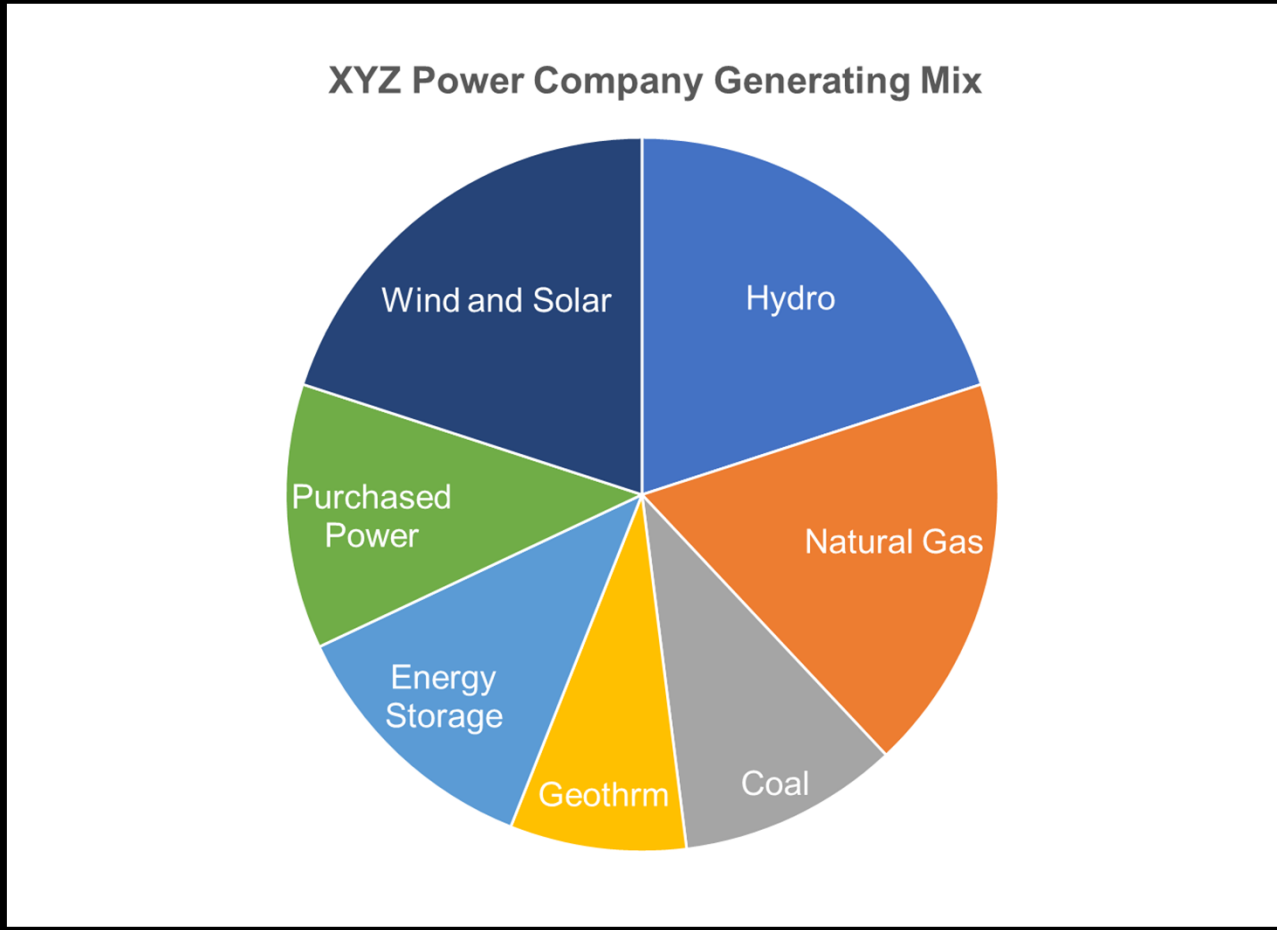
Reducing atmospheric impacts

We expect our energy mix to be 70% carbon free by 2040 based on current commitments and mandates, and we're working to deliver the right resources and technologies to make that happen.

Energy Strategy; www.portlandgeneral.com

Reducing atmospheric impacts

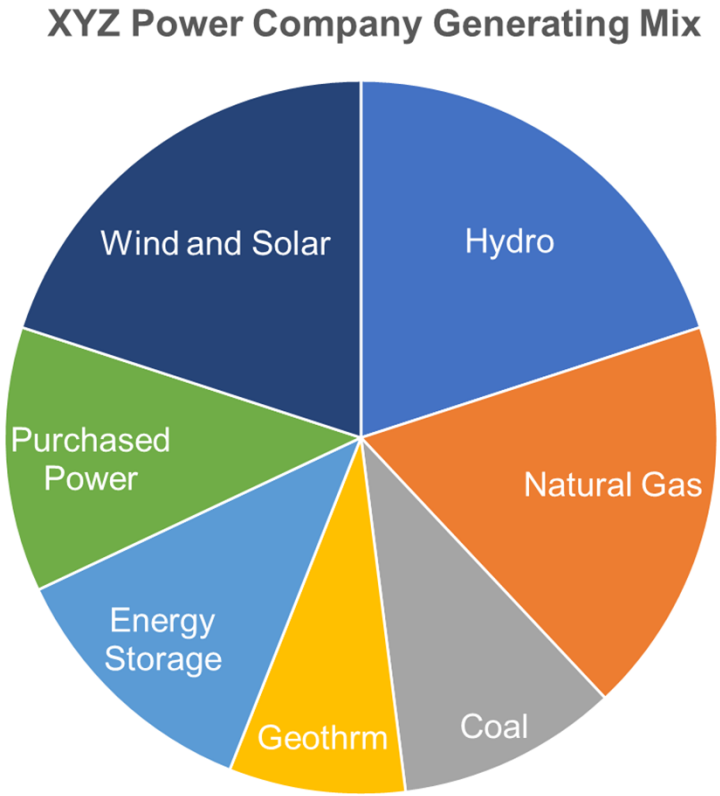
Moving away from carbon fuels is a common, long term goal for many utilities



Reducing atmospheric impacts

The commissioning tool set can have an immediate impact by reducing the need for energy in the first place

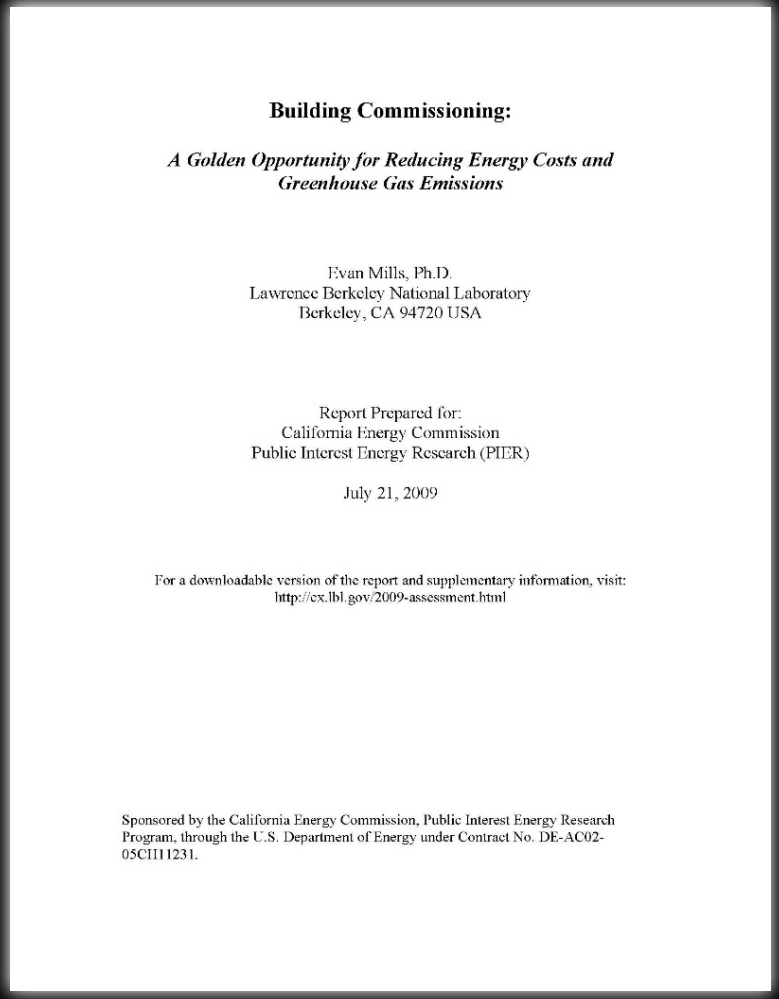
It's a win-win situation



Start to have your own impact

Survey your building inventory for big energy users.

- Read LBNLs report on the costs and benefits of commissioning at http://cx.lbl.gov/cost-benefit.html
- LBNL metrics indicate that the median savings from an EBCx process will be in the range of 16% of the annual energy cost



Building Commissioning:

A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions

Evan Mills, Ph.D.
Lawrence Berkeley National Laboratory
Berkeley, CA 94720 USA

Report Prepared for:
California Energy Commission
Public Interest Energy Research (PIER)

July 21, 2009

For a downloadable version of the report and supplementary information, visit:
http://cx.lbl.gov/2009-assessment.html

Sponsored by the California Energy Commission, Public Interest Energy Research Program, through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.