How Water and Steam Systems; Basic Principles, Ongoing Commissioning, Operation, and Optimization

Please Visit This Link While We Are Waiting to Begin

https://tinyurl.com/Lcl39SteamHHWD1Intro

Presented By:

David Sellers

Senior Engineer, Facility Dynamics Engineering

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Learning Objectives

Attendees will be able to:

1. Define How Heat is Generated, Distributed and Transferred in Buildings and How Buildings Use Heat
2. Recognize Key Differences Between Steam and Hot Water Systems
3. Describe the Different Types of Heating Processes Used in Buildings
4. Identify Opportunities to Improve Performance and Save Energy with HHW and Steam Systems.

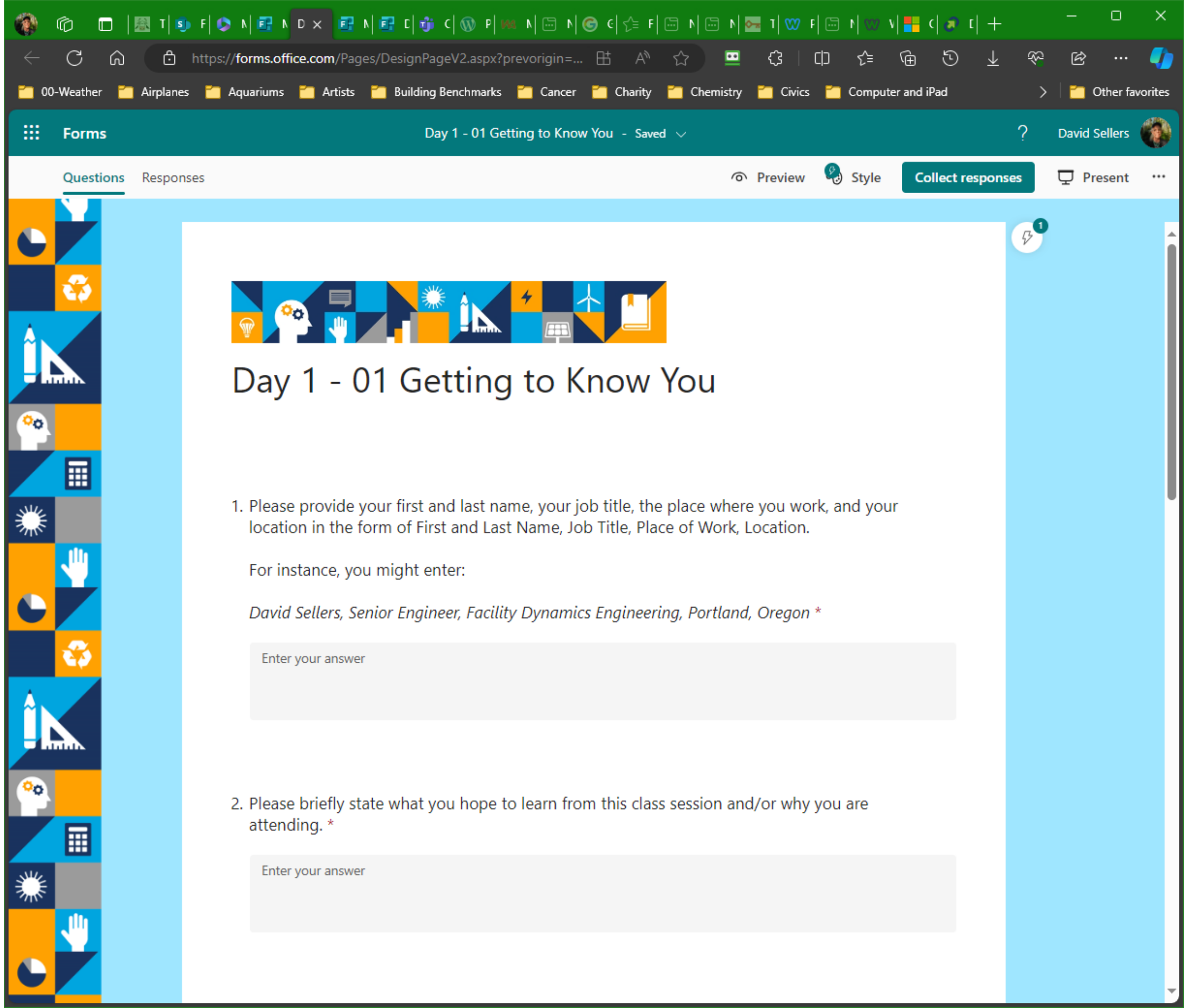
Agenda

1. Introduction
2. How Buildings Use Heat
3. Steam Systems

Introductions

Introductions

https://tinyurl.com/Lcl39SteamHHWD1Intro



A Bit About Me

I intended to be an aircraft maintenance engineer

A Bit About Me

I intended to be an aircraft maintenance engineer

- I’m doing something ***totally*** different

A Bit About Me

I'm doing something *totally* different

- HVAC field technician

A Bit About Me

- HVAC field technician
- Control system designer

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A Bit About Me

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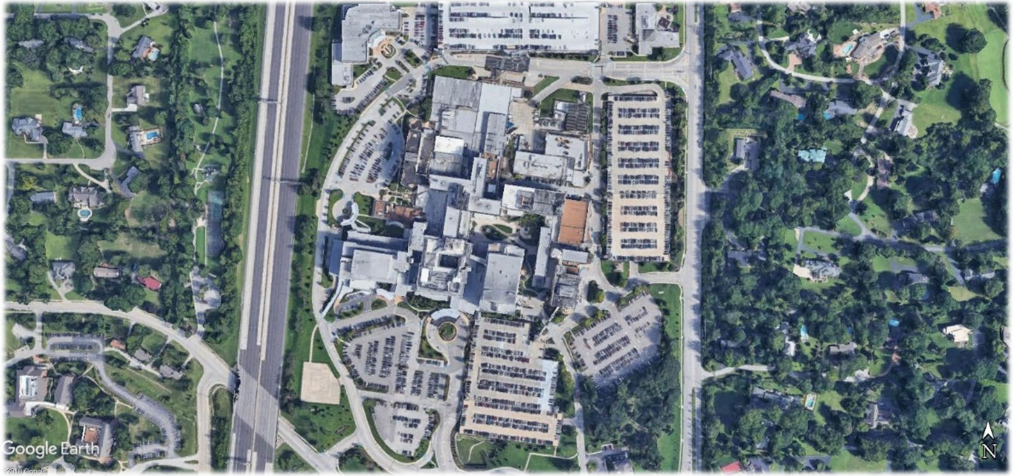
- Project engineer



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- Project engineer
- Wafer fab facilities engineer and system owner

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- Wafer fab facilities engineer and system owner
- PECI technical support engineer

A Bit About Me

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- Murphy Company controls and start-up engineer
- Project engineer
- Wafer fab facilities engineer and system owner
- A happily married PECI technical support engineer

A Bit About Me

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- Control system designer
- HVAC designer
- MCC Powers system engineer
- Murphy Company controls and start-up engineer
- Project engineer
- Wafer fab facilities engineer and system owner
- A happily married PECI technical support engineer and trainer

A Bit About Me

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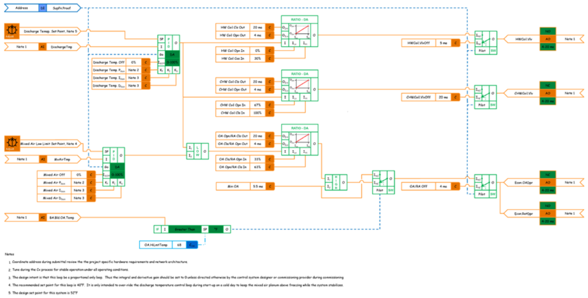
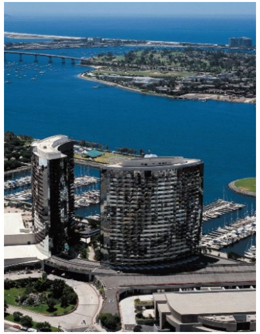
- Murphy Company controls and start-up engineer
- Project engineer
- Wafer fab facilities engineer and system owner
- A happily married PECI technical support engineer and trainer
- FDE Senior Engineer





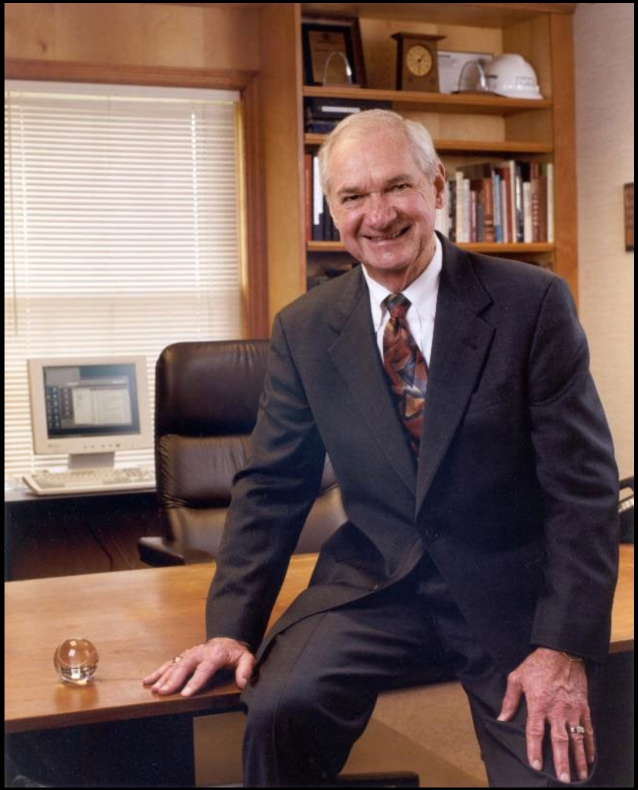
I’ve Had Great Mentors Along the Way

Bill Coad's Thoughts on Energy Conservation

"… 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."

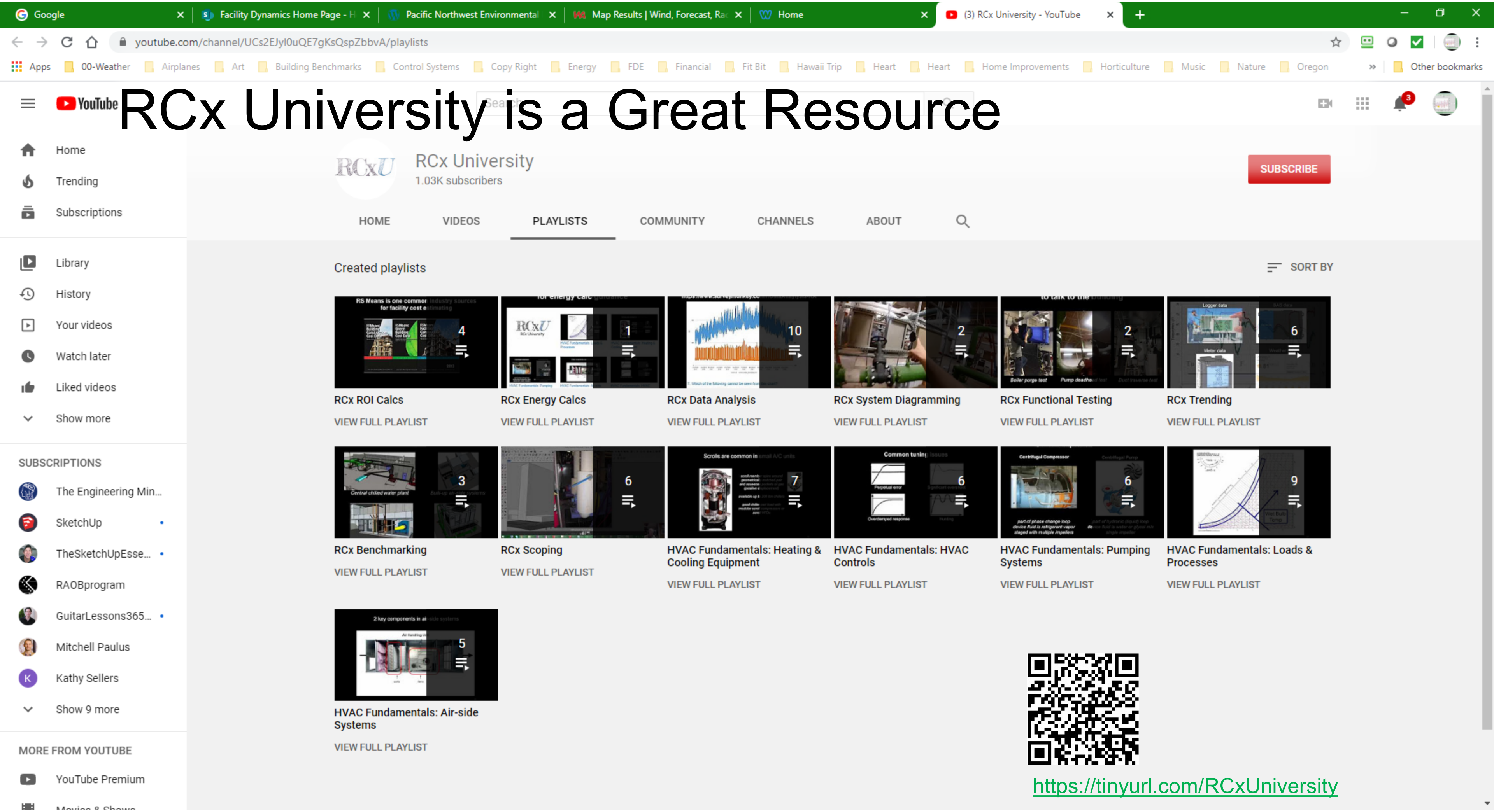
Energy Conservation is an Ethic
ASHRAE Journal, vol. 42, no. 7, p. 16-21

PDF available at
https://tinyurl.com/EnergyConservationEthic



A Few Resources

RCx University is a Great Resource



https://tinyurl.com/RCxUniversity

A Resource List Built Around the 10 Skills

https://tinyurl.com/CxResourceList

Resource List

The list is organized by the ten key technical skills we thing are important for anyone who wants to work in the commissioning and building operations fields. If you want to know what we think those skills are and why, just click here.

If you turn on the bookmarks in the .pdf document (typically, you can do that by clicking on the little ribbon shaped icon on the left side of the Acrobat window), you will links that will let you easily and quickly move around in the document. The document also includes a description of how to navigate through it in a section that starts on page 2.

We try to update the document every year or so, adding new things we have found, removing items that are obsolete, and verifying to the extent possible that the links all work. So, you may want to check back every once-in-a-while to see if there is a newer version or if a link in your version no longer works.

If you discover a link that is not working or have a resource you want to suggest we add to the list, let us know and we will check into it.

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Resources and Reading List

Date: November 2, 2011, (*Revised October 9, 2014*)

Overview

Over the years, one of the challenges we have faced in delivering technical classes for the Pacific Energy Center, the University of Wisconsin, SMUD, and other venues is to establish a common level of understanding of the fundamentals behind the topics to be discussed. Classes are often attended by people with a broad range of experience, including operators and facilities engineers who deal with technical issue and machinery on a day to day basis at one end of the technical spectrum and people new to the industry or who function more in management roles than technical roles at the other end. There can also be people with very deep knowledge in a focused area of expertise who have less depth in other areas.

Initially, we tried to address this by starting with the fundamentals and working our way up to the targeted content. But this tended to frustrate the more experienced attendees, reduced the time we had to spend on the intended topic, and could be overwhelming for the less experienced folks because we went at a pretty fast pace.

Over the past several years, we have successfully experimented with a different approach where-in we distribute a resource and reading list to attendees prior to class to allow them to self-educate where necessary. Typically, we supplement this list with a class specific cover memorandum to focus the pre-class preparation effort on topics we feel it is essential for you to understand to fully appreciate the class content that is associated with the class. This affords opportunity to everyone to come into the class at about the same level in terms of background knowledge. And the list serves as a resource for further reference and learning after the class.

Version 15 of the list (indicated by the "v15" in the file name) went through a major reorganization from the previous list. Specifically, the resources were categorized to follow the ten key retrocommissioning skills I discuss in the blog post titled *Key Retrocommissioning Skills*. In the past, I have coded changes by using a colored italic font, usually red. But with the reorganization, everything would have been in red italic font. So, I reserved colored font convention to highlight items that have been added to the list since the last time it was updated no matter how they are organized. So, new items will be *highlighted in green italic font* (someone told me red meant that I was yelling at them, which I'm not, so sorry if I created that impression in the past; besides green is my favorite color).

Generally, all of the resources are publically available via the internet or by simply showing up in person someplace and asking for them. And many of them are free all-though some may require a modest

The EBCx Skills Guidebook is Built Around the 10 Skills

http://www.av8rdas.com/ebcx-skills-guidebook.html

Existing Building Commissioning Skills Guidebook

The guidebook is organized using the 10 Key Commissioning Skills as a framework and provides:

- A description and example of why the skill is important;
- Learning objectives to help guide a self study effort;
- Links to primary resources that can be used to learn about the skill in a self study effort;
- Links to secondary resources that can be used to dig in deeper if you have a particular interest in a particular topic.

The *10 Skills Learning Objectives Checklist* is intended to complement the guidebook by providing a list of all of the learning objectives with a check-box that allows you to track your progress as you work your way through the guidebook in a self study effort.

EBCx Skills Guidebook (ebcx_technical_skills_guidebook_v2017-07-07_web.pdf)
Download File

10 Skills Learning Objectives Checklist (skills_table_web_v5.xlsx)
Download File

Facility Dynamics Engineering — *Existing Building Commissioning Guidebook*

Introduction

Over the years, Facility Dynamics has been involved with providing technical training with a focus on existing building commissioning in a number of different venues and for a number of different clients including the Pacific Energy Center, Marriott, and IMCOM. For those programs, I have frequently been the lead technical trainer.

As the training agendas evolved, it started to become clear that there were a number of key skills that it would be desirable to develop if you were going to pursue existing building commissioning. About 5 years ago, Russ Good and Barry Estes of Marriott International asked me to make a list of the ten most important skills and to complement it with a list of the three primary resources that were available were available to help develop each skill.

At that point in time, I had already compiled a list of technical resources that we used to support the classes, but it was about 40 pages long and always growing. So, it could be a bit overwhelming if you were just getting into this and Russ and Barry wanted me to figure out how to focus things a bit.

That forced me to think about what really mattered from a technical stand point if you are out in the field doing this sort of work. It was really hard for me to whittle the list down to only 10 skills, but Barry and Russ were pretty firm on that, and I finally pulled it off. Truth be told, I kind of cheated in a way because I made one of the skills Familiarity with HVAC fundamentals and then put 10 sub-skills under that.

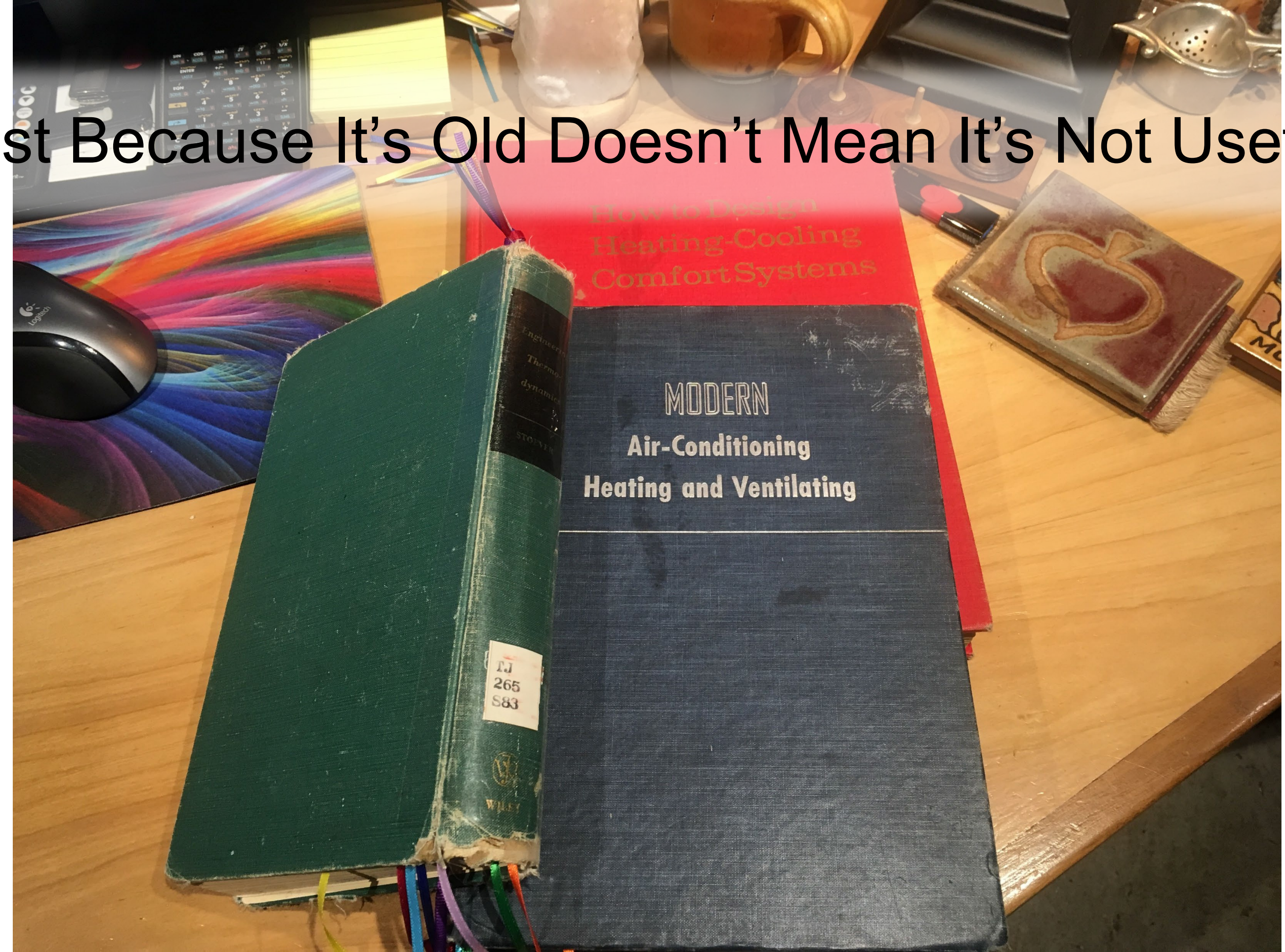
But the exercise was a really good one and when I was finished, I realized that the list was a pretty good framework for organizing the technical side of any of the training classes and I have been using it ever since in that manner. In addition, I reorganized the resource list so that the resources were grouped under headings that correlated with the 10 skills.

I also should point out that while the driver for developing the list of the 10 skills was Existing Building Commissioning training, the skills really apply across the boards. In other words, you generally will use the same skills for new construction commissioning, ongoing commissioning, and general building operations.

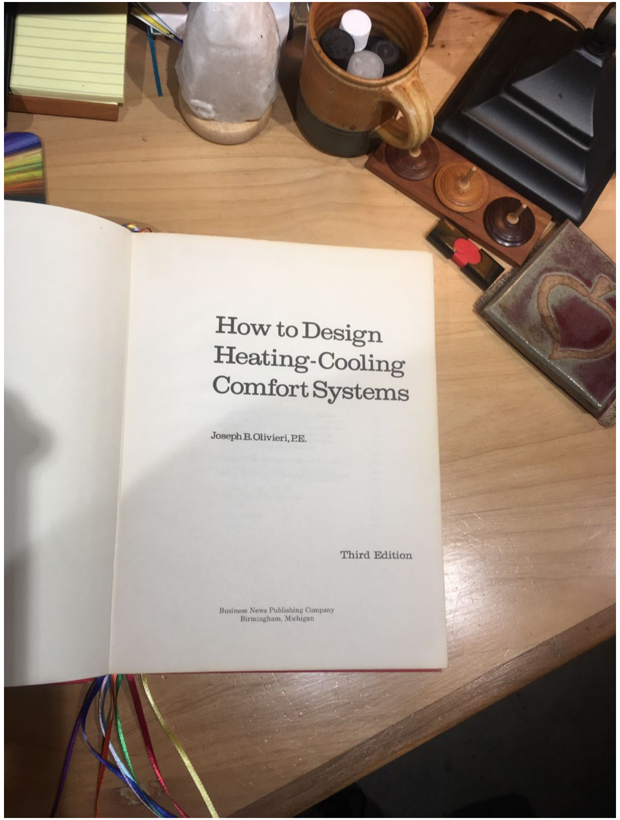
In fact, one of my little jokes in class is that there are all sorts of names and acronyms applied to processes where you apply the 10 skills, including Existing Building Commissioning, EBCx, Retrocommissioning, RCx, Building Tune-ups, Ongoing Commissioning, NCx, Facility Operations, etc. I have had the opportunity to work on projects where all of those names have been applied to what I was doing.

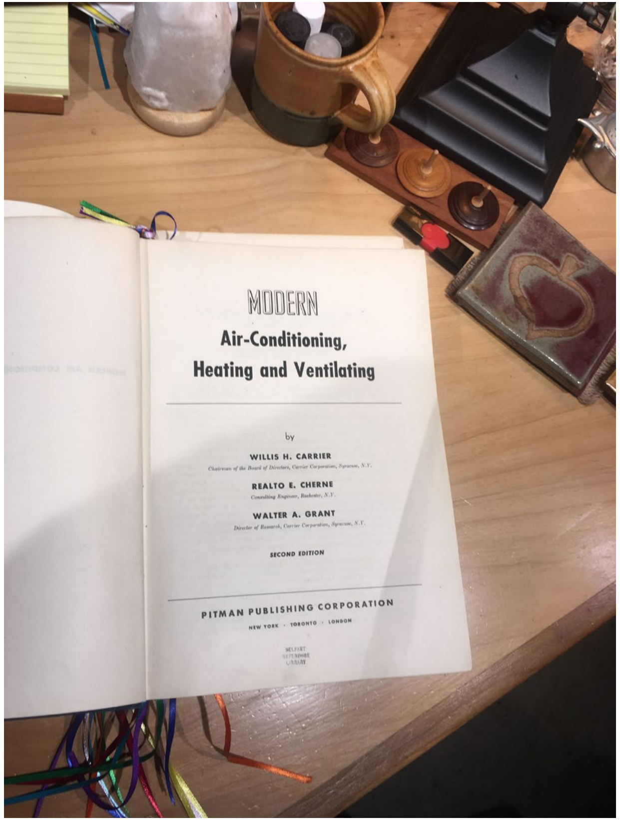
But when I think about it, all of them generally are technically the same thing that I was doing back in 1976, when I first became involved with the industry. Back then, we just called it

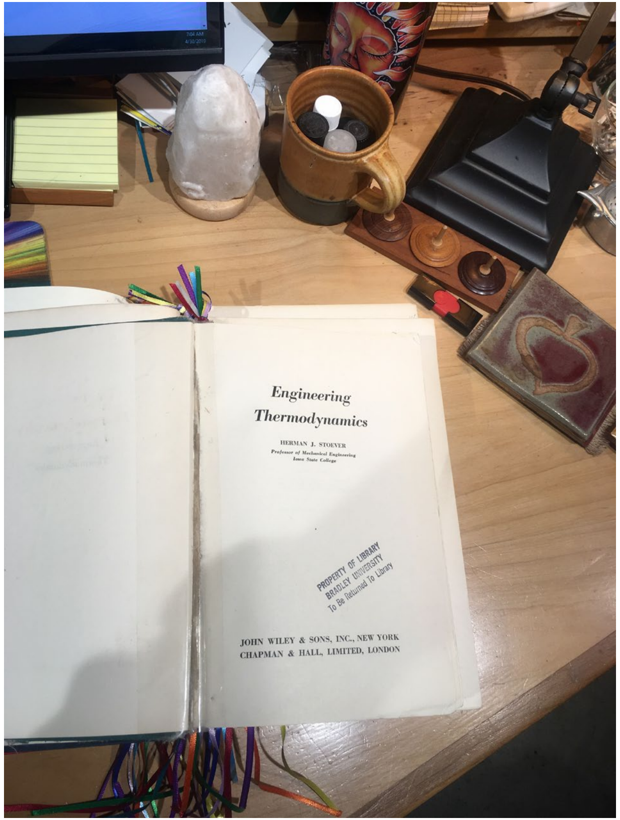
Just Because It's Old Doesn't Mean It's Not Useful



https://tinyurl.com/OlivieriChapters







A Blog with a Field Perspective on Building Systems

https://av8rdas.wordpress.com/

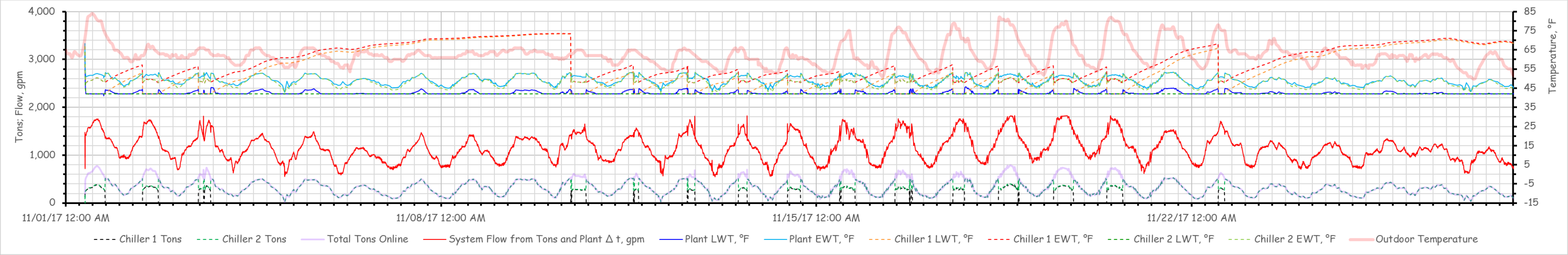
A Commissioning Resources Web Site

http://www.av8rdas.com/

Loads and Load Profiles

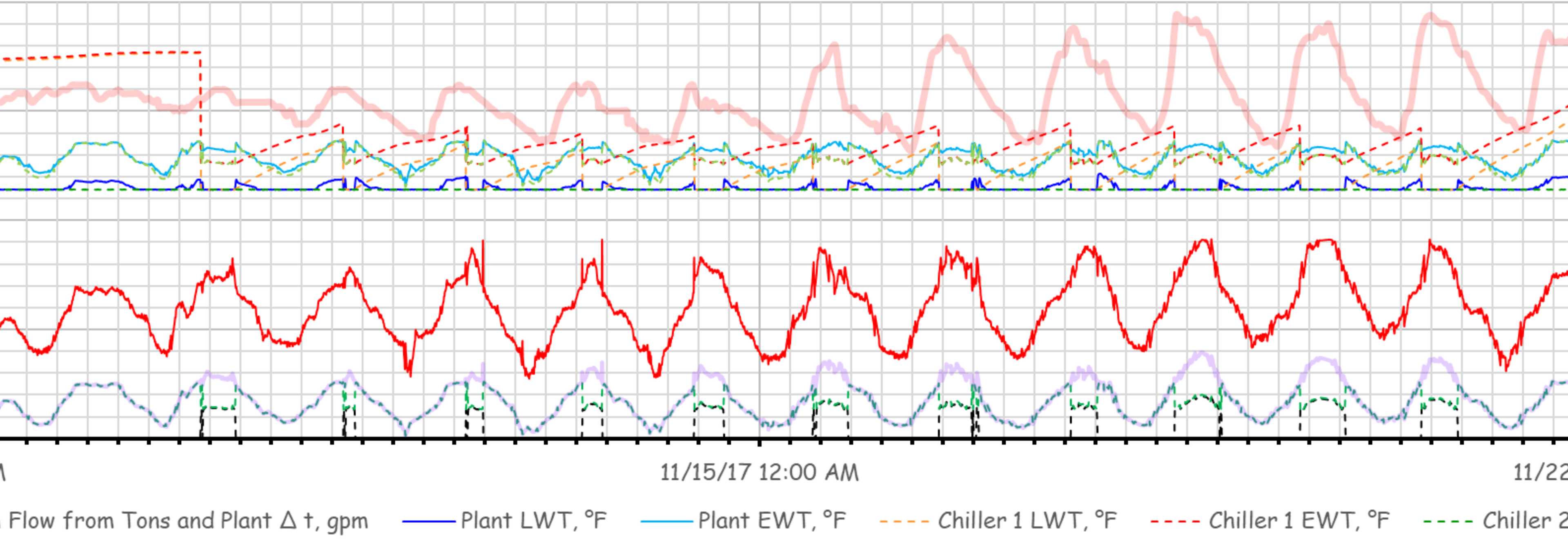
My Most Important Lesson

It’s all about the load profile



My Most Important Lesson

It's all about the load profile, both daily and seasonal



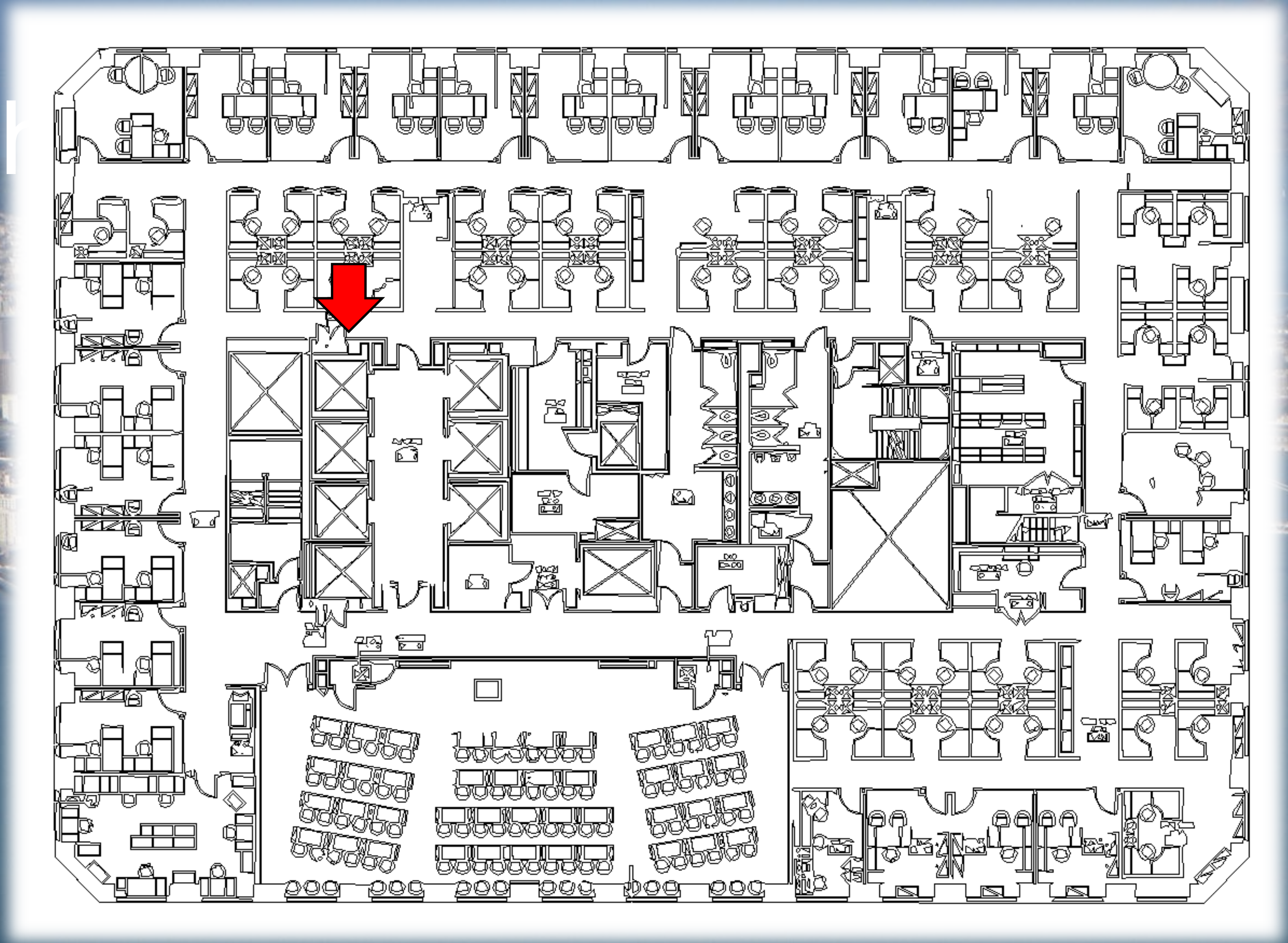
The Built Environment

The Built Environment

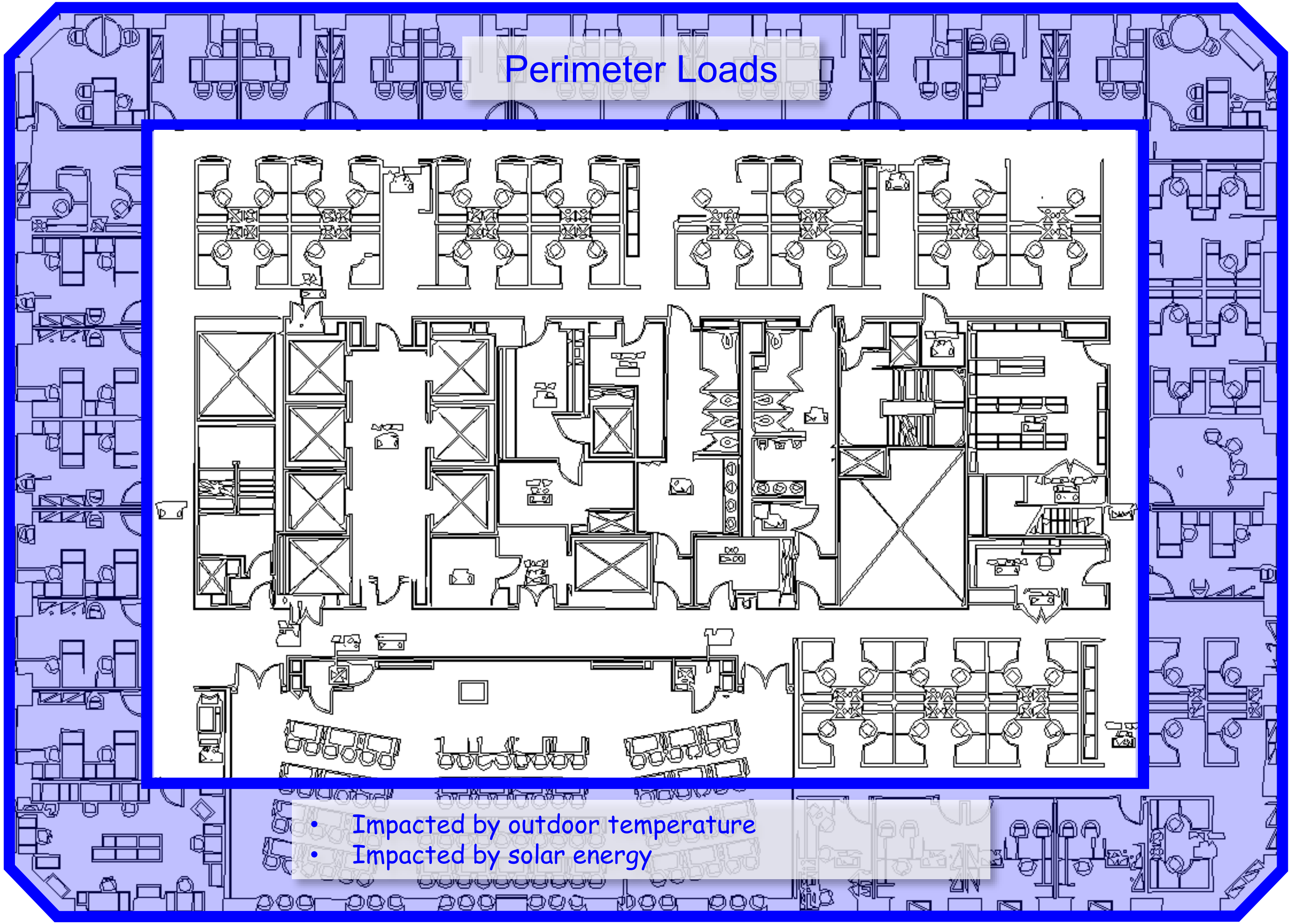
- Keeping the built environment safe, productive, clean, and comfortable is a fundamental goal of HVAC systems and their controls
  - Ventilation systems control contaminants by introducing filtered, conditioned outdoor air
  - Heating and cooling systems track the loads to control comfort

The Built Environment

Th

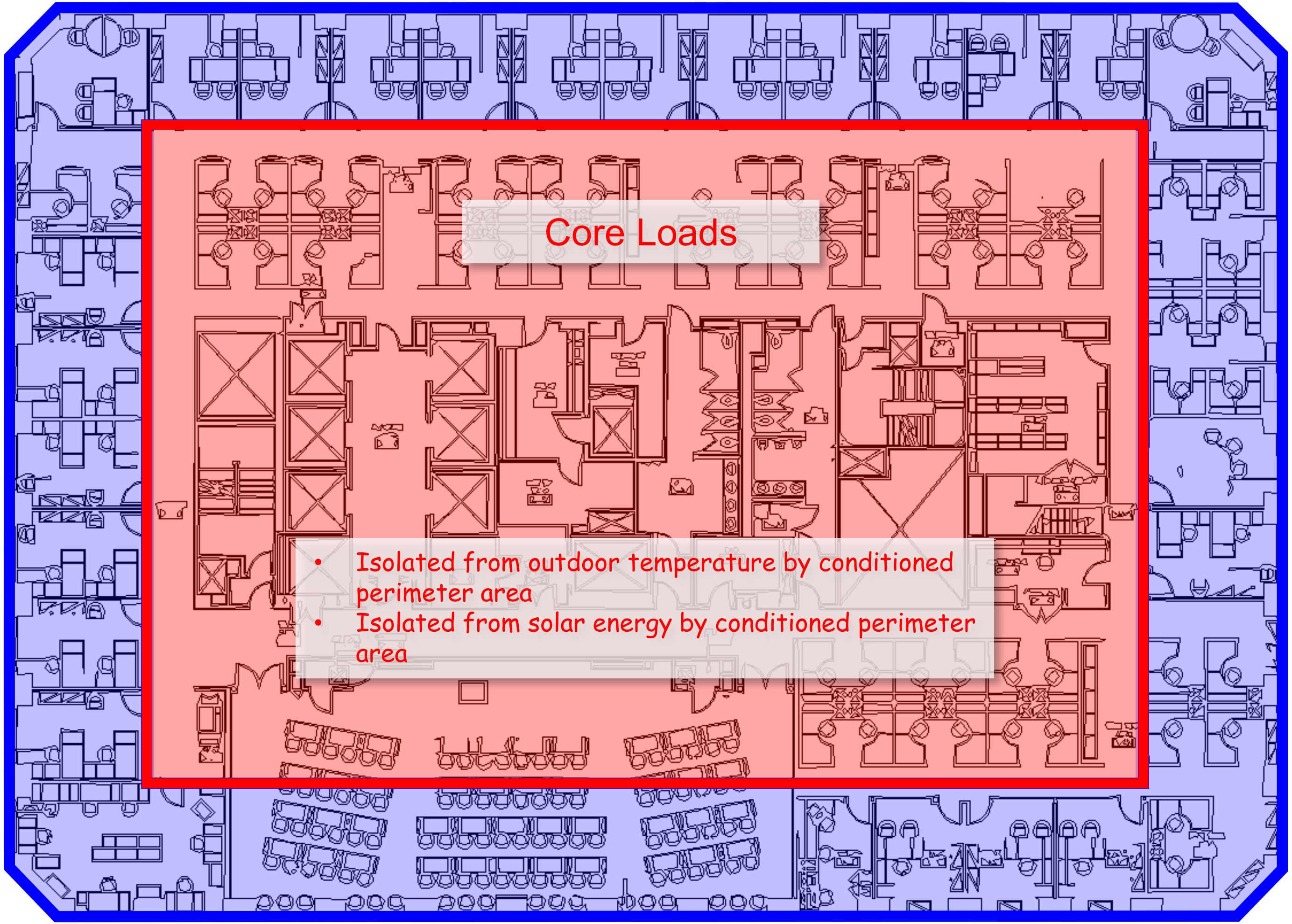


Perimeter Loads



- Impacted by outdoor temperature
- Impacted by solar energy

Core Loads



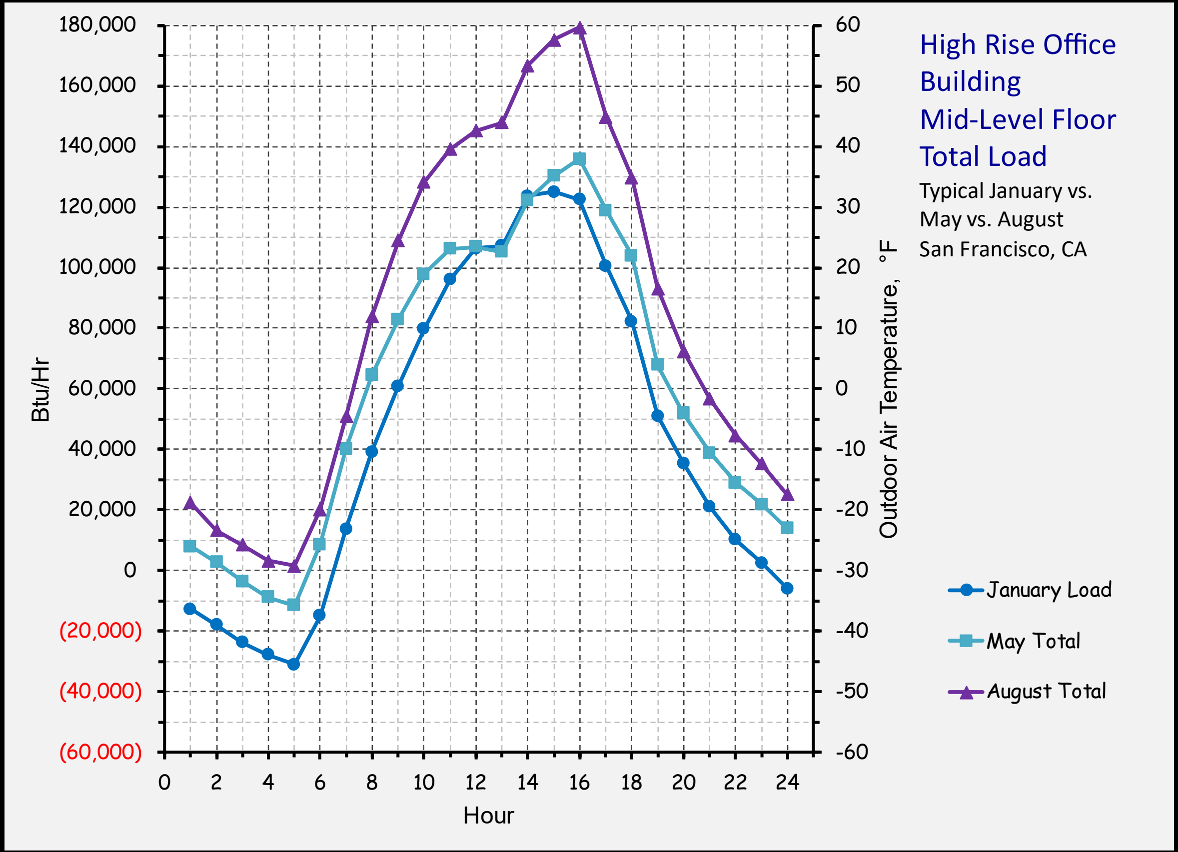
- Isolated from outdoor temperature by conditioned perimeter area
- Isolated from solar energy by conditioned perimeter area

Ventilation Loads

- Conditioning outdoor air (OA) that is brought in for ventilation and pressurization
  - Mathematically = energy required to condition the OA to the space condition (neutral air)
  - Can be handled separately or by mixing minimum OA with return air
- Occurs at the AHU, not at the zone

Infiltration Loads

- Occur if the zone is negative
- Become part of the zone load
- Affected by the location of the neutral plane in a high-rise building


High Rise Office Building
Mid-Level Floor
Total Load
Typical January vs.
May vs. August
San Francisco, CA
Btu/Hr
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Outdoor Air Temperature, °F
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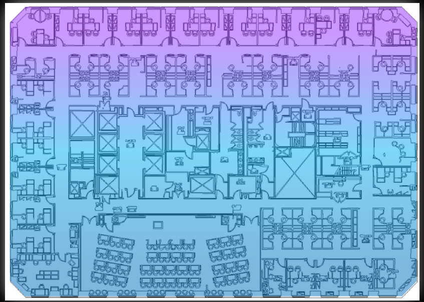
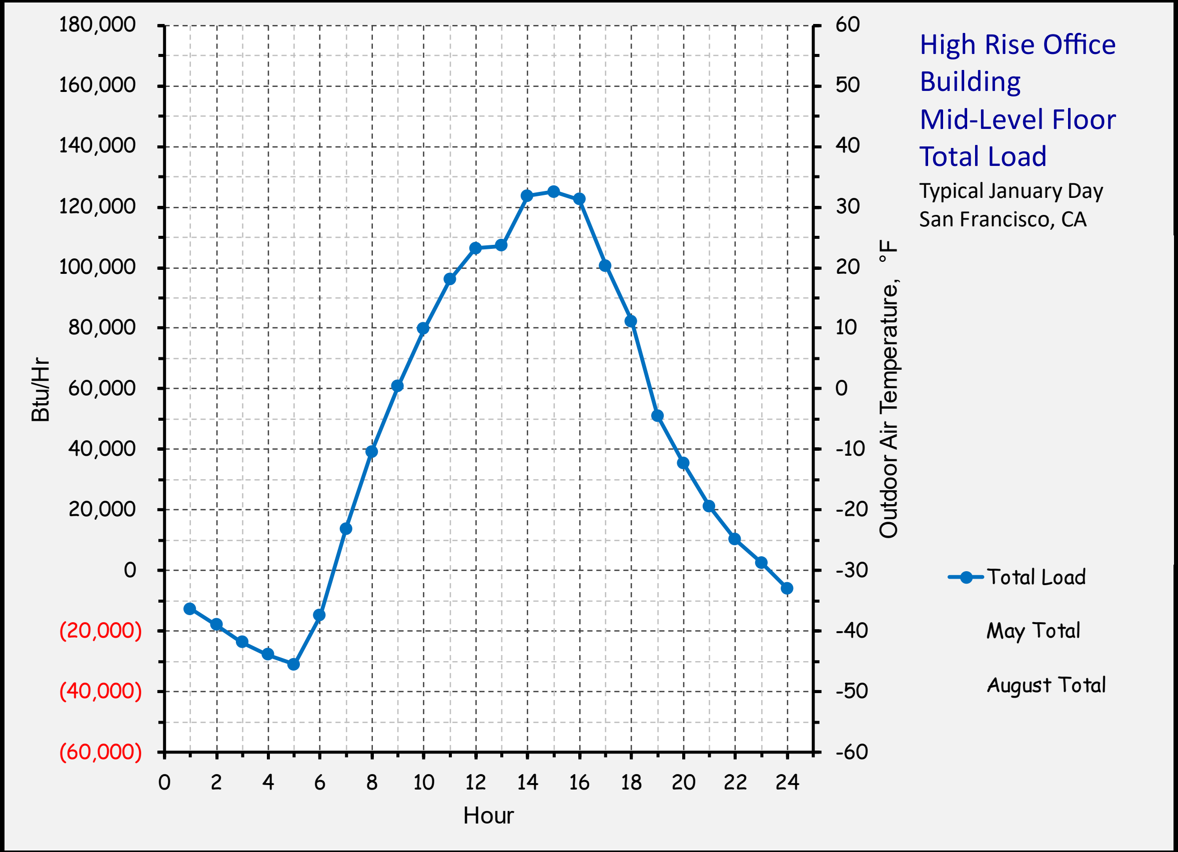
January Load
May Total
August Total





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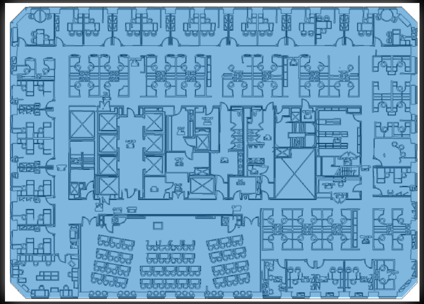
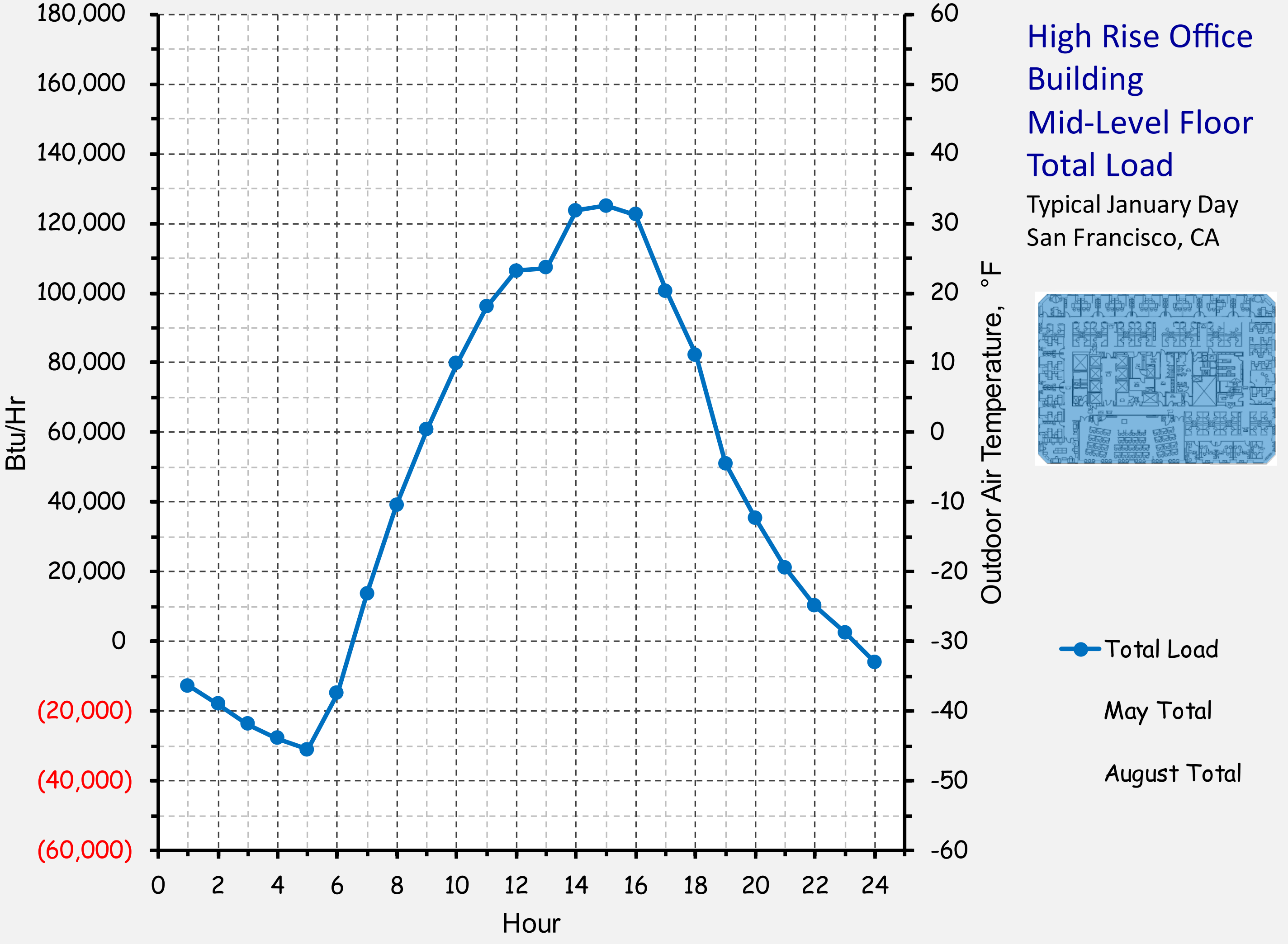
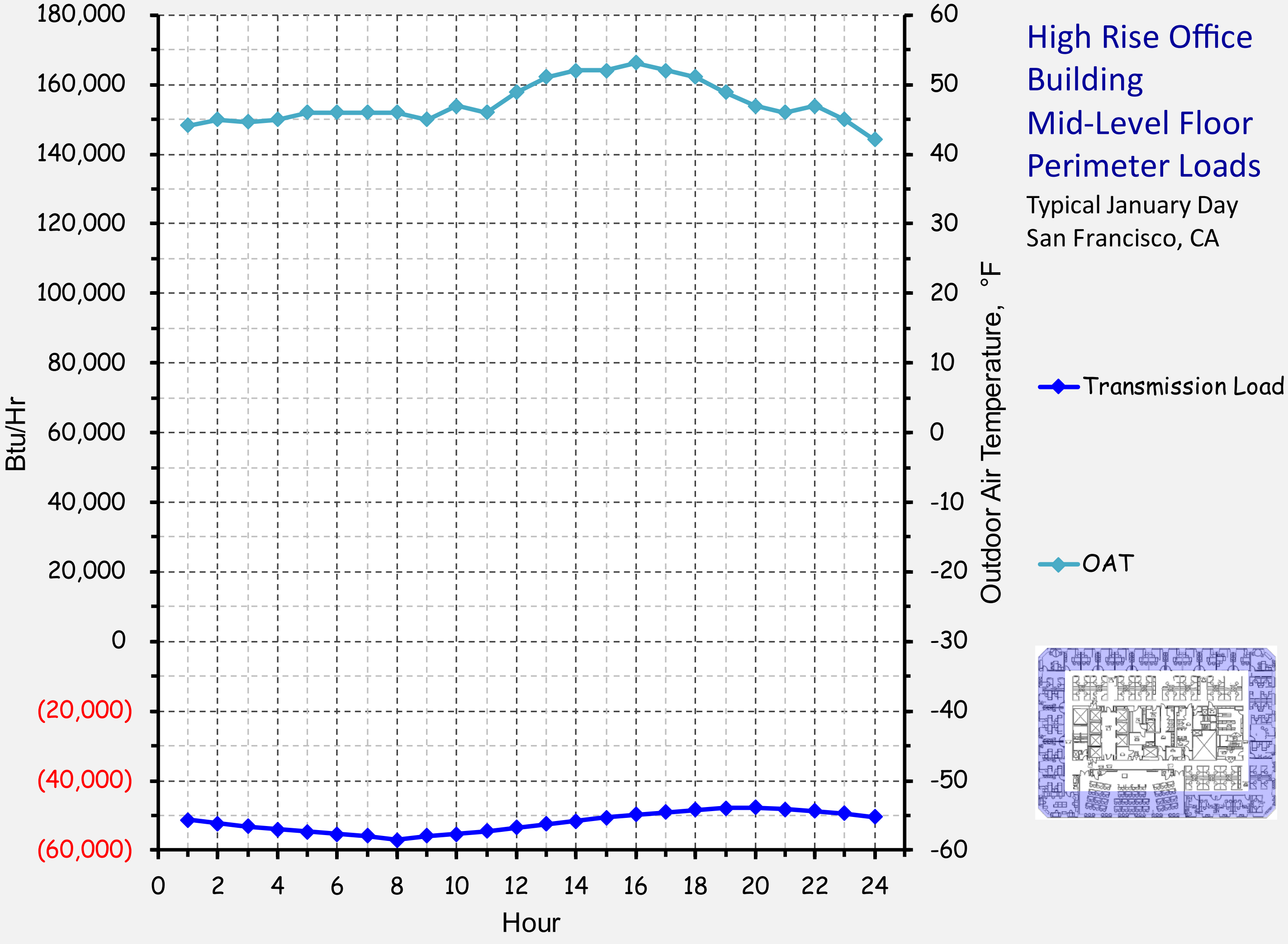




High Rise Office Building Mid-Level Floor Total Load

Typical January Day
San Francisco, CA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Mid-Level Floor
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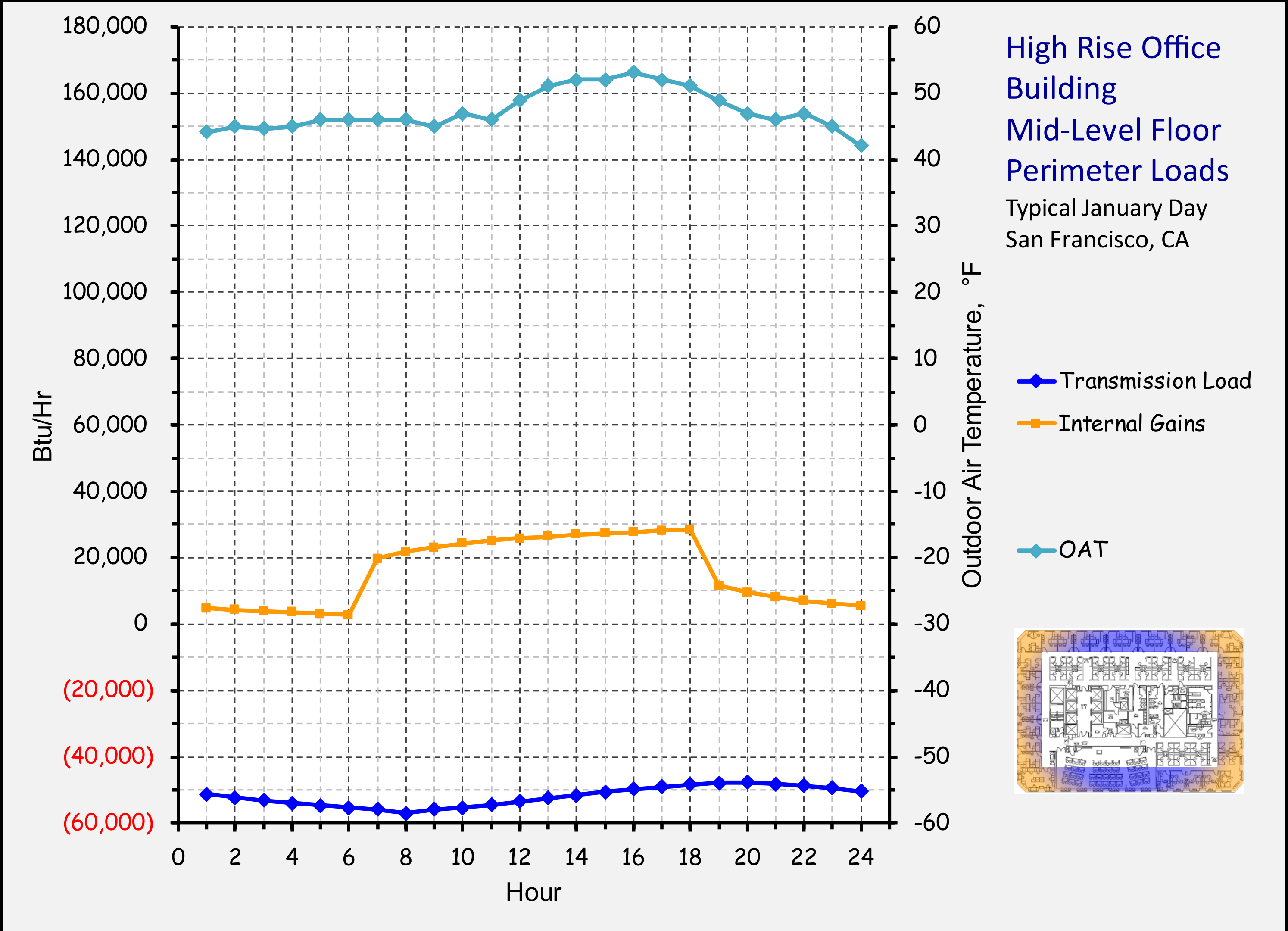

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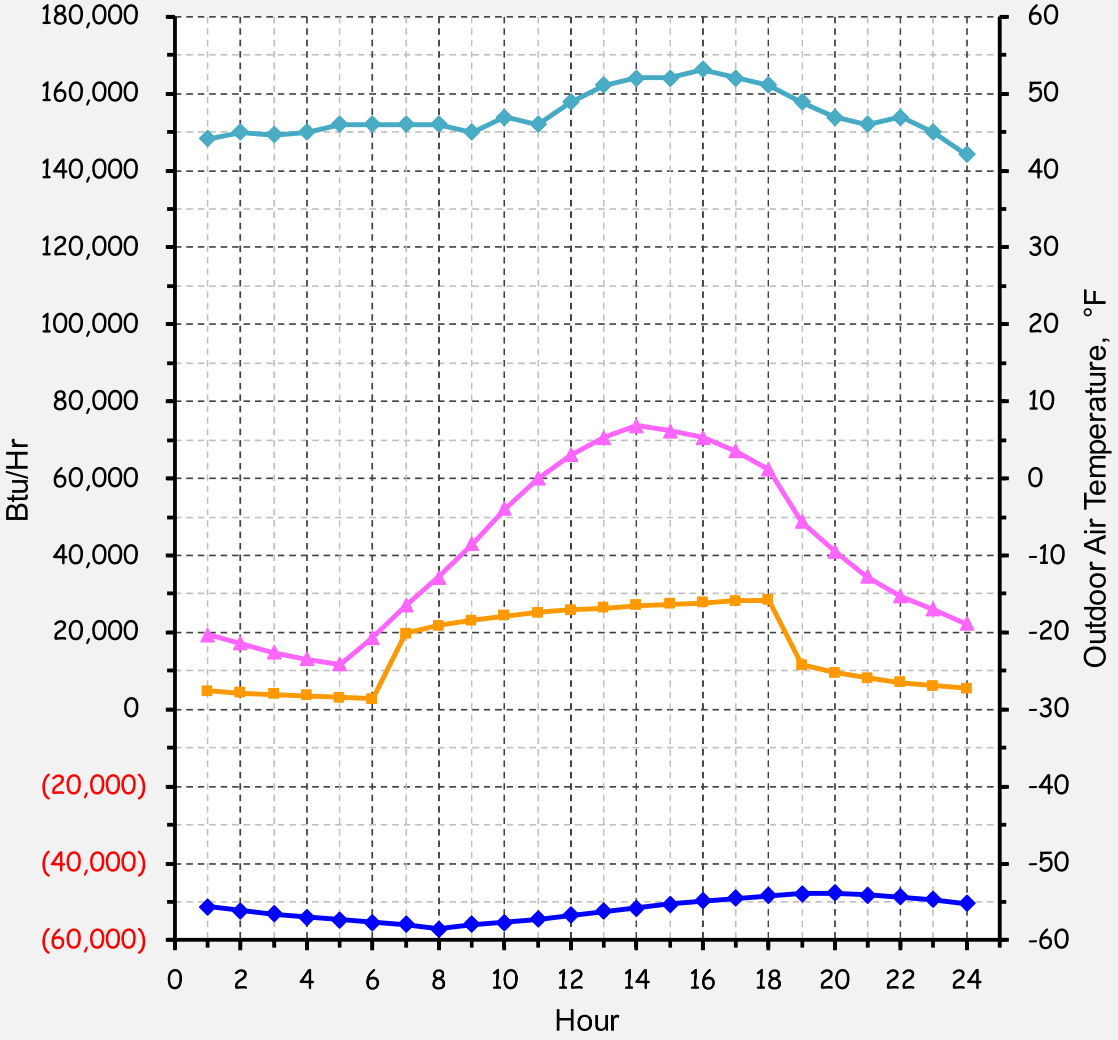
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Solar Gains
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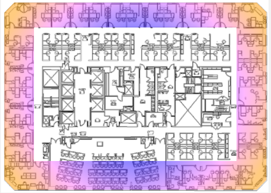

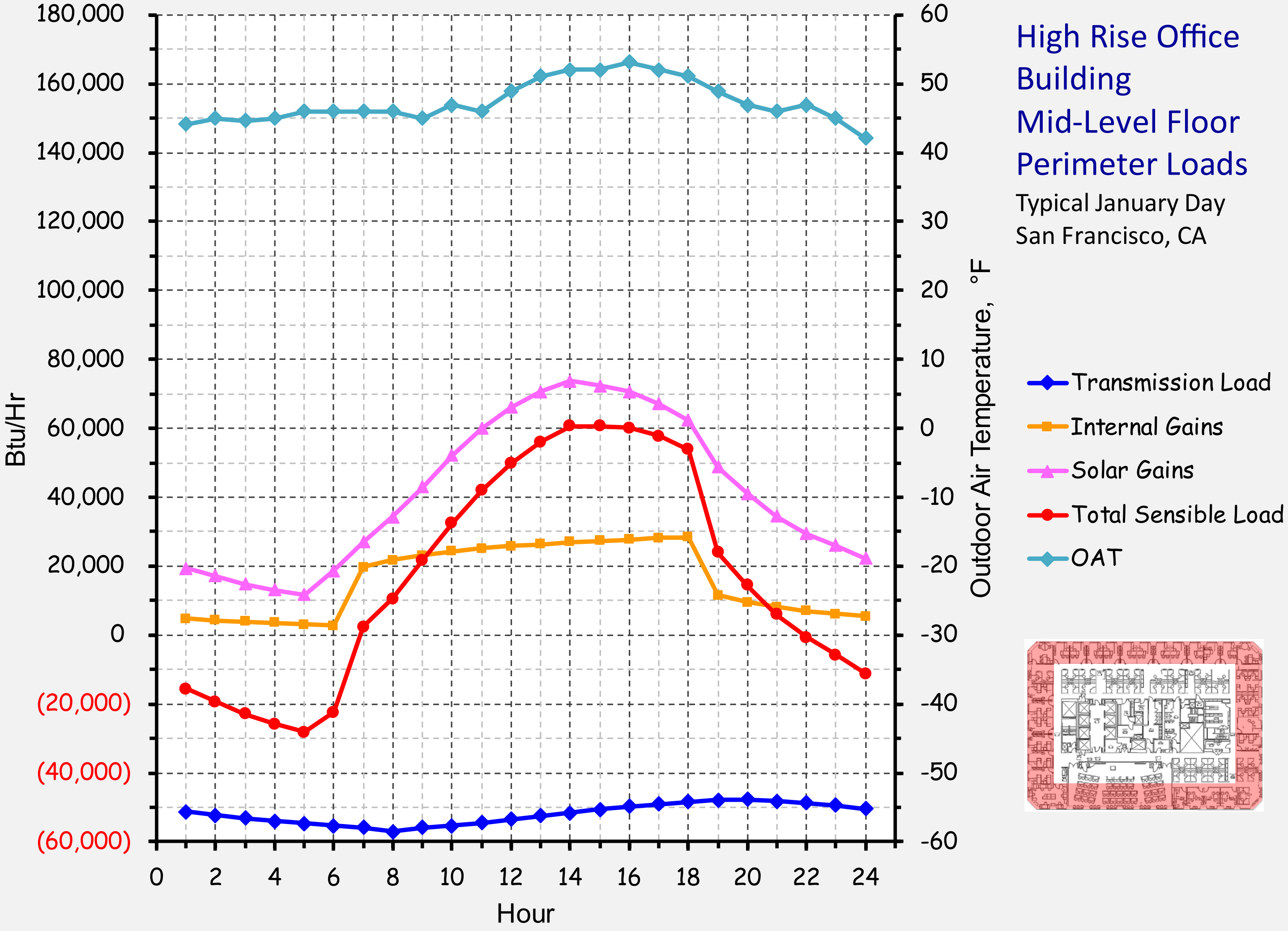
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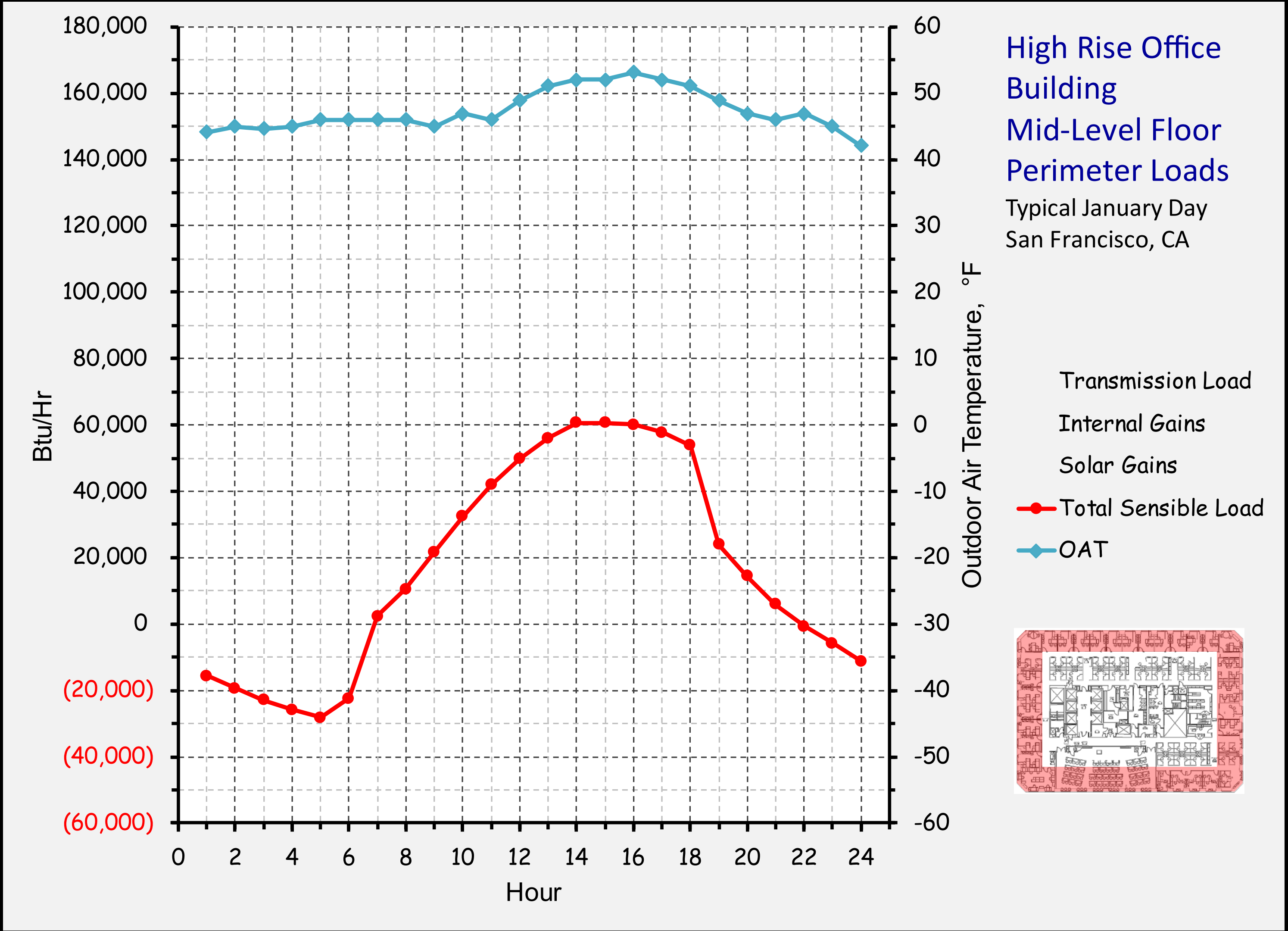
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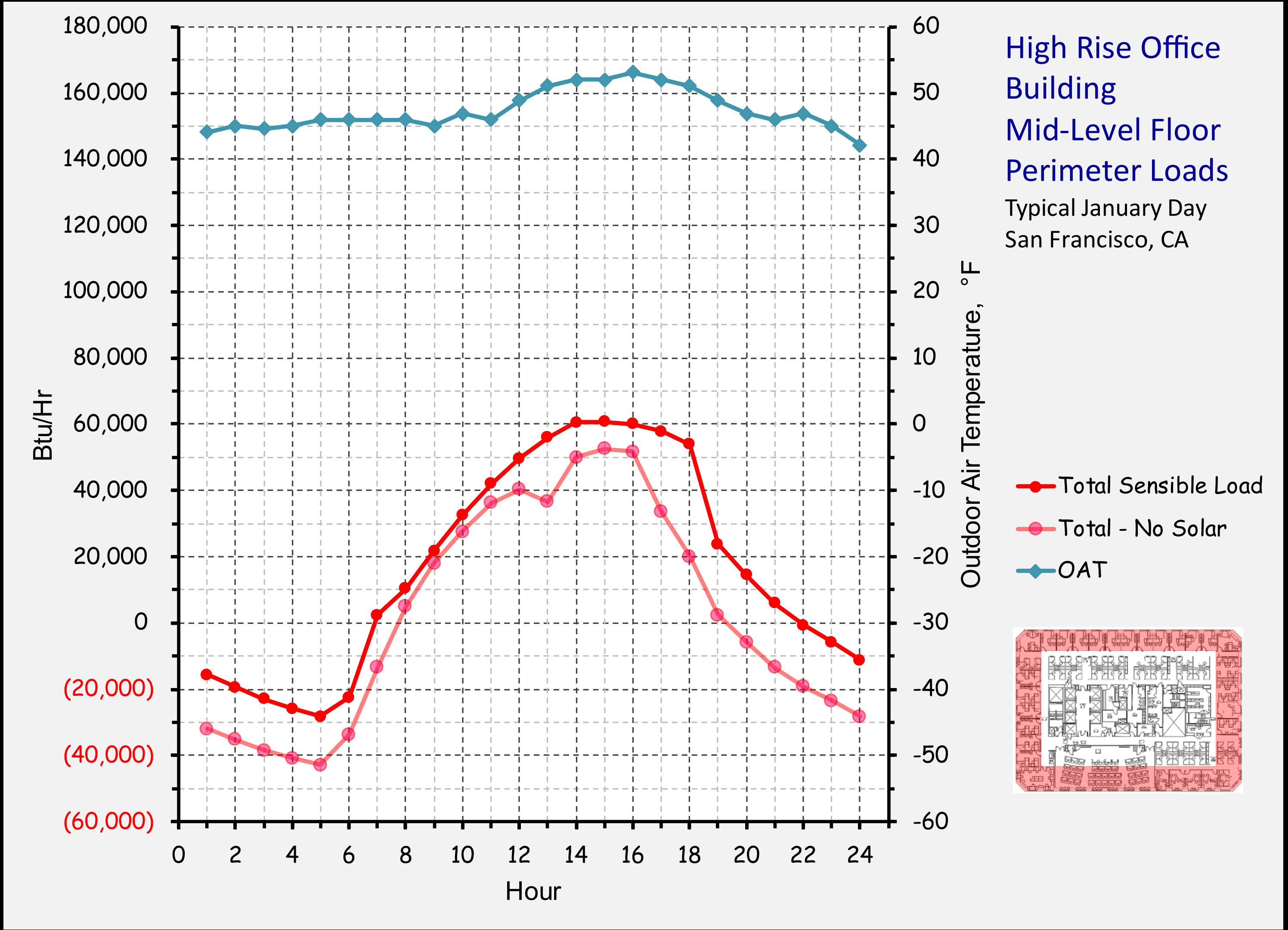
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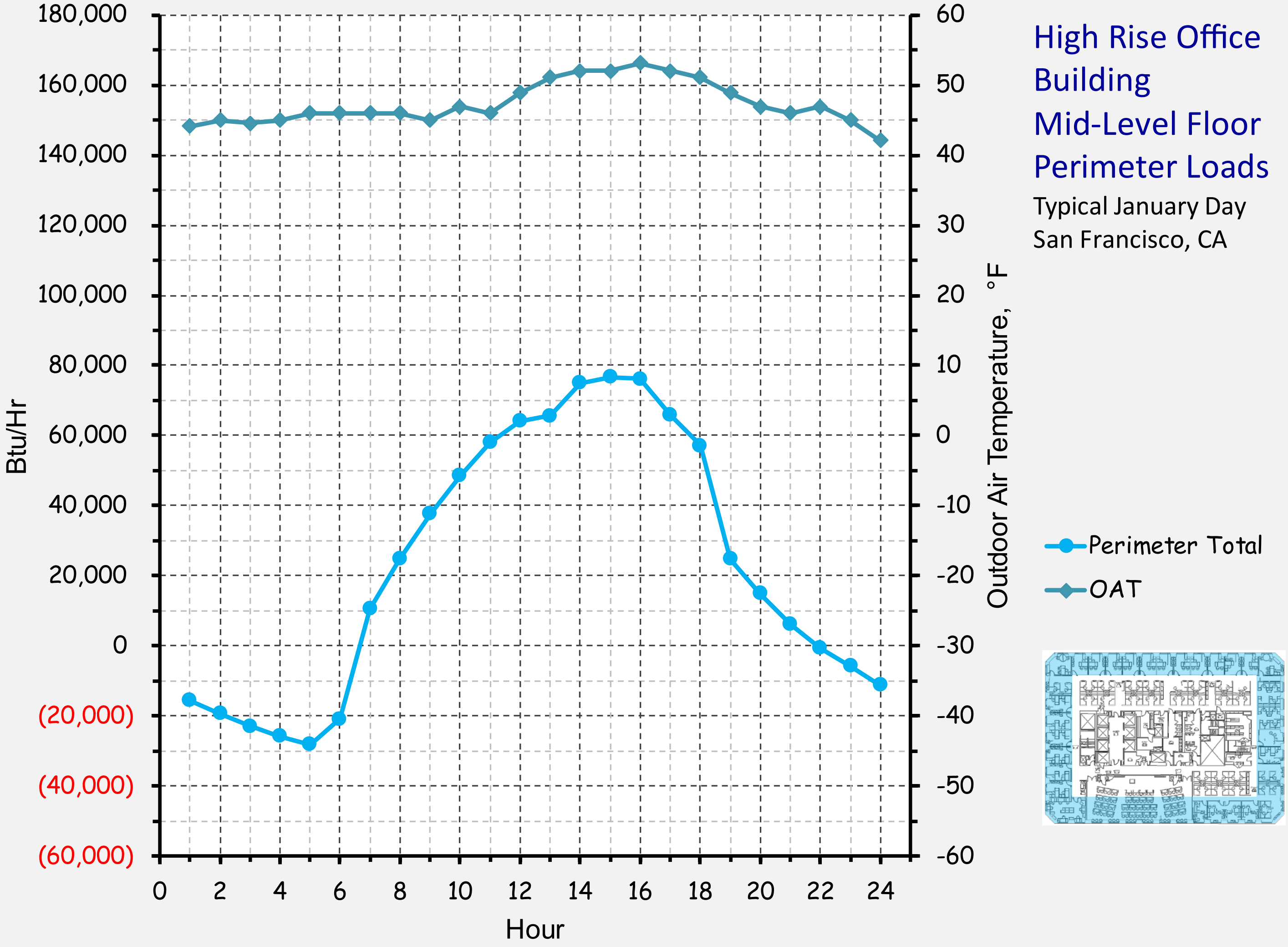

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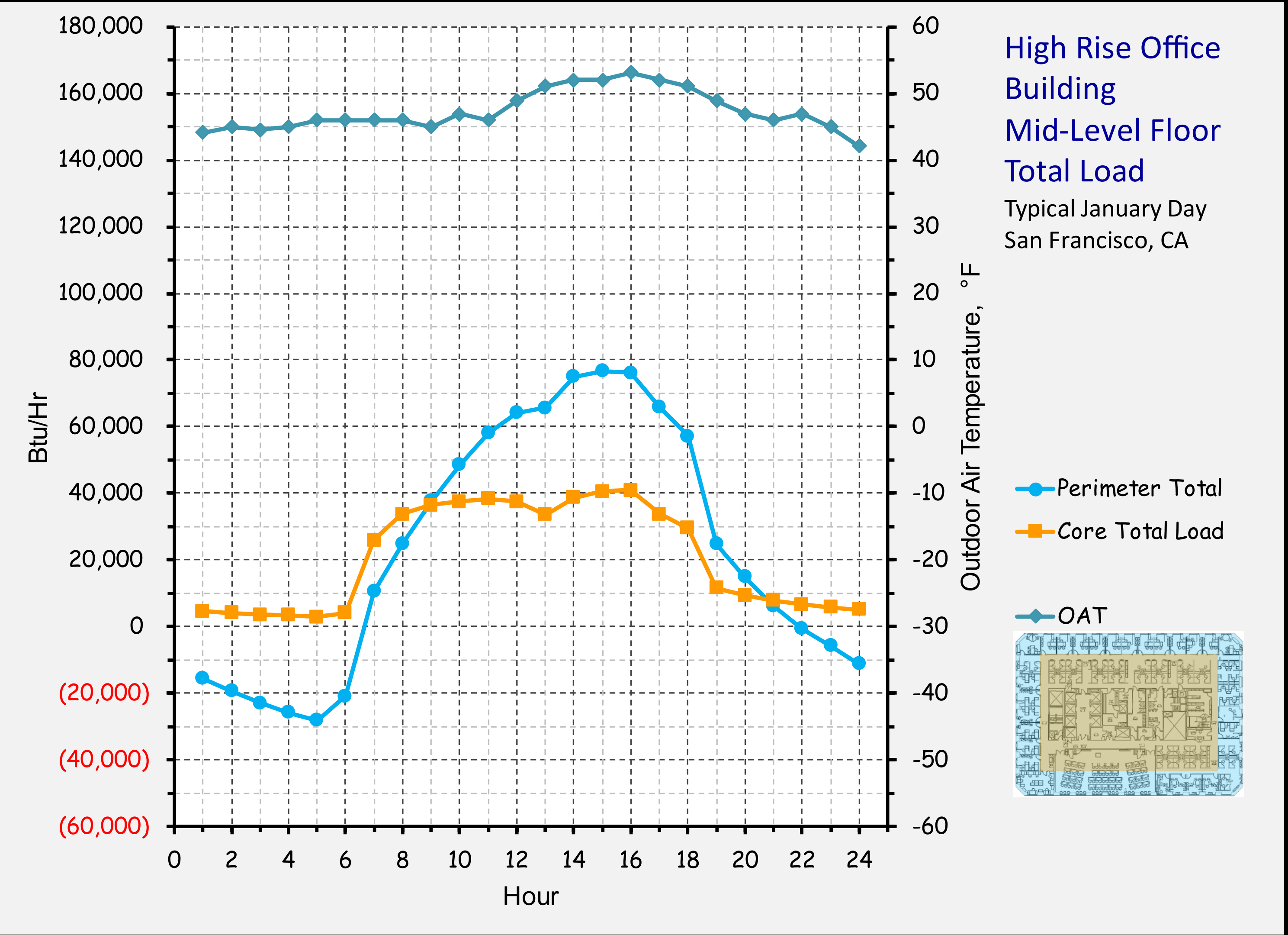
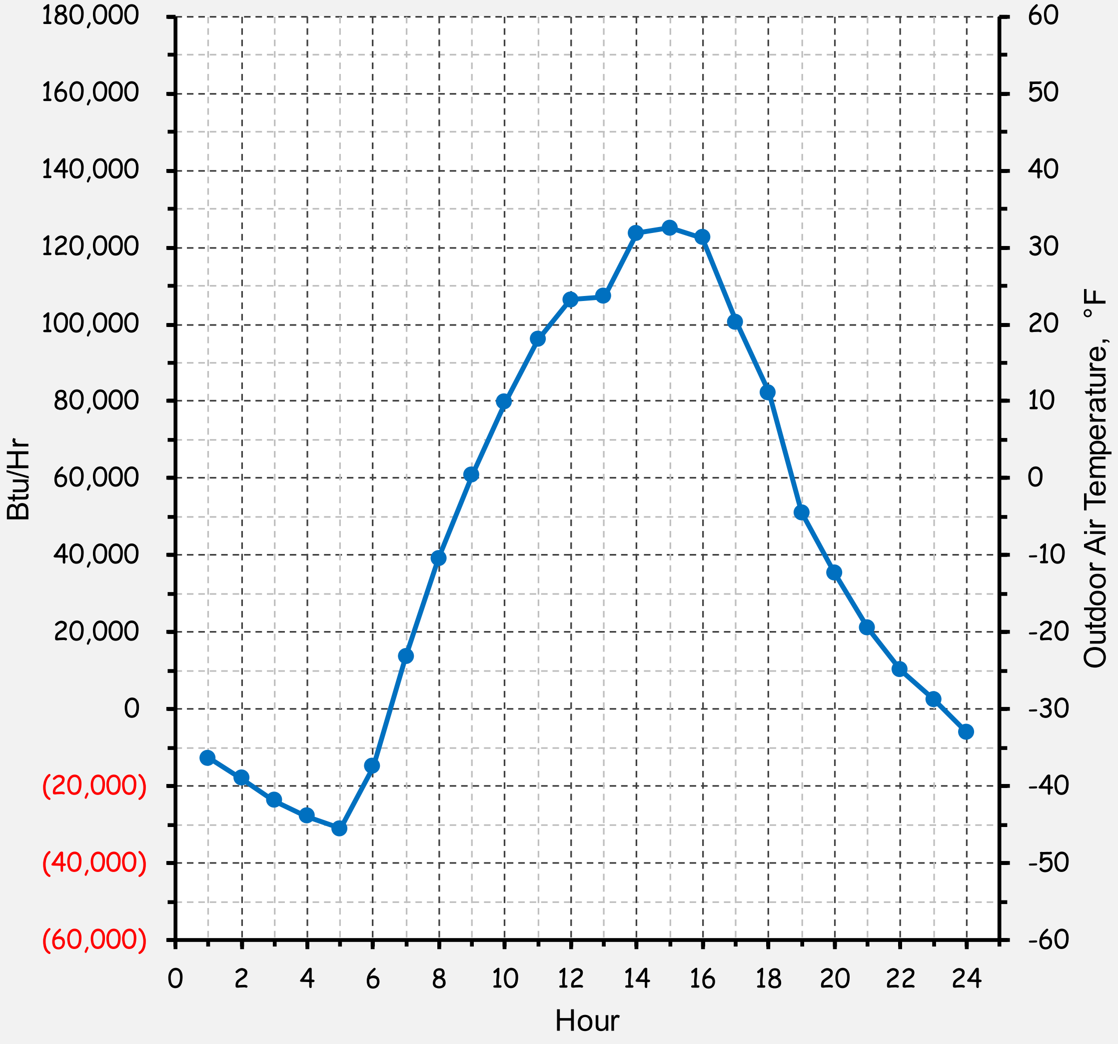
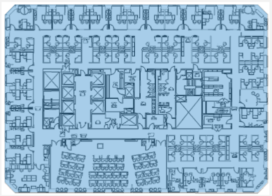
-30
-40
-50
-60
0
2
4
6
8
10
12
14
16
18
20
22
24
Hour
Perimeter Total
OAT

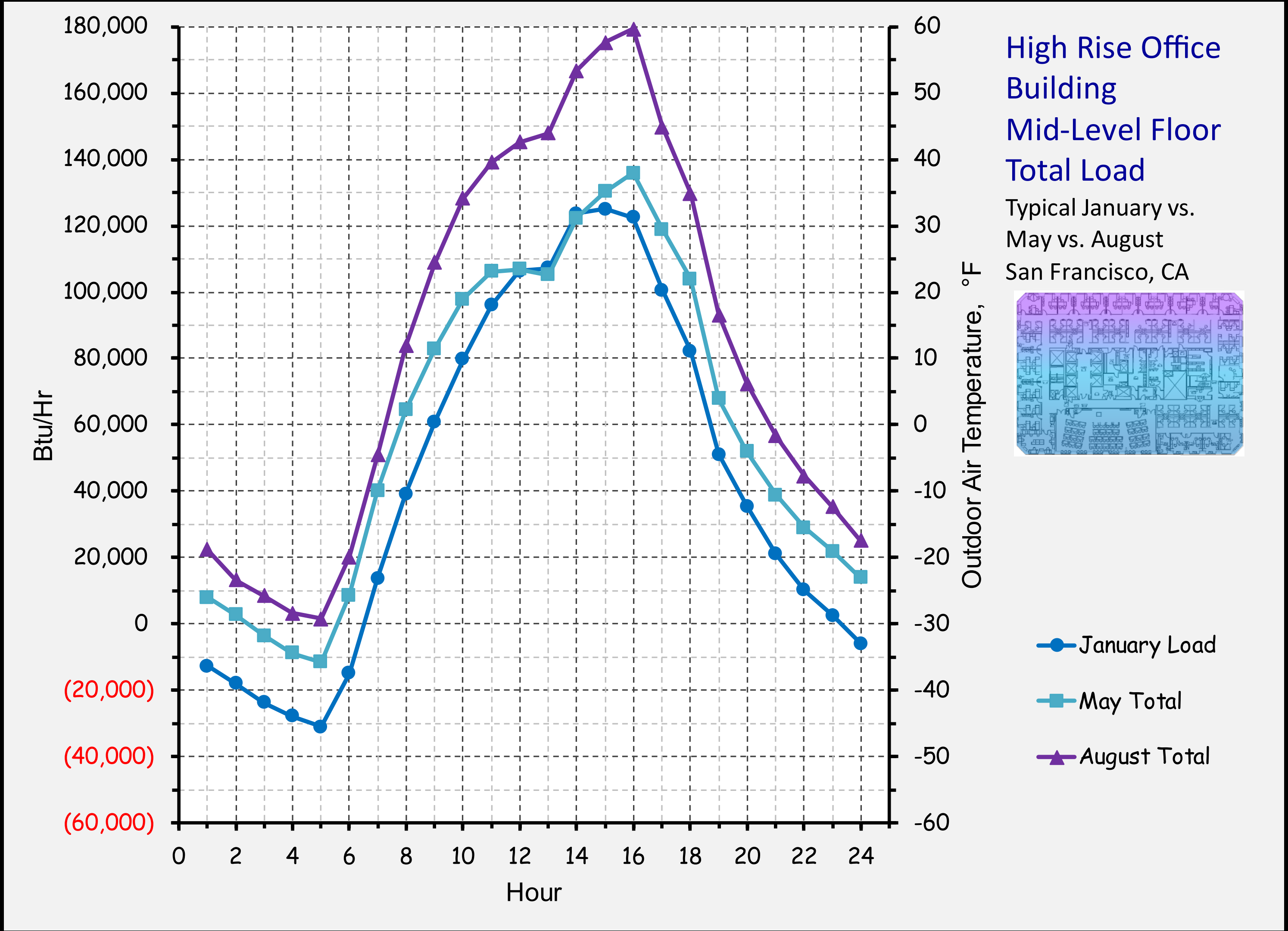

High Rise Office Building
Mid-Level Floor
Total Load
Typical January Day
San Francisco, CA
Perimeter Total
Core Total Load
OAT
Btu/Hr
Outdoor Air Temperature, °F
Hour
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
(20,000)
(40,000)
(60,000)
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
2
4
6
8
10
12
14
16
18
20
22
24

High Rise Office Building Mid-Level Floor Total Load

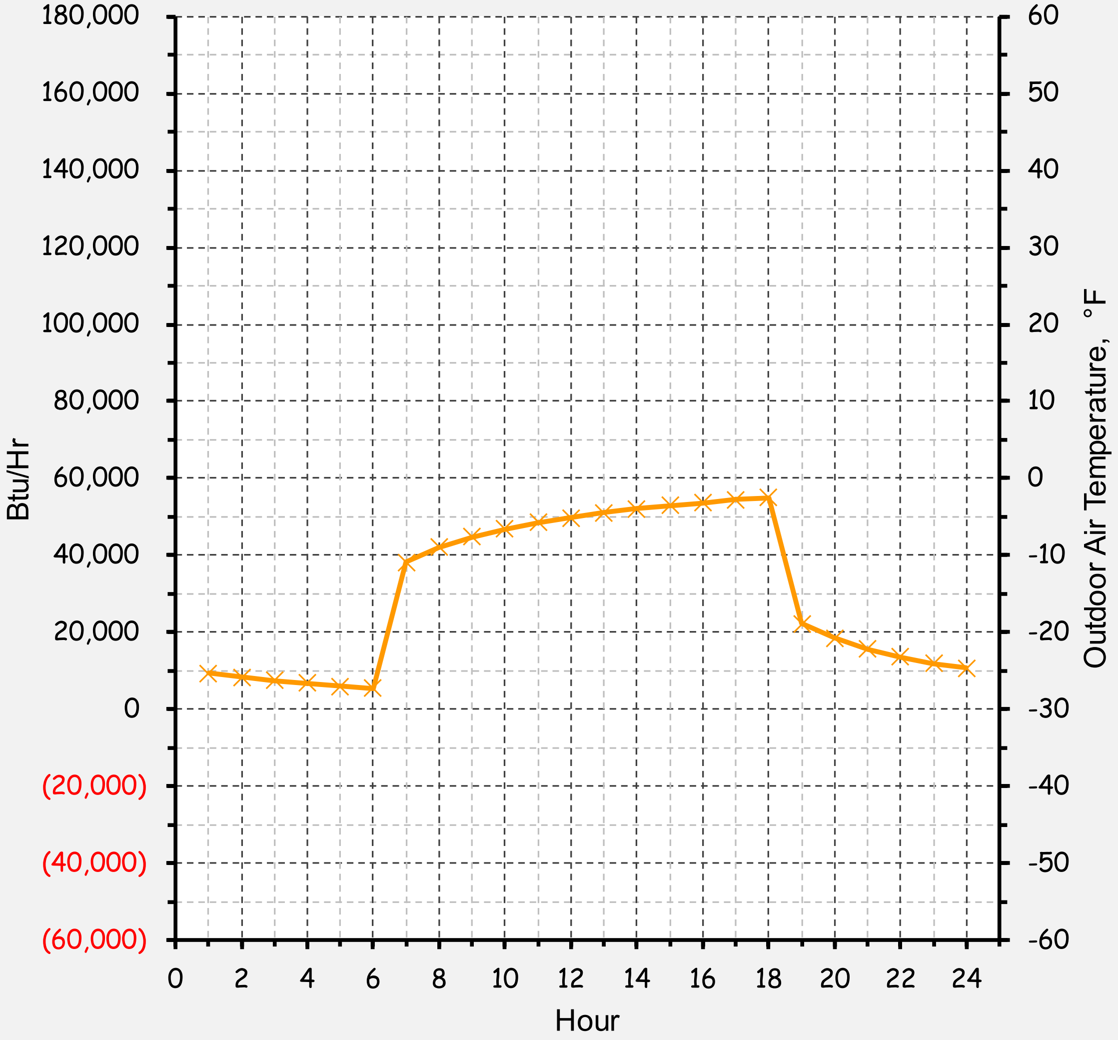
Typical January Day
San Francisco, CA





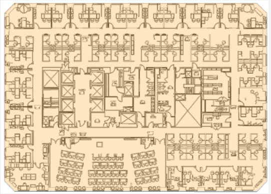


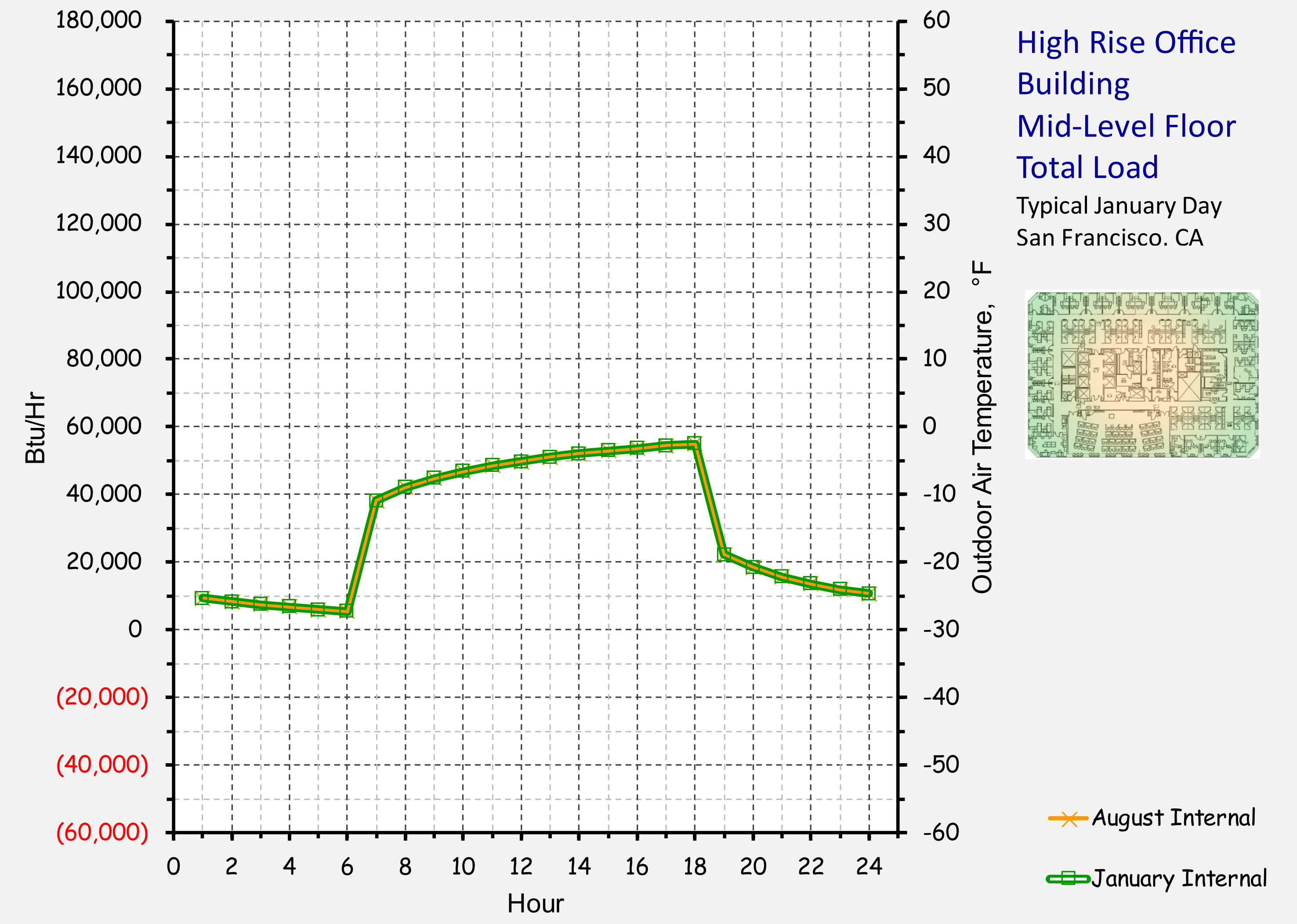
High Rise Office Building
Mid-Level Floor
Total Load
Typical January vs.
May vs. August
San Francisco, CA
Btu/Hr
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
(20,000)
(40,000)
(60,000)
Outdoor Air Temperature, °F
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Hour
0
2
4
6
8
10
12
14
16
18
20
22
24
January Load
May Total
August Total



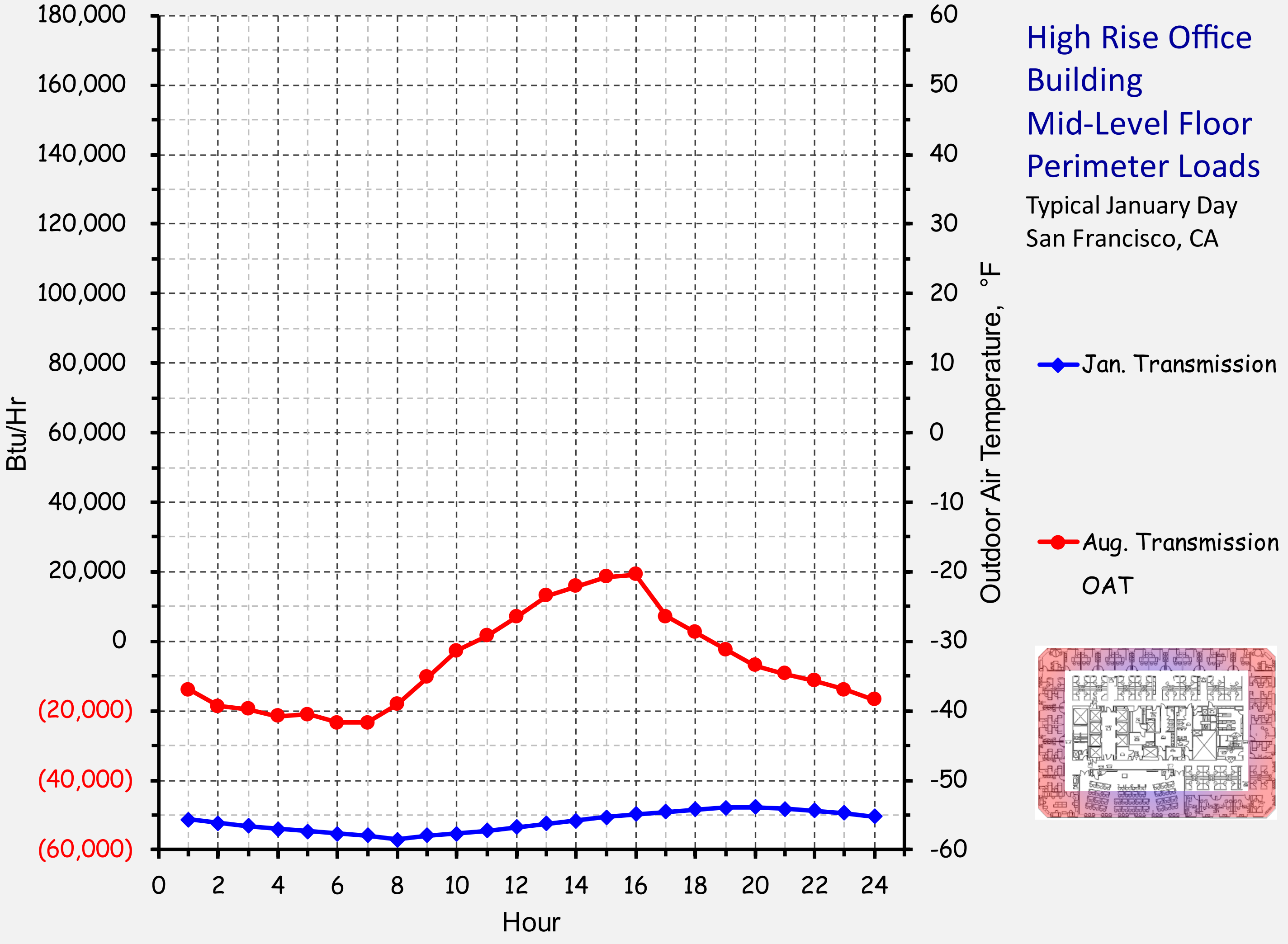
High Rise Office Building Mid-Level Floor Total Load

Typical January Day
San Francisco, CA





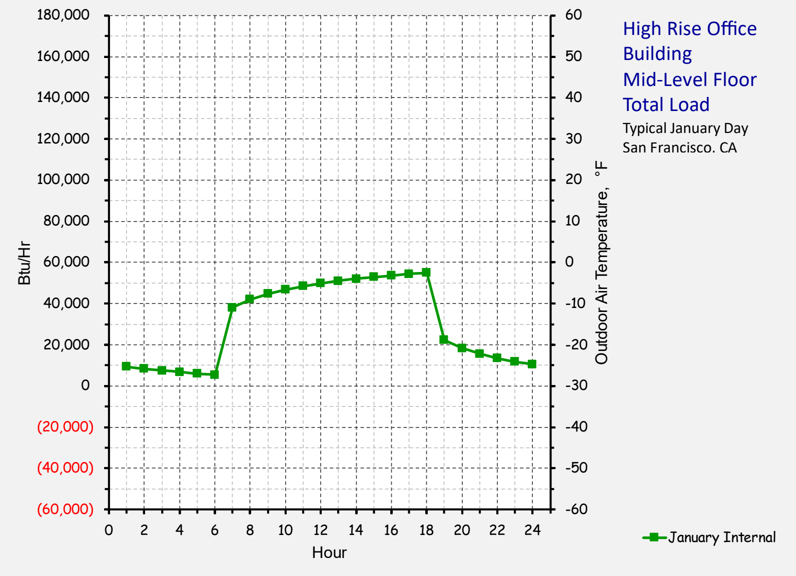
High Rise Office
Building
Mid-Level Floor
Total Load
Typical January Day
San Francisco. CA
Btu/Hr
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
(20,000)
(40,000)
(60,000)
Outdoor Air Temperature, °F
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
2
4
6
8
10
12
14
16
18
20
22
24
Hour
August Internal
January Internal

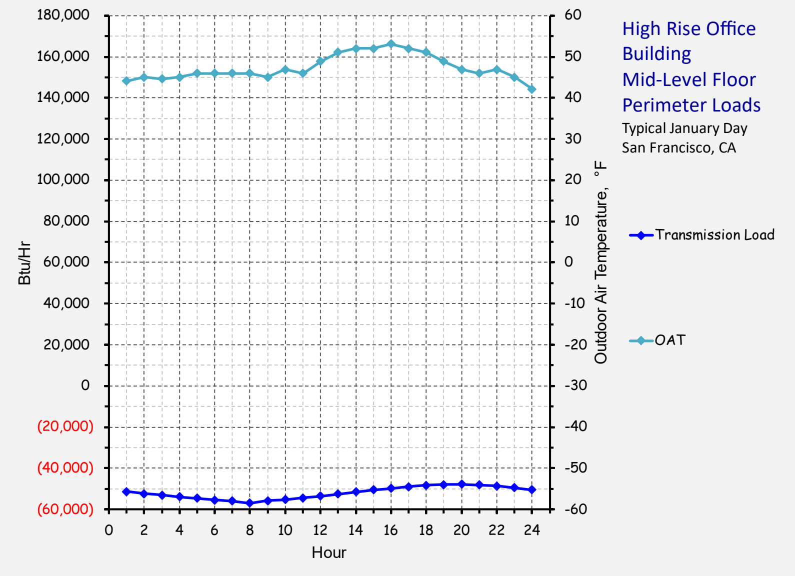


High Rise Office Building
Mid-Level Floor
Perimeter Loads
Typical January Day
San Francisco, CA
Btu/Hr
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
(20,000)
(40,000)
(60,000)
Outdoor Air Temperature, °F
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Hour
0
2
4
6
8
10
12
14
16
18
20
22
24
Jan. Transmission
Aug. Transmission
OAT

Internal Gains = Heat Recovery Potential

The current drive towards electrification and heat pumps may make the internal gains we threw away with an economizer cycle a resource for offsetting perimeter loads





Internal Gains = Heat Recovery Potential

For many facilities the electrical consumption expressed as Btus equals or exceeds the thermal consumption

Annual Building Energy Consumption Totals

Facility Description	Annual Site Thermal, kBtu	Annual Site Electric, kBtu	Thermal vs. Electric Difference	
			kBtu (Positive means thermal exceeds electrical)	% of thermal met by electrical when electrical converted to heat
Monterey, California Office/Training Facility	1,299,800	1,245,199	54,601	96%
Monterey, California Dental Clinic	402,149,182	650,914,664	-248,765,482	162%
Seattle High-rise Office and Courthouse	589,732,280	938,067,784	-348,335,504	159%
Columbus Ohio Full Service High Rise Hospitality Facility	36,513,882,901	22,107,926,113	14,405,956,788	61%
San Francisco California Full Service High Rise Hospitality Facility	18,507,084,000	20,176,973,400	-1,669,889,400	109%

How Buildings Use Heat

How Buildings Use Heat

- Heating
- Preheat
- Reheat
- Cooling
- Processes
- Power Generation

Revisiting a Definition

Heating

- A process that adds energy
  - For a space, this is often accomplished by circulating air through it at a temperature above the required set point
  - For a fluid stream, this is often accomplished by passing it over a surface that is above the required supply temperature

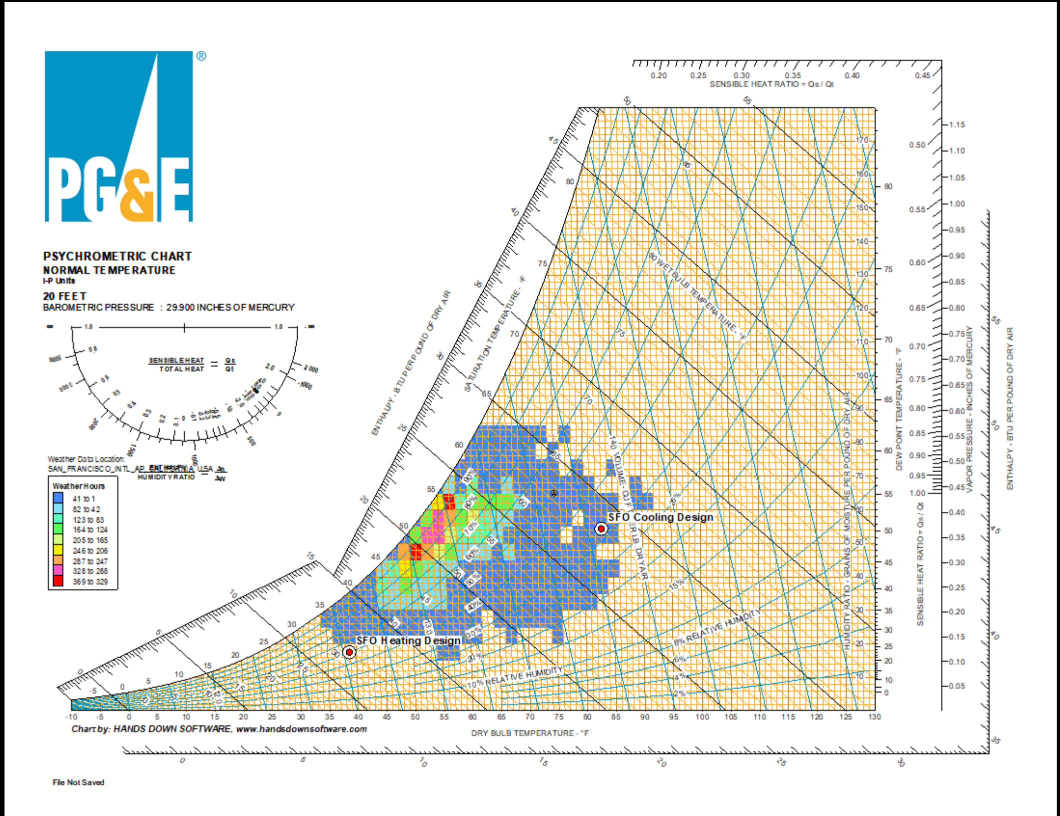
A Few More Definitions

Ventilation

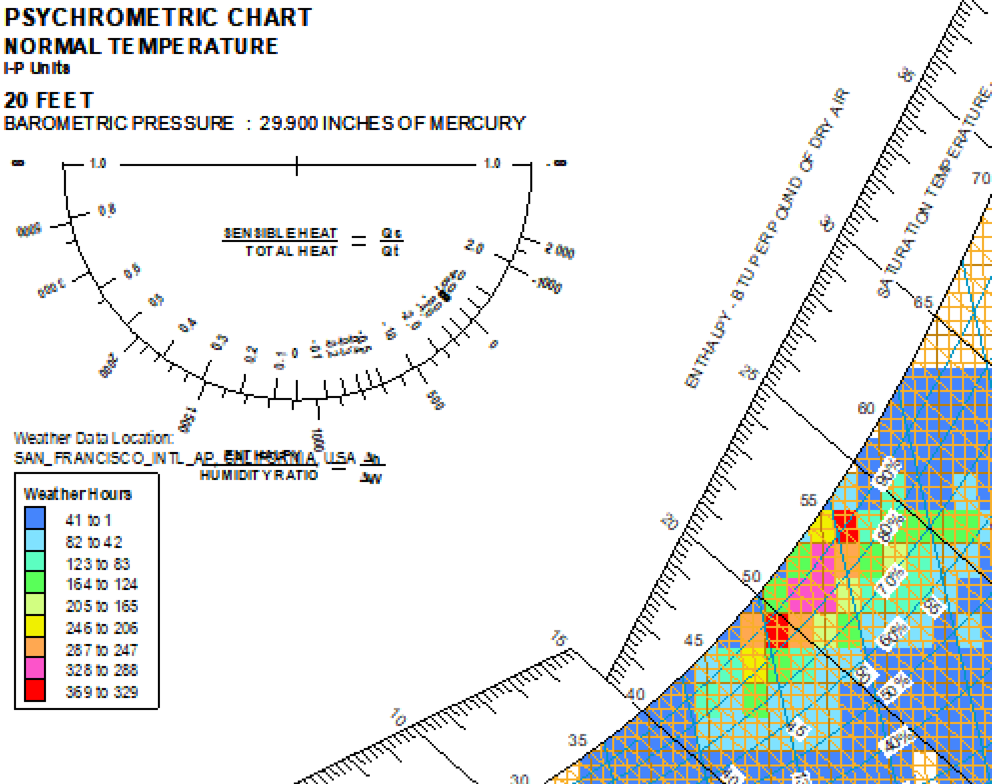
- Outdoor air that is brought into the building to manage contaminates, generally by dilution
- The outdoor air volume is dictated by:
  - Type of contaminant
  - Capture velocity
  - Occupant count
  - Code requirements
- ASHRAE Standard 62.1 is usually the basis for design
- Ventilation air typically is removed by exhaust systems

Keeping Things Safe by Controlling Contaminants

- Can be quite challenging as the climate varies from day to day

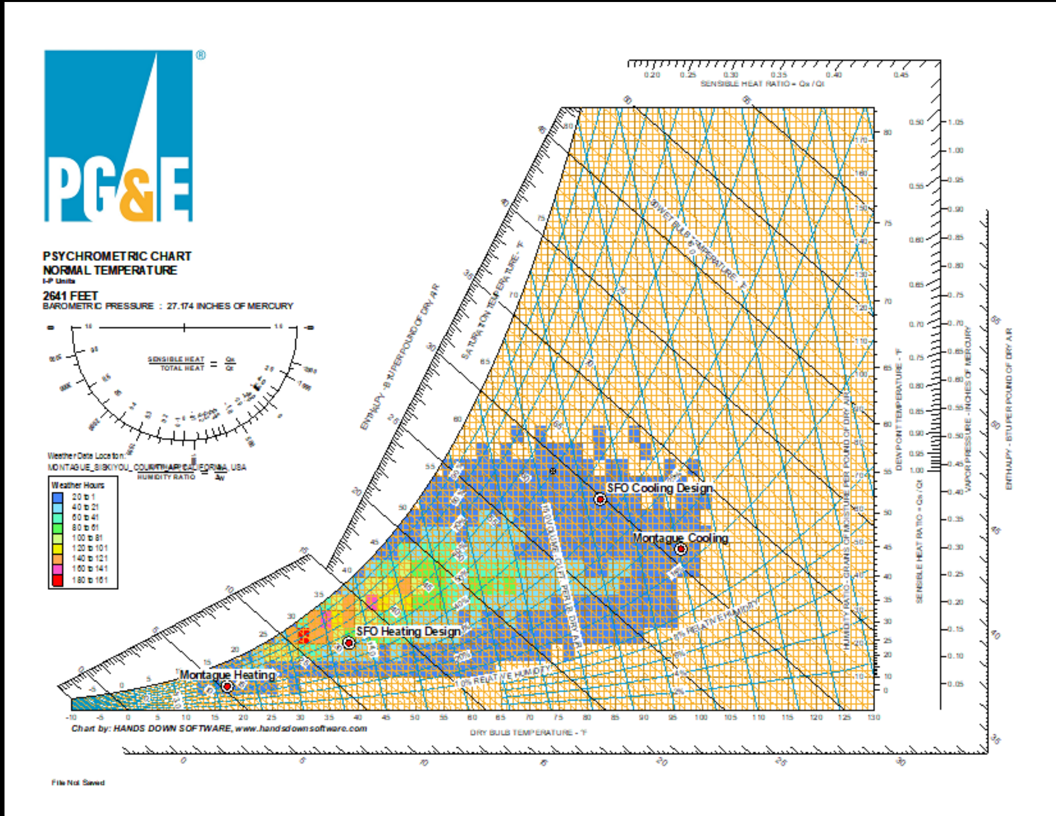


- Can be quite challenging as the climate varies from day to day



Keeping Things Safe by Controlling Contaminants

- Can be quite challenging as the climate varies from day to day
- Becomes more challenging when outdoor air is below 32°F



A Few More Definitions

Freezing

- A condition that occurs when water is cooled to the point where it changes phase from a solid to a liquid

A Few More Definitions

Water Damage

- A condition that occurs after frozen water contained in a HVAC coil changes back to the liquid phase

A Few More Definitions

Expletive

- A generic reference to the field terminology used to describe and discuss water damage when it occurs

A Few More Definitions

Significant Emotional Event

- An event that has life-changing emotions associated with it
- Triggering conditions:
  - Flurry of expletives
  - Lawsuits
- Freezing a coil is an example

How Buildings Use Heat

- Heating ✓
- Preheat
- Reheat
- Cooling
- Processes
- Power Generation

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat
- Reheat
- Cooling
- Processes
- Power Generation

A Few More Definitions

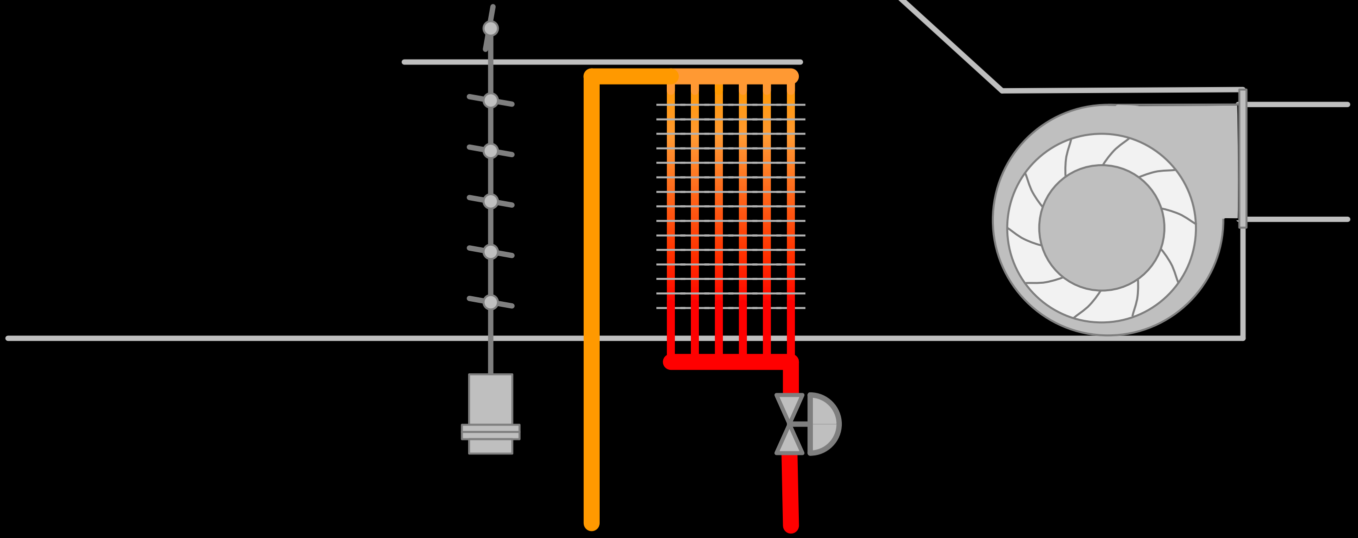
Preheat

- A process that heats a fluid stream to prepare it for a subsequent HVAC process
- In air handling systems, this process is used to raise subfreezing air above freezing to protect water filled elements down stream from damage due to freezing

See the Functional Testing Guide (https://www.av8rdas.com/functional-testing-guide.html) Air Handling System Reference Guide Chapter 5 – Preheat, Table 5.1 to contrast preheat, reheat and heating applications

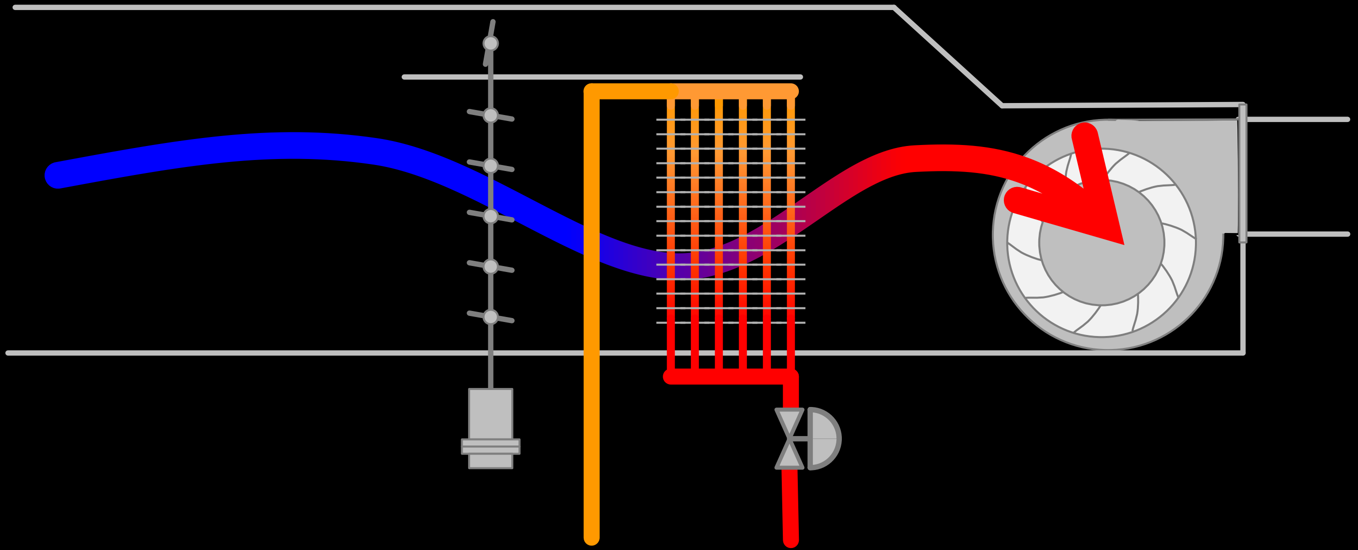
Face and Bypass Damper Control

- Coil discharge temperature regulation strategy



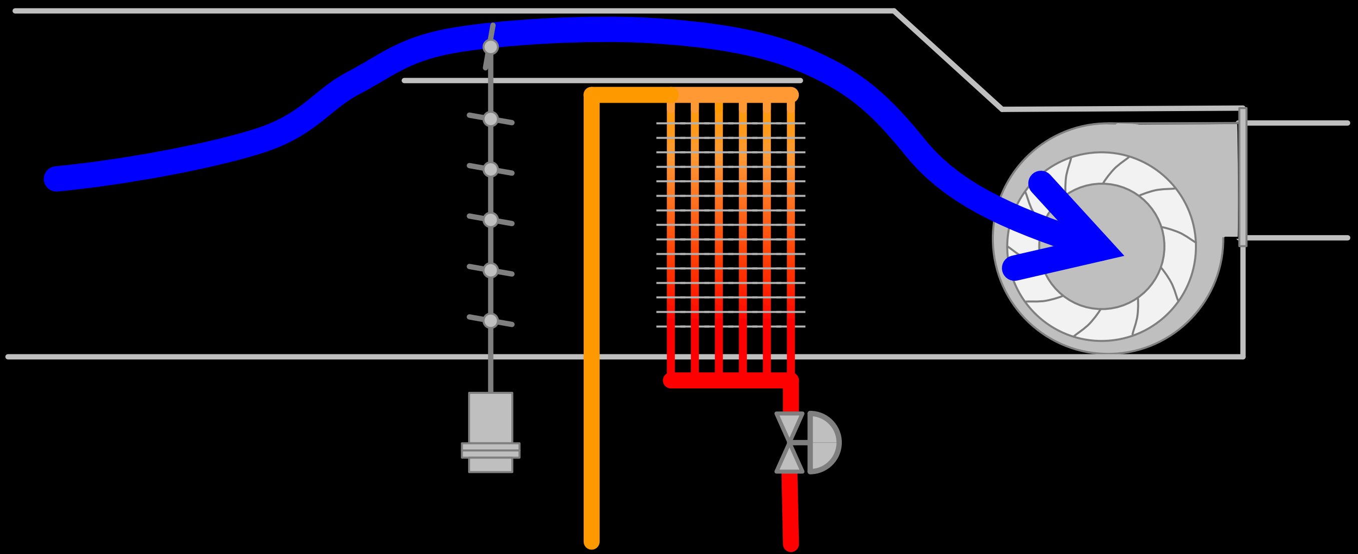
Face and Bypass Damper Control

- Coil discharge temperature regulation by mixing air that passes through the coil



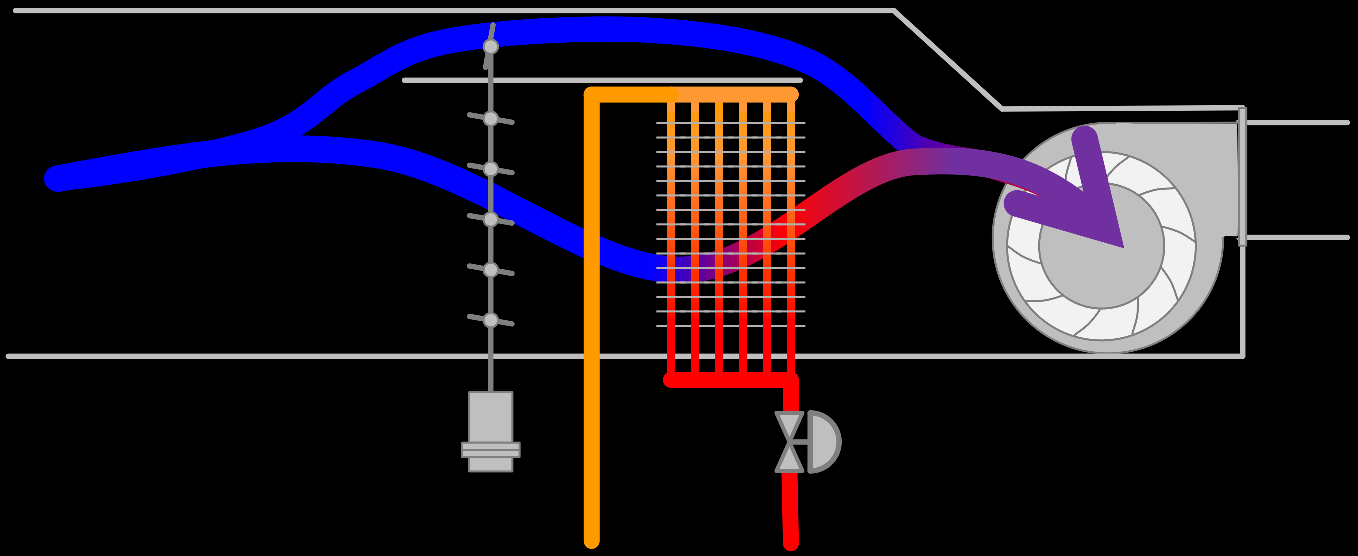
Face and Bypass Damper Control

- Coil discharge temperature regulation by mixing air that passes through the coil with air that bypasses the coil



Face and Bypass Damper Control

- Coil discharge temperature regulation by mixing air that passes through the coil with air that bypasses the coil



Why Face and Bypass

Flow remains steady in the steam/water side of the coil

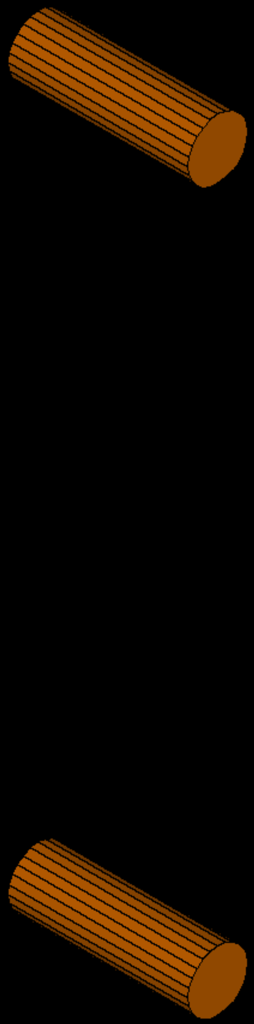
- Keeps the coil face active
  - Ensures dehumidification for cooling and dehumidification applications
  - Ensures freeze protection for preheat applications
- Moving water is less likely to freeze
- Compatible with water systems requiring constant flow


Bypass Damper
The Traditional Approach
Face Damper (Covers the Heating Coil Face)

Integral Face and Bypass

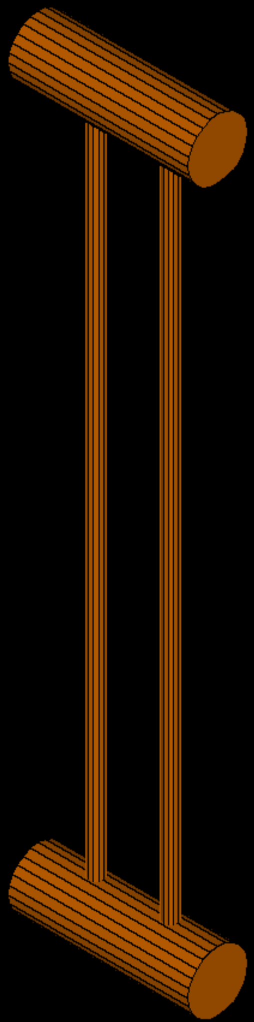
- "Wing" coil
- Targeted at preheat applications
- Ensures steam coils will not freeze

An Alternative Approach



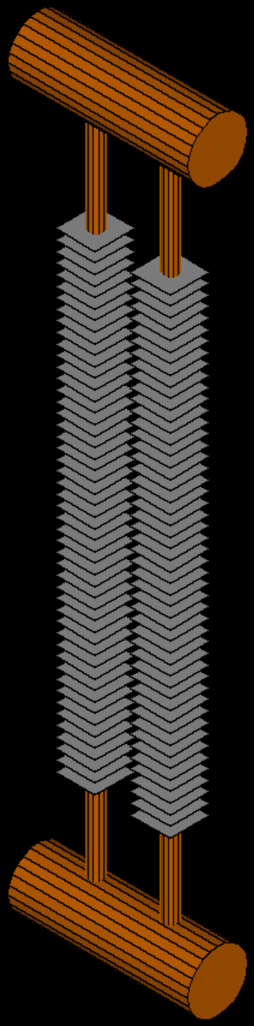
Integral Face and Bypass

- Horizontal supply and return headers are located out of the air stream



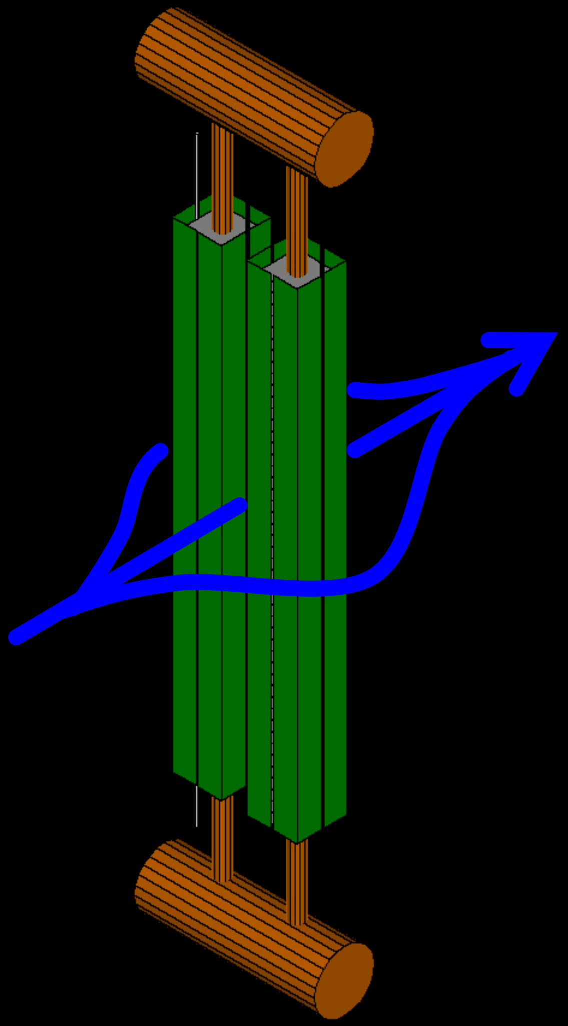
Integral Face and Bypass

- Horizontal supply and return headers are located out of the air stream
- Vertical tubes connect headers and ensure condensate drains out of the air stream



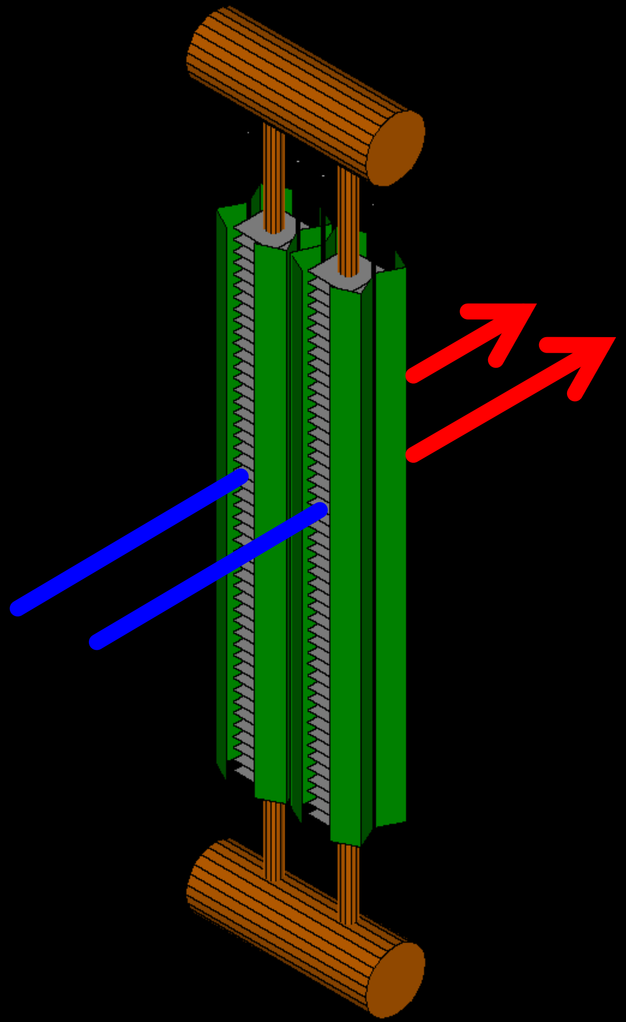
Integral Face and Bypass

- Horizontal supply and return headers are located out of the air stream
- Vertical tubes connect headers and ensure condensate drains out of the air stream
- Fins make tubes heat transfer elements



Integral Face and Bypass

- Horizontal supply and return headers are located out of the air stream
- Vertical tubes connect headers and ensure condensate drains out of the air stream
- Fins make tubes heat transfer elements
- “Clam shell” dampers around finned tubes direct air around the tubes …

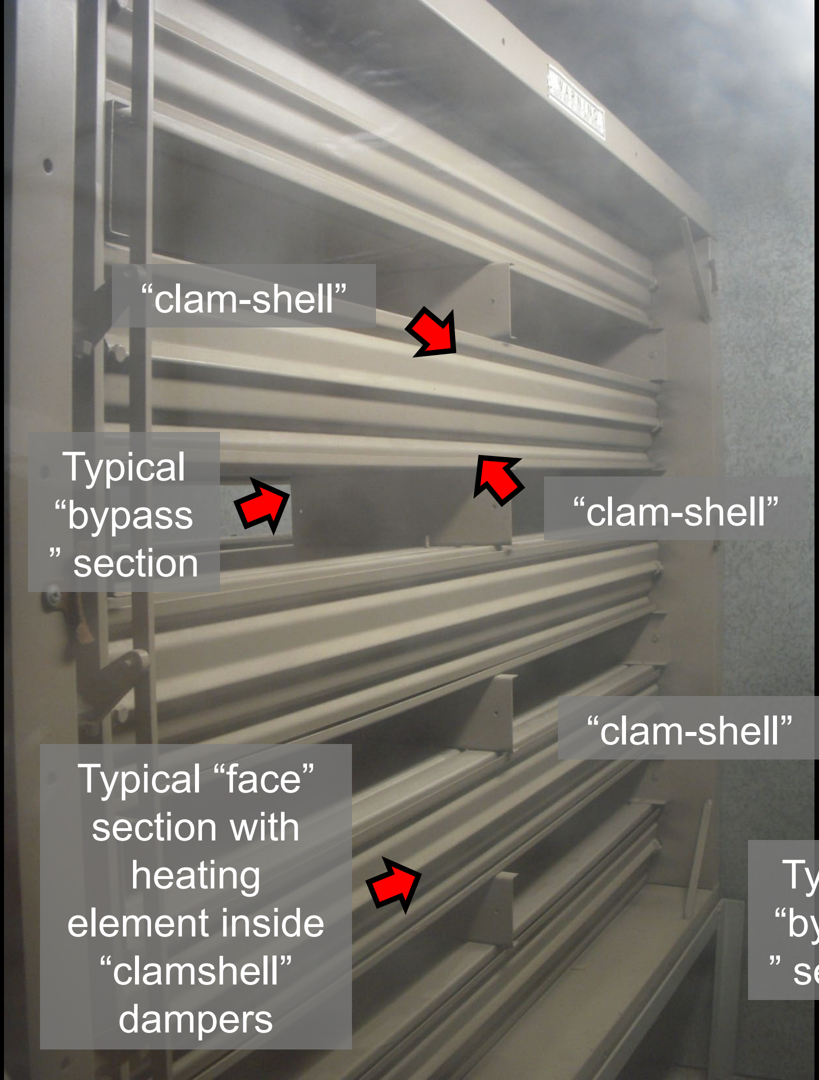


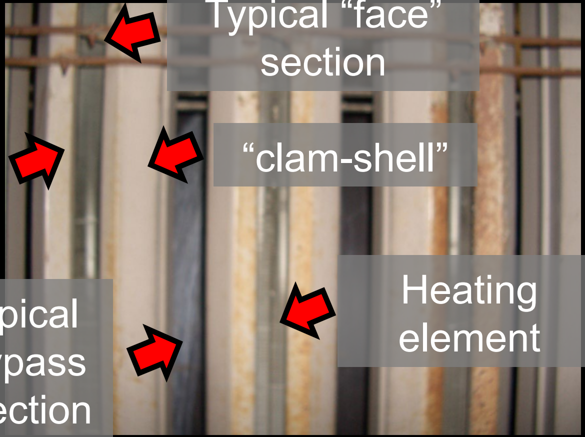
Integral Face and Bypass

- Horizontal supply and return headers are located out of the air stream
- Vertical tubes connect headers and ensure condensate drains out of the air stream
- Fins make tubes heat transfer elements
- “Clam shell” dampers around finned tubes direct air around the tubes …

  … or through the tubes

Integral Face and Bypass





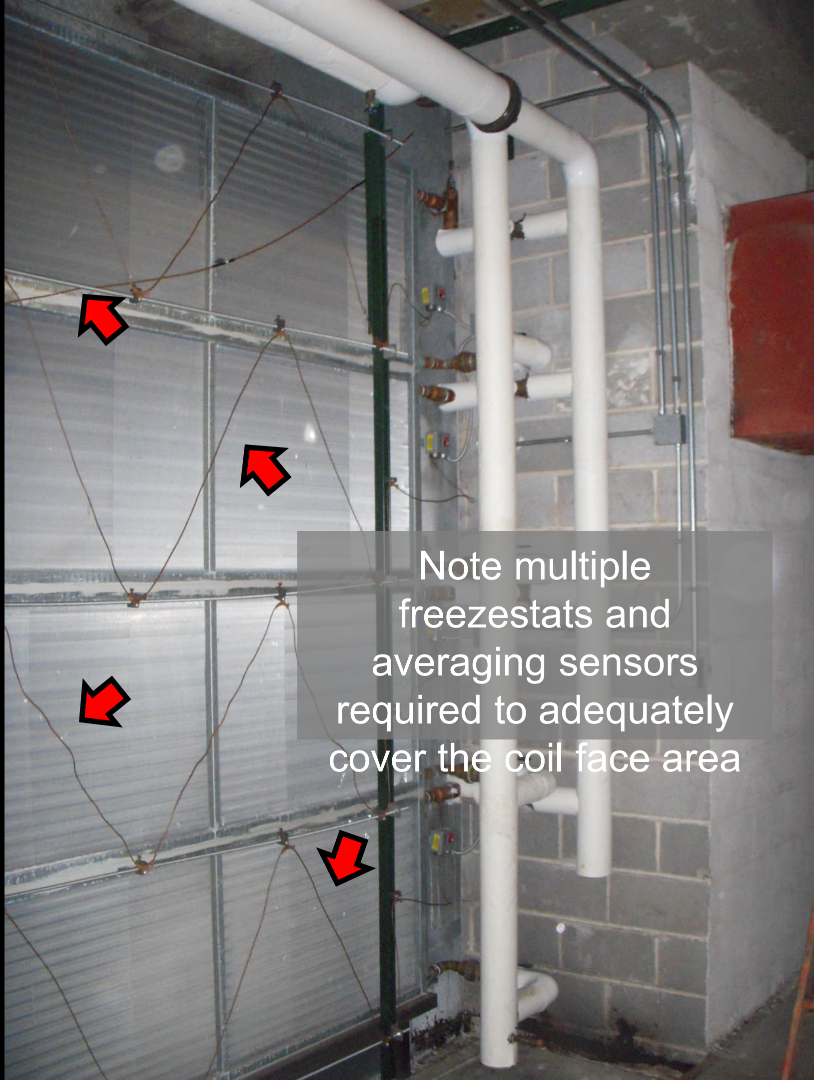
Control Considerations

- Damper sizing is critical for linear control response
  - Low velocity required at the coil face to minimize coil pressure drop and carry over
  - Deep coils have high pressure drops
  - The bypass side needs to be sized for the combined pressure drop of the coil and face damper

Control Considerations

- Water/steam side is typically on or off
- Temperature control achieved via damper modulation
- Hot water and steam coils can see significant temperature rises in full bypass
  - 4°F or more
  - Parasitic load
  - Shut down heat source when its not needed

Constant Volume Pumped Hot Water Preheat Coil



Preheat Bottom Lines

- Just because a coil is piped to hot water or steam does not mean it can safely deal with subfreezing air
- Freeze protection and sensing elements need to be installed to reflect/compensate for:
  - Non-uniform flow conditions
  - Temperature stratification
- The control system can not compensate for equipment that is not configured and piped to handle sub-freezing air
- The control system will be the first thing blamed if a coil freezes

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat
- Reheat
- Cooling
- Processes
- Power Generation

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat
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- Power Generation

A Few More Definitions

Reheat

- A process that uses heat to warm air being delivered to a zone to prevent over cooling
  - The temperature of the air was set by the need to hit a dehumidification target, *or*
  - By the requirements of another zone
    - Thus, it can not be raised at the central system
    - The volume can not be reduced because it has been set to assure proper ventilation (contaminant control)

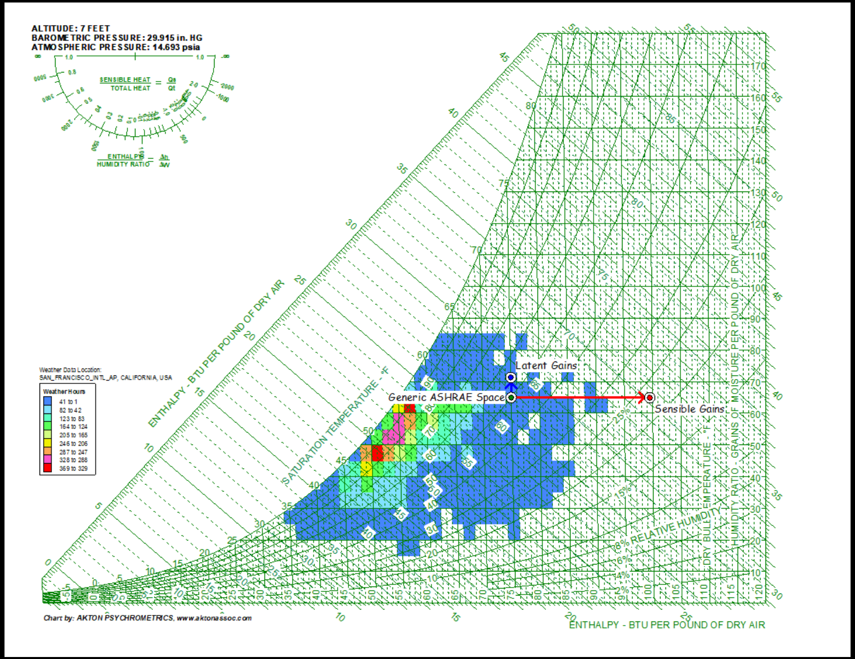
A Few More Definitions

Reheat

- In the limit, *at the most*:
  - Reheat will raise the supply temperature *to* the zone temperature but not *above* it

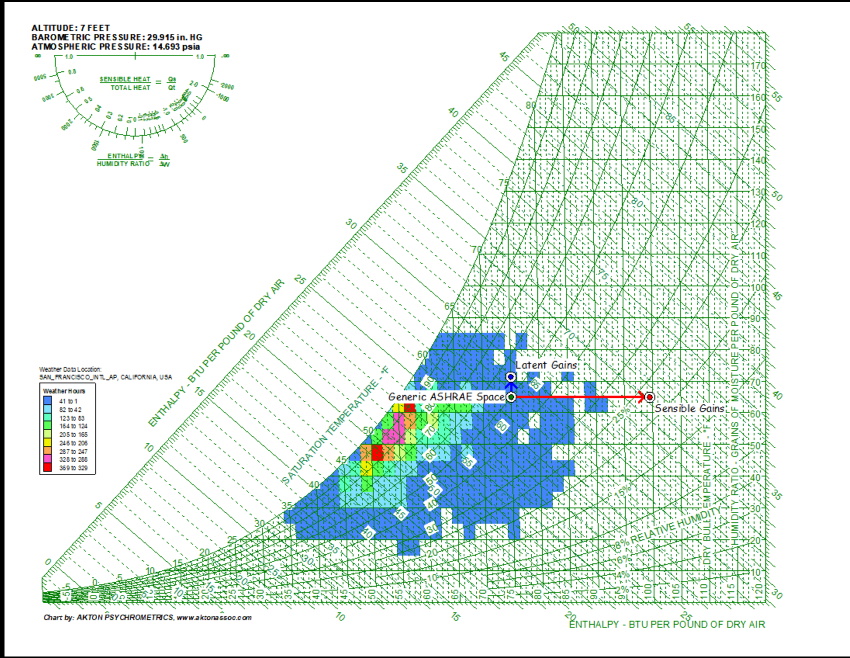
Addressing the HVAC Goals

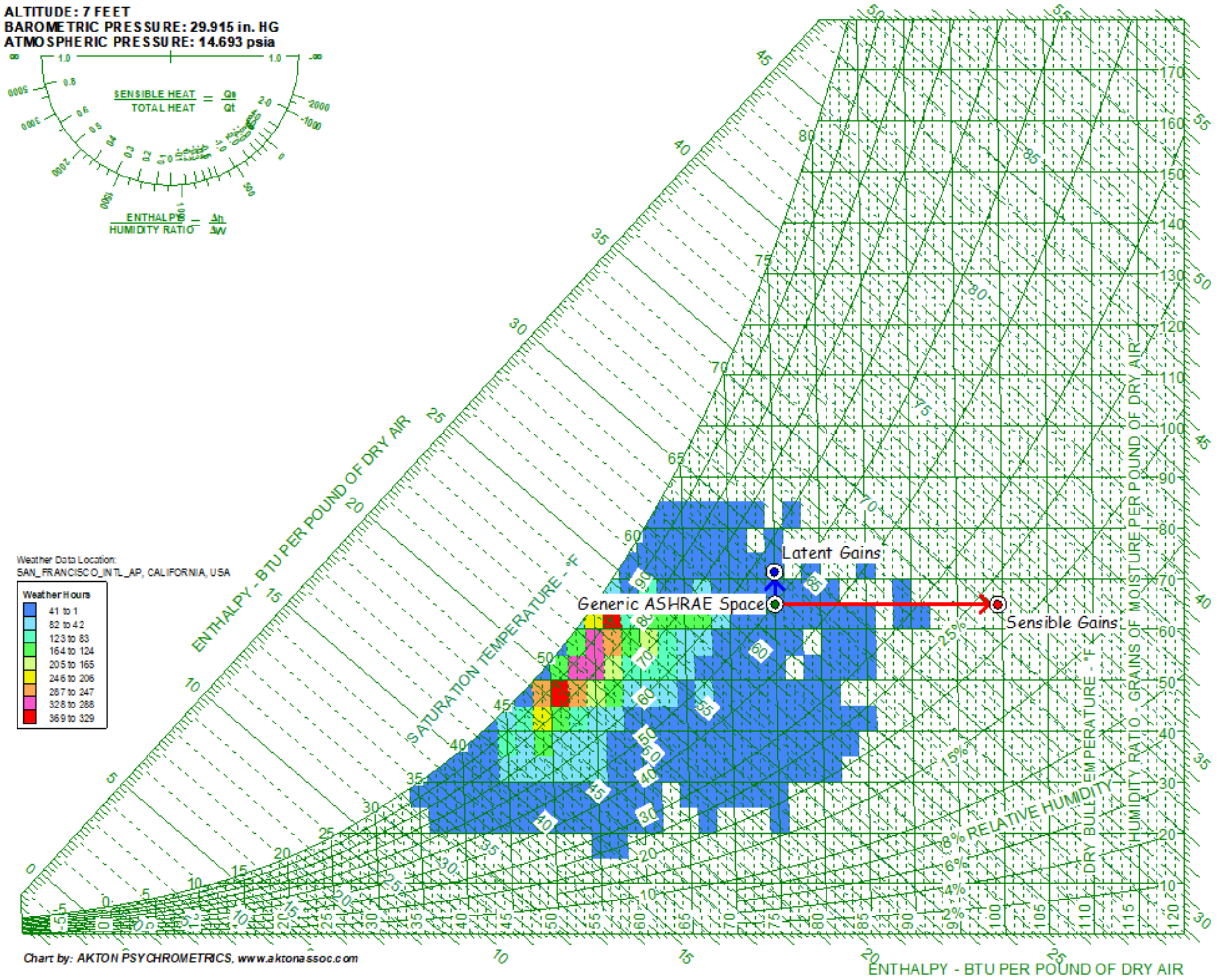
Given that there are people in the space, we will need to provide some quantity of fresh outdoor air to control contaminants



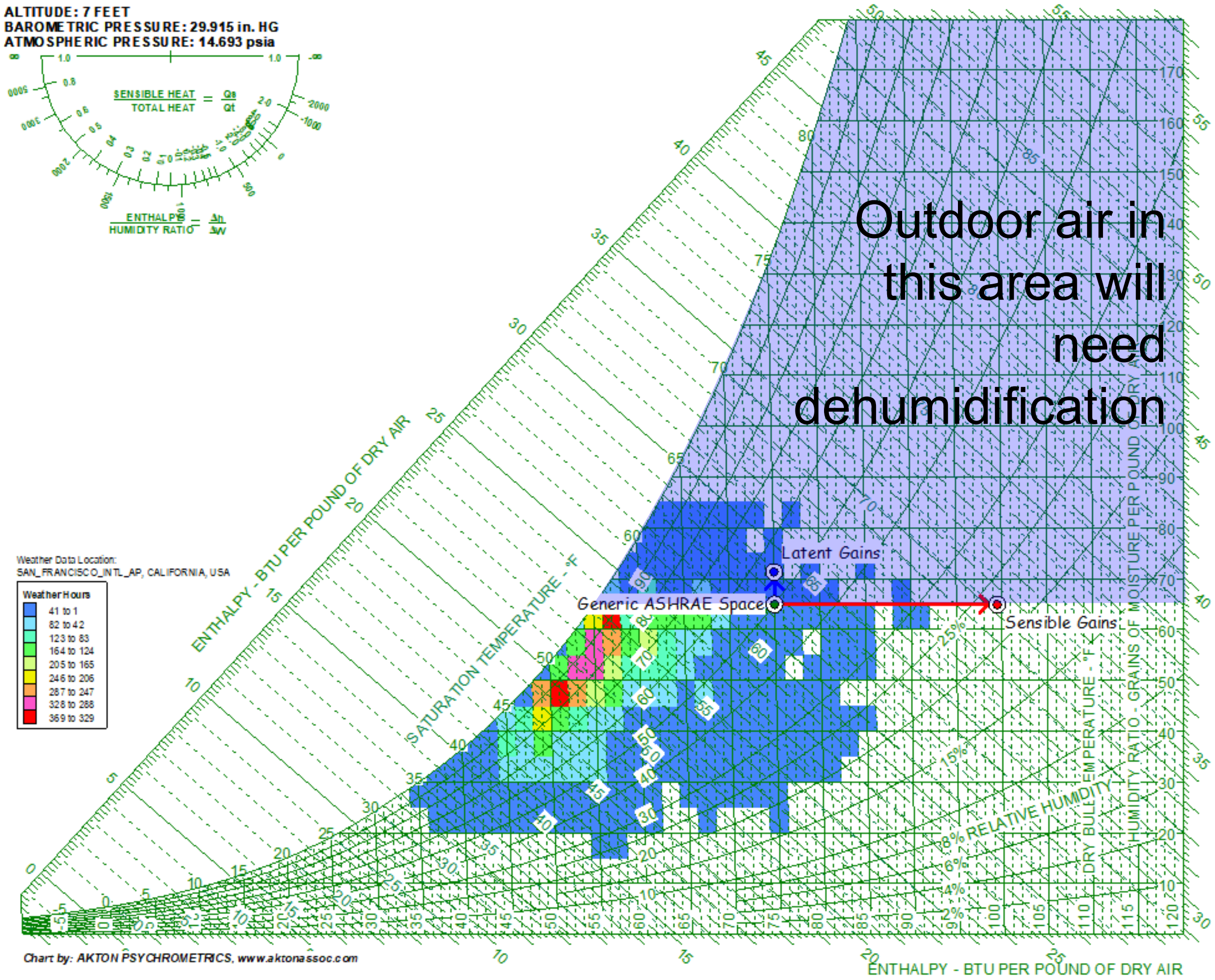
Addressing the HVAC Goals

Given the nature of the climate and the loads, this air and any recirculated air will need to be cooled and dehumidified during warm, humid weather





ALTITUDE: 7 FEET
BAROMETRIC PRESSURE: 29.915 in. HG
ATMOSPHERIC PRESSURE: 14.693 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Weather Data Location:
SAN_FRANCISCO_INTL_AP, CALIFORNIA, USA
Weather Hours
41 to 1
82 to 42
123 to 83
164 to 124
205 to 165
246 to 206
287 to 247
328 to 288
369 to 329
Latent Gains
Generic ASHRAE Space
Sensible Gains
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
ENTHALPY - BTU PER POUND OF DRY AIR
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com


ALTITUDE: 7 FEET
BAROMETRIC PRESSURE: 29.915 in. HG
ATMOSPHERIC PRESSURE: 14.693 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Outdoor air in this area will need dehumidification
Latent Gains
Generic ASHRAE Space
Sensible Gains
Weather Data Location:
SAN_FRANCISCO_INTL_AP, CALIFORNIA, USA
Weather Hours
41 to 1
82 to 42
123 to 83
164 to 124
205 to 165
246 to 206
287 to 247
328 to 288
369 to 329
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
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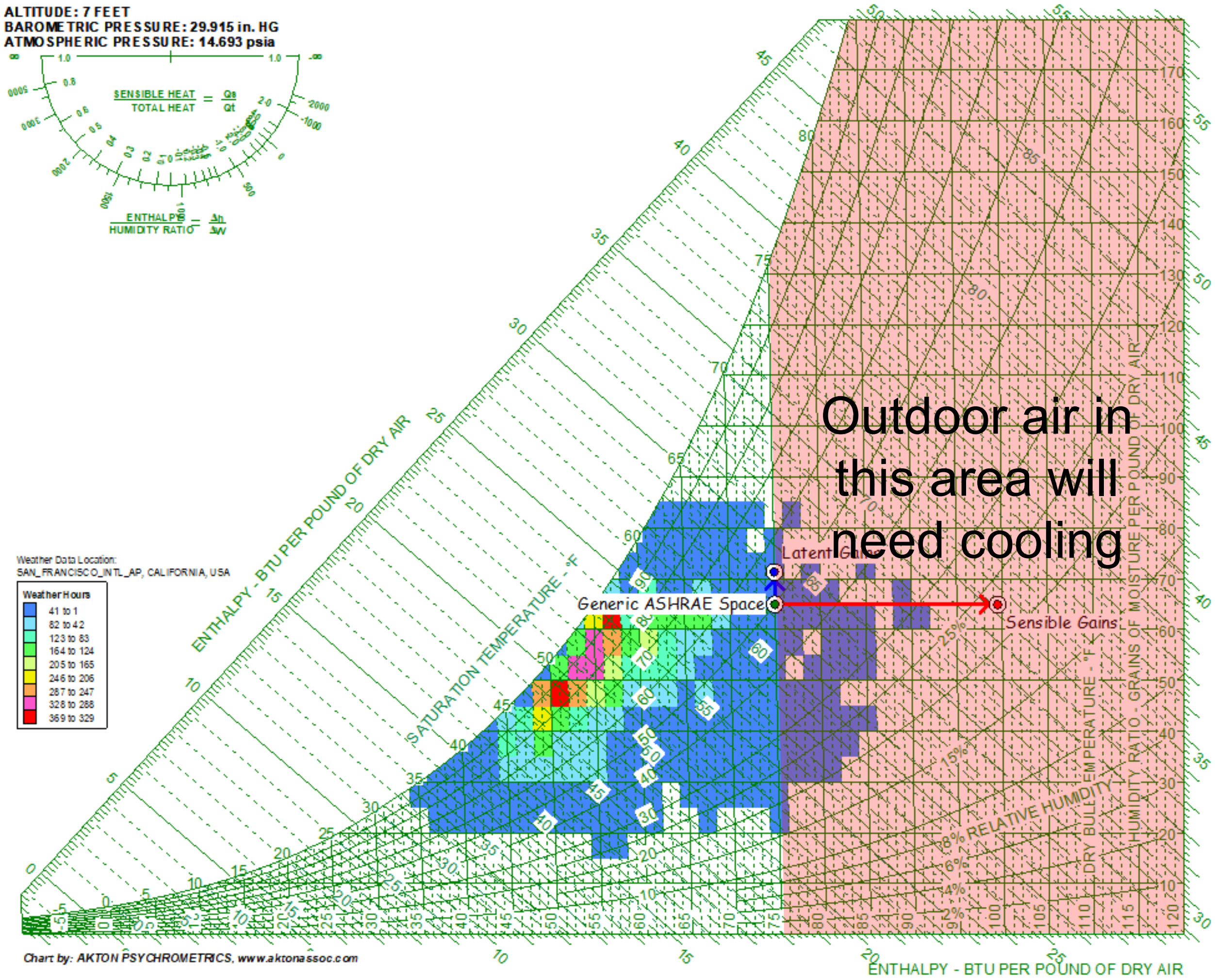
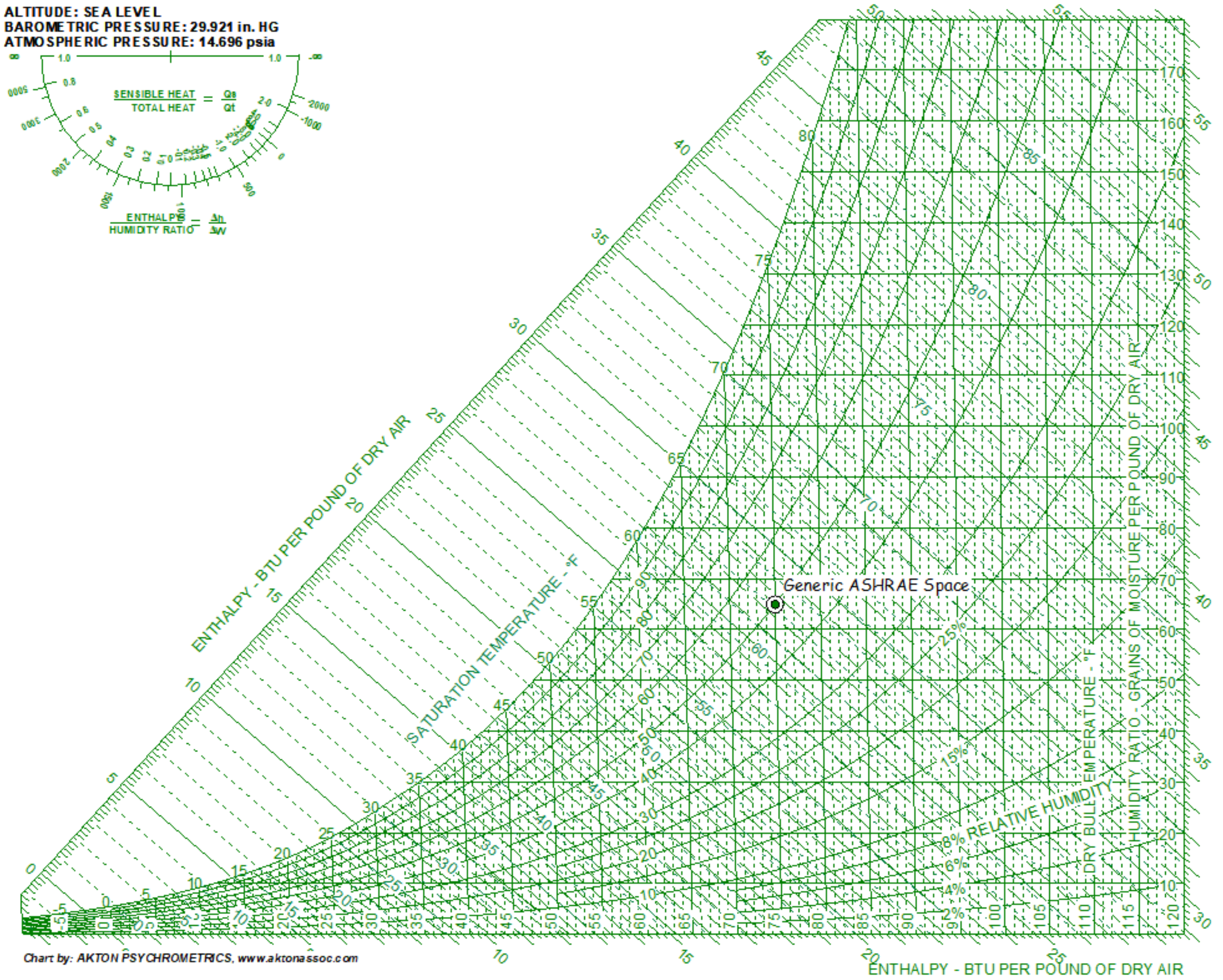
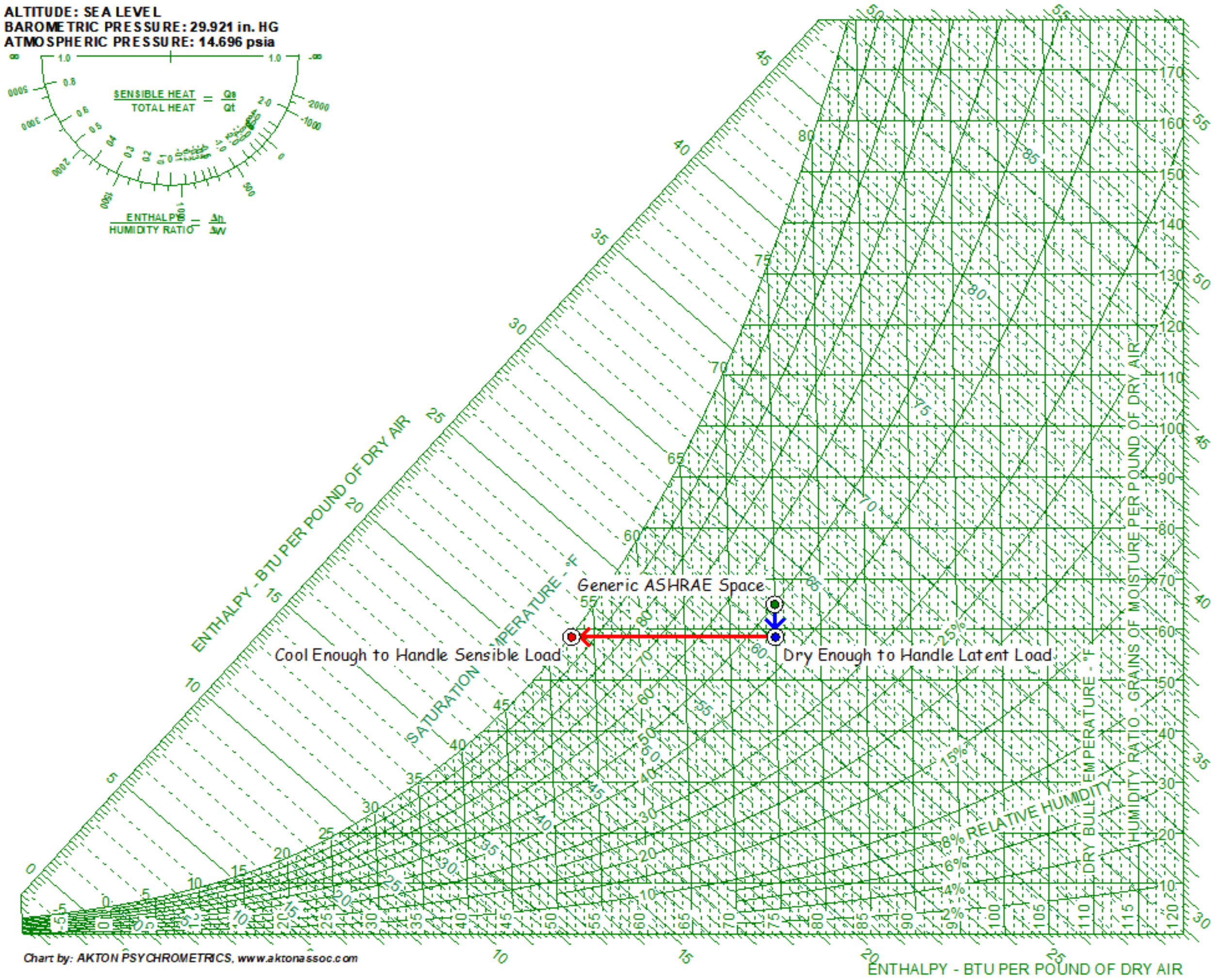
ENTHALPY - BTU PER POUND OF DRY AIR



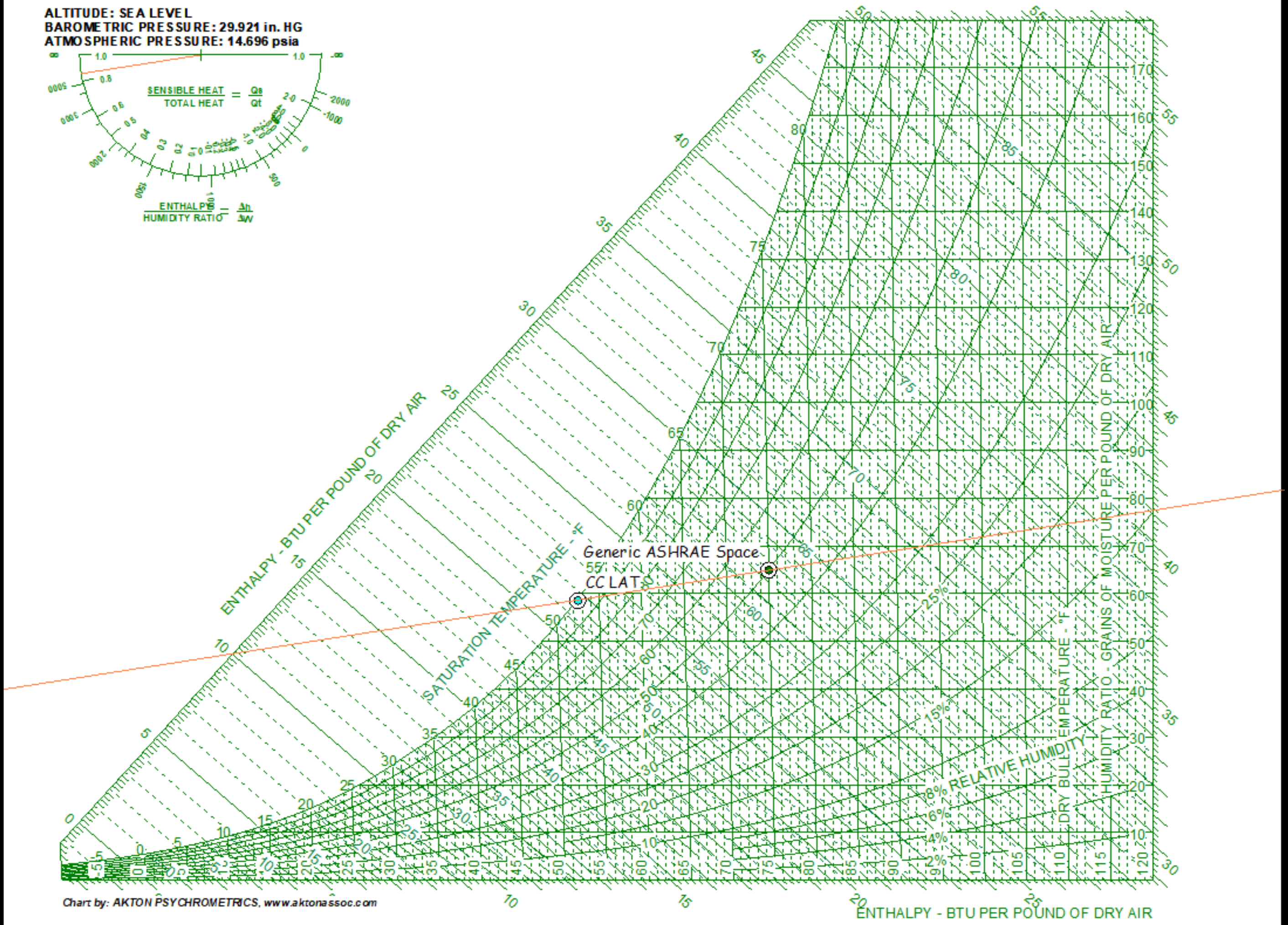
ALTITUDE: 7 FEET
BAROMETRIC PRESSURE: 29.915 in. HG
ATMOSPHERIC PRESSURE: 14.693 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Weather Data Location:
SAN_FRANCISCO_INTL_AP, CALIFORNIA, USA
Weather Hours
41 to 1
82 to 42
123 to 83
164 to 124
205 to 165
246 to 206
287 to 247
328 to 288
369 to 329
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
Generic ASHRAE Space
Latent Gains
Sensible Gains
Outdoor air in this area will need cooling
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
ENTHALPY - BTU PER POUND OF DRY AIR



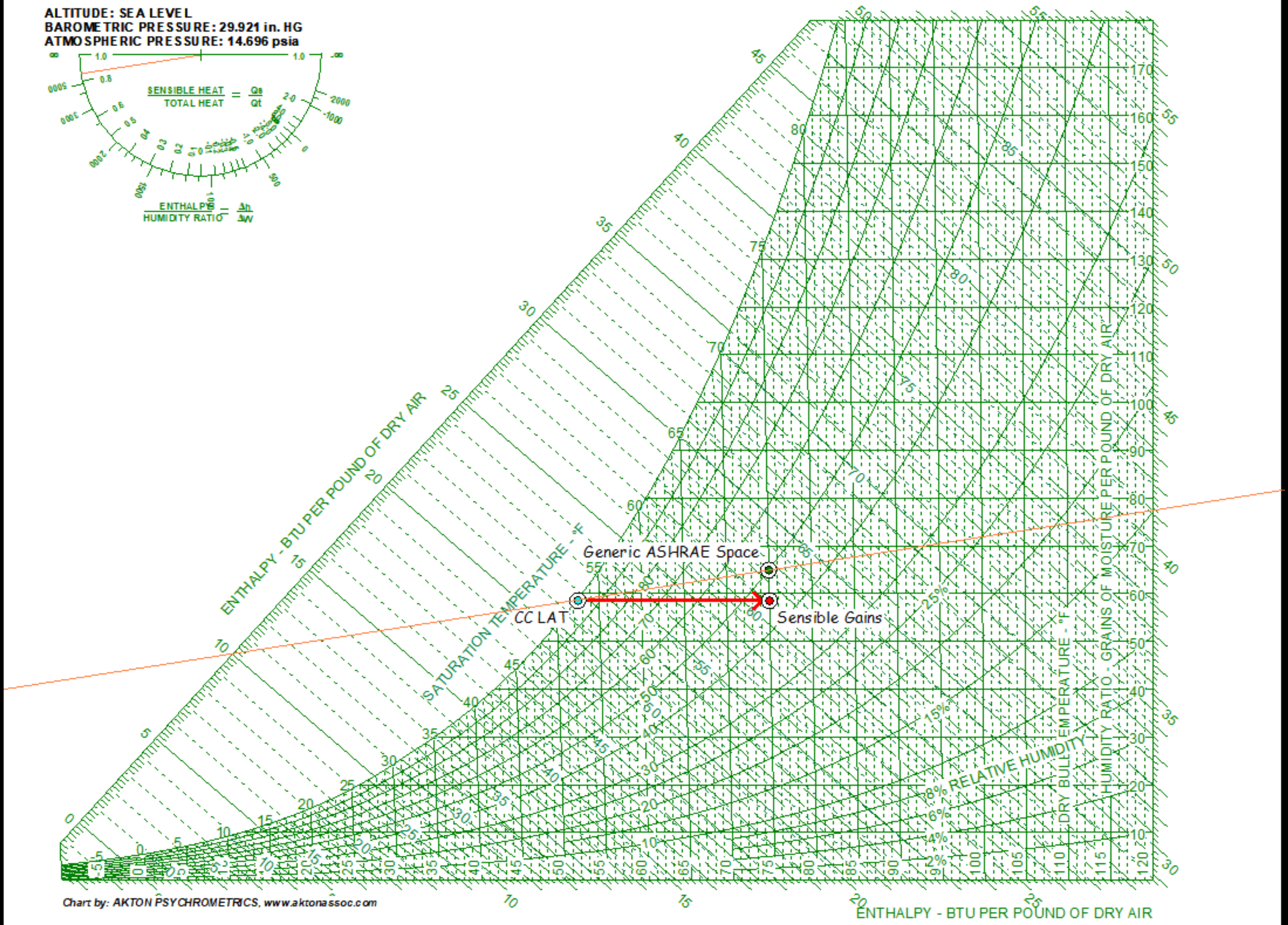
ALTITUDE: SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ATMOSPHERIC PRESSURE: 14.696 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
Generic ASHRAE Space
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
ENTHALPY - BTU PER POUND OF DRY AIR
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com



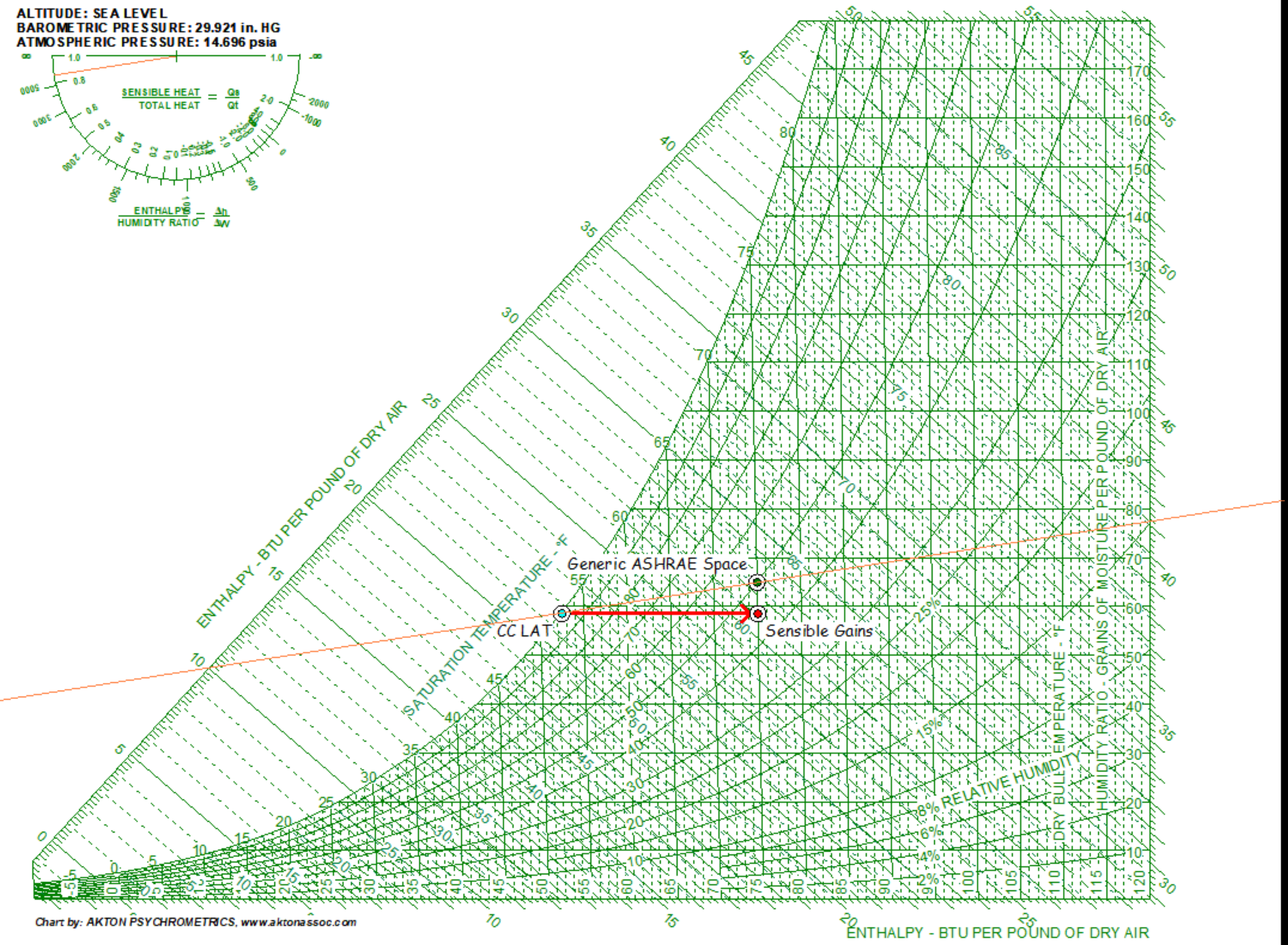
ALTITUDE: SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ATMOSPHERIC PRESSURE: 14.696 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
Generic ASHRAE Space
Cool Enough to Handle Sensible Load
Dry Enough to Handle Latent Load
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
ENTHALPY - BTU PER POUND OF DRY AIR



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
Generic ASHRAE Space
55
CC LAT
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
ENTHALPY - BTU PER POUND OF DRY AIR
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com



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
Generic ASHRAE Space
CC LAT
Sensible Gains
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
ENTHALPY - BTU PER POUND OF DRY AIR


ALTITUDE: SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ATMOSPHERIC PRESSURE: 14.696 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
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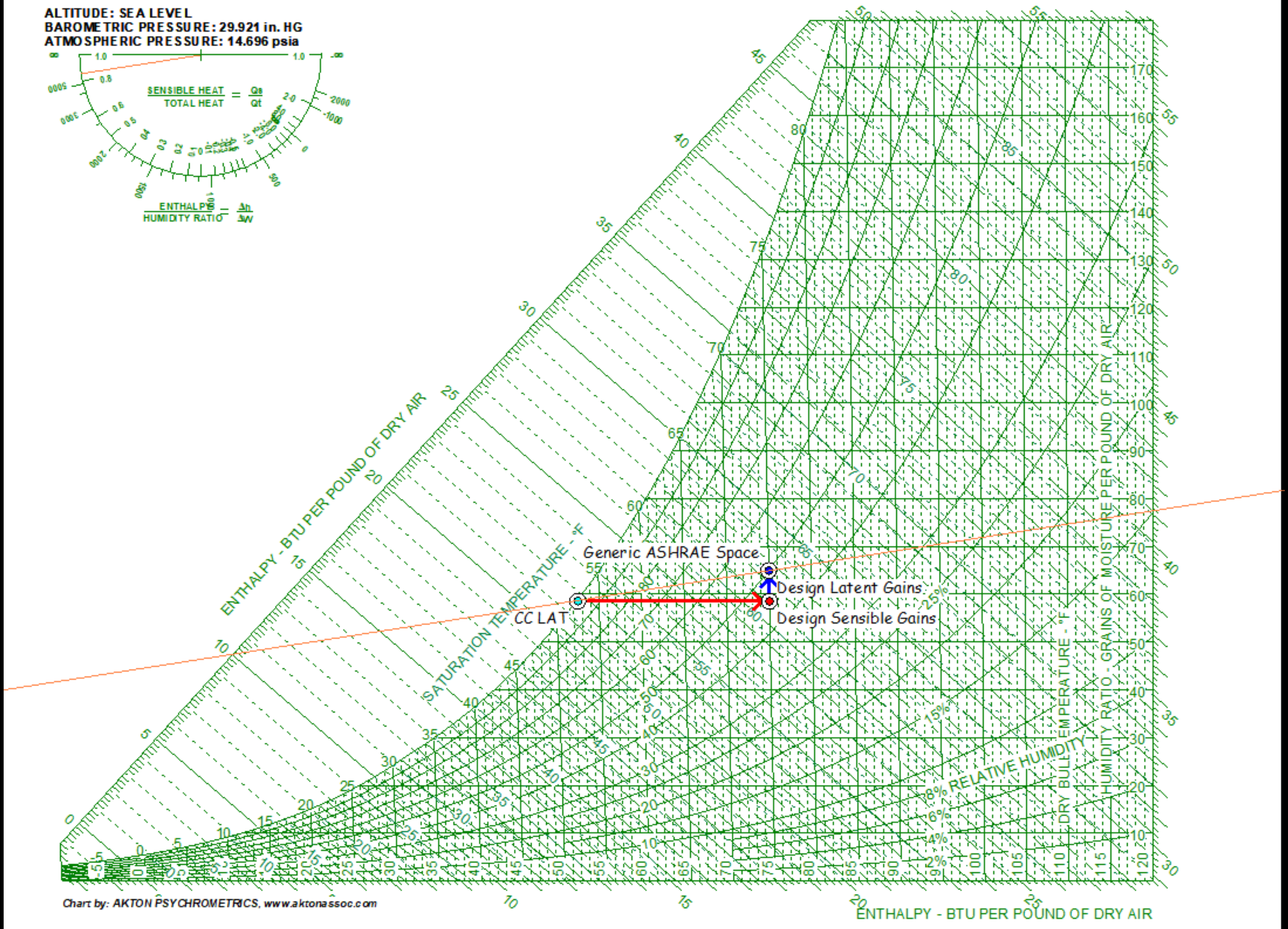
ALTITUDE: SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ATMOSPHERIC PRESSURE: 14.696 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
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Generic ASHRAE Space
Design Latent Gains
CC LAT
Design Sensible Gains
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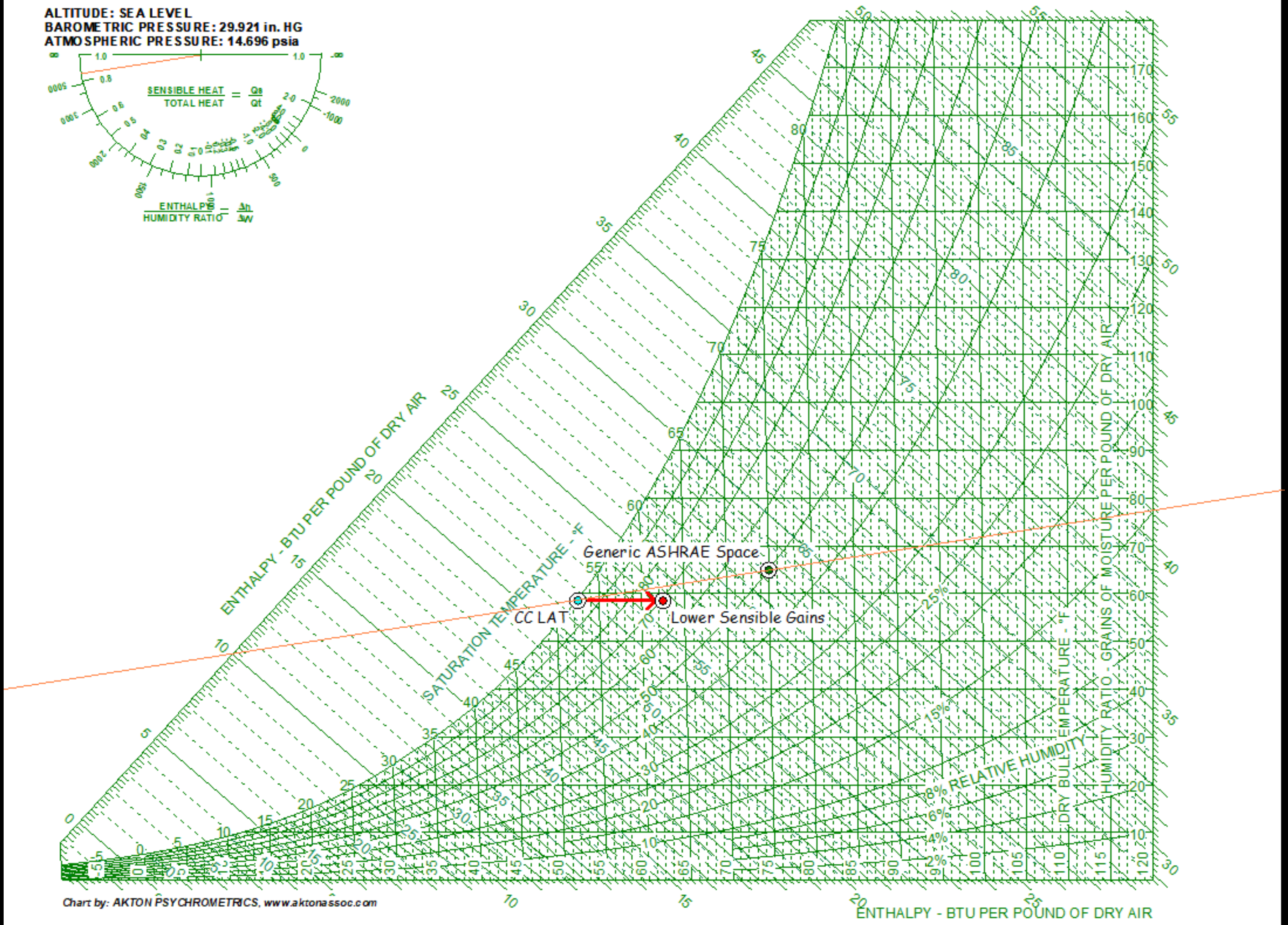
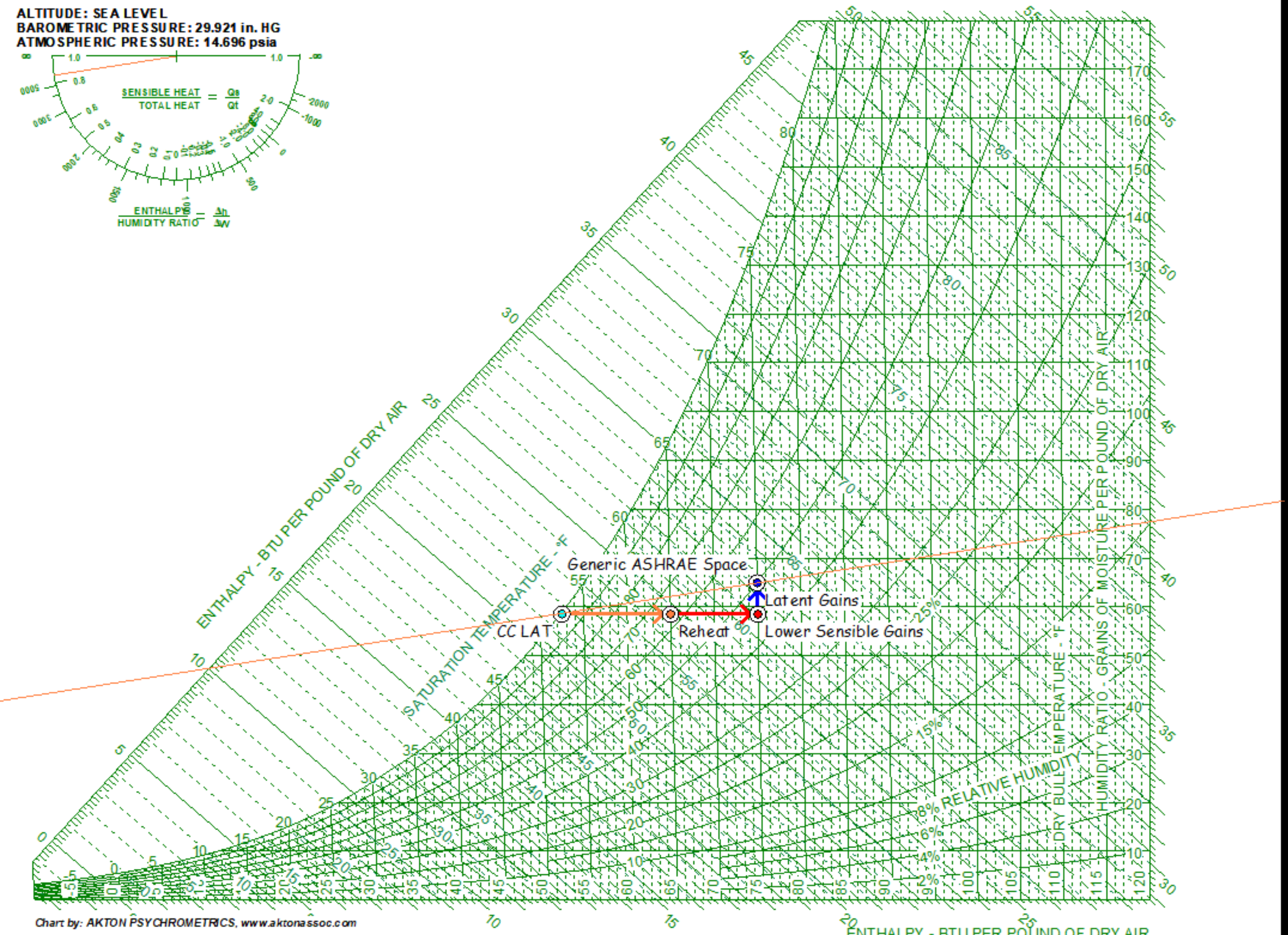

ALTITUDE: SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ATMOSPHERIC PRESSURE: 14.696 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
Generic ASHRAE Space
CC LAT
Lower Sensible Gains
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
ENTHALPY - BTU PER POUND OF DRY AIR



ALTITUDE: SEA LEVEL
BAROMETRIC PRESSURE: 29.921 in. HG
ATMOSPHERIC PRESSURE: 14.696 psia
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
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ENTHALPY - BTU PER POUND OF DRY AIR
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Latent Gains
CC LAT
Reheat
Lower Sensible Gains
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
ENTHALPY - BTU PER POUND OF DRY AIR
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat ✓
- Cooling
- Processes
- Power Generation

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
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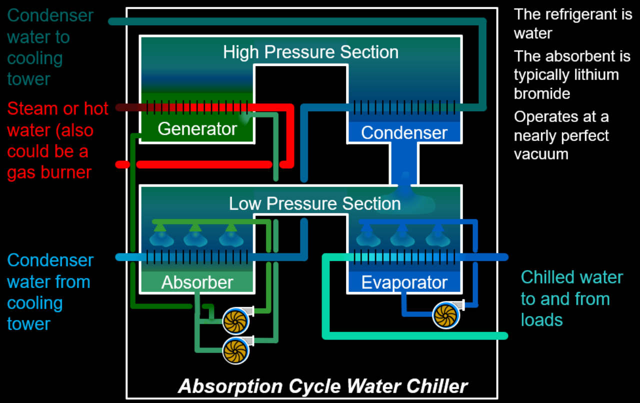
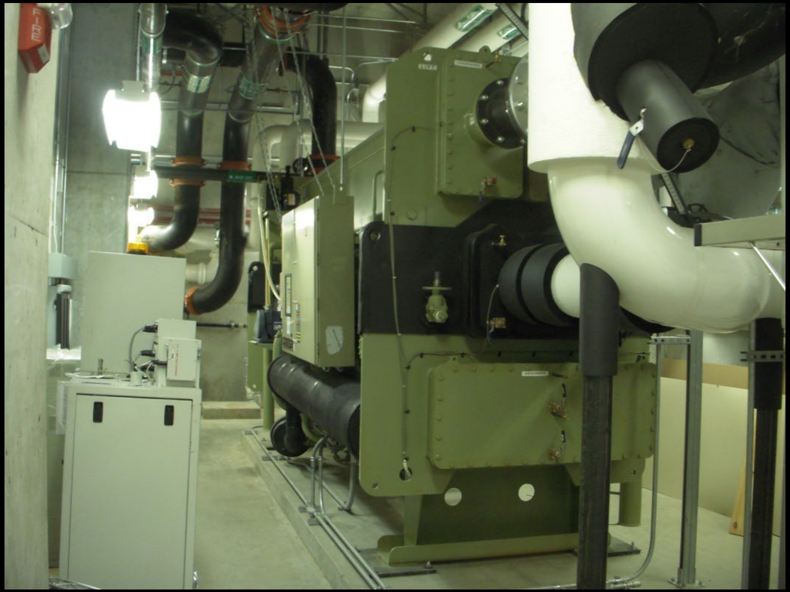
A Few More Definitions

Absorption Refrigeration

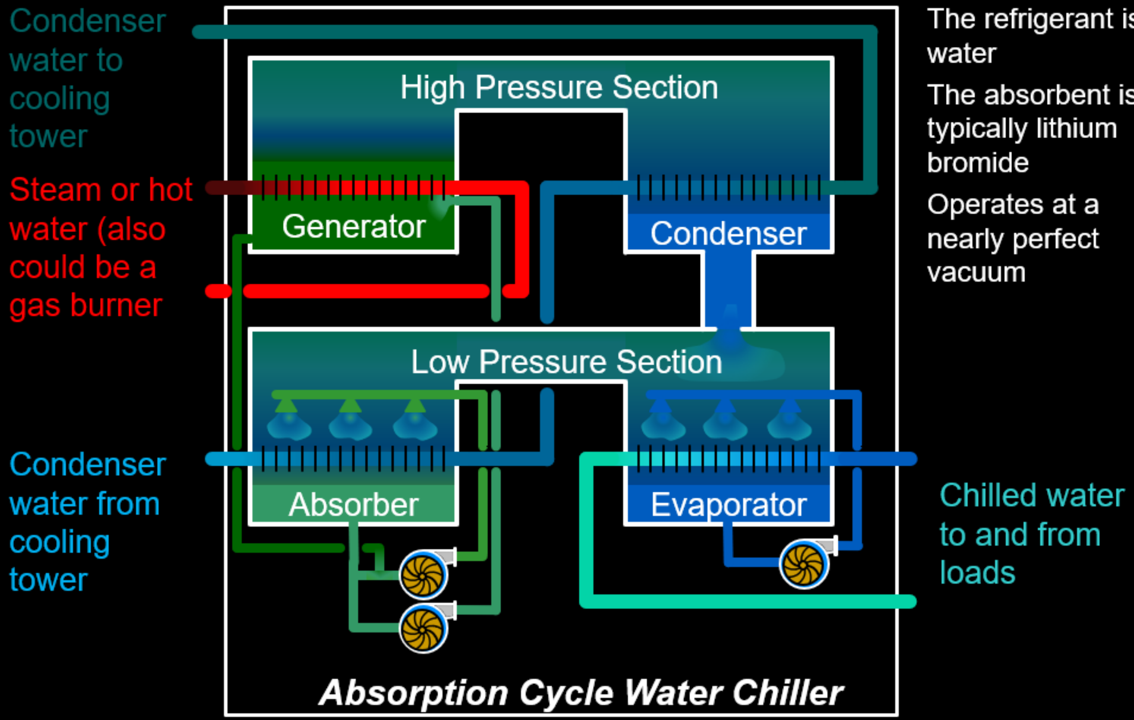
– A cooling process that is driven by heat

Absorption Chiller





Absorption Chiller



The refrigerant is water

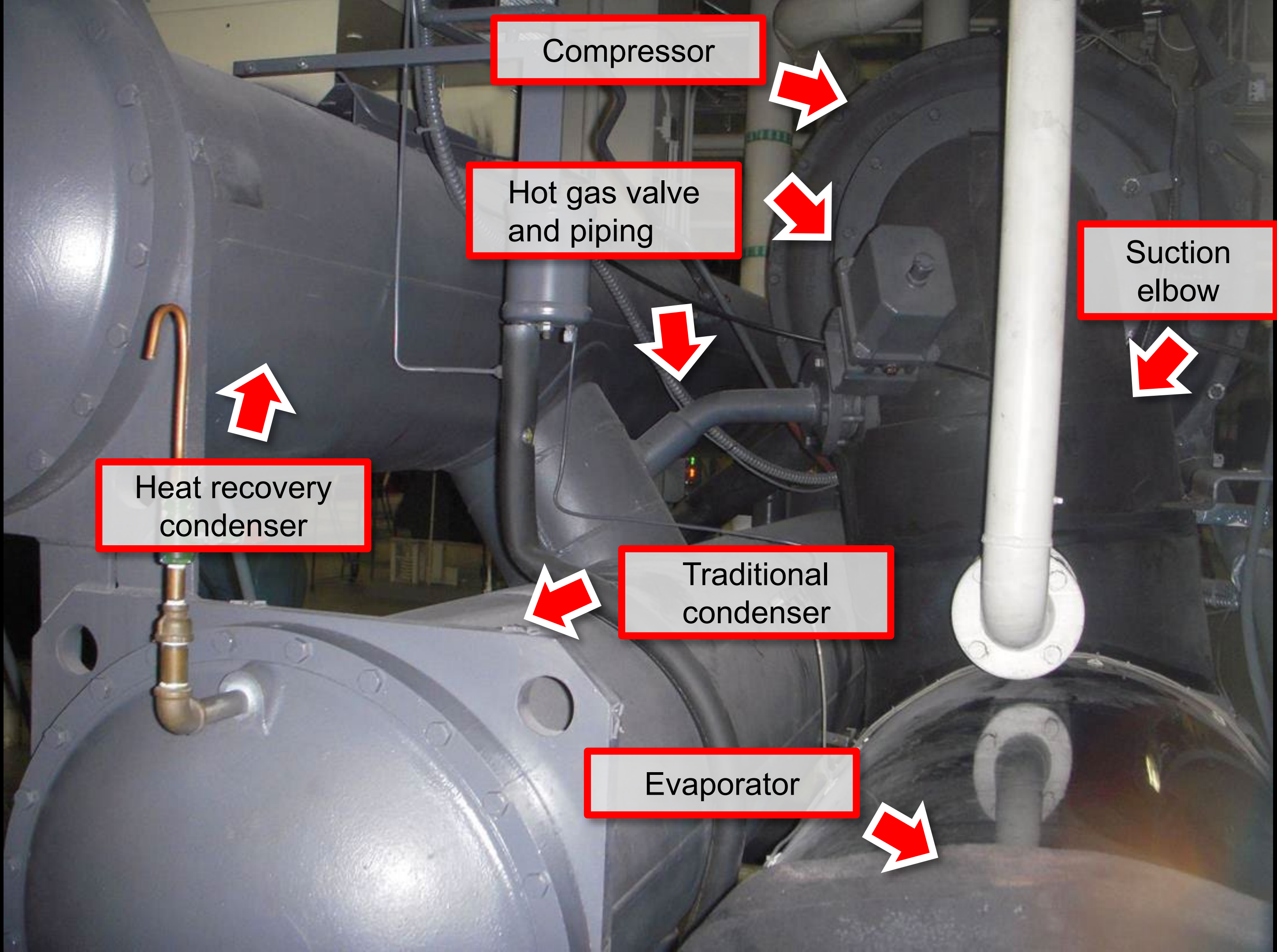
The absorbent is typically lithium bromide

Operates at a nearly perfect vacuum

A Heat Recovery Centrifugal Chiller

The chiller in the following slide has a second condenser tube bundle that is piped to the heating hot water system. This allows the hot gas off of the compressor to be used to generate hot water for reheat loads prior to having its heat rejected to the cooling tower via the traditional condenser.


HEATING WATER RETURN
HEATING WATER SUPPLY
REFRIGERANT DISCHARGE
UCP2
UCP2


Compressor
Hot gas valve and piping
Suction elbow
Heat recovery condenser
Traditional condenser
Evaporator

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat ✓ Core is rejecting heat when we need to do this
- Cooling ✓
- Processes
- Power Generation

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat ✓ Core is rejecting heat when we need to do this
- Cooling ✓ Can be driven by heat
- Processes
- Power Generation

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat ✓ Core is rejecting heat when we need to do this
- Cooling ✓ Can move heat to where its needed
- Processes
- Power Generation

A Few More Definitions

Humidification

- A process that adds moisture to the air
  - RH levels between 40 and 60 percent are optimum for comfort and disease prevention
  - The influenza virus has its highest mortality rate at 50% percent RH
  - Equipment may require specific humidity levels for optimum performance
  - Production may require specific humidity levels to maintain manufacturing tolerance

Indirect Steam Humidifier

Evaporative Cooler

A Few More Definitions

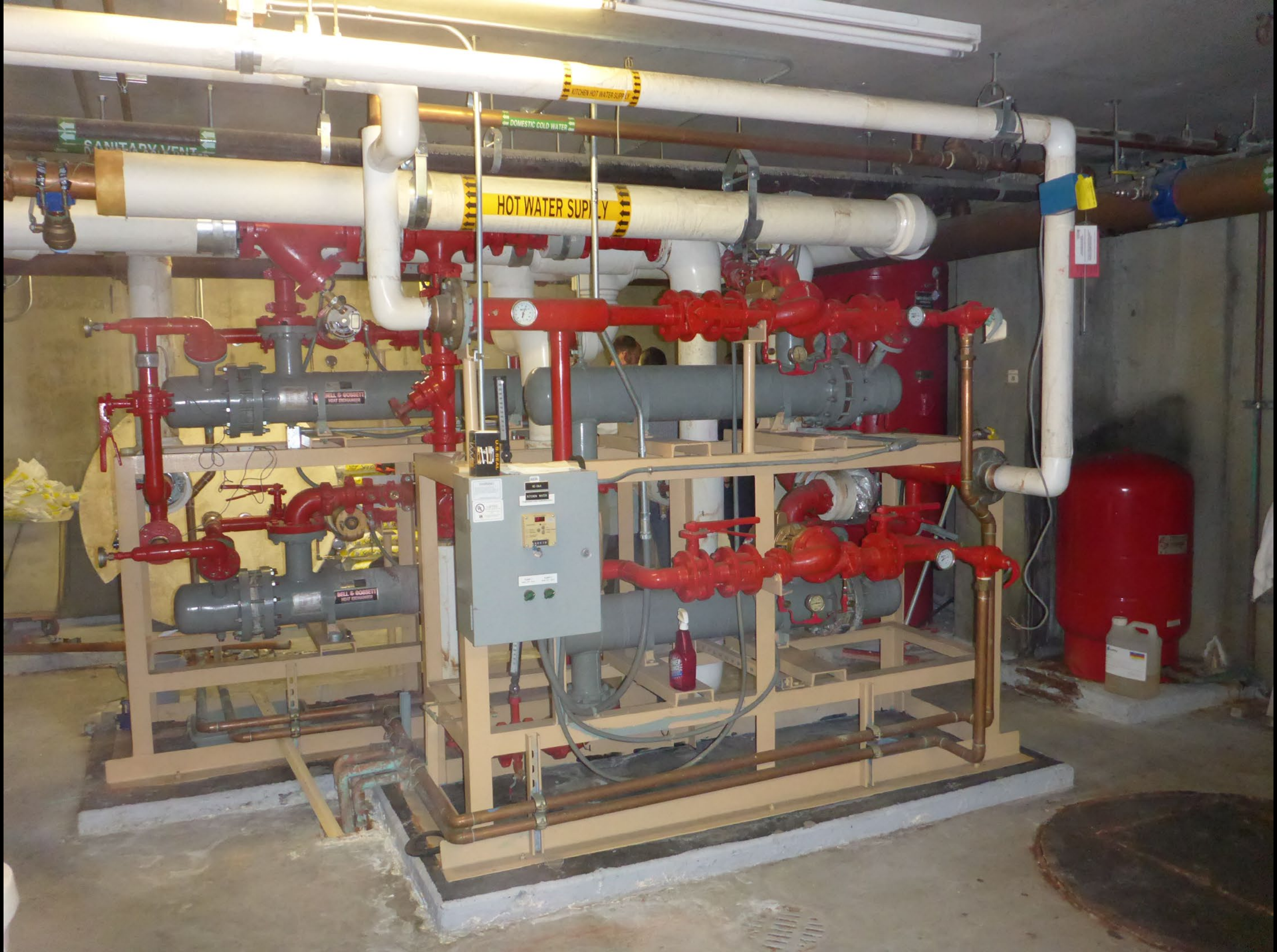
Sterilization

- A process that makes something free from bacteria or other living microorganisms
  - Common in health care and laboratory applications

A Few More Definitions

Domestic Hot Water

- Water that is intended for human consumption
  - Showers
  - Cleaning
  - Dishwashing
- Concerns regarding legionella dictate storage temperatures
- Concerns about scalding dictate distribution temperatures


KITCHEN HOT WATER SUPPLY
DOMESTIC COLD WATER
SANITARY VENT
HOT WATER SUPPLY
BELL & GOSSETT
BELL & GOSSETT


HEATING WATER SUPPLY


AERCO
SmartPlate™
USER MANUAL
AERCO


AERCO
OVER TEMP SWITCH
135
127
173
TEMP CONTROLLER
BOILER WATER TEMP
WATER HEATER
AERCO
SmartPlate

AERCO
WATER HEATER
AERCO
SmartPlate
AERCO
SmartPlate

A Few More Definitions

Cooking

- Applying heat to food

Image courtesy of https://www.pinterest.com/pin/541206080211952343/

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat ✓ Core is rejecting heat when we need to do this
- Cooling ✓ Can move heat to where its needed
- Processes ✓
- Power Generation

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat ✓ Core is rejecting heat when we need to do this
- Cooling ✓ Can move heat to where its needed
- Processes ✓ Some harder to address with a heat pump
- Power Generation

A Few More Definitions

Power Generation

– A process that generates power by converting one form of energy into a different, more useful form for the task at hand

State	% of Total Electric Power Generation											Non-renewable + Nuclear Percent of Total	Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
	Non-Renewable					Renewable					Nuclear				
	Combustion Processes						Non-Combustion Processes								
	Coal	Oil	Gas	Other Fossil Fuel	Purchased, Fuel Generated	Biomass	Hydro	Wind	Solar	Geothermal					
CA	0.2%	0.0%	47.7%	0.8%	0.3%	3.0%	11.0%	7.0%	15.7%	5.9%	8.4%	57.4%	42.6%	52.0%	48.0%
DC	0.0%	0.0%	61.3%	0.0%	0.0%	31.4%	0.0%	0.0%	7.3%	0.0%	0.0%	61.3%	38.7%	92.7%	7.3%
DE	2.0%	0.2%	92.6%	2.8%	0.0%	1.4%	0.0%	0.1%	1.0%	0.0%	0.0%	97.6%	2.5%	99.0%	1.1%
HI	12.8%	67.8%	0.0%	0.0%	1.3%	5.0%	1.1%	6.4%	5.3%	0.1%	0.0%	81.9%	17.9%	86.9%	12.9%
IA	23.7%	0.2%	11.8%	0.0%	0.0%	0.3%	1.7%	57.3%	0.0%	0.0%	4.9%	40.6%	59.3%	36.0%	63.9%
NH	0.8%	0.3%	22.3%	0.0%	0.0%	5.6%	7.5%	3.2%	0.0%	0.0%	60.4%	83.8%	16.3%	29.0%	71.1%
NV	4.8%	0.0%	66.3%	0.0%	0.1%	0.1%	4.8%	0.7%	13.7%	9.4%	0.0%	71.2%	28.7%	71.3%	28.6%
OR	2.6%	0.0%	29.9%	0.0%	0.0%	1.6%	50.2%	13.8%	1.7%	0.3%	0.0%	32.5%	67.6%	34.1%	66.0%
RI	16.8%	49.9%	30.9%	0.0%	0.0%	0.0%	0.0%	0.8%	1.6%	0.0%	0.0%	97.6%	2.4%	97.6%	2.4%
WA	0.0%	0.1%	0.1%	0.0%	0.0%	21.3%	52.4%	17.8%	8.4%	0.0%	0.0%	0.2%	99.9%	21.5%	78.6%
WY	88.6%	0.3%	4.9%	0.1%	0.0%	0.0%	2.8%	3.3%	0.0%	0.0%	0.0%	93.9%	6.1%	93.9%	6.1%
Minimum	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.2%**	**2.4%**	**18.2%**	**1.1%**
Maximum	**88.6%**	**67.8%**	**93.0%**	**2.8%**	**1.3%**	**31.4%**	**65.8%**	**57.3%**	**15.7%**	**9.4%**	**60.4%**	**97.6%**	**99.9%**	**99.0%**	**81.9%**
Average	**19.8%**	**2.9%**	**36.2%**	**0.3%**	**0.1%**	**3.0%**	**10.2%**	**9.4%**	**2.3%**	**0.3%**	**15.4%**	**74.7%**	**25.3%**	**62.3%**	**37.7%**
US	19.3%	0.7%	40.5%	0.3%	0.1%	1.5%	7.0%	8.4%	2.2%	0.4%	19.6%	80.5%	19.5%	62.4%	37.6%

A Few More Definitions

Power Generation

– The heat can come from burning things like coal

State	% of Total Electric Power					
	Non-Renewable					
	Combustion Processes					
	Coal	Oil	Gas	Other Fossil Fuel	Purchased, Fuel Generated	Biomass
CA	0.2%	0.0%	47.7%	0.8%	0.3%	3.0%
DC	0.0%	0.0%	61.3%	0.0%	0.0%	31.4%
DE	2.0%	0.2%	92.6%	2.8%	0.0%	1.4%
HI	12.8%	67.8%	0.0%	0.0%	1.3%	5.0%
IA	23.7%	0.2%	11.8%	0.0%	0.0%	0.3%
NH	0.8%	0.3%	22.3%	0.0%	0.0%	5.6%
NV	4.8%	0.0%	66.3%	0.0%	0.1%	0.1%
OR	2.6%	0.0%	29.9%	0.0%	0.0%	1.6%
RI	16.8%	49.9%	30.9%	0.0%	0.0%	0.0%
WA	0.0%	0.1%	0.1%	0.0%	0.0%	21.3%
WY	88.6%	0.3%	4.9%	0.1%	0.0%	0.0%
Minimum	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
Maximum	**88.6%**	**67.8%**	**93.0%**	**2.8%**	**1.3%**	**31.4%**
Average	**19.8%**	**2.9%**	**36.2%**	**0.3%**	**0.1%**	**3.0%**
US	19.3%	0.7%	40.5%	0.3%	0.1%	1.5%

A Few More Definitions

Power Generation

– The heat can come from burning things like coal, gas

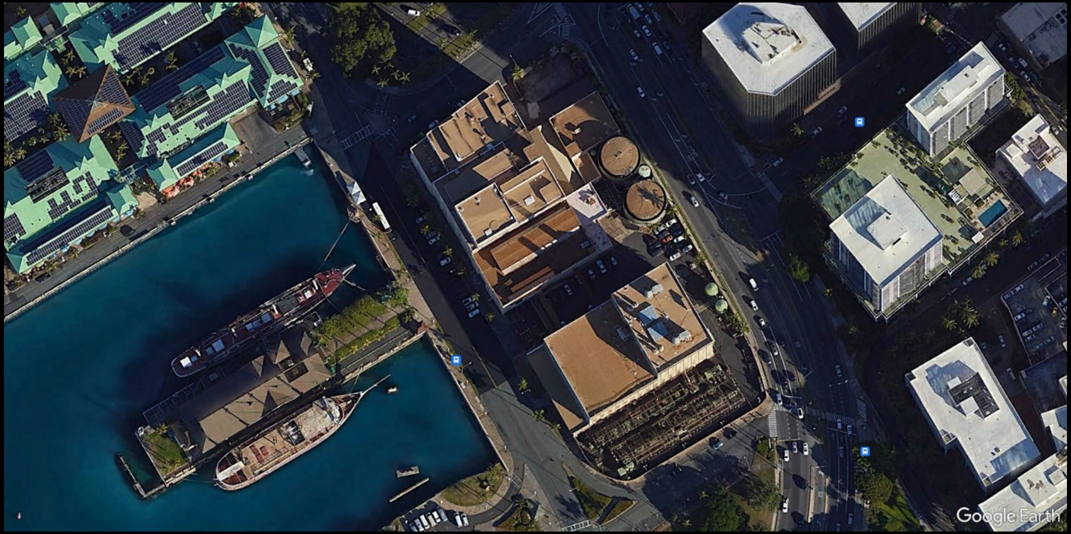
State	% of Total Electric Power					
	Non-Renewable					
	Combustion Processes					
	Coal	Oil	Gas	Other Fossil Fuel	Purchased, Fuel Generated	Biomass
CA	0.2%	0.0%	47.7%	0.8%	0.3%	3.0%
DC	0.0%	0.0%	61.3%	0.0%	0.0%	31.4%
DE	2.0%	0.2%	92.6%	2.8%	0.0%	1.4%
HI	12.8%	67.8%	0.0%	0.0%	1.3%	5.0%
IA	23.7%	0.2%	11.8%	0.0%	0.0%	0.3%
NH	0.8%	0.3%	22.3%	0.0%	0.0%	5.6%
NV	4.8%	0.0%	66.3%	0.0%	0.1%	0.1%
OR	2.6%	0.0%	29.9%	0.0%	0.0%	1.6%
RI	16.8%	49.9%	30.9%	0.0%	0.0%	0.0%
WA	0.0%	0.1%	0.1%	0.0%	0.0%	21.3%
WY	88.6%	0.3%	4.9%	0.1%	0.0%	0.0%
Minimum	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
Maximum	**88.6%**	**67.8%**	**93.0%**	**2.8%**	**1.3%**	**31.4%**
Average	**19.8%**	**2.9%**	**36.2%**	**0.3%**	**0.1%**	**3.0%**
US	19.3%	0.7%	40.5%	0.3%	0.1%	1.5%

A Few More Definitions

Power Generation

– The heat can come from burning things like coal, gas, oil

State	% of Total Electric Power					
	Non-Renewable					
	Combustion Processes					
	Coal	Oil	Gas	Other Fossil Fuel	Purchased, Fuel Generated	Biomass
CA	0.2%	0.0%	47.7%	0.8%	0.3%	3.0%
DC	0.0%	0.0%	61.3%	0.0%	0.0%	31.4%
DE	2.0%	0.2%	92.6%	2.8%	0.0%	1.4%
HI	12.8%	67.8%	0.0%	0.0%	1.3%	5.0%
IA	23.7%	0.2%	11.8%	0.0%	0.0%	0.3%
NH	0.8%	0.3%	22.3%	0.0%	0.0%	5.6%
NV	4.8%	0.0%	66.3%	0.0%	0.1%	0.1%
OR	2.6%	0.0%	29.9%	0.0%	0.0%	1.6%
RI	16.8%	49.9%	30.9%	0.0%	0.0%	0.0%
WA	0.0%	0.1%	0.1%	0.0%	0.0%	21.3%
WY	88.6%	0.3%	4.9%	0.1%	0.0%	0.0%
Minimum	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
Maximum	**88.6%**	**67.8%**	**93.0%**	**2.8%**	**1.3%**	**31.4%**
Average	**19.8%**	**2.9%**	**36.2%**	**0.3%**	**0.1%**	**3.0%**
US	19.3%	0.7%	40.5%	0.3%	0.1%	1.5%



A Few More Definitions

Power Generation

– The heat can come from burning things like coal, gas, oil, or biomass …

State	% of Total Electric Power					
	Non-Renewable					
	Combustion Processes					
	Coal	Oil	Gas	Other Fossil Fuel	Purchased, Fuel Generated	Biomass
CA	0.2%	0.0%	47.7%	0.8%	0.3%	3.0%
DC	0.0%	0.0%	61.3%	0.0%	0.0%	31.4%
DE	2.0%	0.2%	92.6%	2.8%	0.0%	1.4%
HI	12.8%	67.8%	0.0%	0.0%	1.3%	5.0%
IA	23.7%	0.2%	11.8%	0.0%	0.0%	0.3%
NH	0.8%	0.3%	22.3%	0.0%	0.0%	5.6%
NV	4.8%	0.0%	66.3%	0.0%	0.1%	0.1%
OR	2.6%	0.0%	29.9%	0.0%	0.0%	1.6%
RI	16.8%	49.9%	30.9%	0.0%	0.0%	0.0%
WA	0.0%	0.1%	0.1%	0.0%	0.0%	21.3%
WY	88.6%	0.3%	4.9%	0.1%	0.0%	0.0%
Minimum	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
Maximum	**88.6%**	**67.8%**	**93.0%**	**2.8%**	**1.3%**	**31.4%**
Average	**19.8%**	**2.9%**	**36.2%**	**0.3%**	**0.1%**	**3.0%**
US	19.3%	0.7%	40.5%	0.3%	0.1%	1.5%

A Few More Definitions

Power Generation

– … or it can come non-combustion process-based sources like hydro, wind

Electric Power Generation

Renewable: Biomass	Renewable Non-Combustion Processes: Hydro	Wind	Solar	Geothermal	Nuclear	Non-renewable + Nuclear Percent of Total	Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
3.0%	11.0%	7.0%	15.7%	5.9%	8.4%	57.4%	42.6%	52.0%	48.0%
31.4%	0.0%	0.0%	7.3%	0.0%	0.0%	61.3%	38.7%	92.7%	7.3%
1.4%	0.0%	0.1%	1.0%	0.0%	0.0%	97.6%	2.5%	99.0%	1.1%
5.0%	1.1%	6.4%	5.3%	0.1%	0.0%	81.9%	17.9%	86.9%	12.9%
0.3%	1.7%	57.3%	0.0%	0.0%	4.9%	40.6%	59.3%	36.0%	63.9%
5.6%	7.5%	3.2%	0.0%	0.0%	60.4%	83.8%	16.3%	29.0%	71.1%
0.1%	4.8%	0.7%	13.7%	9.4%	0.0%	71.2%	28.7%	71.3%	28.6%
1.6%	50.2%	13.8%	1.7%	0.3%	0.0%	32.5%	67.6%	34.1%	66.0%
0.0%	0.0%	0.8%	1.6%	0.0%	0.0%	97.6%	2.4%	97.6%	2.4%
21.3%	52.4%	17.8%	8.4%	0.0%	0.0%	0.2%	99.9%	21.5%	78.6%
0.0%	2.8%	3.3%	0.0%	0.0%	0.0%	93.9%	6.1%	93.9%	6.1%
0.0%	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.2%**	**2.4%**	**18.2%**	**1.1%**
31.4%	**65.8%**	**57.3%**	**15.7%**	**9.4%**	**60.4%**	**97.6%**	**99.9%**	**99.0%**	**81.9%**
3.0%	**10.2%**	**9.4%**	**2.3%**	**0.3%**	**15.4%**	**74.7%**	**25.3%**	**62.3%**	**37.7%**
1.5%	7.0%	8.4%	2.2%	0.4%	19.6%	80.5%	19.5%	62.4%	37.6%

A Few More Definitions

Power Generation

– … or it can come non-combustion process-based sources like hydro, wind

Electric Power Generation									
Renewable					Nuclear	Non-renewable + Nuclear Percent of Total	Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
	Non-Combustion Processes								
Biomass	Hydro	Wind	Solar	Geothermal					
3.0%	11.0%	7.0%	15.7%	5.9%	8.4%	57.4%	42.6%	52.0%	48.0%
31.4%	0.0%	0.0%	7.3%	0.0%	0.0%	61.3%	38.7%	92.7%	7.3%
1.4%	0.0%	0.1%	1.0%	0.0%	0.0%	97.6%	2.5%	99.0%	1.1%
5.0%	1.1%	6.4%	5.3%	0.1%	0.0%	81.9%	17.9%	86.9%	12.9%
0.3%	1.7%	57.3%	0.0%	0.0%	4.9%	40.6%	59.3%	36.0%	63.9%
5.6%	7.5%	3.2%	0.0%	0.0%	60.4%	83.8%	16.3%	29.0%	71.1%
0.1%	4.8%	0.7%	13.7%	9.4%	0.0%	71.2%	28.7%	71.3%	28.6%
1.6%	50.2%	13.8%	1.7%	0.3%	0.0%	32.5%	67.6%	34.1%	66.0%
0.0%	0.0%	0.8%	1.6%	0.0%	0.0%	97.6%	2.4%	97.6%	2.4%
21.3%	52.4%	17.8%	8.4%	0.0%	0.0%	0.2%	99.9%	21.5%	78.6%
0.0%	2.8%	3.3%	0.0%	0.0%	0.0%	93.9%	6.1%	93.9%	6.1%
0.0%	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.2%**	**2.4%**	**18.2%**	**1.1%**
31.4%	**65.8%**	**57.3%**	**15.7%**	**9.4%**	**60.4%**	**97.6%**	**99.9%**	**99.0%**	**81.9%**
3.0%	**10.2%**	**9.4%**	**2.3%**	**0.3%**	**15.4%**	**74.7%**	**25.3%**	**62.3%**	**37.7%**
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A Few More Definitions

Power Generation

- … or it can come non-combustion process-based sources like hydro, wind, solar

Electric Power Generation									
	Renewable Non-Combustion Processes				Nuclear	Non-renewable + Nuclear Percent of Total	Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
Biomass	Hydro	Wind	Solar	Geothermal					
3.0%	11.0%	7.0%	15.7%	5.9%	8.4%	57.4%	42.6%	52.0%	48.0%
31.4%	0.0%	0.0%	7.3%	0.0%	0.0%	61.3%	38.7%	92.7%	7.3%
1.4%	0.0%	0.1%	1.0%	0.0%	0.0%	97.6%	2.5%	99.0%	1.1%
5.0%	1.1%	6.4%	5.3%	0.1%	0.0%	81.9%	17.9%	86.9%	12.9%
0.3%	1.7%	57.3%	0.0%	0.0%	4.9%	40.6%	59.3%	36.0%	63.9%
5.6%	7.5%	3.2%	0.0%	0.0%	60.4%	83.8%	16.3%	29.0%	71.1%
0.1%	4.8%	0.7%	13.7%	9.4%	0.0%	71.2%	28.7%	71.3%	28.6%
1.6%	50.2%	13.8%	1.7%	0.3%	0.0%	32.5%	67.6%	34.1%	66.0%
0.0%	0.0%	0.8%	1.6%	0.0%	0.0%	97.6%	2.4%	97.6%	2.4%
21.3%	52.4%	17.8%	8.4%	0.0%	0.0%	0.2%	99.9%	21.5%	78.6%
0.0%	2.8%	3.3%	0.0%	0.0%	0.0%	93.9%	6.1%	93.9%	6.1%
0.0%	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.2%**	**2.4%**	**18.2%**	**1.1%**
31.4%	**65.8%**	**57.3%**	**15.7%**	**9.4%**	**60.4%**	**97.6%**	**99.9%**	**99.0%**	**81.9%**
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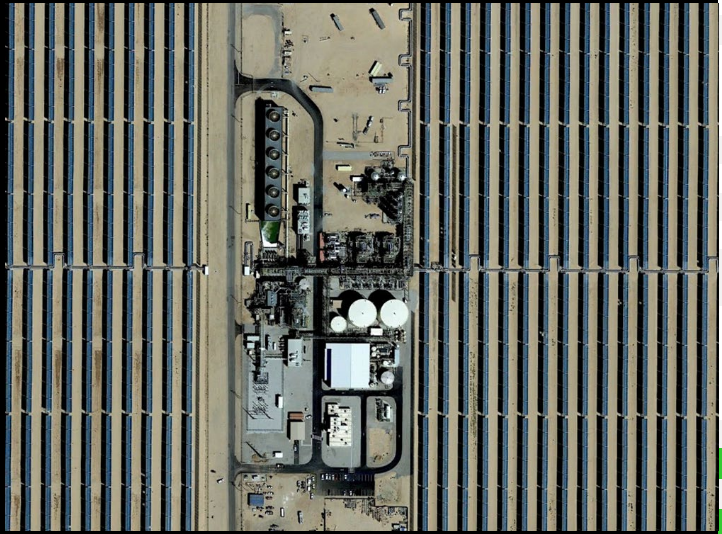
Power Generation

– … or it can come non-combustion process-based sources like hydro, wind, solar



Electric Power Generation									
	Renewable				Nuclear	Non-renewable + Nuclear Percent of Total	Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
	Non-Combustion Processes								
Biomass	Hydro	Wind	Solar	Geothermal					
3.0%	11.0%	7.0%	15.7%	5.9%	8.4%	57.4%	42.6%	52.0%	48.0%
31.4%	0.0%	0.0%	7.3%	0.0%	0.0%	61.3%	38.7%	92.7%	7.3%
1.4%	0.0%	0.1%	1.0%	0.0%	0.0%	97.6%	2.5%	99.0%	1.1%
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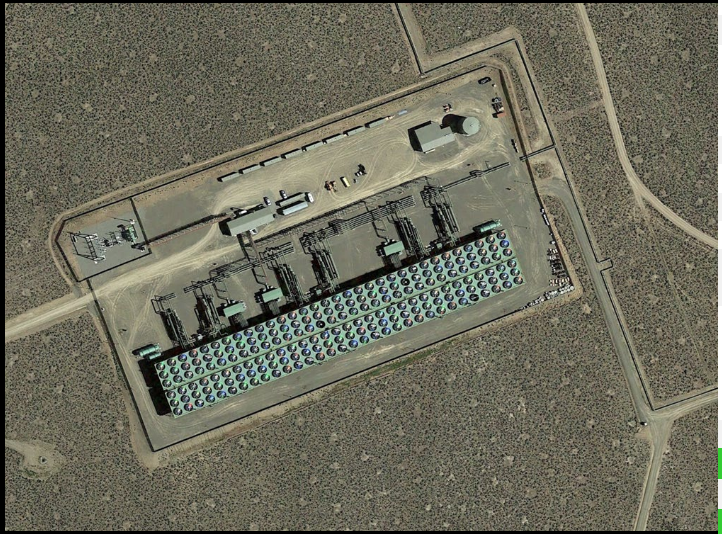
5.6%	7.5%	3.2%	0.0%	0.0%	60.4%	83.8%	16.3%	29.0%	71.1%
0.1%	4.8%	0.7%	13.7%	9.4%	0.0%	71.2%	28.7%	71.3%	28.6%
1.6%	50.2%	13.8%	1.7%	0.3%	0.0%	32.5%	67.6%	34.1%	66.0%
0.0%	0.0%	0.8%	1.6%	0.0%	0.0%	97.6%	2.4%	97.6%	2.4%
21.3%	52.4%	17.8%	8.4%	0.0%	0.0%	0.2%	99.9%	21.5%	78.6%
0.0%	2.8%	3.3%	0.0%	0.0%	0.0%	93.9%	6.1%	93.9%	6.1%
0.0%	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.2%**	**2.4%**	**18.2%**	**1.1%**
31.4%	**65.8%**	**57.3%**	**15.7%**	**9.4%**	**60.4%**	**97.6%**	**99.9%**	**99.0%**	**81.9%**
3.0%	**10.2%**	**9.4%**	**2.3%**	**0.3%**	**15.4%**	**74.7%**	**25.3%**	**62.3%**	**37.7%**
1.5%	7.0%	8.4%	2.2%	0.4%	19.6%	80.5%	19.5%	62.4%	37.6%

A Few More Definitions

Power Generation

– … or it can come non-combustion process-based sources like hydro, wind, solar, geothermal



Electric Power Generation									
	Renewable				Nuclear	Non-renewable + Nuclear Percent of Total	Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
	Non-Combustion Processes								
Biomass	Hydro	Wind	Solar	Geothermal					
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0.3%	1.7%	57.3%	0.0%	0.0%	4.9%	40.6%	59.3%	36.0%	63.9%
5.6%	7.5%	3.2%	0.0%	0.0%	60.4%	83.8%	16.3%	29.0%	71.1%
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1.6%	50.2%	13.8%	1.7%	0.3%	0.0%	32.5%	67.6%	34.1%	66.0%
0.0%	0.0%	0.8%	1.6%	0.0%	0.0%	97.6%	2.4%	97.6%	2.4%
21.3%	52.4%	17.8%	8.4%	0.0%	0.0%	0.2%	99.9%	21.5%	78.6%
0.0%	2.8%	3.3%	0.0%	0.0%	0.0%	93.9%	6.1%	93.9%	6.1%
0.0%	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.2%**	**2.4%**	**18.2%**	**1.1%**
31.4%	**65.8%**	**57.3%**	**15.7%**	**9.4%**	**60.4%**	**97.6%**	**99.9%**	**99.0%**	**81.9%**
3.0%	**10.2%**	**9.4%**	**2.3%**	**0.3%**	**15.4%**	**74.7%**	**25.3%**	**62.3%**	**37.7%**
1.5%	7.0%	8.4%	2.2%	0.4%	19.6%	80.5%	19.5%	62.4%	37.6%

A Few More Definitions

Power Generation

- … or it can come non-combustion process-based sources like hydro, wind, solar, geothermal, and nuclear energy

Electric Power Generation						Non-renewable + Nuclear Percent of Total	Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
	Renewable				Nuclear				
	Non-Combustion Processes								
Biomass	Hydro	Wind	Solar	Geothermal					
3.0%	11.0%	7.0%	15.7%	5.9%	8.4%	57.4%	42.6%	52.0%	48.0%
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1.4%	0.0%	0.1%	1.0%	0.0%	0.0%	97.6%	2.5%	99.0%	1.1%
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5.6%	7.5%	3.2%	0.0%	0.0%	60.4%	83.8%	16.3%	29.0%	71.1%
0.1%	4.8%	0.7%	13.7%	9.4%	0.0%	71.2%	28.7%	71.3%	28.6%
1.6%	50.2%	13.8%	1.7%	0.3%	0.0%	32.5%	67.6%	34.1%	66.0%
0.0%	0.0%	0.8%	1.6%	0.0%	0.0%	97.6%	2.4%	97.6%	2.4%
21.3%	52.4%	17.8%	8.4%	0.0%	0.0%	0.2%	99.9%	21.5%	78.6%
0.0%	2.8%	3.3%	0.0%	0.0%	0.0%	93.9%	6.1%	93.9%	6.1%
0.0%	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.2%**	**2.4%**	**18.2%**	**1.1%**
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1.5%	7.0%	8.4%	2.2%	0.4%	19.6%	80.5%	19.5%	62.4%	37.6%

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat ✓ Core is rejecting heat when we need to do this
- Cooling ✓ Can move heat to where its needed
- Processes ✓ Harder to address with a heat pump
- Power Generation ✓

How Buildings Use Heat

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- Processes ✓ Harder to address with a heat pump
- Power Generation ✓ Behind the internal gains in a building

How Buildings Use Heat

- Heating ✓ Core is rejecting heat when we need to do this
- Preheat ✓ Core is rejecting heat when we need to do this
- Reheat ✓ Core is rejecting heat when we need to do this
- Cooling ✓ Can move heat to where its needed
- Processes ✓ Harder to address with a heat pump
- Power Generation ✓ Heat pumps can leverage this

How Buildings Use Heat

Application	Electrification Target
Heating ✓	✓
Preheat ✓	✓
Reheat ✓	✓
Cooling ✓	✓
Processes ✓	
Power Generation ✓	

Why Electrification?

The traditional approach to generating heat has been to burn fossil fuels

Good News

- Fairly simple
- High grade heat
- Fairly inexpensive

Why Electrification?

The traditional approach to generating heat has been to burn fossil fuels

Good News

- Fairly simple
- High grade heat
- Fairly inexpensive

Bad News

- CO_2 Intensive

CO_2 Emissions for Different Fuels

Fuel	lb CO_2 per million Btu Burned	lb CO_2 per million Btu Delivered						
		Boiler Efficiency						
		95%	90%	85%	80%	75%	70%	65%
Natural Gas	117	123	130	137	146	156	167	179
Propane	139	146	154	163	173	185	198	213
Oil	163	172	182	192	204	218	234	251
Coal	212	223	235	249	265	282	303	326
Emmissions Factor Source - https://www.eia.gov/environment/emissions/co2_vol_mass.php								

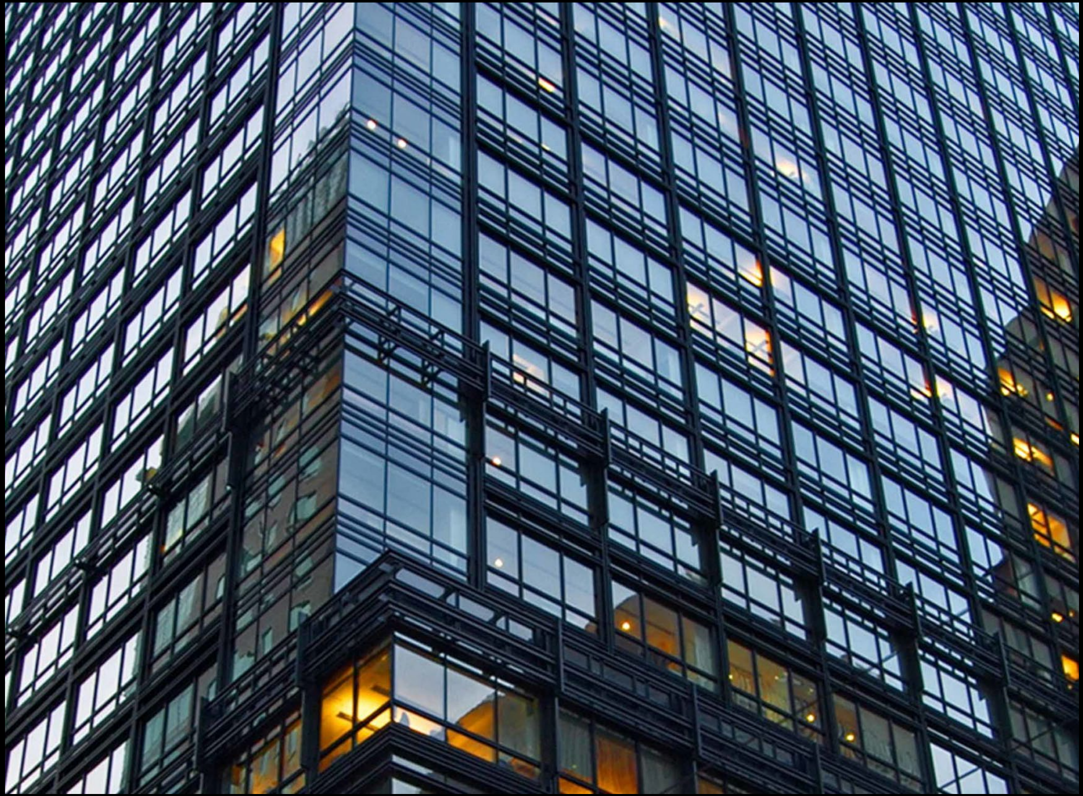
The Goal

Stop burning fossil fuels by switching to an all-electric grid powered by renewable resources

Electrification and the Already All-Electric Building

I have 300 kW of electric resistance heat, and the energy it uses is a major portion of our utility bills. And yet the building is cold!

Gary Walters, Chief Engineer



The Challenges

1. Currently about 60-63% of our electricity is generated by burning something

The Challenges

2. Heat rates (efficiencies) for our power plants are not particularly high …

Heat Rates for Different Types of Power Plants

Generating Station Type	Typical Heat Rate				Emissions	lb CO_2 per kWh Generated	
	Minimum		Maximum		lb CO_2 per million Btu	Minimum	Maximum
	Btu/kWh	Efficiency	Btu/kWh	Efficiency			
Natural Gas with Cogeneration	5,000	68%	6,500	53%	117	0.58	0.76
Natural Gas Combined Cycle	6,200	55%	8,000	43%	117	0.72	0.93
Natural Gas Reciprocating Engine	7,500	46%	8,500	40%	117	0.87	0.99
Natural Gas Combustion Turbine	8,000	43%	10,000	34%	117	0.93	1.17
Coal Steam Turbine	9,000	38%	11,000	31%	212	1.91	2.33
Natural Gas Steam Turbine	10,000	34%	12,000	28%	117	1.17	1.40
Nuclear Power Plant	10,446	33%	10,459	33%	0	0.00	0.00
Heat Rate Source -	https://energyknowledgebase.com/topics/heat-rate.asp						
Emmissions Factor Source -	https://www.eia.gov/environment/emissions/co2_vol_mass.php						

2. Heat rates (efficiencies) for our power plants are not particularly high and CO2 emissions potentially would not be much different

Heat Rates for Different Types of Power Plants

Generating Station Type	Typical Heat Rate				Emissions	lb CO_2 per kWh Generated	
	Minimum		Maximum		lb CO_2 per million Btu	Minimum	Maximum
	Btu/kWh	Efficiency	Btu/kWh	Efficiency			
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Natural Gas Combined Cycle	6,200	55%	8,000	43%	117	0.72	0.93
Natural Gas Reciprocating Engine	7,500	46%	8,500	40%	117	0.87	0.99
Natural Gas Combustion Turbine	8,000	43%	10,000	34%	117	0.93	1.17
Coal Steam Turbine	9,000	38%	11,000	31%	212	1.91	2.33
Natural Gas Steam Turbine	10,000	34%	12,000	28%	117	1.17	1.40
Nuclear Power Plant	10,446	33%	10,459	33%	0	0.00	0.00

Heat Rate Source - https://energyknowledgebase.com/topics/heat-rate.asp

CO_2 Emissions for Different Fuels

Fuel	lb CO_2 per million Btu Burned	lb CO_2 per million Btu Delivered by Boilers							lb CO_2 per Million Btu Delivered as Electric Resistance Heat *
		Boiler Efficiency							
		95%	90%	85%	80%	75%	70%	65%	
Natural Gas	117	123	130	137	146	156	167	179	214
Propane	139	146	154	163	173	185	198	213	
Oil	163	172	182	192	204	218	234	251	
Coal	212	223	235	249	265	282	303	326	

Emmissions Factor Source - https://www.eia.gov/environment/emissions/co2_vol_mass.php

Heat Rate Source - "Heat Rates" tab of this spreadsheet

* This is the average value for the various fossil fuel power plants listed in the "Heat Rates" tab

Recall That:

- Heat pumps don't create energy; they use energy to move energy from a Cold Location to a Hot Location

Recall That:

- Heat pumps don't create energy; they use energy to move energy from a Cold Location to a Hot Location
- The COP (Coefficient of Performance) defines how much energy they need to spend relative to the energy they move
- COPs can be easily be 3 or higher

Coefficient of performance for a heat pump

$$COP_{Heating} = \frac{Q_{Heat}}{W_{In}}$$

or, solving for Q_{Heat}

$$Q_{Heat} = COP_{Heating} \times W_{In}$$

Where:

$COP_{Heating}$ = Coefficient of performance as a heat pump

Q_{Heat} = The heat delivered to the area served in consistent units, which is the heat rejected by the heat pump

W_{In} = The work done to deliver the heat in consistent units

As a Result:

CO_2 Emissions for Different Fuels

Fuel	lb CO_2 per million Btu Burned	lb CO_2 per million Btu Delivered by Boilers — Boiler Efficiency 95%	90%	85%	80%	75%	70%	65%	lb CO_2 per Million Btu Delivered as Electric Resistance Heat *	lb CO_2 per Million Btu Delivered by a Heat Pump with a COP of 3.7*
Natural Gas	117	123	130	137	146	156	167	179	214	91
Propane	139	146	154	163	173	185	198	213		
Oil	163	172	182	192	204	218	234	251		
Coal	212	223	235	249	265	282	303	326		

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Heat Rate Source - "Heat Rates" tab of this spreadsheet

* This is the average value for the various fossil fuel power plants listed in the "Heat Rates" tab

Learning More

If you are intrigued, the PEC will be offering a 5 part (half day per part) class on Commissioning Heat Pumps in May of 2024

1. Heat pump fundamentals and system types
2. Integrating ventilation with heat pumps
3. Heat pumps in new construction
4. Heat pumps in existing buildings
5. The Already All Electric Building

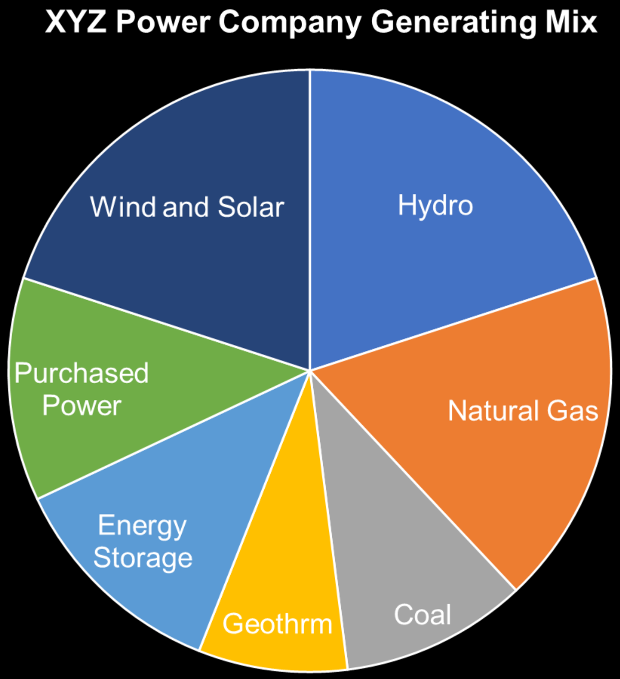
Reducing Atmospheric Impacts

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

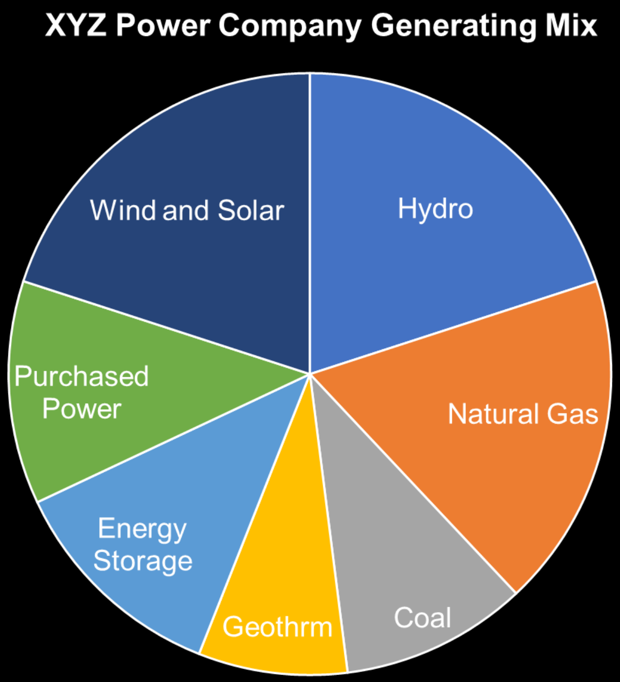
Moving away from carbon fuels is a common, long-term goal for many utilities



Reducing Atmospheric Impacts

- Applying the commissioning tool set can have an immediate impact by reducing the need for energy in the first place
- Using heat pumps to leverage the electricity we use to create heat makes best use of the electricity consumed to create heat

It's a win-win situation



How Buildings Use Heat

Application	Electrification Target	Heat Pump Target
• Heating ✓	✓	✓
• Preheat ✓	✓	✓
• Reheat ✓	✓	✓
• Cooling ✓	✓	✓
• Processes ✓	✓	✓*
• Power Generation		

* *Some are easier to serve with a heat pump than others*

How Buildings Use Heat

Application	Electrification Target	Heat Pump Target	Conservation/ EBCx Target
• Heating ✓	✓	✓	✓
• Preheat ✓	✓	✓	✓
• Reheat ✓	✓	✓	✓
• Cooling ✓	✓	✓	✓
• Processes ✓	✓	✓*	✓
• Power Generation			

How Buildings Use Heat

Application	Electrification Target	Heat Pump Target	Conservation/ EBCx Target
• Heating ✓	✓	✓	✓
• Preheat ✓	✓	✓	✓
• Reheat ✓	✓	✓	✓
• Cooling ✓	✓	✓	✓
• Processes ✓	✓	✓*	✓
• Power Generation	*Heat pumps and best practices in terms of ongong commissioning use our power to best advantage*		

How Buildings Use Heat – An Example

How Buildings Use Heat – An Example

How Buildings Use Heat – An Example

- Preheat Ventilation Air
- Reheat
- Space Heat
  - Radiant slabs
  - Air
  - Finned tube radiation
- Drive Processes
  - Domestic Hot Water
  - Humidification
  - Cooling
  - Sterilization

How Buildings Use Heat – An Example

- Preheat Ventilation Air 50°F - 75°F
- Reheat
- Space Heat
  - Radiant slabs
  - Air
  - Finned tube radiation
- Drive Processes
  - Domestic Hot Water
  - Humidification
  - Cooling
  - Sterilization

How Buildings Use Heat – An Example

- Preheat Ventilation Air 50°F - 75°F
- Reheat 50°F - 75°F
- Space Heat
  - Radiant slabs
  - Air
  - Finned tube radiation
- Drive Processes
  - Domestic Hot Water
  - Humidification
  - Cooling
  - Sterilization

How Buildings Use Heat – An Example

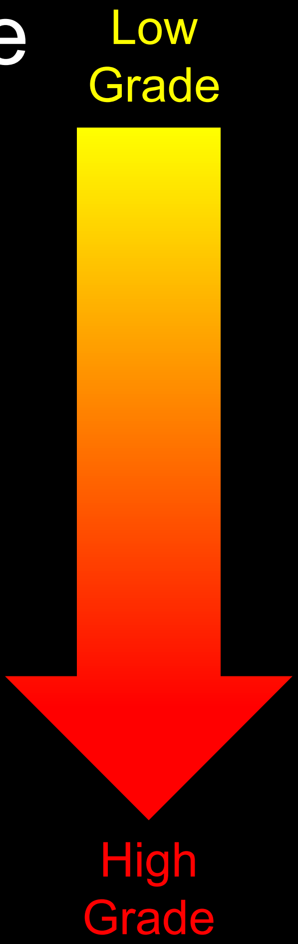
- Preheat Ventilation Air 50°F - 75°F
- Reheat 50°F - 75°F
- Space Heat
  - Radiant slabs 80°F - 85°F
  - Air 95°F - 110°F
  - Finned tube radiation 120°F – 220°F
- Drive Processes
  - Domestic Hot Water
  - Humidification
  - Cooling
  - Sterilization

How Buildings Use Heat – An Example

• Preheat Ventilation Air	50°F - 75°F
• Reheat	50°F - 75°F
• Space Heat	
• Radiant slabs	80°F - 85°F
• Air	95°F - 110°F
• Finned tube radiation	120°F – 220°F
• Drive Processes	
• Domestic Hot Water	120°F – 140°F or higher
• Humidification	212°F or higher
• Cooling	212°F or higher; hotter is better
• Sterilization	300°F or higher

How Buildings Use Heat – An Example

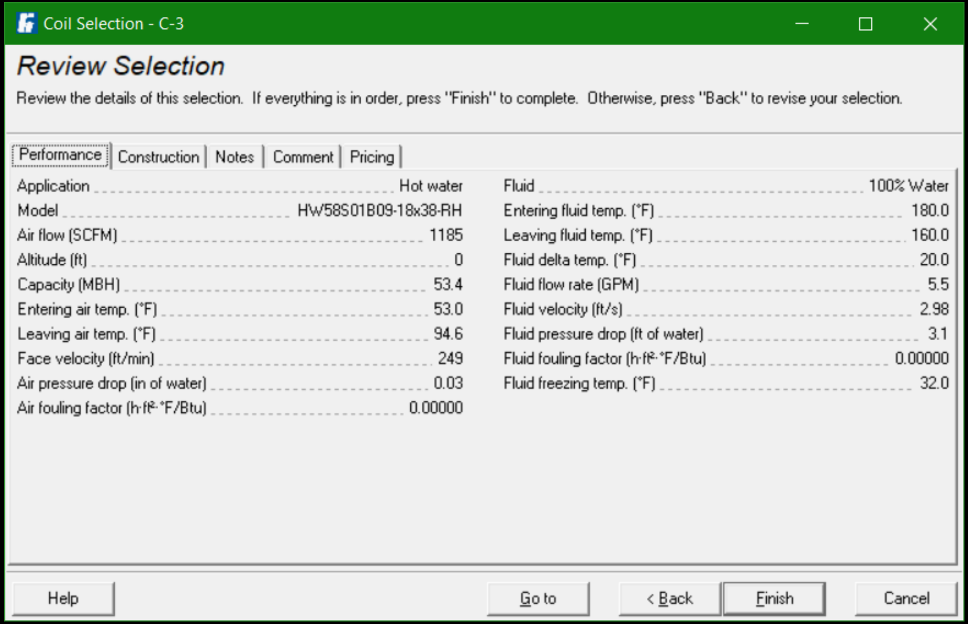
- Preheat Ventilation Air — 50°F - 75°F
- Reheat — 50°F - 75°F
- Space Heat
  - Radiant slabs — 80°F - 85°F
  - Air — 95°F - 110°F
  - Finned tube radiation — 120°F – 220°F
- Drive Processes
  - Domestic Hot Water — 120°F – 140°F or higher
  - Humidification — 212°F or higher
  - Cooling — 212°F or higher; hotter is better
  - Sterilization — 300°F or higher



A Preheat Coil Can Do Its Thing with 100°F Water or Less (i.e. Lower Grade Heat)

https://tinyurl.com/GreenheckCoilSelection

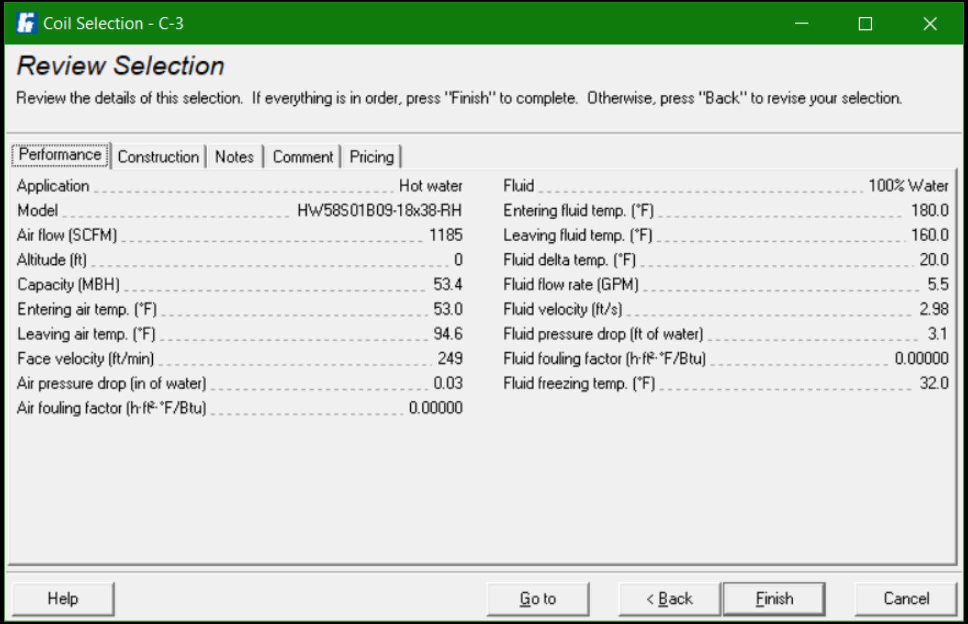
https://tinyurl.com/LowTempHW



A Reheat Coil Selected for Space Heating Can Do Reheat With Much Cooler Water (i.e. Lower Grade Heat)

https://tinyurl.com/GreenheckCoilSelection

https://tinyurl.com/LowTempHW



Questions?

Together, Building
a Better California