Fans, Ducts and Air Handling Systems: Design, Performance and Commissioning Issues

Introduction

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November 7, 2017

Class Material Location

The slides and other supporting information for the class can be found at:

- http://www.av8rdas.com/pacific-energy-center-classes.html
- They will be there until the next class, at which time they will be relocated to the PEC Class materials link from my blog

About using my spreadsheets and other resources:

- They are my tools vs. tools I developed to be used by others
- Use at your own risk; I provide them as a resource for you to use as a starting point
- You still need to understand how it works and fix it if it doesn't work for you

Disclaimer

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Learning Objectives

After completing this course you should be able to:

- Identify the major components typically found in an air handling system
- Understand the general function of the components found in an air handling system
- Understand that the components have to work together as a system, which is highly interactive. Integrating everything is key to success
- Be familiar with some of the fundamental equations describing how an air handling system works
- Understand how air handling systems use energy and resources

Agenda

- Introduction to Fans, Ducts, and Air Handling Systems
- Exploring an Air Handling System
- Focused Discussion on Various Air Handling System Components
- Applying Concepts to Identify Resource Savings Opportunities
  - Slide decks include a lot of supplemental information and resources
  - Sketch-up models will be used through-out the class to illustrate features of different components

Why a Class on Air Handling Equipment?

Just about every building has at least one fan

Air handling can account for 30-40% of a buildings energy consumption

PIER* research indicates significant fan energy savings potential by simply applying best practices

- 10 – 15% in for small commercial buildings
- $0.12 per square foot for large commercial buildings

**Public Interest Efficiency Research*

How Fans Use Power and Energy

$$bhp = \left(\frac{Flow \times Static}{6{,}356 \times \eta_{Fan}} \right)$$

Where :

bhp = Brake horse power into the fan drive shaft

$Flow$ = Flow rate in cubic feet per minute

$Static$ = Fan static in inches water column

$6{,}356$ = A units conversion constant

η_{Fan} = Fan efficiency

Calculating Power Into the Motor

$$kW = \left(\frac{Flow_{cfm} \times Static_{in.w.c.}}{6{,}356 \times \eta_{Fan} \times \eta_{Belts} \times \eta_{Motor} \times \eta_{VSD}} \right) \times .746$$

Where:

kW	=	Input to the system to produce the flow and static pressure.
Flow	=	Flow rate in cubic feet per minute. Generally speaking, we try to use a field measurement for this. If that is not available we will use a value from a tab report. Lacking that we will use a design metric from the original drawings or an equipment submittal.
Static	=	The fan static pressure in inches water column. Since fan static as defined by AMCA is difficult to measure in the field, we usually try to derive this number from the fan curve using two other feild measurements like flow and fan speed or flow and power. Lacking those measurements we will use a value derived from a TAB report or the design value.
6,356	=	A units conversion constant that is good for air at approximately 0 - 2,000 $feet_{msl}$ and between -40°F and 120°F.
η_{Fan}	=	Fan static efficiency. We usually try to get this number from the fan curve or from the fan's rated brake horse power (bhp), flow and static. Lacking that, we will make a geometrically similar fan selection (same flow rate, static, wheel diameter, wheel type, and speed) using manufacturer's software and use that efficiency.
η_{Motor}	=	Motor efficiency. We usually try to get the motor performance curve and select the efficiency from the curve for the bhp that the fan wheel is extracting from it. If we can't get the motor curve, we use a similar motor selected from MotorMaster™ International. In all cases we adjust the efficiency for the motor operating point vs. using the motor's rated nameplate efficiency.
η_{VSD}	=	Variable speed drive efficiency. Where possible, we try to get the manufacturer's data for this. But this data is difficult to obtain and not consistent in its development. Lacking manufacture specific data, we use generic data as published by the Department of Energy on their Industrial Best Practices web site.
.746	=	Horsepower to kW conversion constant.

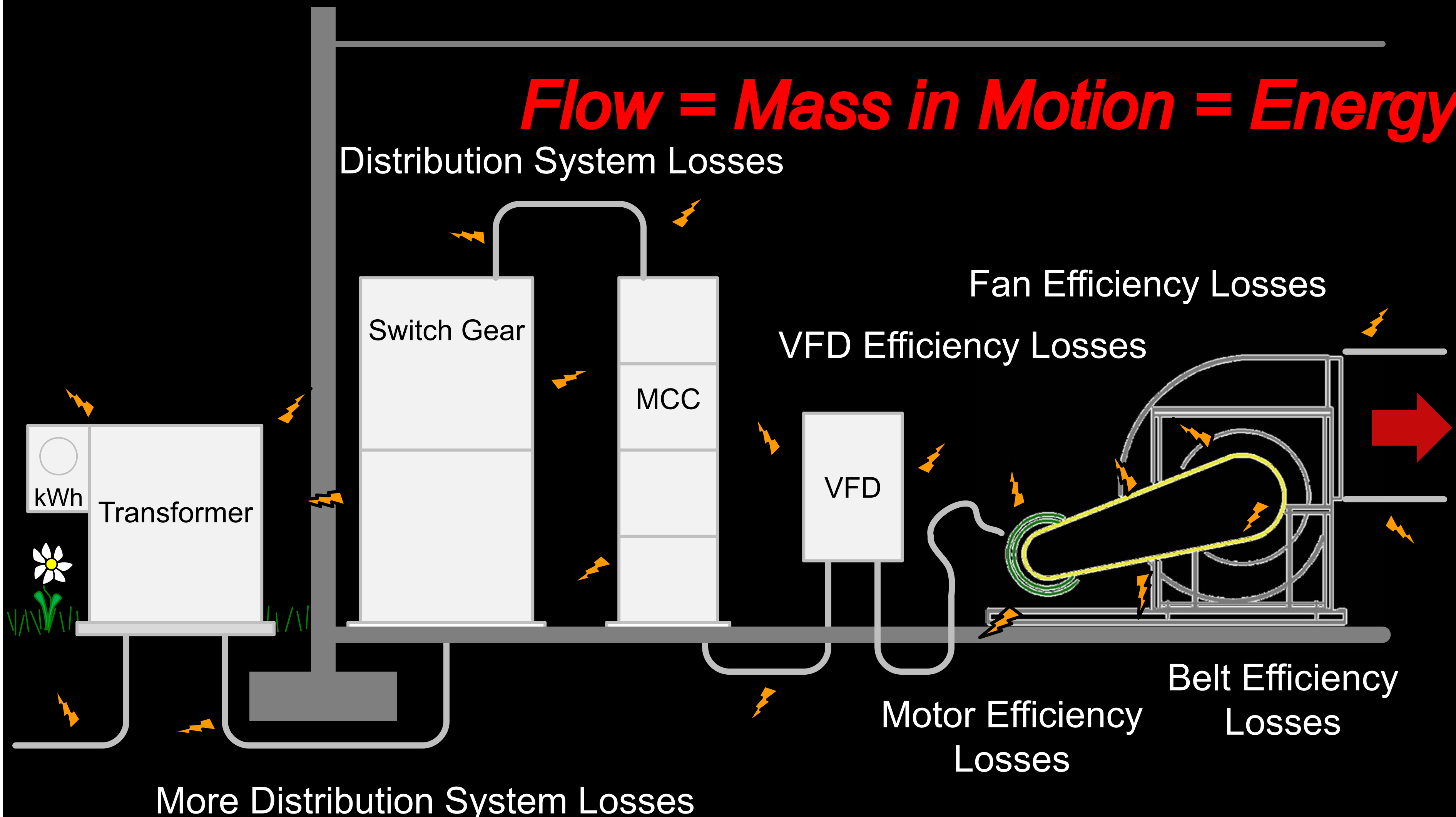
Energy = Power Applied Over Time

1 horsepower used for one hour = 1 horsepower-hour

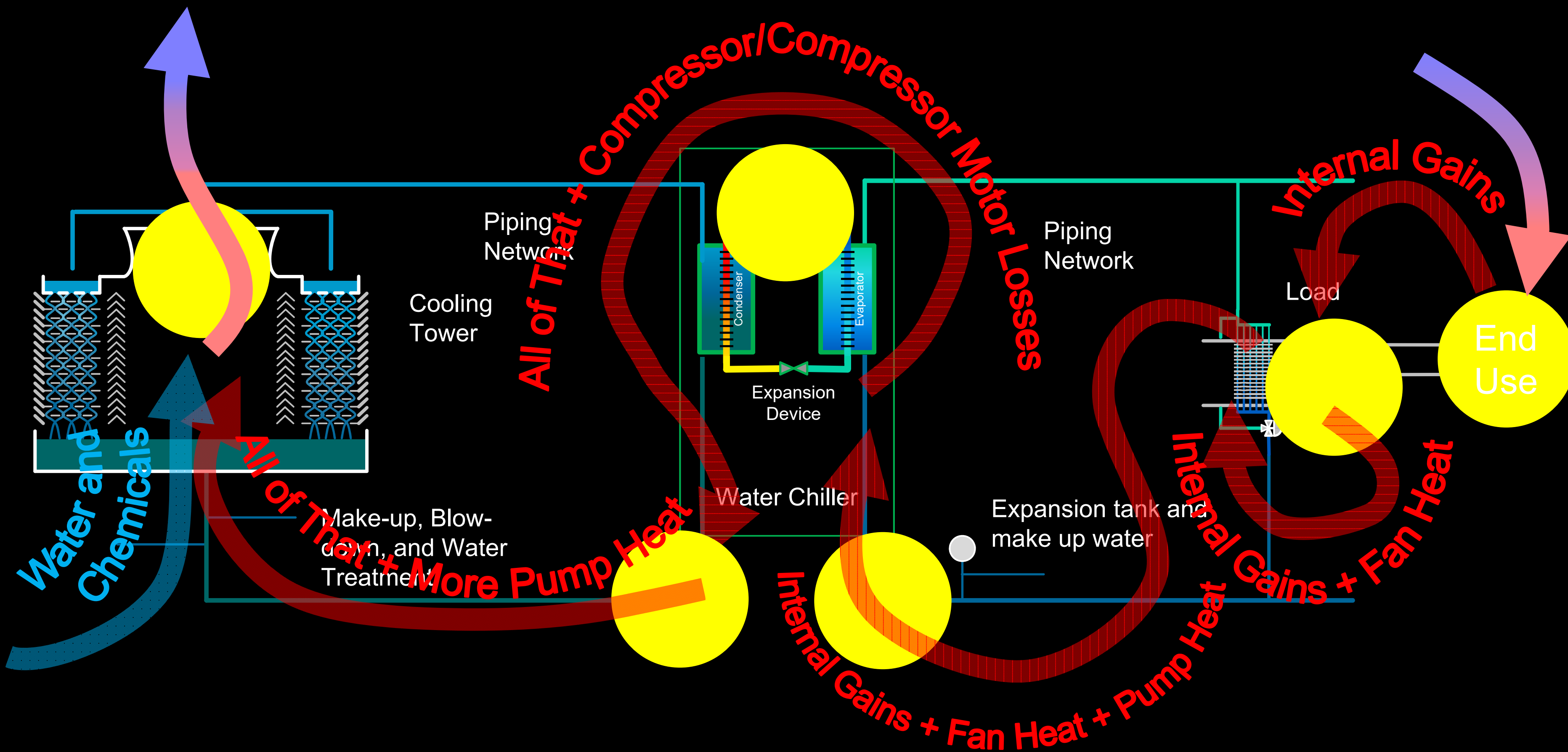
1 kilowatt used for one hour = one kilowatt-hour

1 kW used for 1 h = 1 kWh

A Bigger Perspective on Delivering Mass in Motion

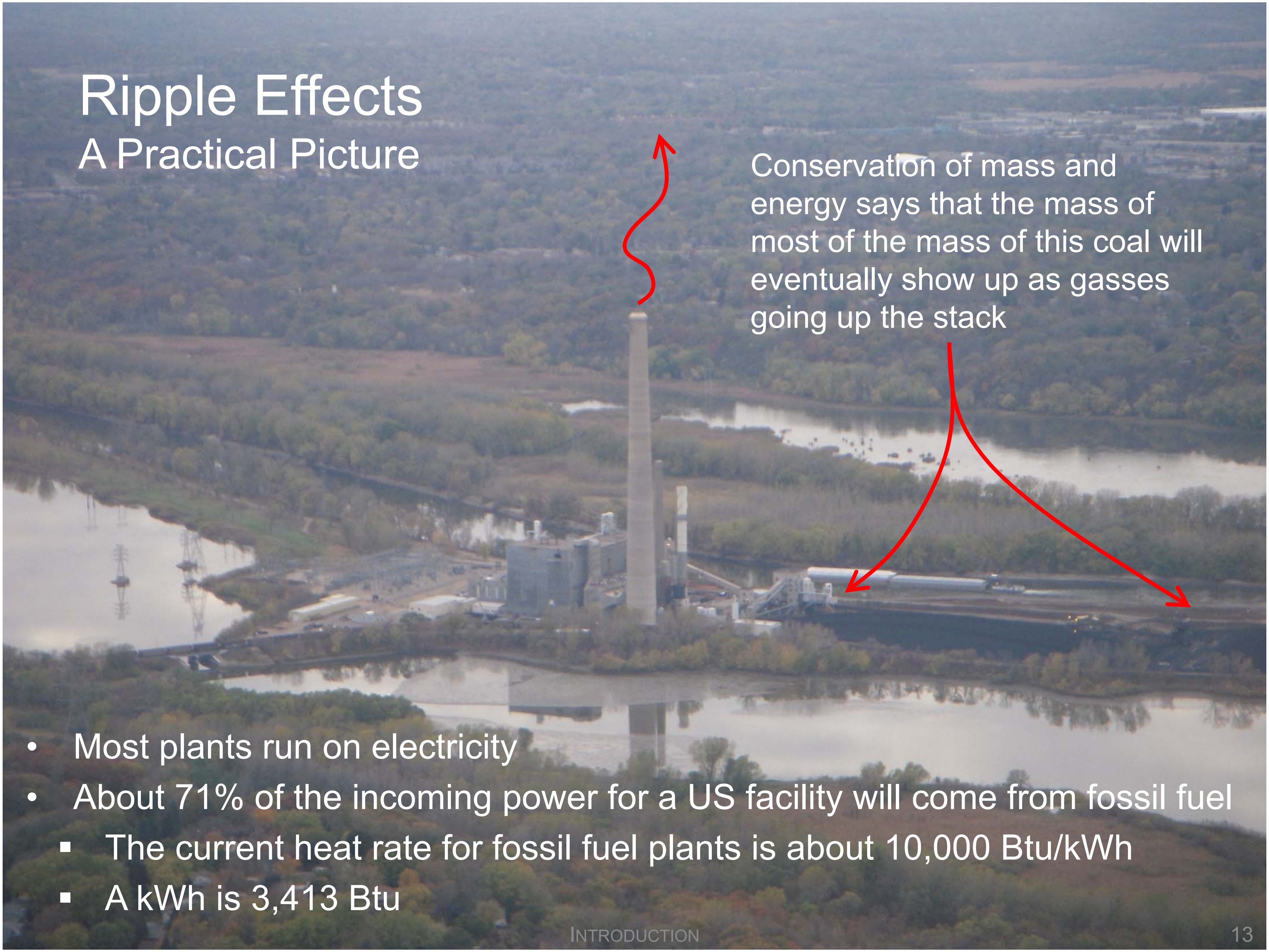


A Bigger Perspective on Delivering Mass in Motion



Ripple Effects

A Practical Picture



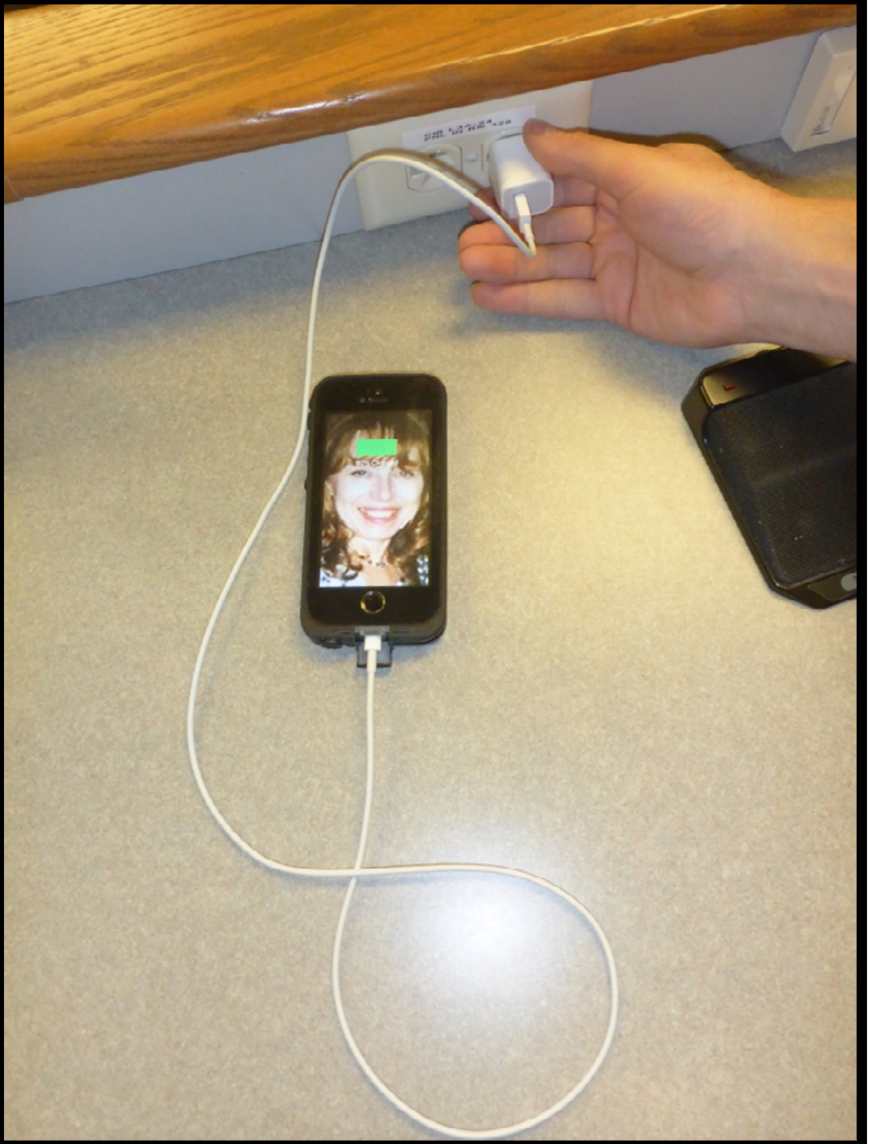
Conservation of mass and energy says that the mass of most of the mass of this coal will eventually show up as gasses going up the stack

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

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

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

The iPhone Food Chain



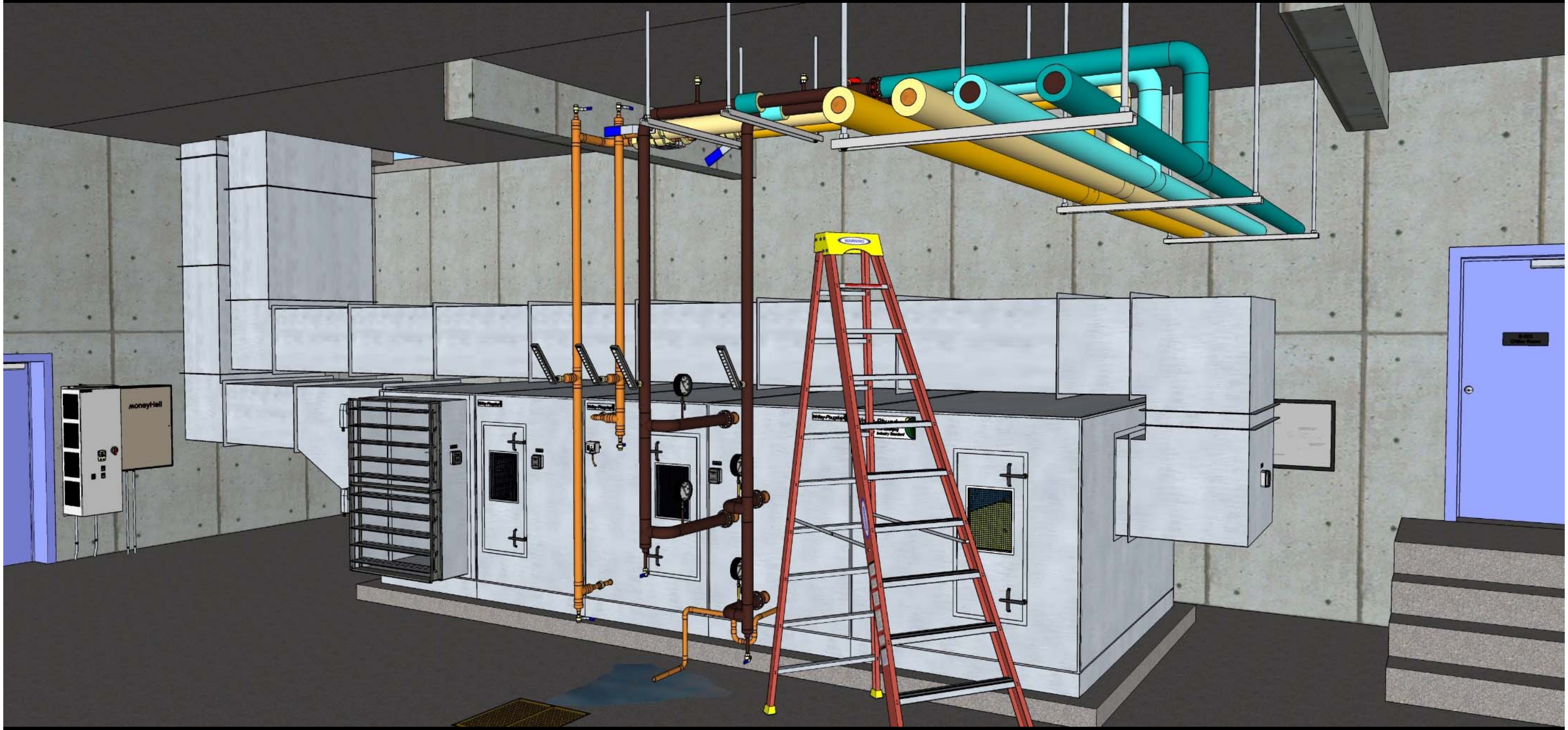
Gas Fired Power Plant as the Energy Source						
Location in the "Food Chain"	Watt-hours at the point in the system	Conversion Loss				
		Device Efficiency	Loss at the Location		Accumulated Losses	
			watt-hours	%	watt-hours	%
End use - Provide a full charge for an iPhone SE Battery	6.17	End Use				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

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

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

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

The AHU Food Chain



Coal Fired Power Plant as the Energy Source						
Location in the "Food Chain"	kWh at the point in the system	Conversion Loss				
		Device Efficiency	Loss at the Location		Accumulated Losses	
			watt-hours	%	watt-hours	%
End use - Cool the Air Delivered to a Ball Room for 1 Hour on a Design Day in St. Louis,	334	End Use				
End use - Move Cool Air from the Equipment Room to the Ball Room for One Hour on a	7	End Use				
kW into the Cooling Plant (The device producing the cooling uses 1 unit of energy to	69	Energy Into the Electrical Panel Serving the Cooling Plant				
kW into the Air Handling Unit Fan and it's Drive System (Motor, Belts, and Motor Speed	12	60.2%	Energy Into the Electrical Panel Serving the Air Handling Unit			
Total kW into the Cooling Plant and the Air Handling Unit	81	This is the electricity that was delivered by the electrical panels in the chiller and air handling system mechanical rooms.				
Building Electical Distribution System Losses (wires, panels, terminations, etc.)	82	99.0%	12.71	15.5%	12.71	15.5%
Transformer Losses	83	99.1%	0.71	0.9%	13.42	16.2%
Transmission From the Power Plant to the Building Transformer	87	95.3%	4.08	4.7%	17.50	20.1%
Coal Fired Power Plant Efficiency	267	32.5%	180.18	67.5%	197.68	74.0%
Delivering Coal from the Coal Mine	281	95.0%	14.06	5.0%	211.74	75.3%
Bottom Lines						
Energy into the process - kWh	281					
Energy delivered to the cooling plant - kWh	81					
Losses - kWh	200					
	71.1%					
Average price of electricity; $/kWh	Residential	Commercial				
(U.S. Average for May, 2017)	$0.1302	$0.1058				
Cost to cool a Ball Room on a Design Day in St. Louis, Missouri for an Hour (Note 3)	$10.58	$8.60				
Cost to Cool a Ball Room for a Typical Hot Day in St. Louis, Missouri (Note 3)	$144.92	$117.76				
Associated Emmissions for One Day, lb.						
CO_2 (Carbon Dioxide)	4.8191	Believed by some to be the primary greenhouse gas emitted by human activities; Respiratory problems occur at high concentrations.				
SO_2 (Sulfur Dioxide)	0.0051	Resiratory system harm and difficult breathing; Harms trees and plants by decreasing foliage and growth; Reacts to create haze.				
NOx (Nitrous Oxide)	0.0038	Reacts to form ozone, aerosols, and NO_2; Respiratory harm; Contributes to acid rain; Impacts water and air quality; Greenhouse gas.				

Using People Power

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

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

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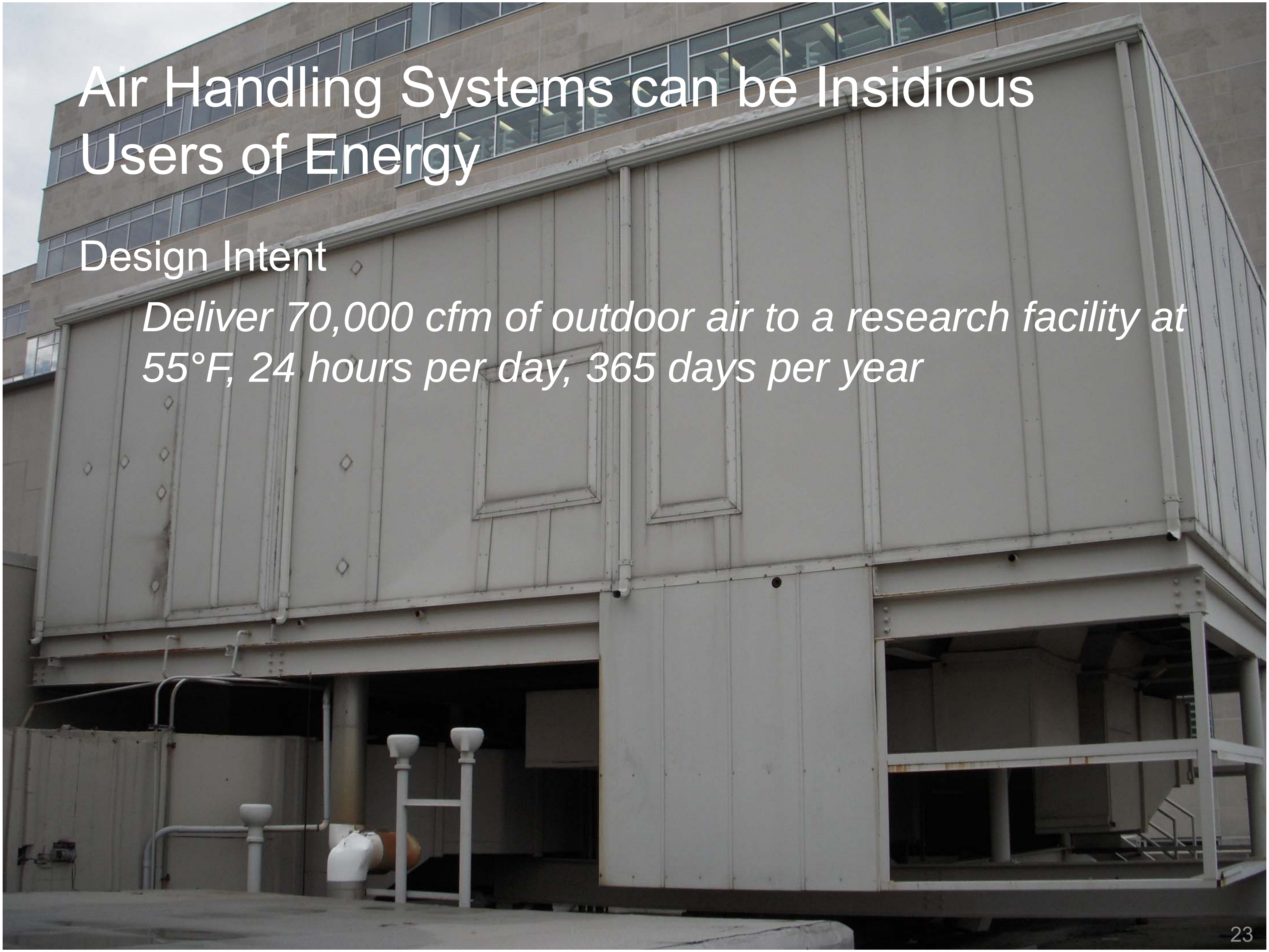
Current walking power rate from above -	264.98 watts
Walking power if some of it went to charge an iPhone -	227.08
Equivalent pace -	2.90 mph
Number of people with the magic machine required to keep the ball room cool for an hour	
	13,169

Fans;

Only One of Many Terms in the Air Handling Resource Consumption Equation

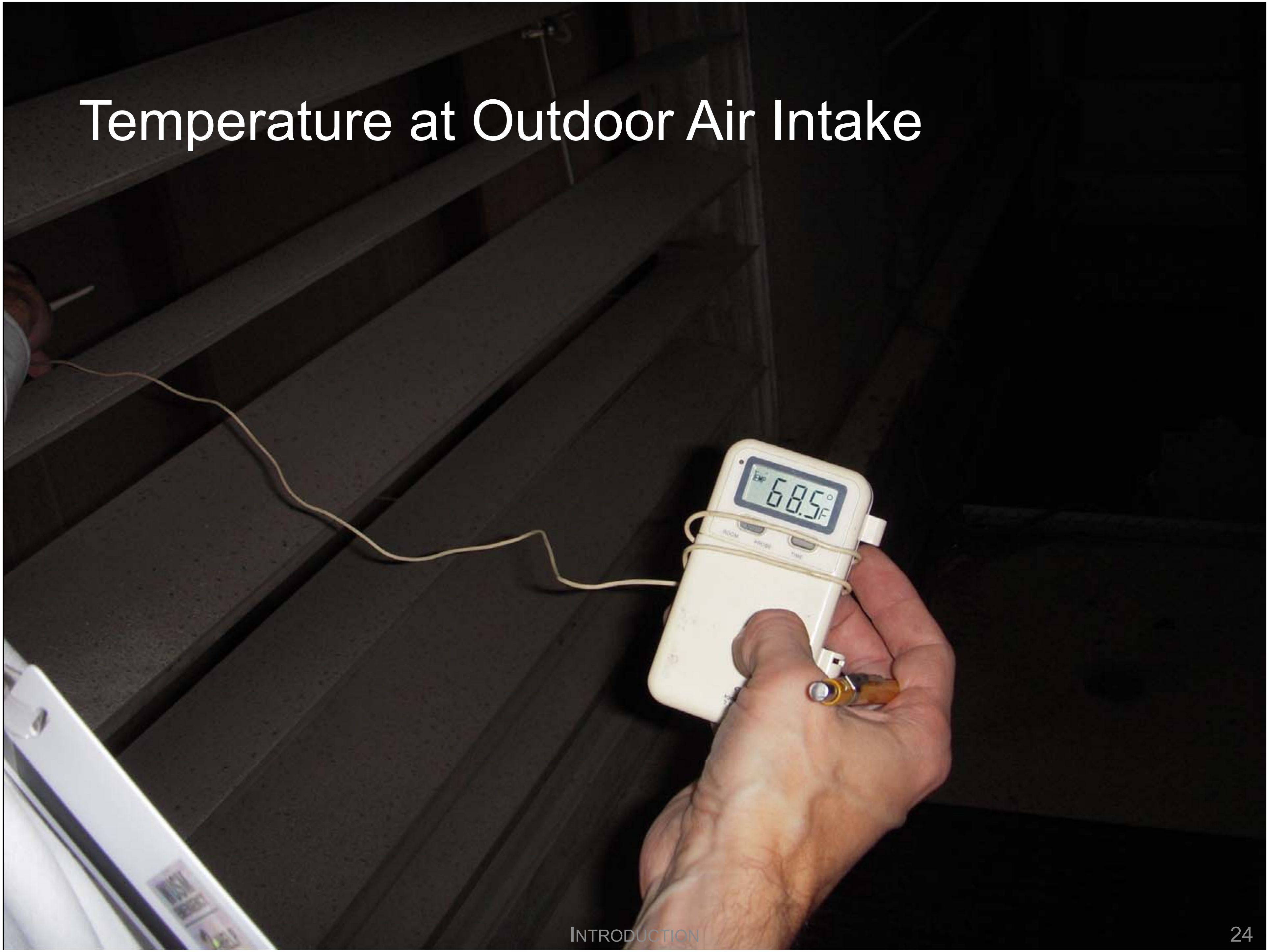
Air Handling Systems can be Insidious Users of Energy



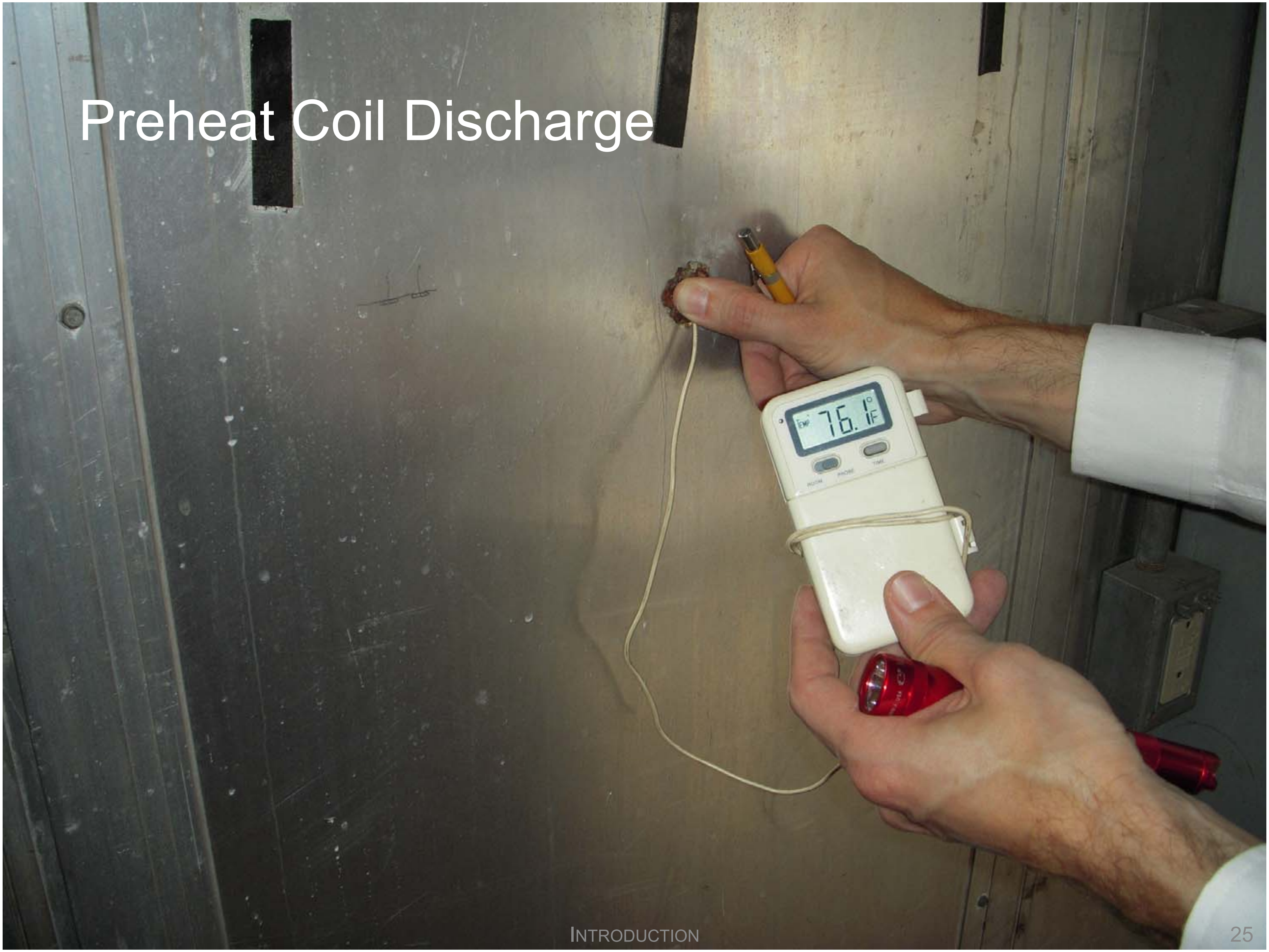
Design Intent

Deliver 70,000 cfm of outdoor air to a research facility at 55°F, 24 hours per day, 365 days per year

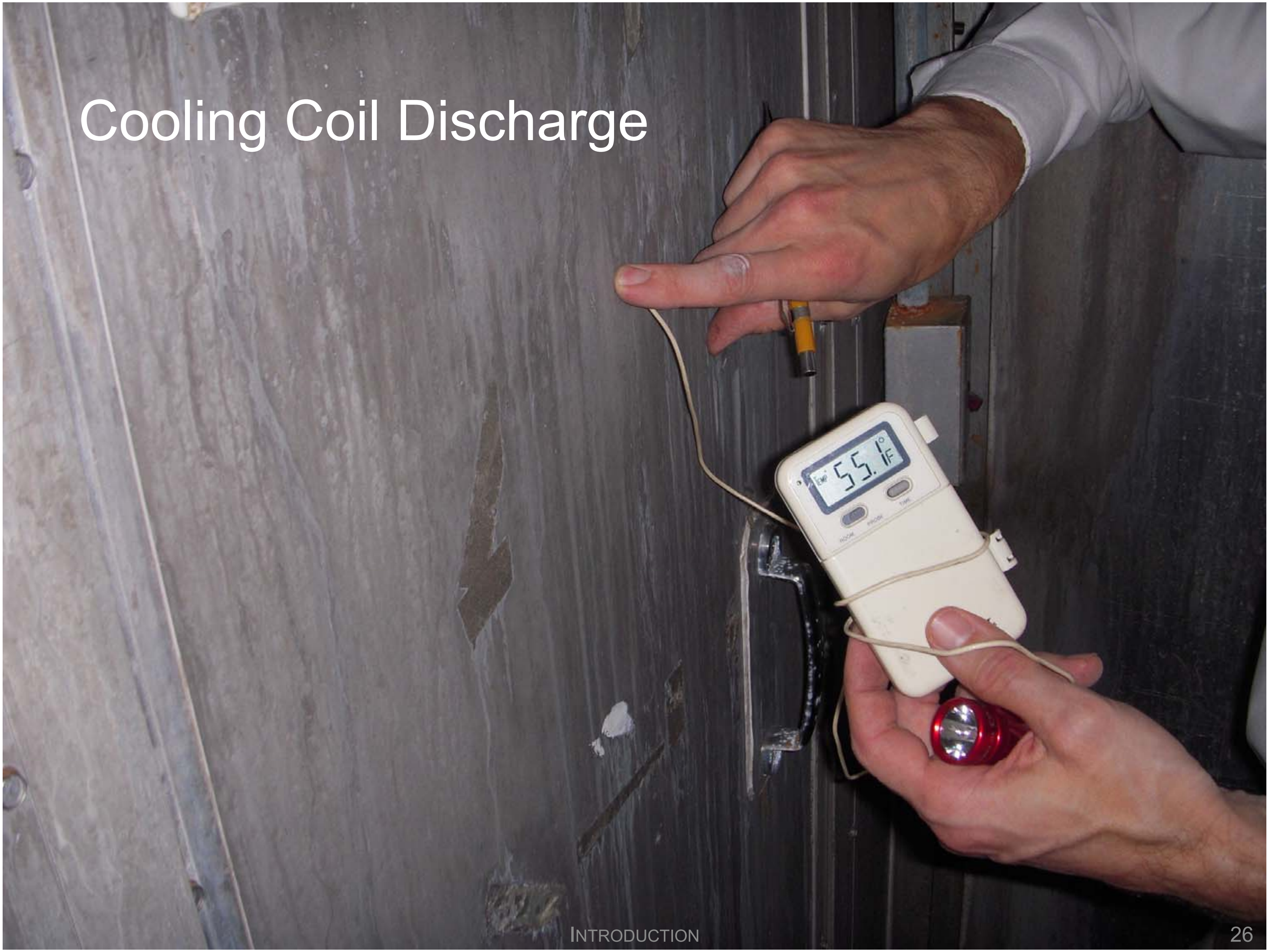
Temperature at Outdoor Air Intake



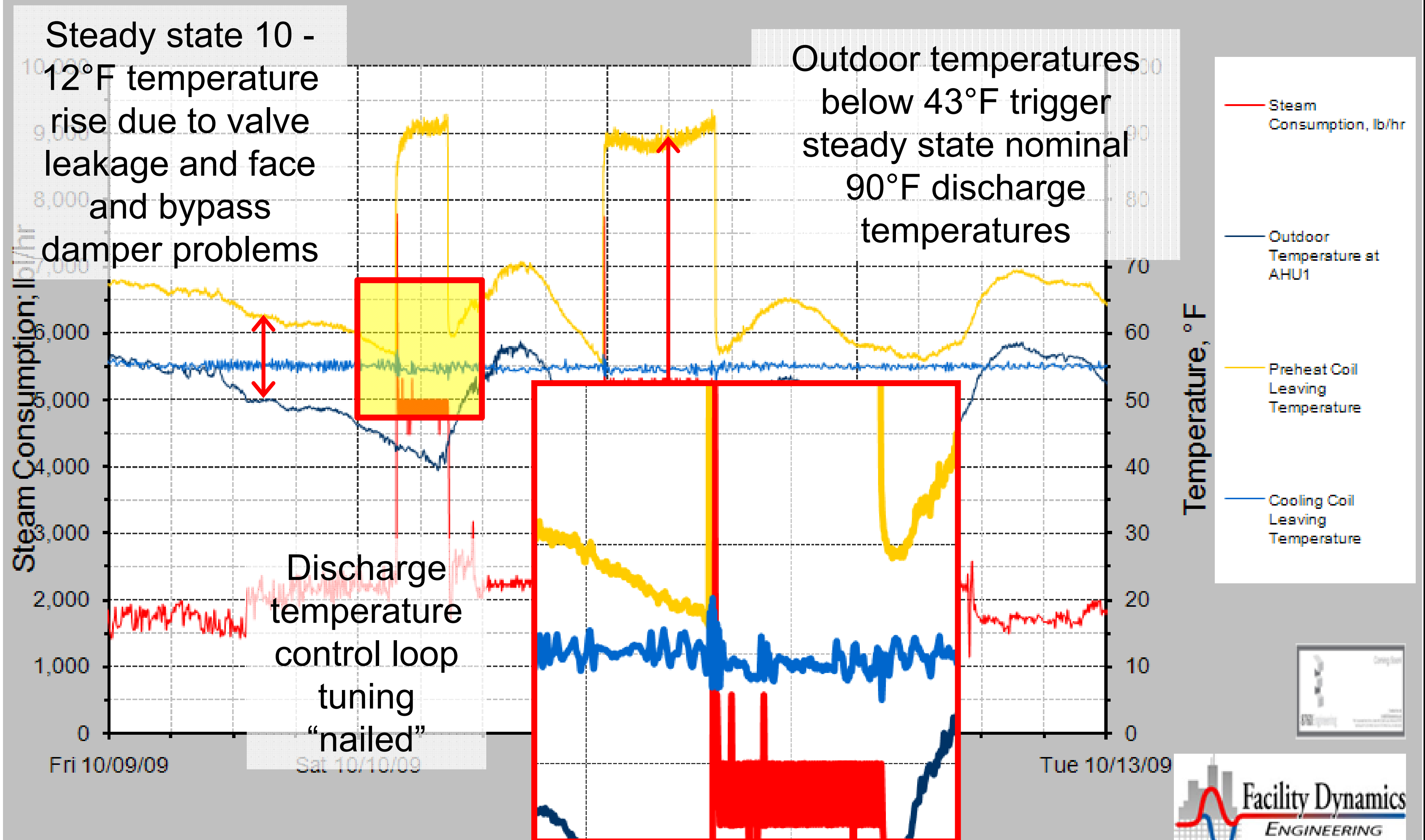
Preheat Coil Discharge



Cooling Coil Discharge

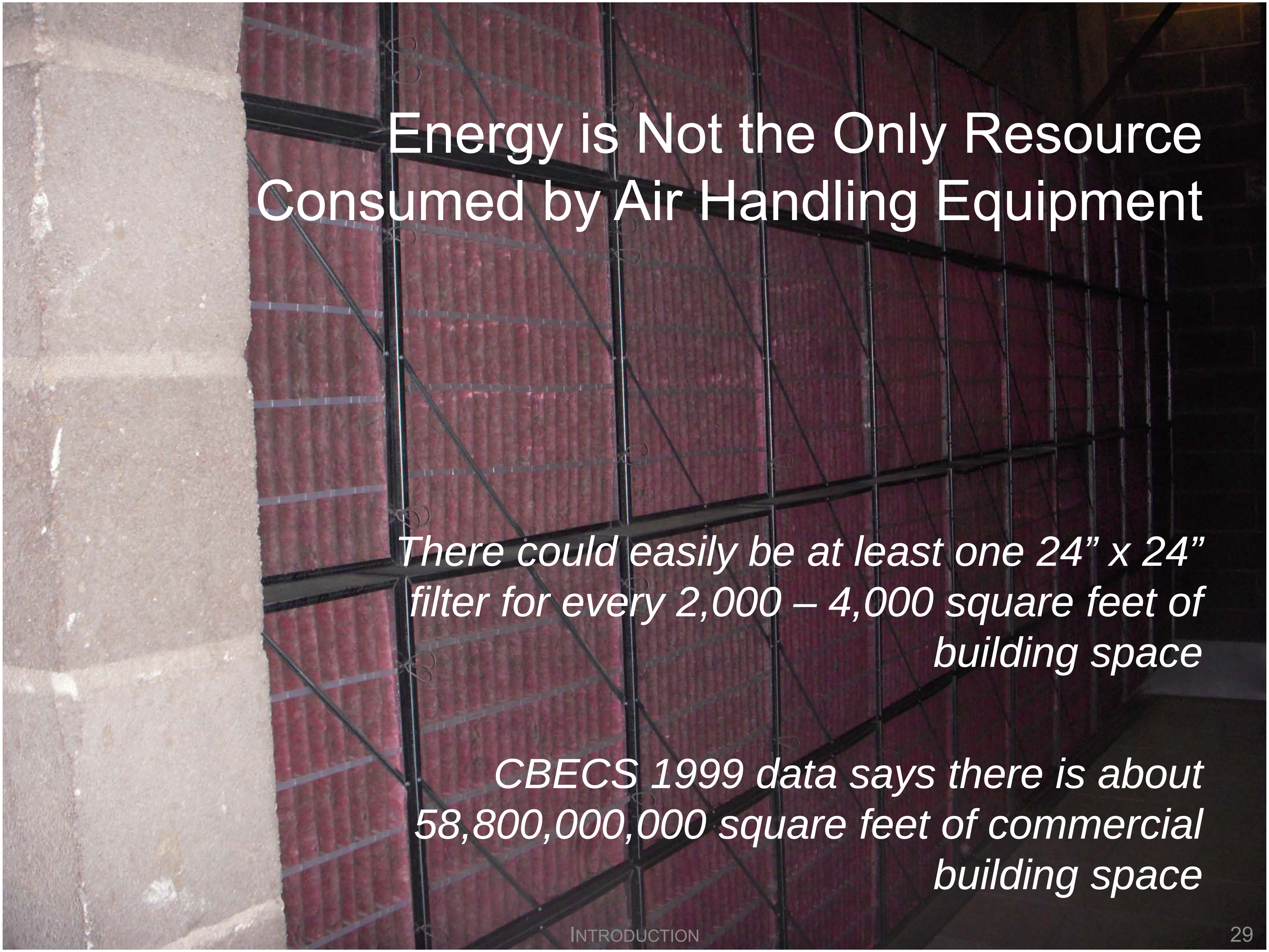


Steam Load from Condensate Pump Operation



Facility Dynamics Engineering

Meanwhile, the Research Environment is Just Fine

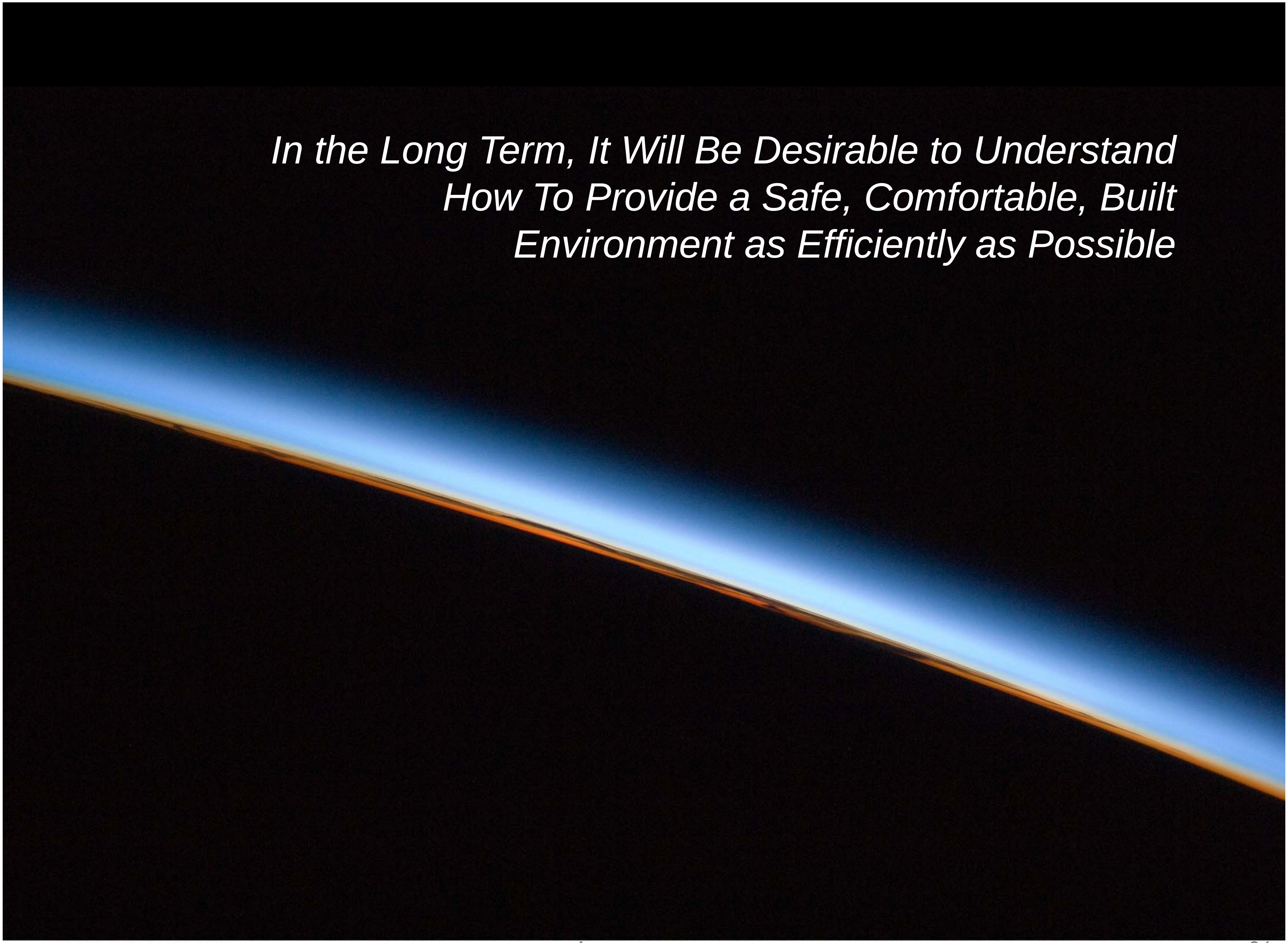


Energy is Not the Only Resource Consumed by Air Handling Equipment

There could easily be at least one 24” x 24” filter for every 2,000 – 4,000 square feet of building space

CBECS 1999 data says there is about 58,800,000,000 square feet of commercial building space

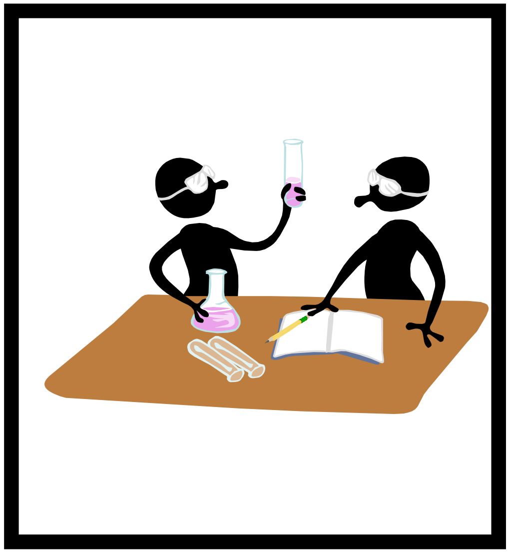
Of Course, There’s a Reason for Doing This

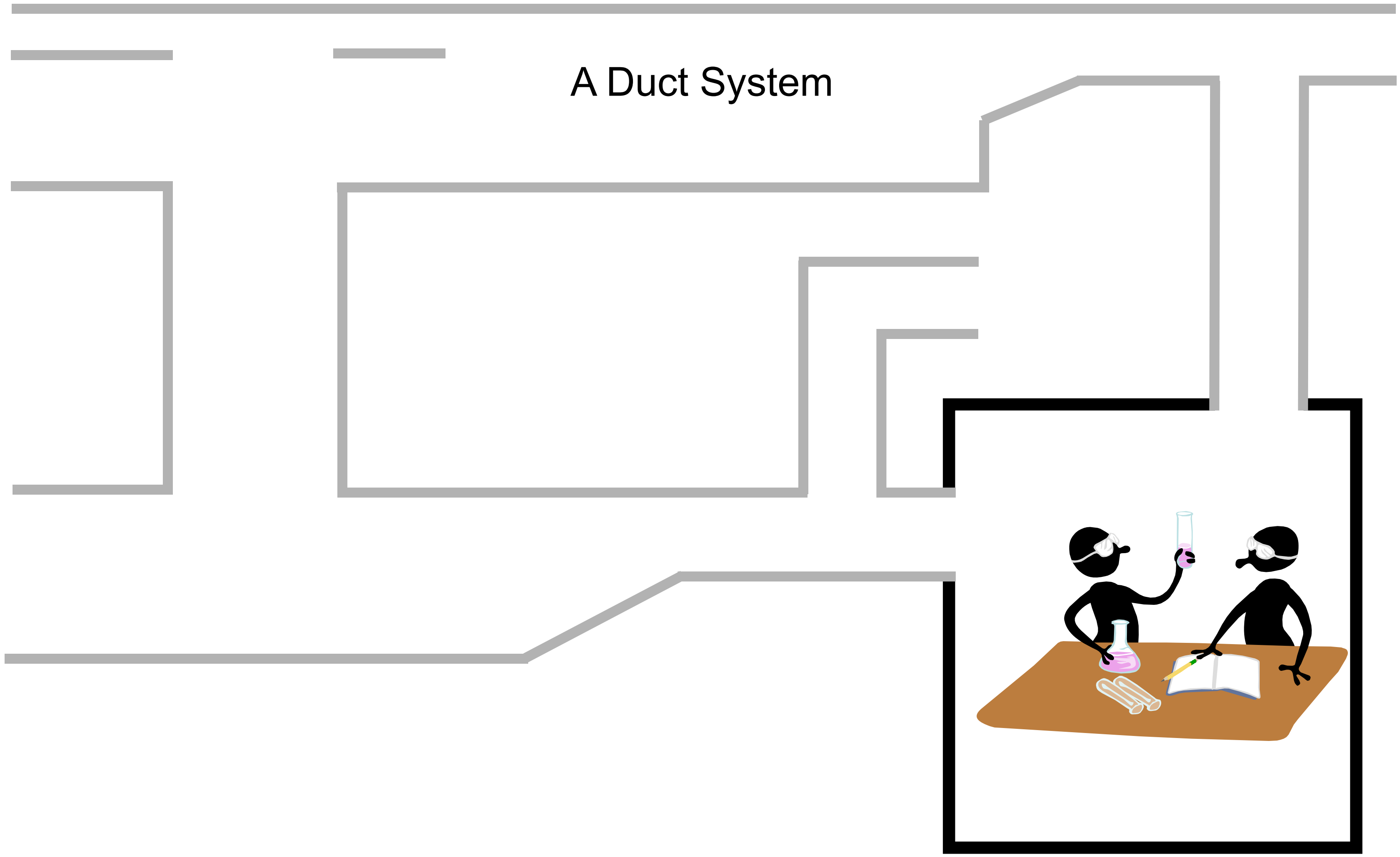


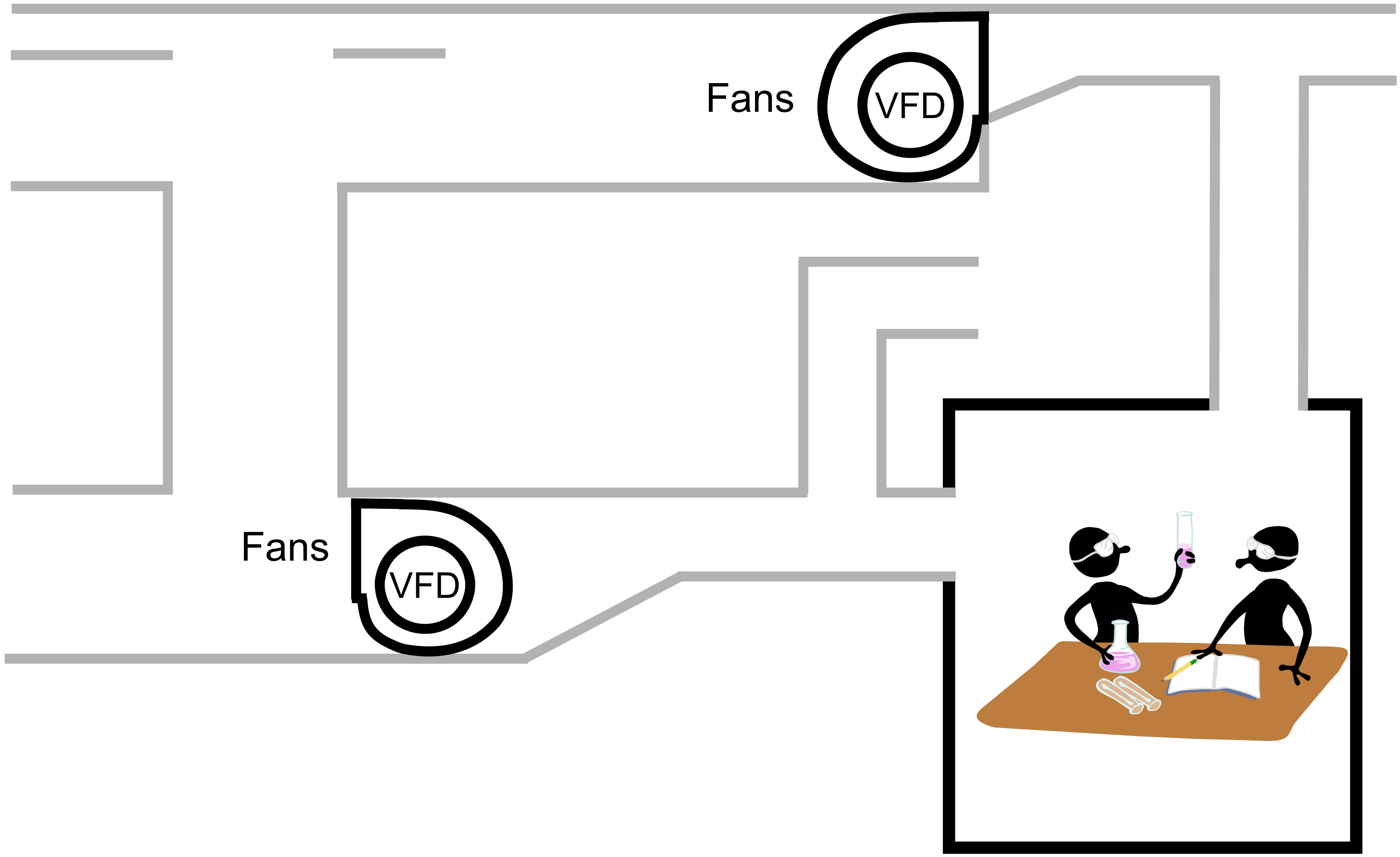
ISS024E013438

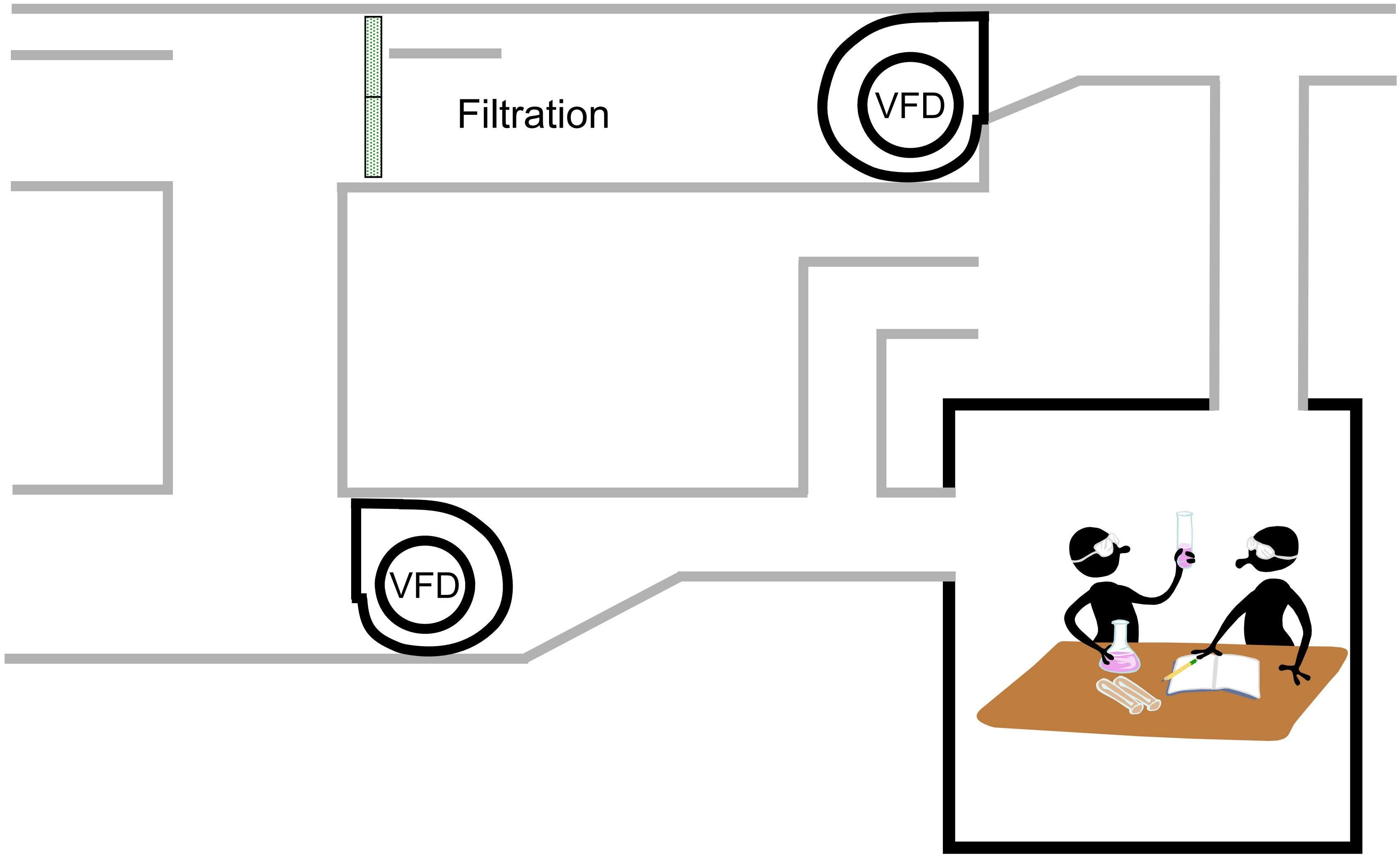
What are the Components of a Typical Air Handling System?

A Load to Serve for Starters

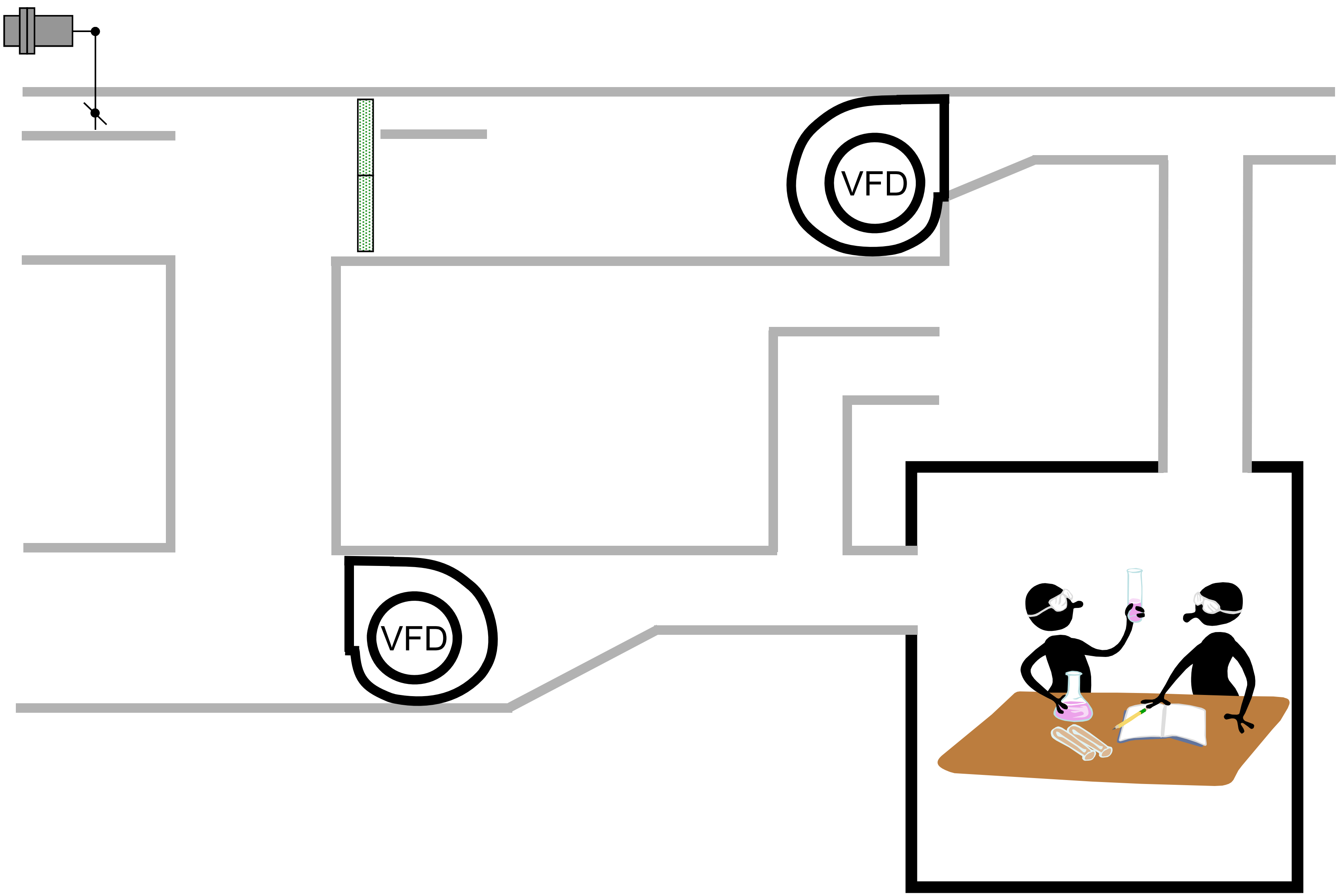


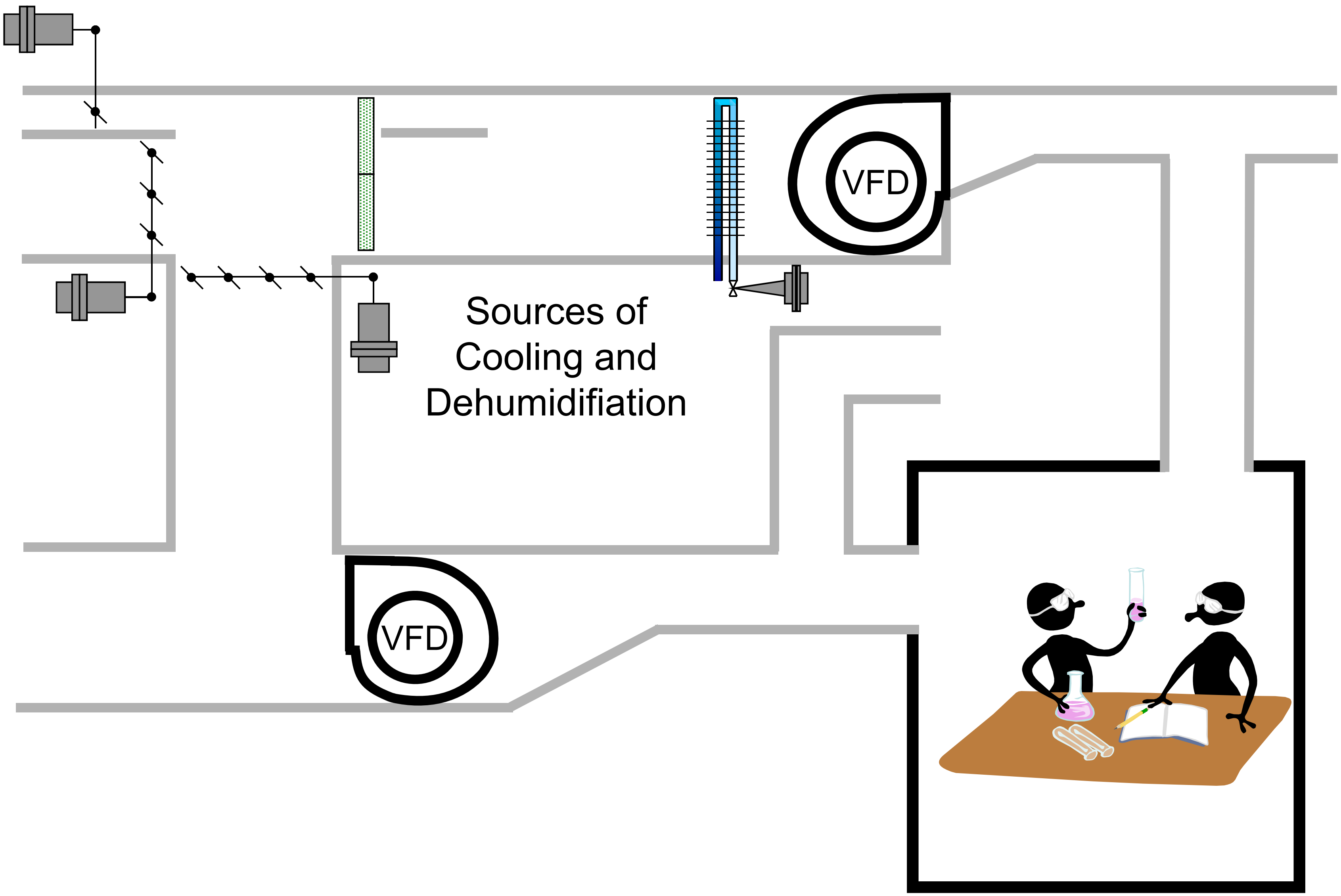

A Duct System

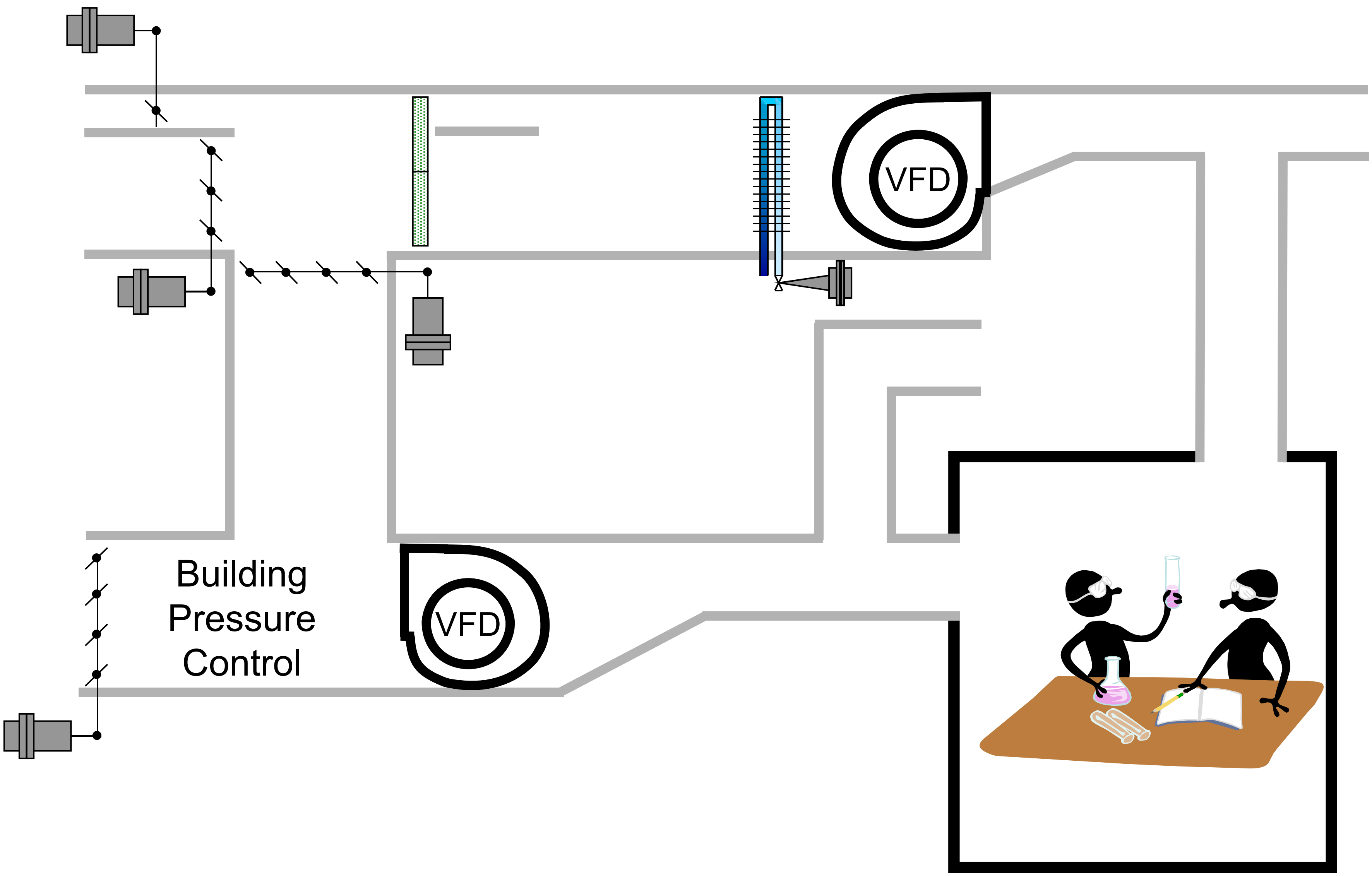

Fans
VFD
Fans
VFD

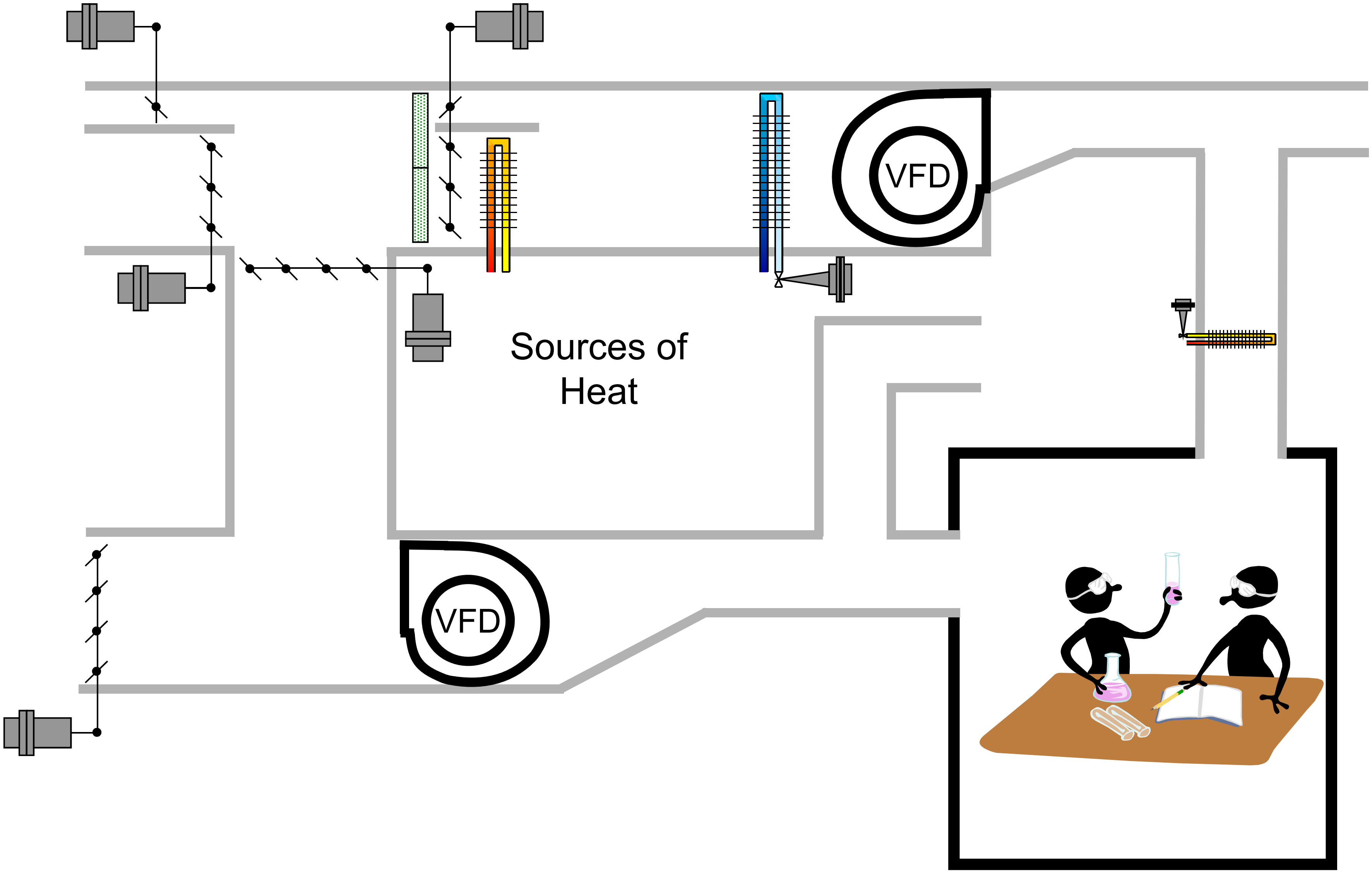

Filtration
VFD
VFD

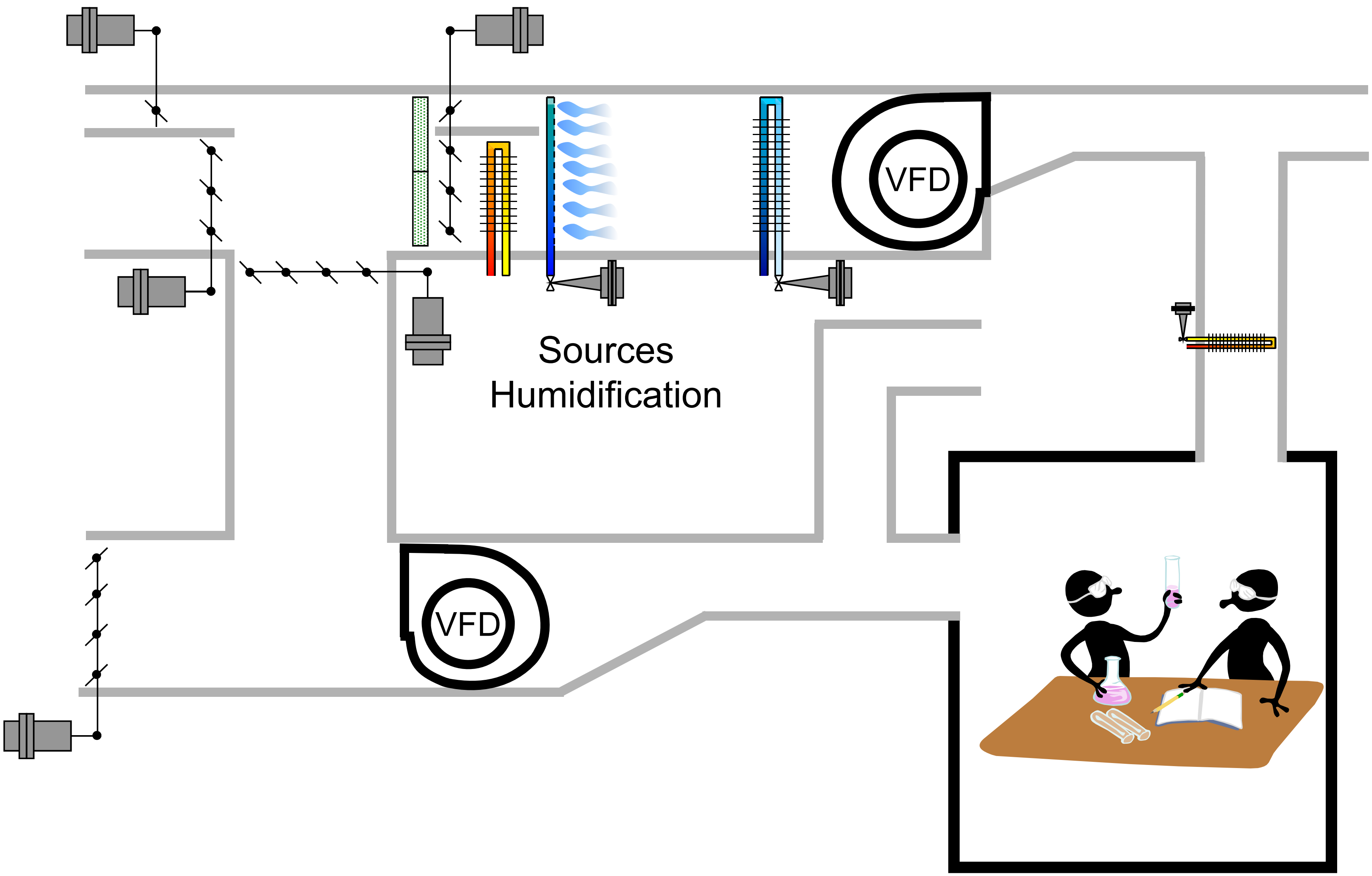
Ventilation



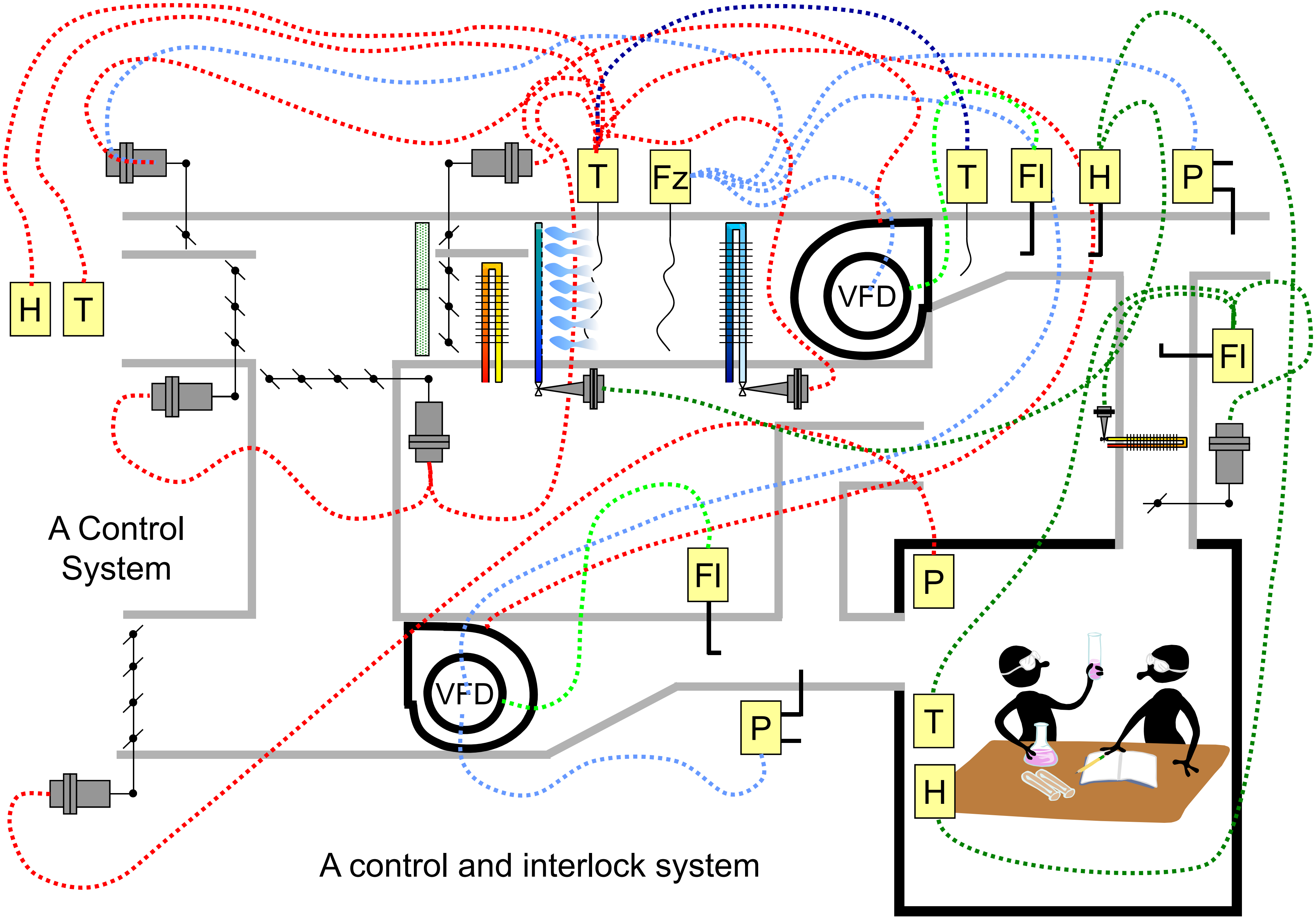

VFD
Sources of Cooling and Dehumidifiation
VFD


VFD
Building
Pressure
Control
VFD


VFD
Sources of Heat
VFD



VFD
Sources
Humidification
VFD



A control and interlock system

Another Important Relationship

$$N_{Config_{Sys}} = \left[\left(\sum_{All} HVAC\ Engineers \right)^2 \times K_{Climate} \times K_{BuildingType} \right] + \frac{\partial Y_{Earth-Moon}}{\partial Z_{Sun-Saturn}}$$

Where:

$N_{Config_{Sys}}$ = The number of potential HVAC system configurations

Another Important Relationship

$$N_{Config_{Sys}} = \left[\left(\sum_{All} HVAC\ Engineers \right)^2 \times K_{Climate} \times K_{BuildingType} \right] + \frac{\partial Y_{Earth-Moon}}{\partial Z_{Sun-Saturn}}$$

Where:

$N_{Config_{Sys}}$ = The number of potential HVAC system configurations

$\sum_{All} HVAC\ Engineers$ = The number of HVAC engineers

$K_{Climate}$ = Climate coefficient; adjusts for the climate type at the system location

$K_{BuildingType}$ = Building type coefficient; adjusts for the building type that the system serves

$\frac{\partial Y_{Earth-Moon}}{\partial Z_{Sun-Saturn}}$ = Planetary alignment compensation factor

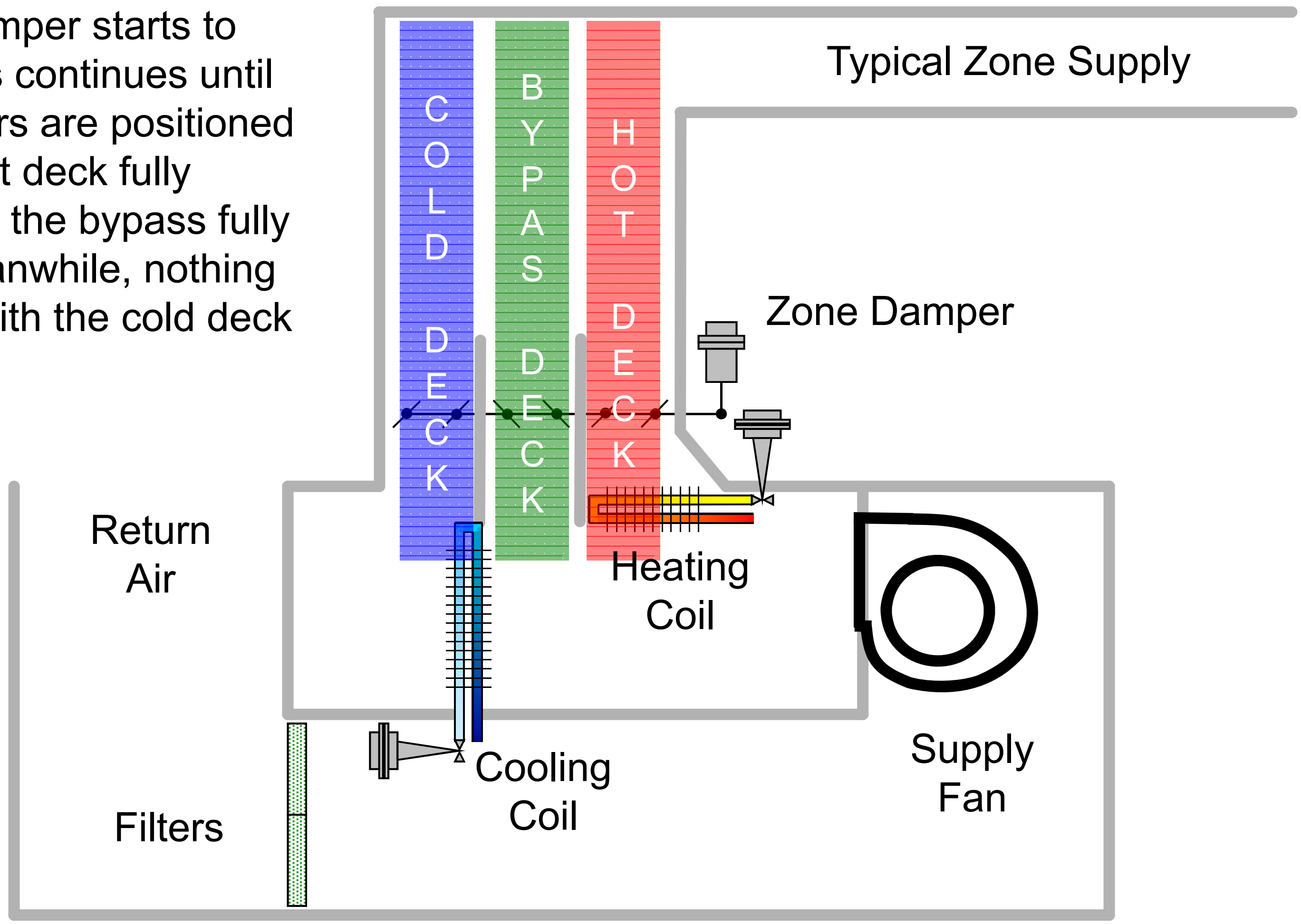
The Pacific Energy Center alone has two very different air handling system types

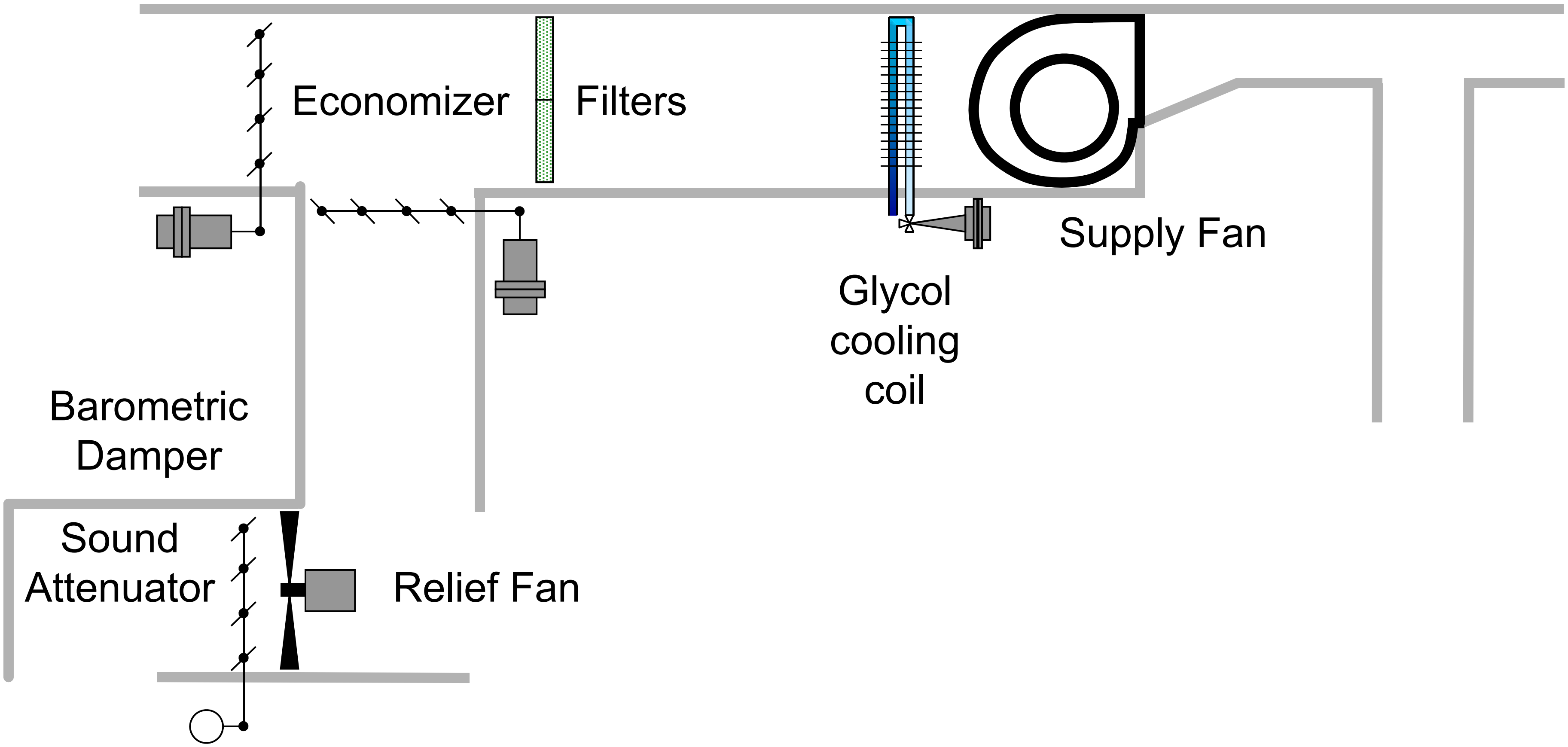
Zone damper linkage system arranged so that as the actuator strokes, the damper blades modulate from:

- Full hot deck, no bypass, no cold deck* to;
- Full bypass deck no cold deck, not hot deck to;
- Full cold deck, no bypass, no hot deck

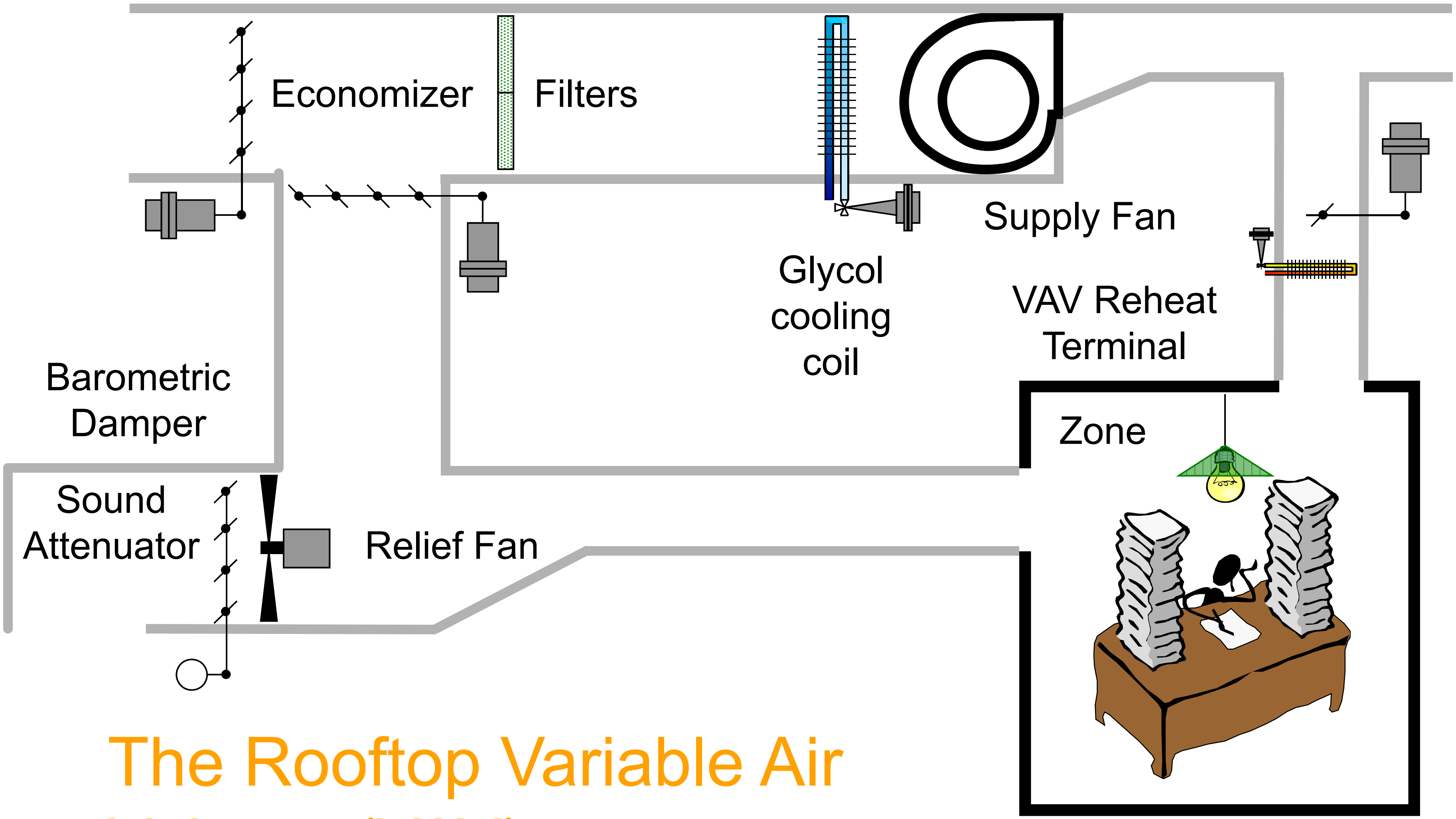
Training Room Multizone Unit

* This means as the hot deck damper starts to close, the bypass damper starts to open. This continues until the dampers are positioned with the hot deck fully closed and the bypass fully open. Meanwhile, nothing happens with the cold deck damper





The Rooftop Variable Air Volume (VAV) Unit



The Rooftop Variable Air Volume (VAV) *System*

A Few of Many Common Air Handling System Configurations

Single Duct, Constant Volume, Single Zone

Single Duct, Constant Volume, Reheat

Single Duct, Constant Volume, Bypass VAV

Single Duct VAV and VAV with Reheat

Hybrid Constant and Variable Volume Systems

Constant Volume and Variable Volume Multizone

Texas Multizone

Three Deck Multizone

Dual Duct Constant Volume and Variable Volume

Dual Duct, Dual Conduit

Low Temperature Air

Natural Ventilation Cycle

See the Control Design Guide for descriptions and standard point lists for these systems

www.peci.org/ftguide/csdg/CSDG.htm

Our Agenda for Today

Take a look at each of the fundamental air system building blocks

- Develop a fundamental understanding of how they work
- Gain insight into how they might interact
- Pave the way for dealing with $N_{Config_{Sys}}$
- Pave the way for future classes
  - VSDs (Next month)
  - Economizers
  - VAV Systems
  - EBCx Workshop Series (New Series Starts next August)
  - Others (To be determined)

A Few Topic Specific Resources

Air Movement and Control Association (AMCA)

- A not-for-profit international association of air system equipment manufacturers
  - Fans
  - Louvers
  - Dampers
  - www.amca.org

Air Conditioning, Heating and Refrigeration Institute

- Represents water heating, ventilation, air conditioning and commercial refrigeration manufacturers
- www.ahrinet.org