2024 Critical
Environments Summit

Clean Manufacturing and the Importance of Environmental Monitoring

Application & Overview

David Rausch with Phoenix Controls

1/17/2024

Agenda

1. Introductions
2. High Purity Manufacturing – What is it?
3. Cleanroom Market Overview
4. Cleanroom Production Critical to Quality Requirements
5. High Purity Manufacturing Application
6. Phoenix Controls
7. How can work together

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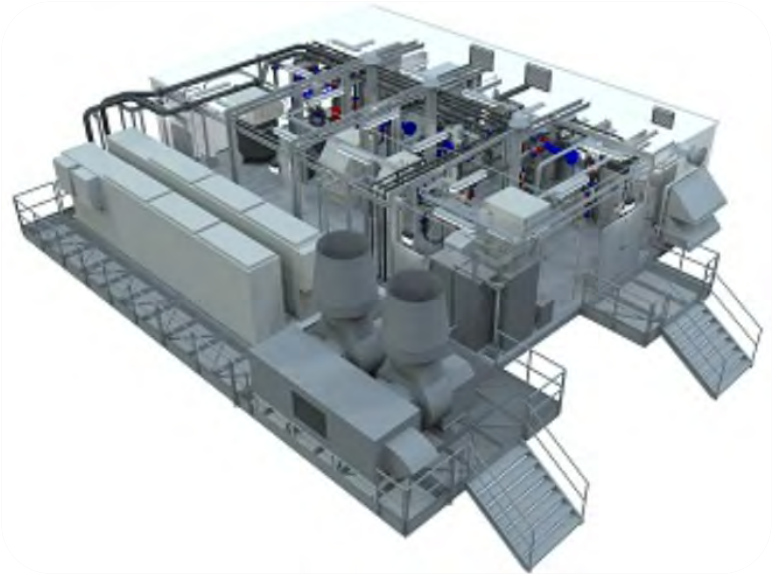
Market Overview

- 200+ projects planned for North America and Europe over the next 36 months
- Stringent requirements for pressurization and particulate control
  - Loss of pressure = lost product = lost profit
  - Loss of environmental control = lower quality product
- Labor shortage – high purity manufacturing boom
- Speed to market without compromising safety or quality is key
- Modular vs Stick built



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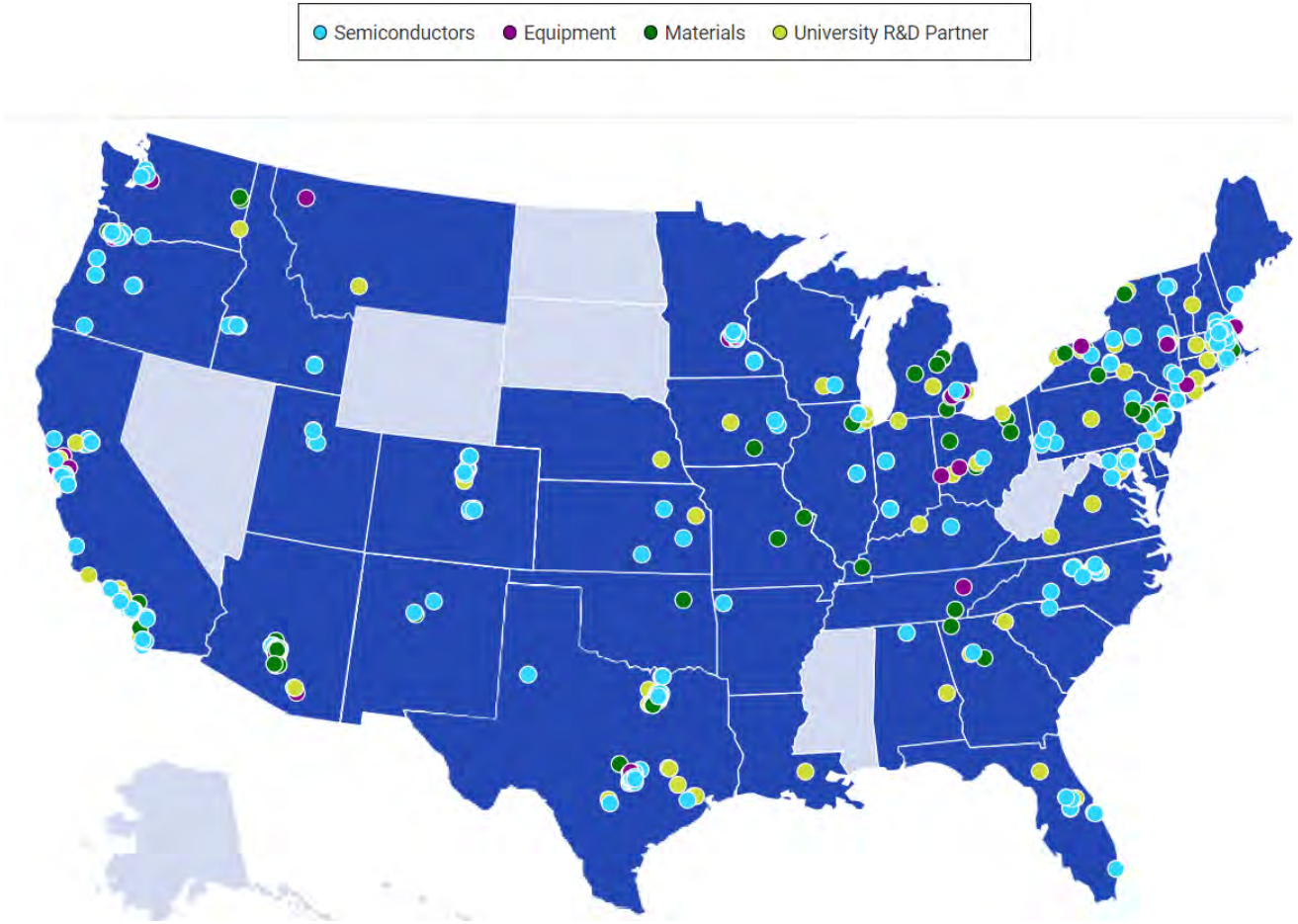
Semiconductor Market Overview

Semiconductor Cleanroom Mfg Plants

- Positive pressure cleanroom
  - Lost pressure = lost product
- Typically, constant volume flows
- Mechanical Pressure independence is key
- Large volume of air (100,000 CFM)
- Phoenix Controls Solutions
  - Venturi Valves
  - Room pressure indicators
  - Vision CE - Monitoring



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Market and Applications

What is High Purity Manufacturing?

- Specialized manufacturing process
- Tight environmental control
- Tight particulate control (Clean Room)

Markets

- EV Mobility (Battery Plants)
- Semiconductor manufacturing
- Pharmaceutical manufacturing
- Good Manufacturing Practice facilities
- Bio Safety Lab Level 2/3

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Challenges to address in Cleanroom Manufacturing

Inconsistent - pressurization = Lost product

- Tight pressurization controls
- Precise, consistent, and repeatable
- Volumetric Offset Approach and tracking Pair capabilities
- Easily adjust Exhaust flows due to leakage over time.

Lack of environmental quality management = Lower quality batteries

(shorter life / shorter range)

- Relative humidity / dewpoint
- Particulate control – volatile or non-volatile

Lack of production space flexibility = Increased downtime and costly test and balance

- "Push Button" ISO Class switching with Vision CE
- Reliable, repeatable **cascading pressurization** from space to space
  - No test and balance required

Sustainability = Reduce air changes to lower operating costs

- Performance Based Ventilation – "Purge Mode"
- Lower air change rates based on ISO Class PM requirements

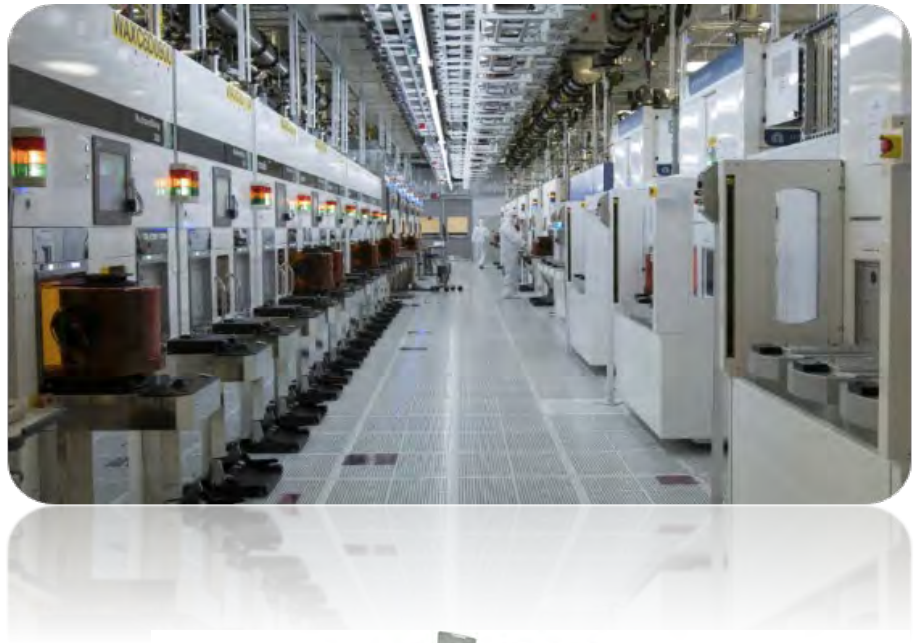
Key Factors in Design

- Constant supply air flow to maintain required air change rate. Constant or variable exhaust flow rate
- Return air flow adjusted to maintain pressure differential.
- Temperature control (generally 18°C - 20° C space) – Humidity < 1% RH
- Pressure management and recording/alarming.
- Airborne Particles – Electro-stactic Discharge (ESD) – Out Gassing
- Individual Exhaust systems on Specialty Machinery

Market & Applications

EV Mobility

- Large facility – 1,000,000 Ft²
- Cleanroom – 400,000 Ft²
  - Anode, Cathode, Electrode Assembly
- High bay spaces (40-60 Ft)
- Environmental control (68-77°F)
- Humidity control
  - Low humidity - (20-40% RH)
  - Dry room – (1-5% RH)
- Particulate control (ISO 5 to ISO 8)



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Market & Applications

Semiconductor Manufacturing

- Large facility – 1,000,000 Ft^2
- Cleanrooms/ Fabrication facilities "Fabs"
  - Lithography
  - Etching
  - Deposition:
  - Packaging
- High bay spaces (40-60 Ft)
- Environmental control (68-75°F)
- Humidity control
- Low humidity - (30-60% RH)
- Particulate control (ISO 5 or better)

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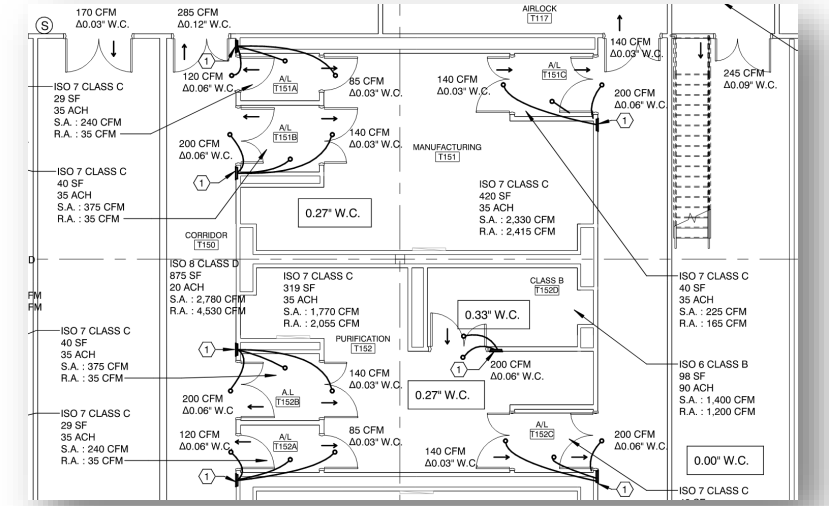
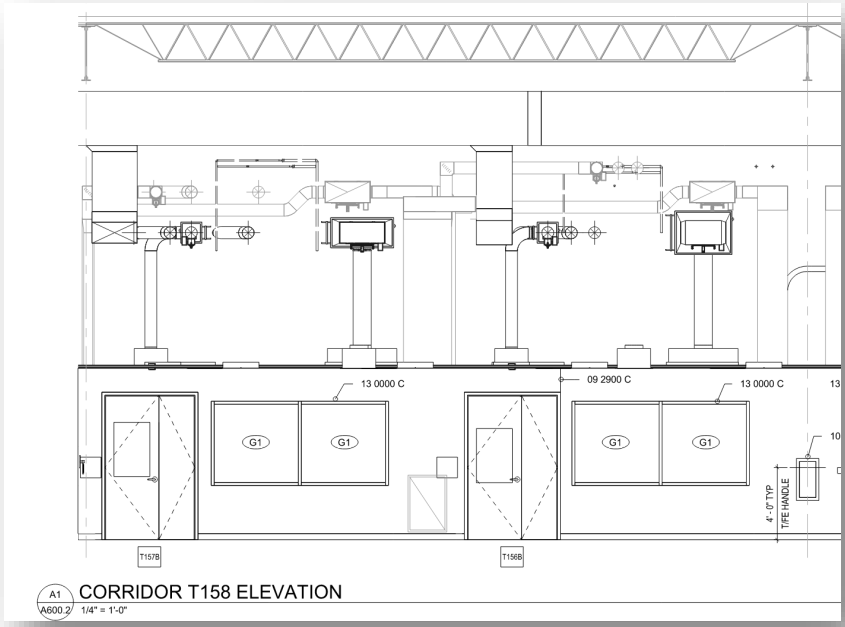
Market & Applications

Pharmaceutical manufacturing

- Cascading pressure requirements
- Typically, constant volume flows
- Mechanical Pressure independence is key
- Phoenix Controls applications
  - Tracking pairs
  - Celeris POC controls
- Room pressure indicators
- Bubble tight airlocks!!!





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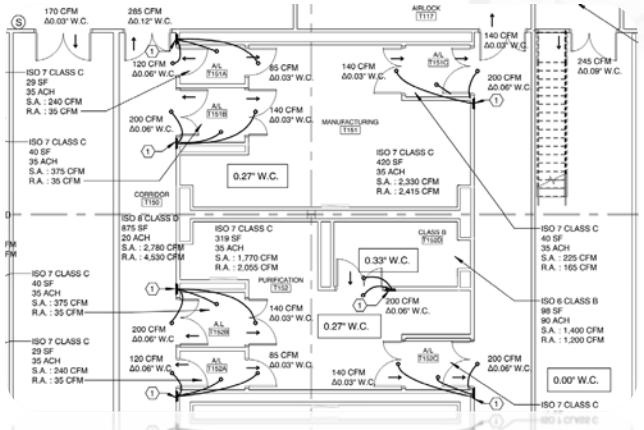
Market & Applications

Pharmaceutical Manufacturing

- Cleanroom requirements – FDA/GMP
- Validated design requirements
- Environmental control (60-72°F)
- Humidity control (40-60 RH)
- Particulate control (ISO 5 to ISO 8)

ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000



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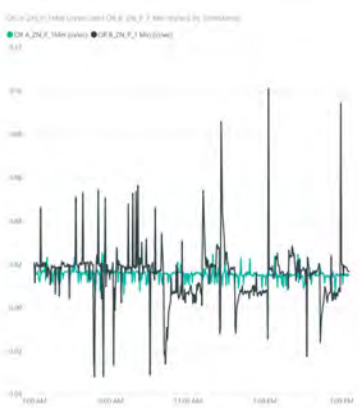
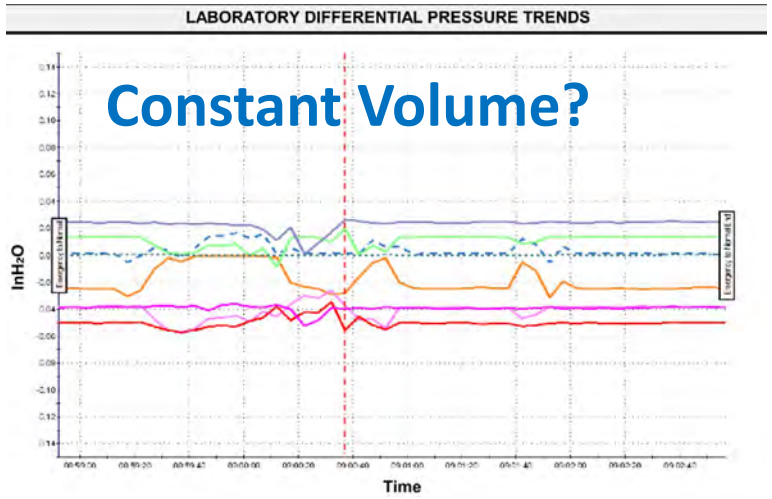
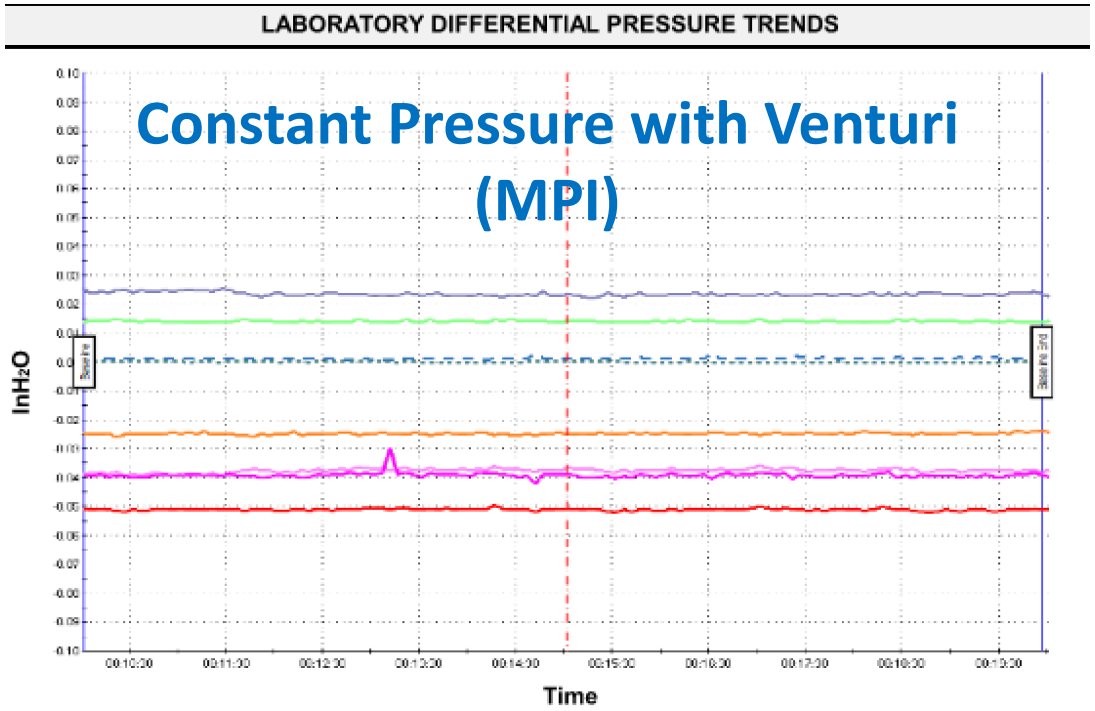
The Phoenix Controls Difference

- **Contamination Control**
  - ISO 14644 ISO7/ISO5
  - Switching/Cascading
- **Precision Environmental Control**
  - Pressure, Temp and RH Control
  - During Dynamic Activity
- **Process air management**
  - Integrated Particulate Monitoring
  - Exhaust, make up, recirculation
  - Demand Based Ventilation for “Best” Sustainability practices / Lower OP-EX
- **Monitoring and reporting**
  - Optimizing your Critical production spaces
  - Review deviations
  - Identify root cause problems







Constant Volume vs. Constant Pressure

Airflow Control and Room Pressurization

Variable Air Volume (VAV)

Space Pressurization by Volumetric Offset

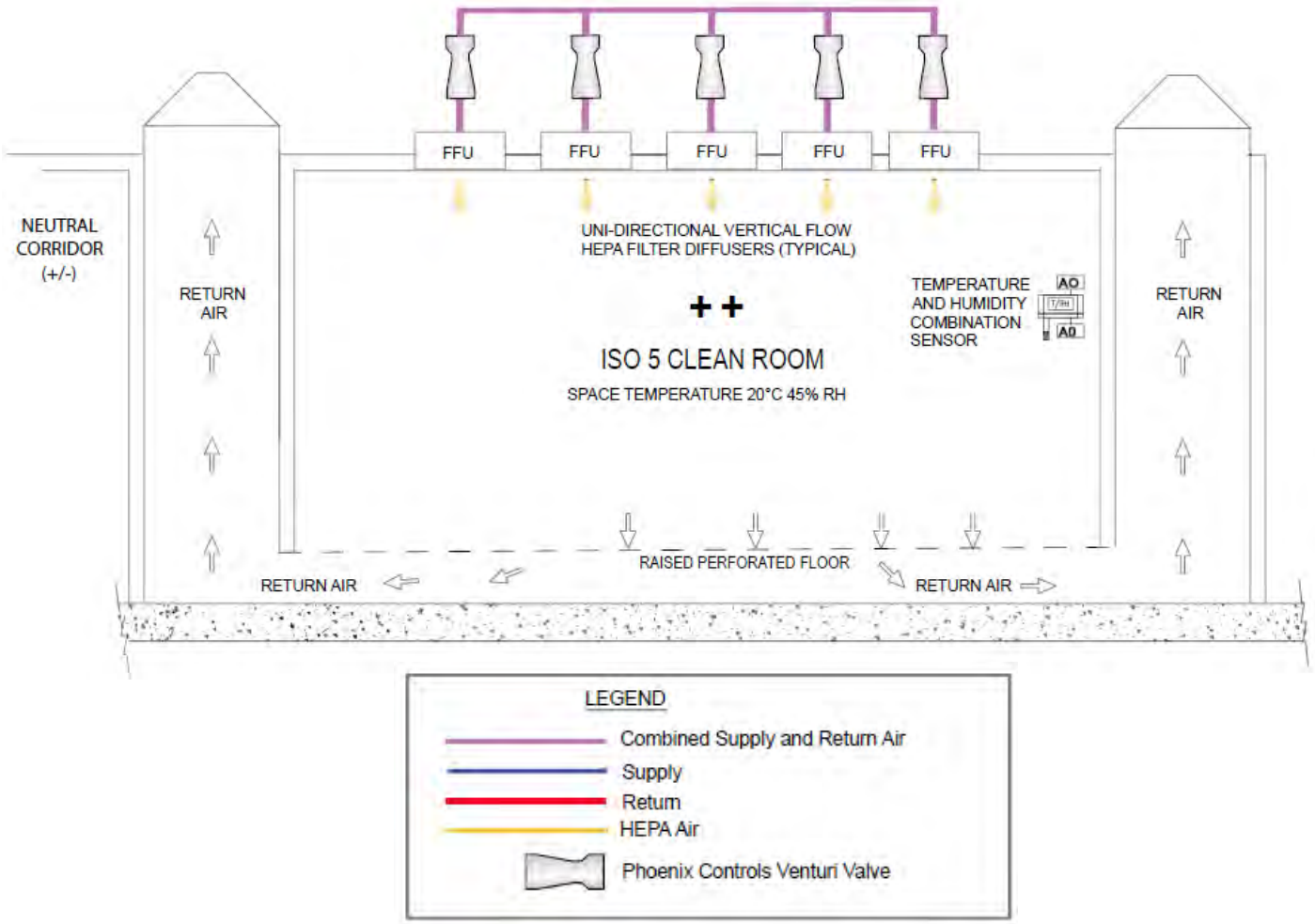
- A volume of air is programmed as a constant offset value that is maintained between the total supply flow and total exhaust flow of a given room.
- With the precision of the Phoenix Controls Venturi Valve, room pressurization (positive or negative) is maintained through this offset.
- Room pressurization is achieved but no specific pressure differential is maintained.

Space Pressurization by Pressure Offset Control (POC)

- By measuring the pressure differential between 2 or more spaces, the volumetric offset is value is adjusted in order to maintain a required pressure setpoint.
- Mainly used when code requires a specific setpoint for pressure differential.
- Rooms must be well sealed in order to attain setpoint.
- Not recommended in spaces with VAV hoods

Airflow and Pressurization Control

- Vertical laminar flow is common inside cleanrooms
- Flows through the holes in the flooring passing upward through the air plenum to be purified through HEPA filters
- The return air is then conditioned to control its temperature and humidity before it is cycled through the cleanroom again
- Directional Pressure and Flow is the best defense to reduce Particle build up.
- Semiconductor cleanrooms requirements can range from ISO 4 (Class 10) to ISO 6 (Class 1,000) cleanrooms



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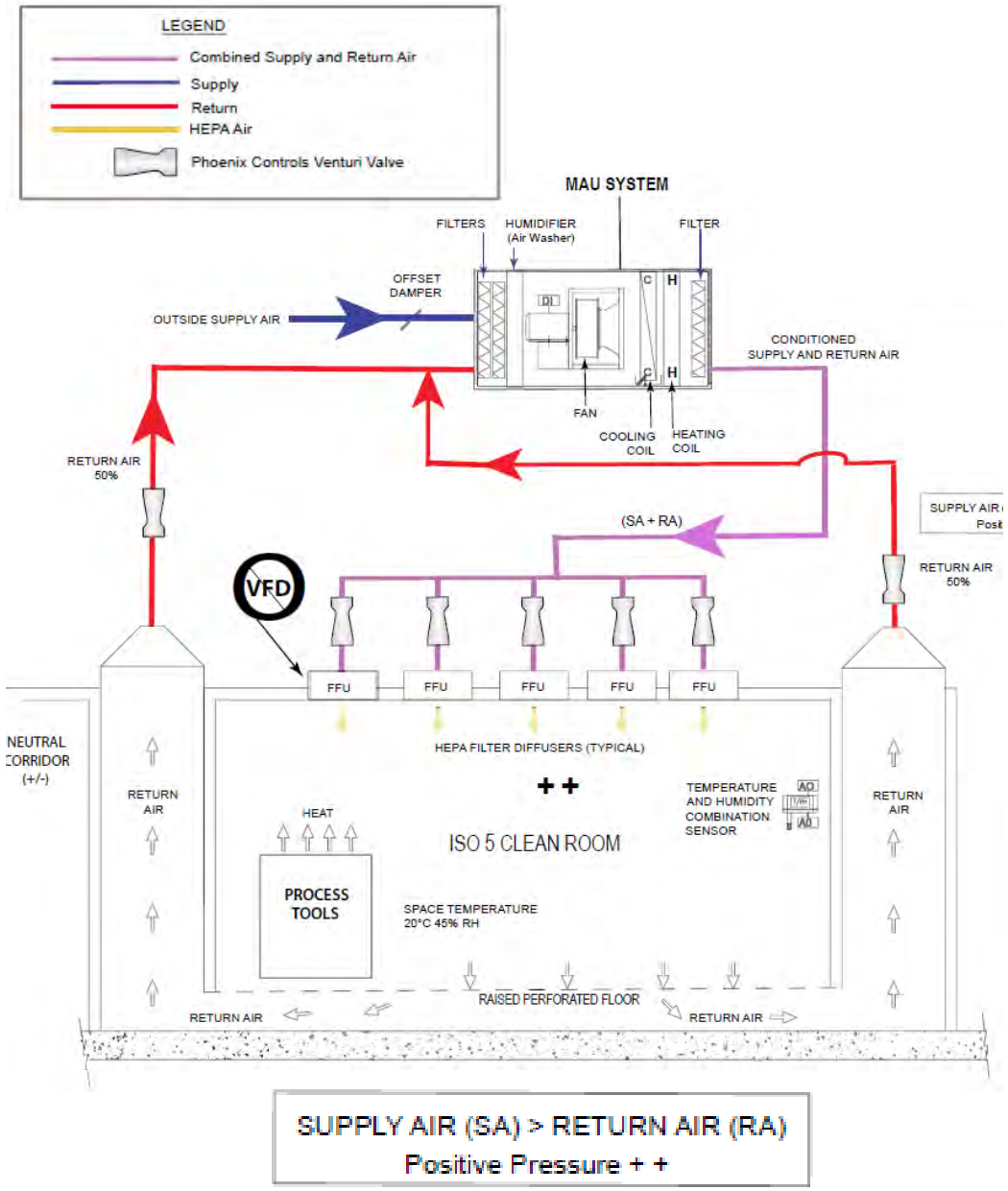
Air Changes and Pressurization

Class ISO 146144-1 (Federal Standard 209E)	Average Airflow Velocity m/s (ft/min)	Air Changes Per Hour	Ceiling Coverage
ISO 8 (Class 100,000)	0.005 – 0.041 (1-8)	5 – 48	5 – 15%
ISO 7 (Class 10,000)	0.051 – 0.076 (10-15)	60 – 90	15 – 20%
ISO 6 (Class 1,000)	0.127 – 0.203 (25-40)	150 – 240	25 – 40%
ISO 5 (Class 100)	0.203 – 0.406 (40-80)	240 – 480	35 – 70%
ISO 4 (Class 10)	0.254 – 0.457 (50-90)	300 – 540	50 – 90%
ISO 3 (Class 1)	0.305 – 0.457 (60-90)	360 – 540	60 – 100%
ISO 1-2	0.305 – 0.508 (60-100)	360 – 600	80 – 100%

Class	Maximum Particles/m^3						FED STD 209E equivalent
	≥ 0.1 µm	≥ 0.2 µm	≥ 0.3 µm	≥ 0.5 µm	≥ 1 µm	≥ 5 µm	
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room Air

Most stringent → Least stringent



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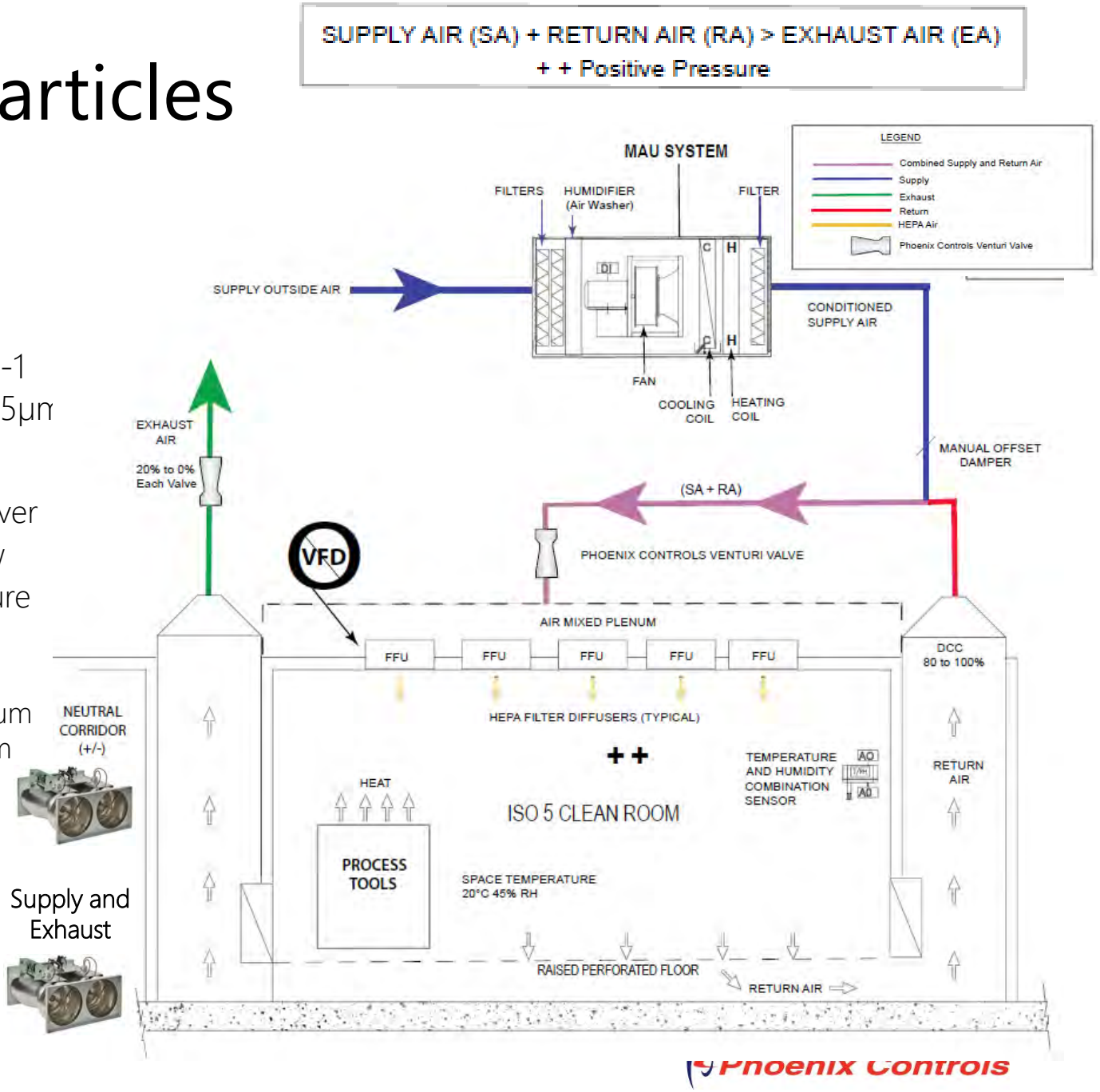
Filtration and Airborne Particles

- Semiconductor cleanrooms requirements can range from ISO 4 (Class 10) to ISO 6 (Class 1,000) cleanrooms.
- Manufacturing space required to meet ISO 14644-1 Class 5 or lower, maximum of 3,520 particles at 0.5µm or smaller per cubic meter of air
- FFU's Built into Supply Diffuser, creating sterile field over operation site. VFD used to increase or decrease flow based on PM monitoring. Is this Best Practice? Pressure control Fluctuations?
- HEPA - High-Efficiency Particulate Air filters 99.9% of 0.3µm
  ULPA – Ultra Low Particulate Air Filters 99.999% of 0.12µm
- Typically, 80% Return Air is used and supplied back up into supply plenum after being re-cooled (DCC)



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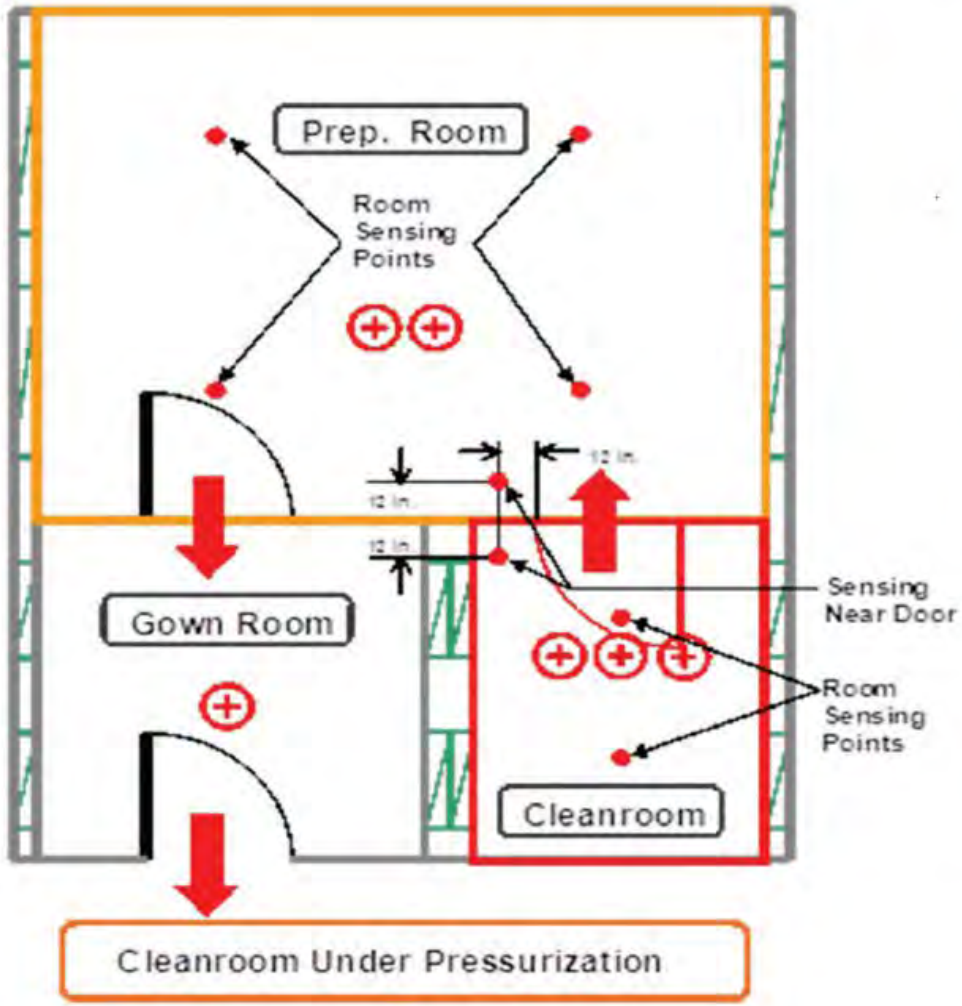
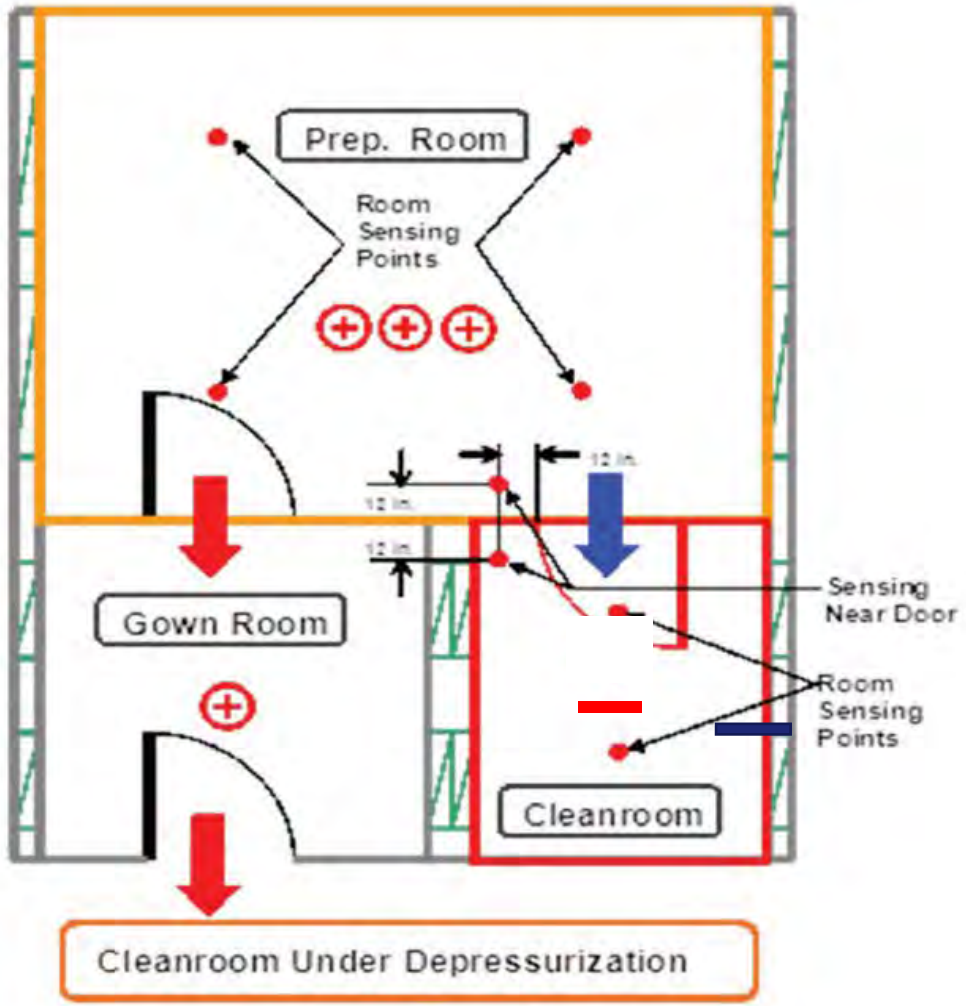
Air Changes + Pressurization





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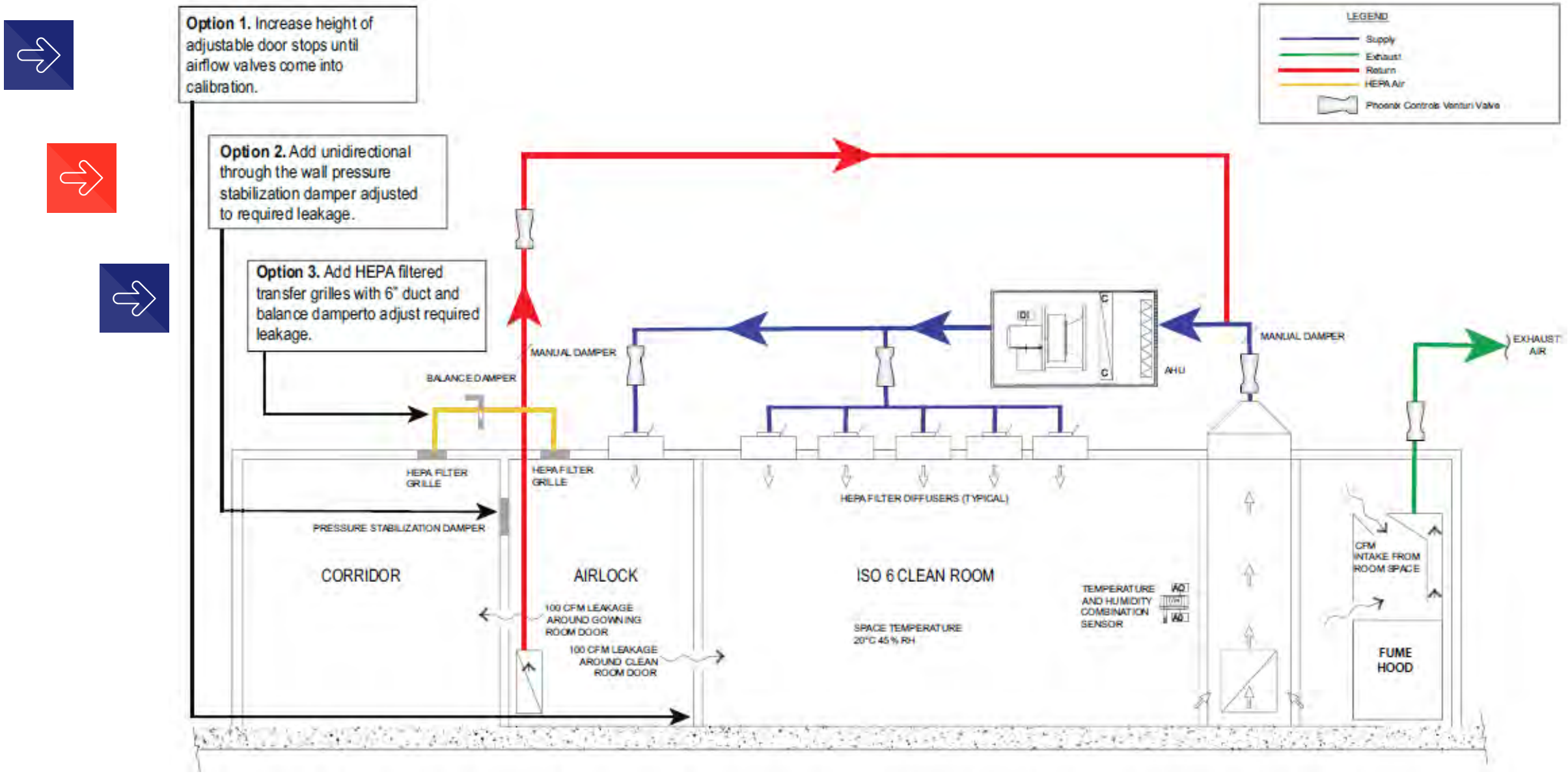
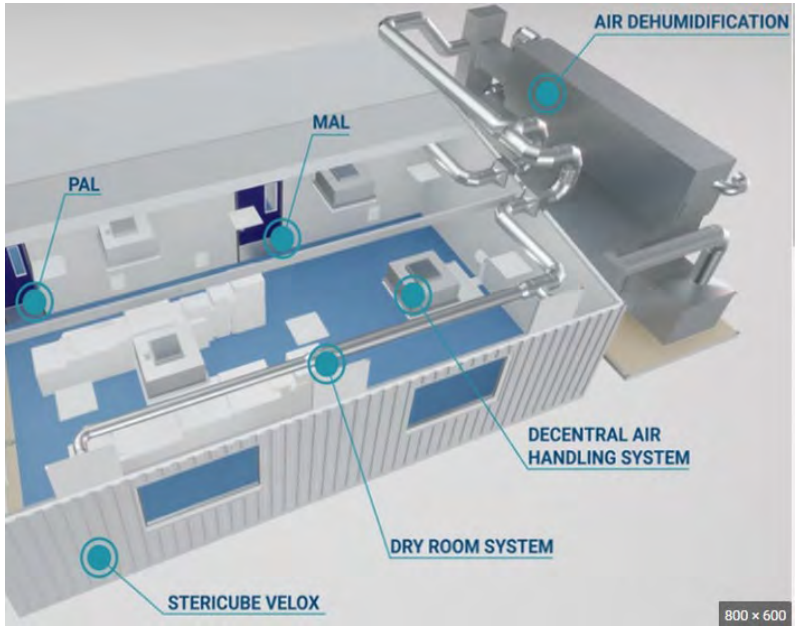
Bubble Tight Strategies



Temp and Humidity

- Temperature needs to be maintained to keep conductance optimal **(18˚- 20˚C) (64˚F – 68˚F)**
- ISO Class 6 – 8 dry rooms, with Relative Humidity level of <1% or a Dew Point of -50° Celsius (122˚F)
- Can be a challenge given High ACH and introducing VAV strategies
- With Phoenix Controls, Temp and Humidity control is highly configurable and tied to zone balance control
- Using customized algorithms, tight dead band settings and multiple parameters to customize configurations



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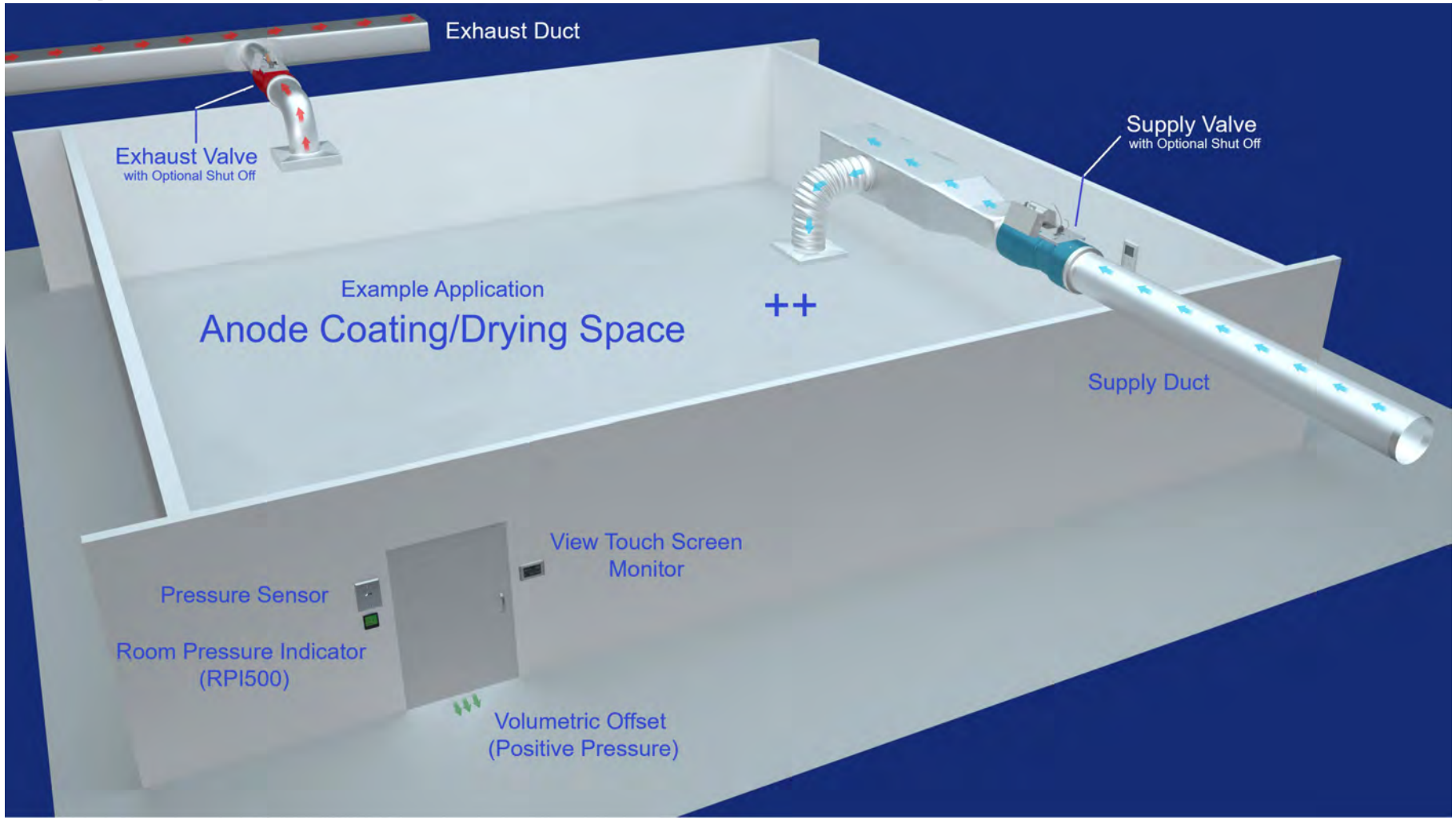
Tracking Pair Venturi Valves (Ideal for EV Solutions)



With tracking pair venturi Solutions, Spaces can easily be repurposed or switched from positive, negative or neutral directional airflow while maintaining tight temperature & Humidity Control.

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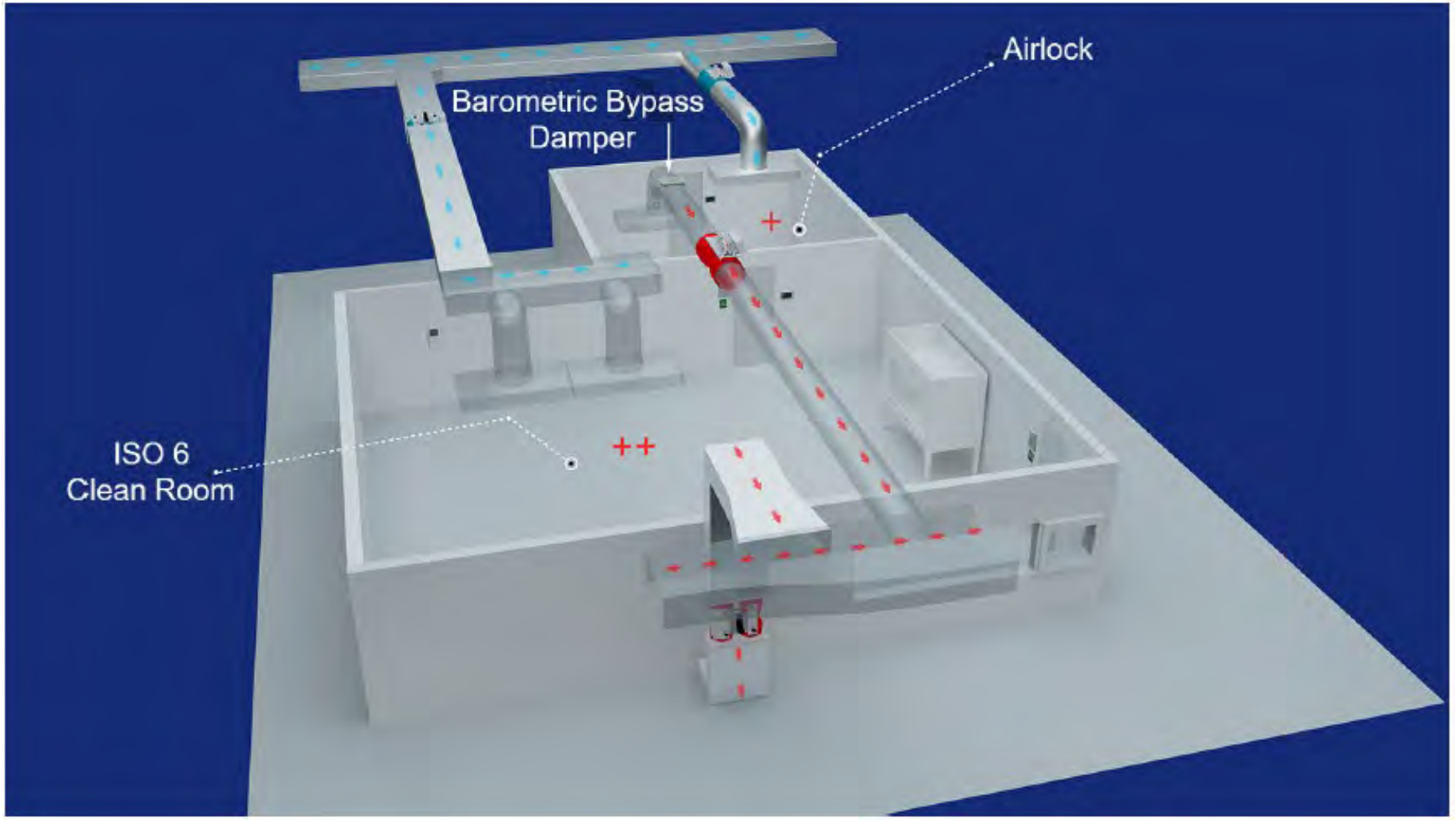
Tracking Pair Venturi Valves (Ideal for Cleanroom Solutions)



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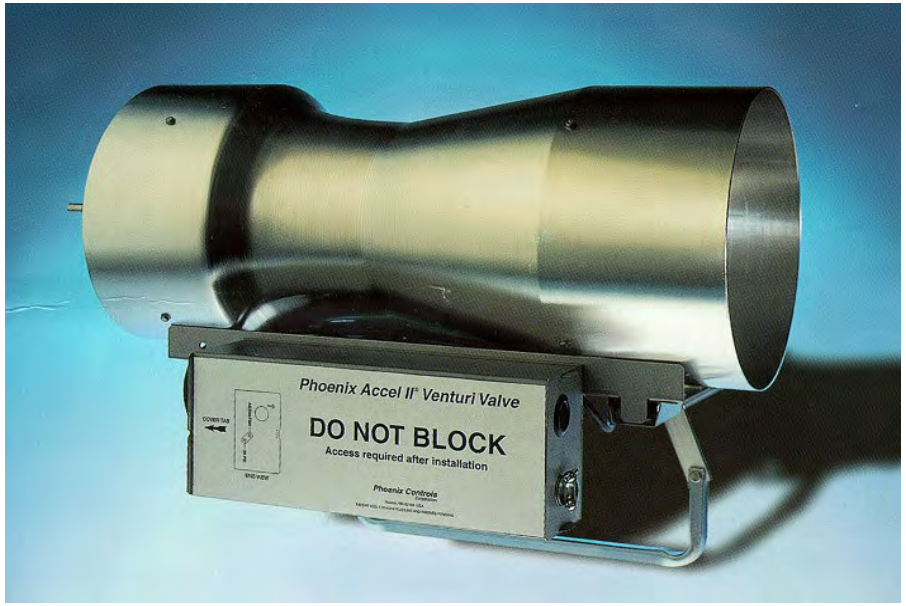
Venturi Valve

NVLAP Accredited Valve characterization at factory



P	Pressure independent (Mechanical)
A	Accuracy of +/- 5% of command
I	Inlet/exit insensitivity
N	No scheduled maintenance
T	Turndown up to 20:1
S	System stability and high-speed response time (<1 second)

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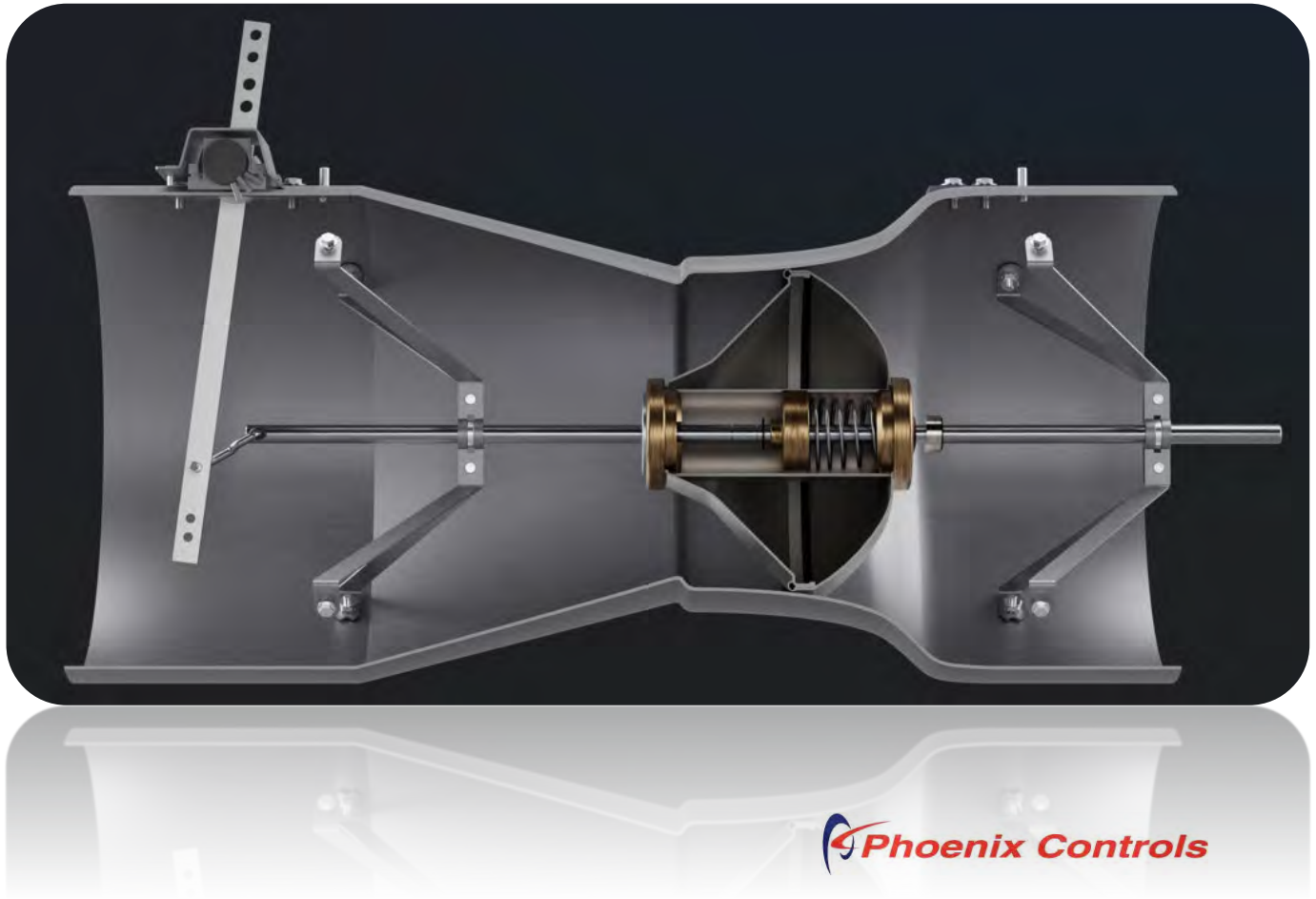
The Venturi Valve from Phoenix Controls

Fully modulating venturi valve with electric or pneumatic actuation

- *Command signal positions cone to provide desired flow*
- *Flow precision of ±5% of requested flow*
- *Manifold systems create constant pressure variations in the duct*
- *Changes in pressure are automatically compensated for by the spring and cone assembly*



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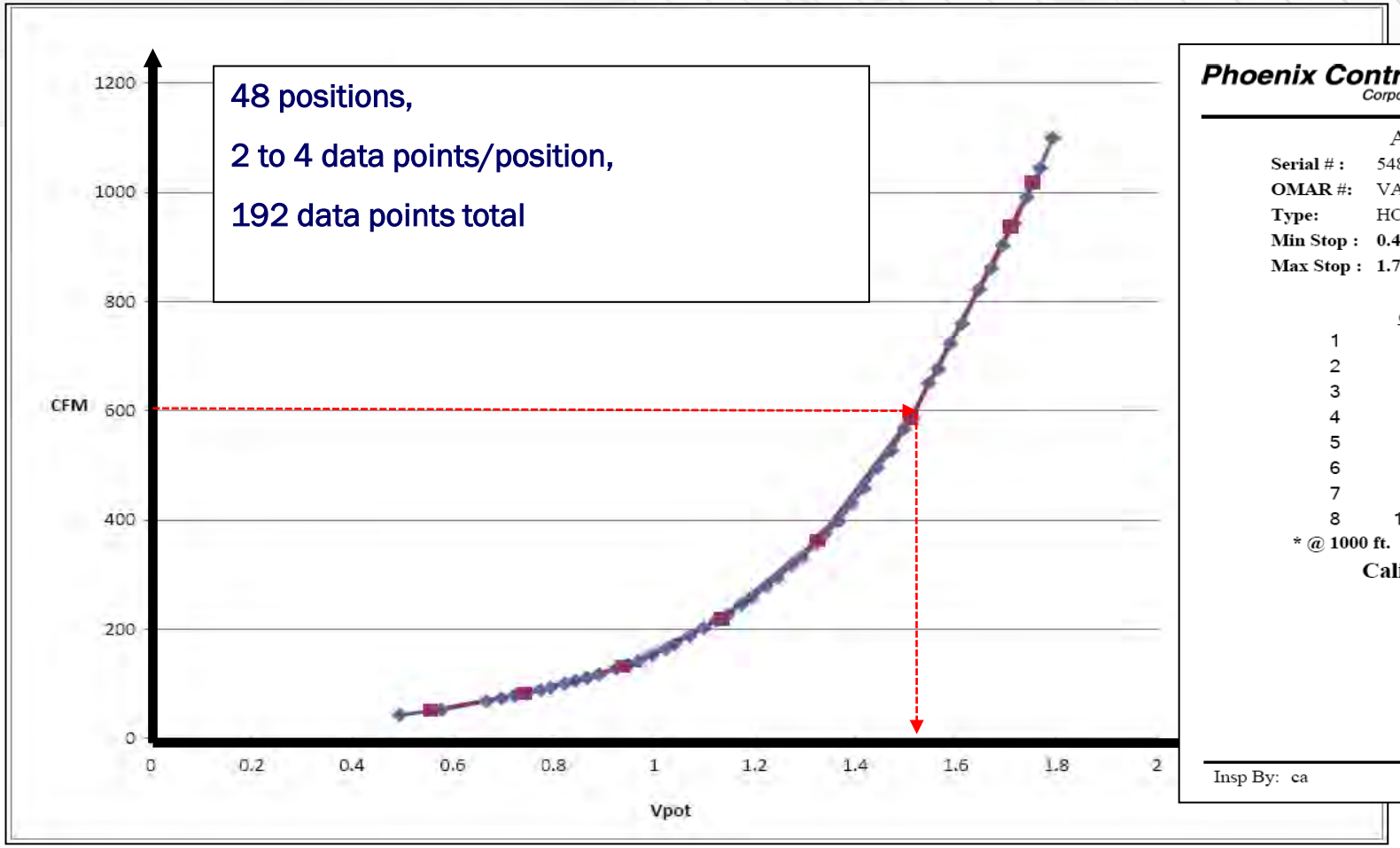
Venturi Air Valve Characterization

Flow



Phoenix Controls® Corporation
Acton, MA
www.phoenixcontrols.com

Accel 10" Valve

Serial # : 548249
OMAR #: VA110MAMEHM
Type: HOR EXHAUST LVC
Min Stop : 0.495
Max Stop : 1.792

Test Data

	CFM *	VPOT
1	51	0.556
2	82	0.742
3	132	0.939
4	219	1.134
5	362	1.325
6	586	1.510
7	937	1.709
8	1018	1.752

*** @ 1000 ft. , 70° F (Corr. Factor 0.982)**

Calibration Data

A	-0.127
B	0.421
C	0.673
D	1.226

Insp By: ca Date : 05/26/2010

Shaft position (volts)

Up to 20:1 turndown with +/- 5% Accuracy within specified flow range

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Venturi Valve: Dimension and Flows

Double, triple, and quadruple configurations available
(one actuator/control card per set of 2 valves)

Venturi Valve flow Ranges	DP across valve 0.3" – 3" WC
6"	30-350 cfm
8"	35-700 cfm
10"	50-1000 cfm
12"	90-1500 cfm
14"	200-2500 cfm

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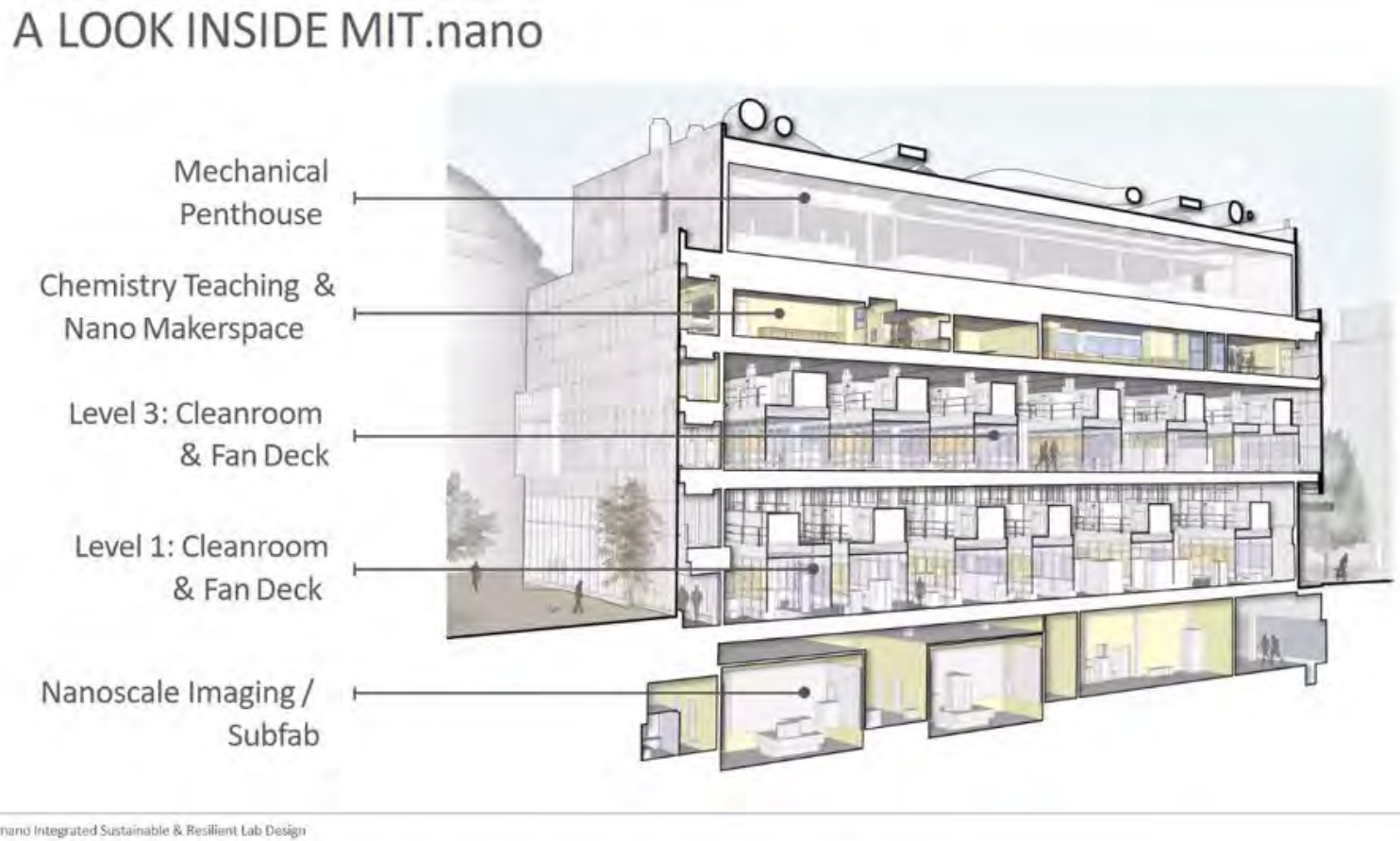
MIT Nano – Case Study

A Balance of Performance and Sustainability

A pilot for the Future in Cleanroom design

I2SL Showcase

Cleanrooms on Display



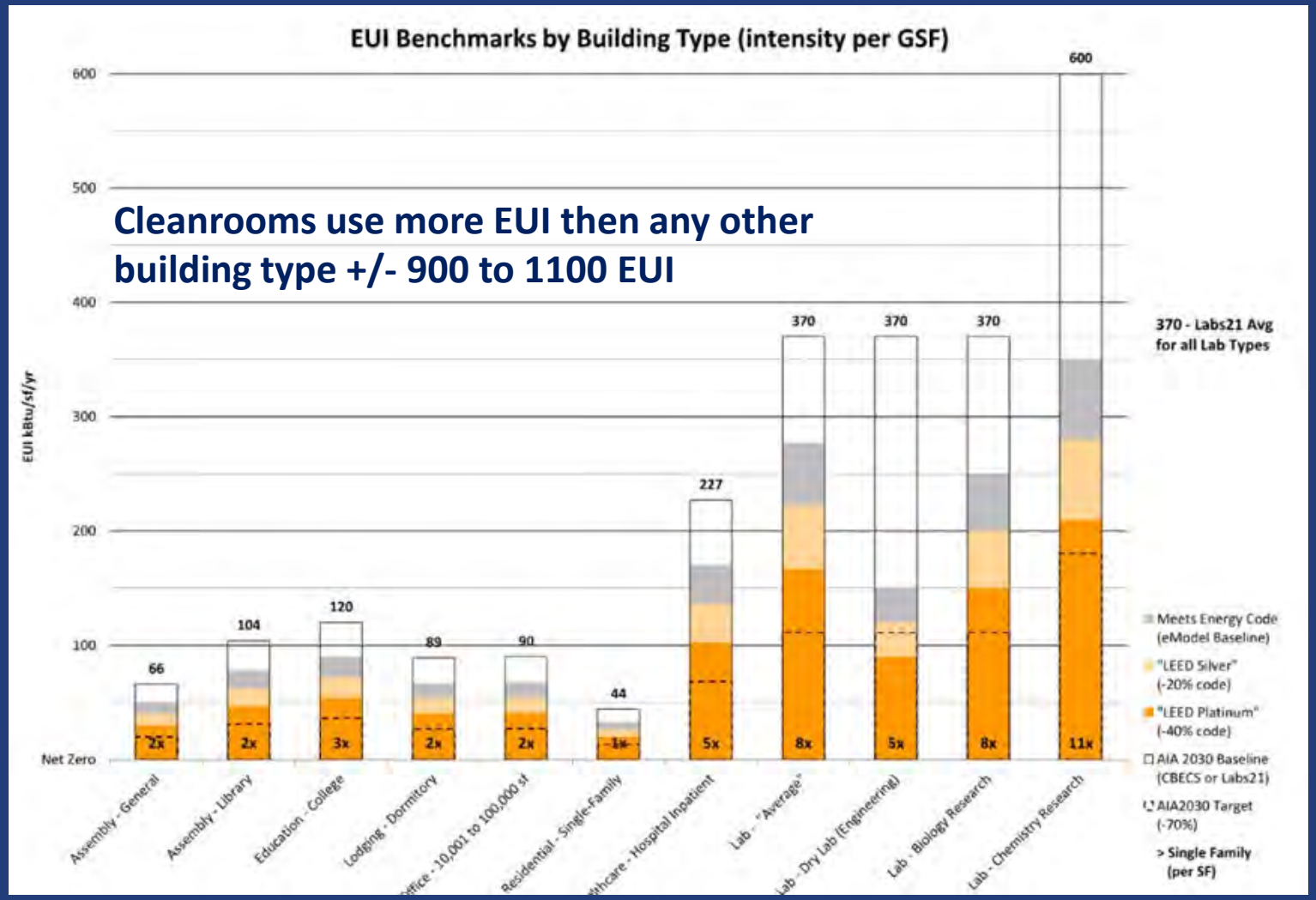
7 MAUs, (4 MAUs have MERV18 for serving the cleanrooms)

Well Organized from the top down.

Integrated with education, discovery to manufacturing and production

Cleanrooms are 2 stories tall

Energy Use Intensity (EUI) by Building Type



Meets Energy Code (eModel Baseline)
"LEED Silver" (-20% code)
"LEED Platinum" (-40% code)
AIA 2030 Baseline (CBECS or Labs21)
AIA2030 Target (-70%)
> Single Family (per SF)

Source: DOE "CBECS"
Source: Labs 21

Facilities Surveyed

- Harvard University — RAHU Plenum
- Vanderbilt University — RAHU Plenum
- Lawrence Berkeley National Lab — Fan Filter Unit
- University of California, Riverside — RAHU Plenum
- Duke University — RAHU Ducted
- Purdue University
- University of Massachusetts, Lowell — RAHU Plenum
- Princeton University
- University of Michigan — RAHU Plenum
- University of Chicago
- Cornell University
- Carnegie Mellon University
- University of Southern California
- University of Illinois
- Georgia Institute of Technology — Fan Filter Unit
- Massachusetts Institute of Technology

All Life Science Labs vs MIT Nano Cleanroom Fabs

Was it really fair?

METRICS

RECIRC AHUs
AIR CHANGES PER HOUR (ACH)
AIR FLOW EFFICIENCY (cfm/kW)

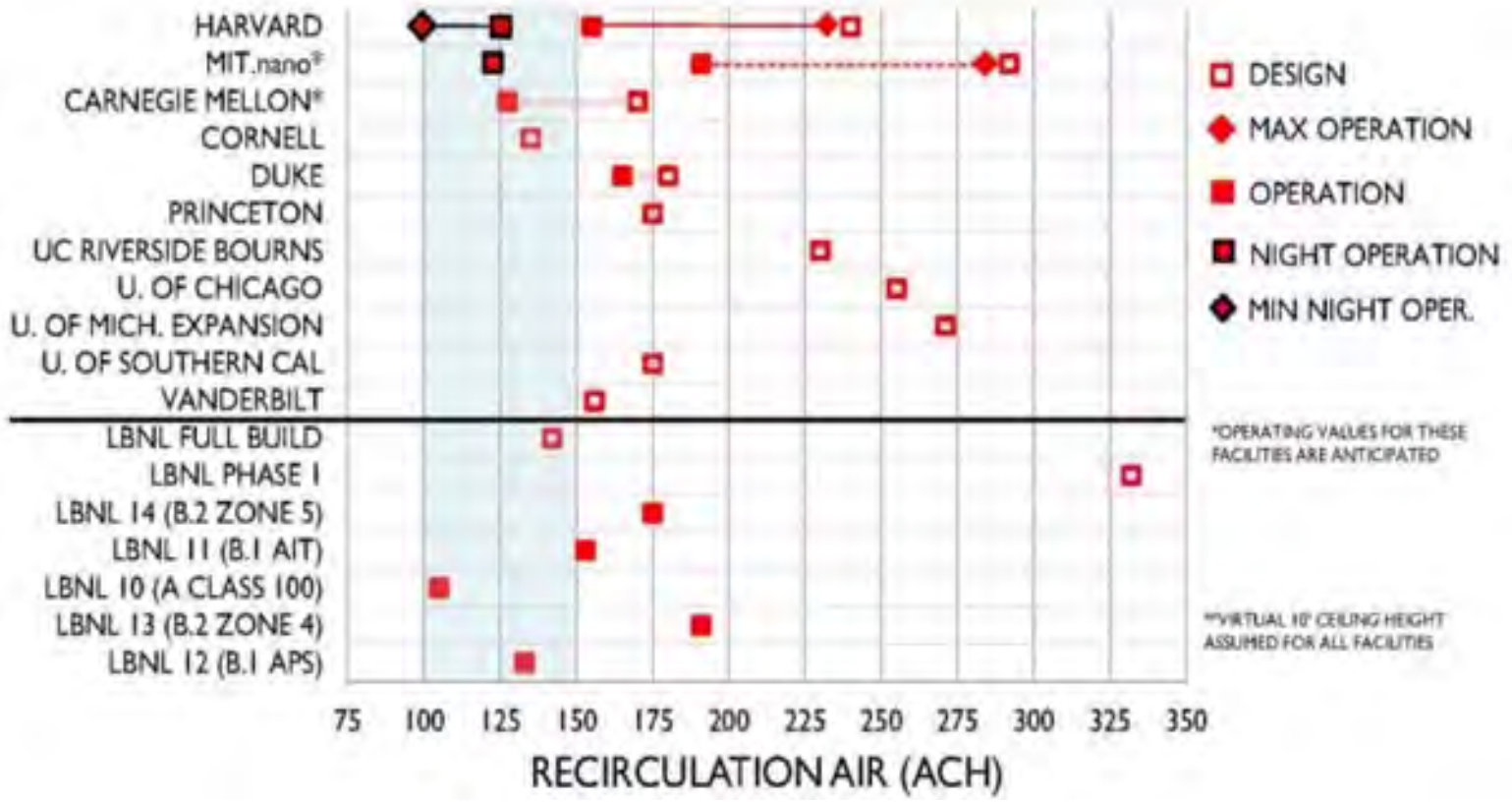
MAKE UP AHUs
AIR CHANGES PER HOUR (ACH)
DEWPOINT CONTROL (°F)

TOOL LOAD
WATTS PER SQUARE FOOT (W/sf)

BEST IN CLASS: LOW ENERGY VS. TIGHT ENVIRONMENTAL CONTROLS

BENCHMARKING: FACILITIES SURVEYED

Recirculation Air (ACH)

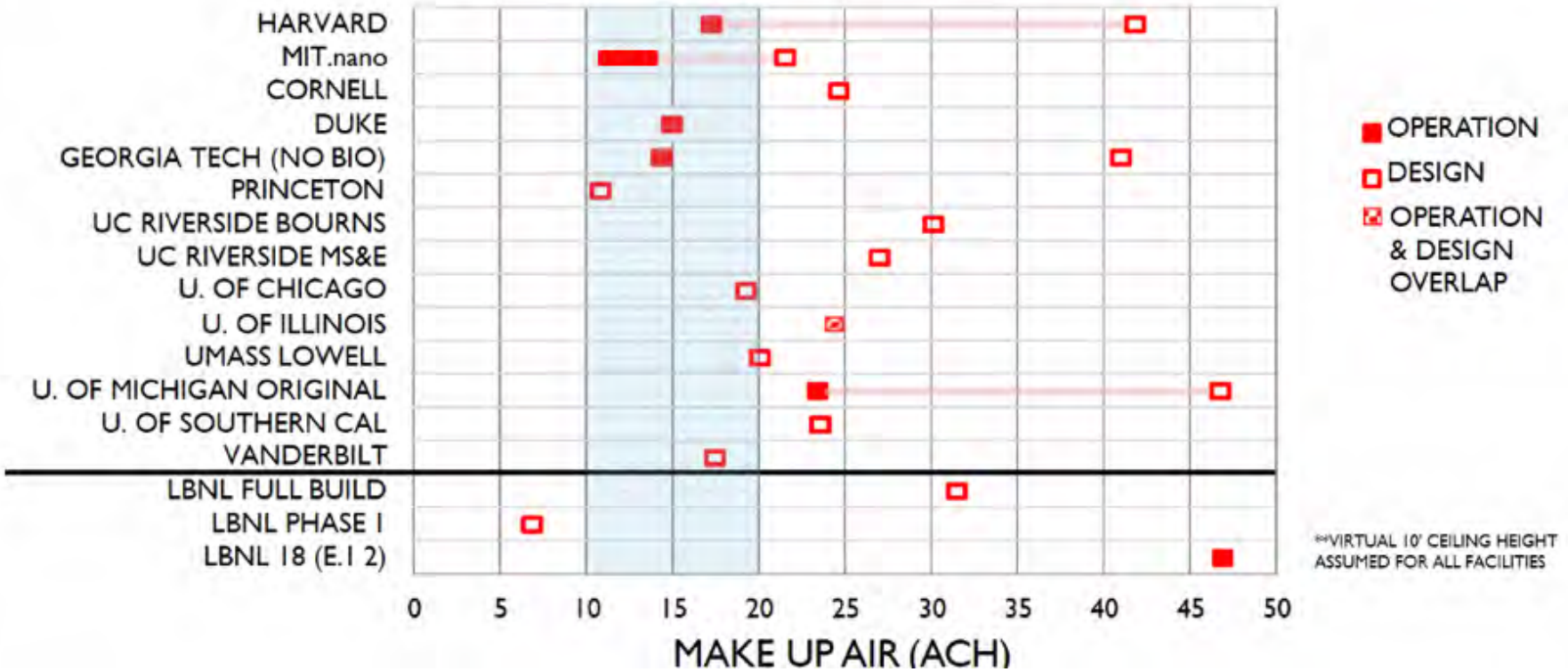


Harvard and MIT Nano used particle counters to turn down the airflow when people are and are not present. They also used occupancy counters.

MIT Nano – Only Manufacturing Cleanroom in list > 23000 Sqft.

All other spaces are Life Science labs under 10,000 Sqft.

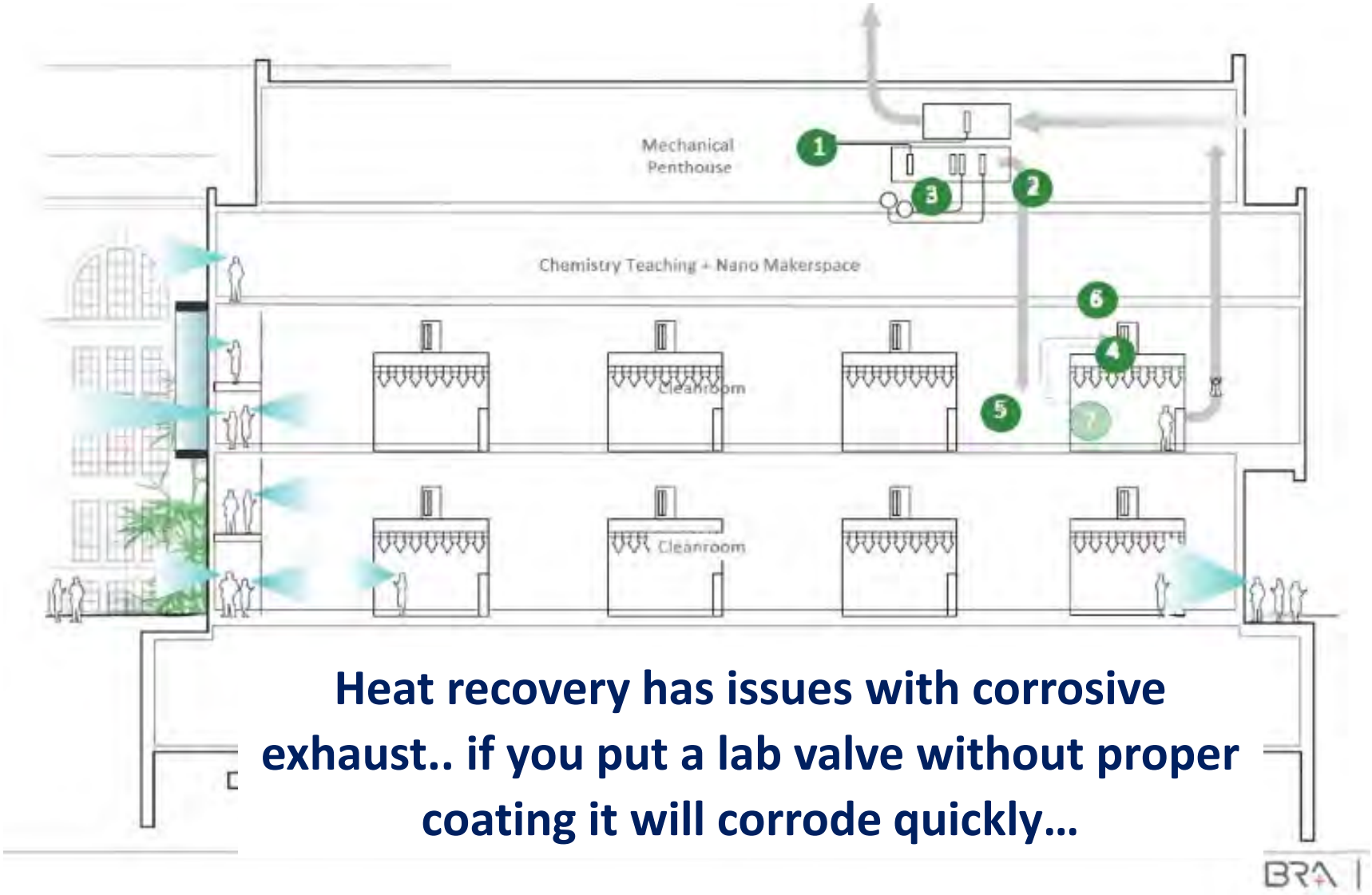
Make-UP Air Change Rate



The more you can turn the systems down the easier it is to move the airflow. (less pressure drop).

There is a need for “Flexibility” to create a more sustainable outcome, without compromising quality.

“Go Beyond” Energy Conservation



1. EAHU Heat Recovery VAV
2. Exhaust + Make-Up Sub-
3. Cool Heat Recovery
4. Low ΔP + 100% Filter Coverage
5. Demand-Controlled RAHU RAHU
6. Reheat
7. CR Airflow ≤ 165 ACH
8. Relaxed Dew point > 49ºF

Vs.

1. No Exhaust Heat Recovery
2. Constant Volume Exhaust + Make-Up
3. Sub-Cooling Via Conventional Chiller 50%
4. Filter Coverage
5. Constant Volume RAHU
6. RAHU Cooling Only

Heat recovery has issues with corrosive exhaust.. if you put a lab valve without proper coating it will corrode quickly…

Vision CE

- Critical Environment Dashboard
- Customizable algorithms provide actionable information for multiple stakeholders
- Visualize the impact of all building systems on performance of your critical environment
- View alarms, trend data, schedule and control network devices and peripherals from a centralized location
- View and control equipment and devices on the building network
- Integrate seamlessly and control any BMS
- Unify control of critical environments and disparate BMS across your real estate portfolio

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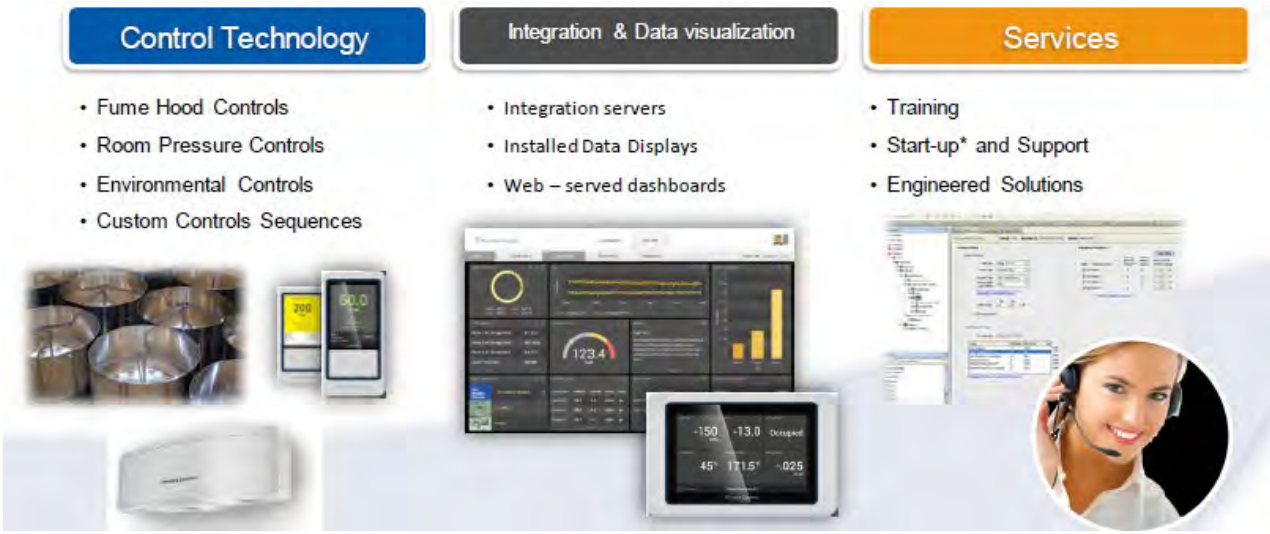
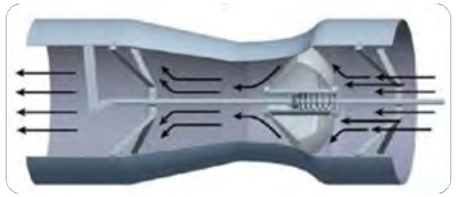
Use location/ Case
Integrated, Specialty HVAC Controls Solution

Application
High Purity Manufacturing Cleanrooms
- Dry Room / Battery Processing/ ISO Class 6/7
- Semiconductor Manufacturing
- Gene/Cell therapy ATMP

Advantages
Reliable, **Repeatable** Pressure Control
Precision Temp and **Humidity control**
Automated Zone Balancing
Demand based ventilation based on environmental monitoring
Experienced network of System integrators

Key Features
Venturi Valve, Mechanically Pressure Independent
Less than a second speed of response to pressure fluctuations
BMS Agnostic – Monitoring and reporting CE dashboard





Mechanical Pressure Independence

ROI
Using a Demand based ventilation approach with Phoenix Controls will not only provide reliable pressure control but will also provide the versatility to incorporate repurposing functional areas and switching of ISO Class criteria for any space while monitoring particulate count. Actively managing Air Changes per Hour can reduce the cost of conditioned exhaust. Providing less then a 3-year payback.

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How can work together

Owner direct

- Tough to get to owner

Engineers

- Product selections/ applications
- Specifications

Cleanroom manufacturers

- Performing design assist on pharmaceuticals
- Providing modular options for semiconductor
- Providing panel construction for EV

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