Reshaping Building Design

Designing for Improved Indoor Air Quality & Energy Efficiency

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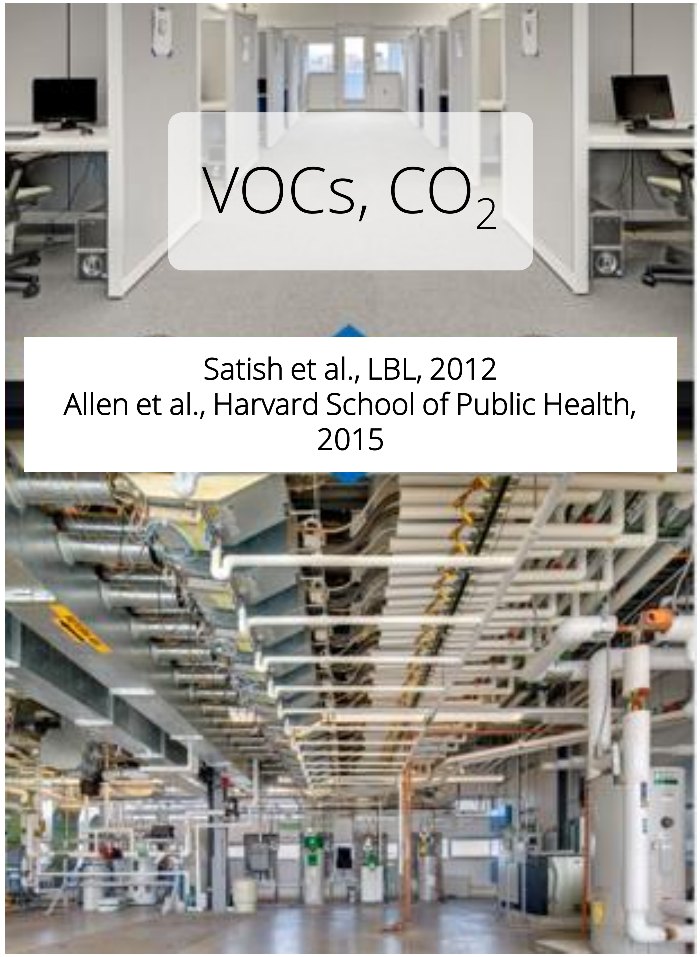
WE SPEND 90% of OUR TIME INDOORS[1]

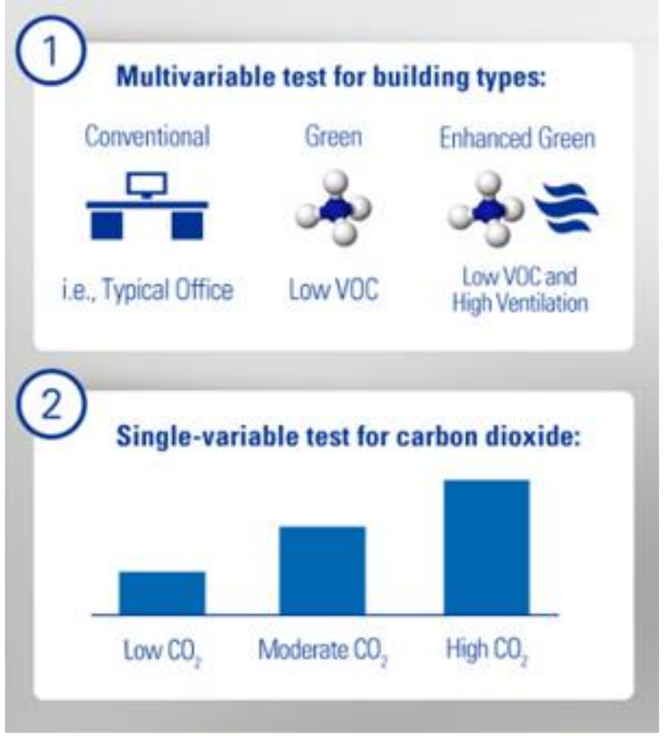
10% OUTDOORS[1]

IAQ Impact on Cognitive Performance

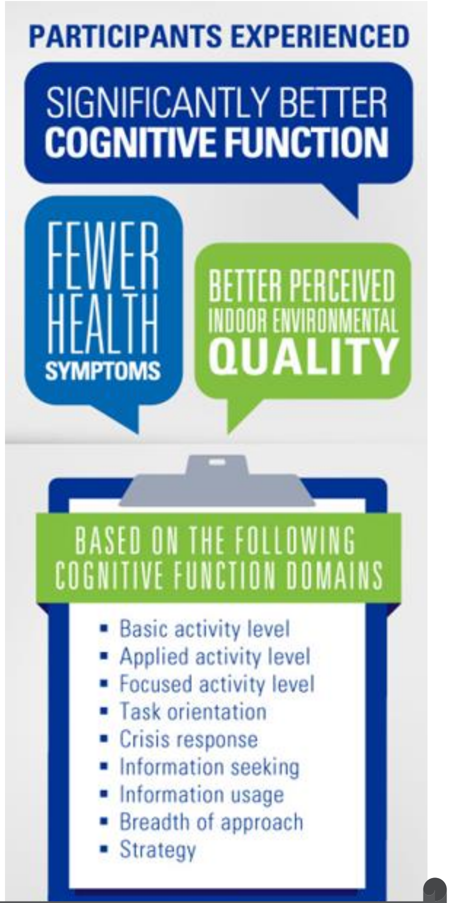


VOCs, CO_2

Satish et al., LBL, 2012
Allen et al., Harvard School of Public Health, 2015



Elevated CO_2 has a direct and negative effect on productivity



Gain of $6,500 per year per employee

Smart Buildings.

Not-So-Smart Ventilation.

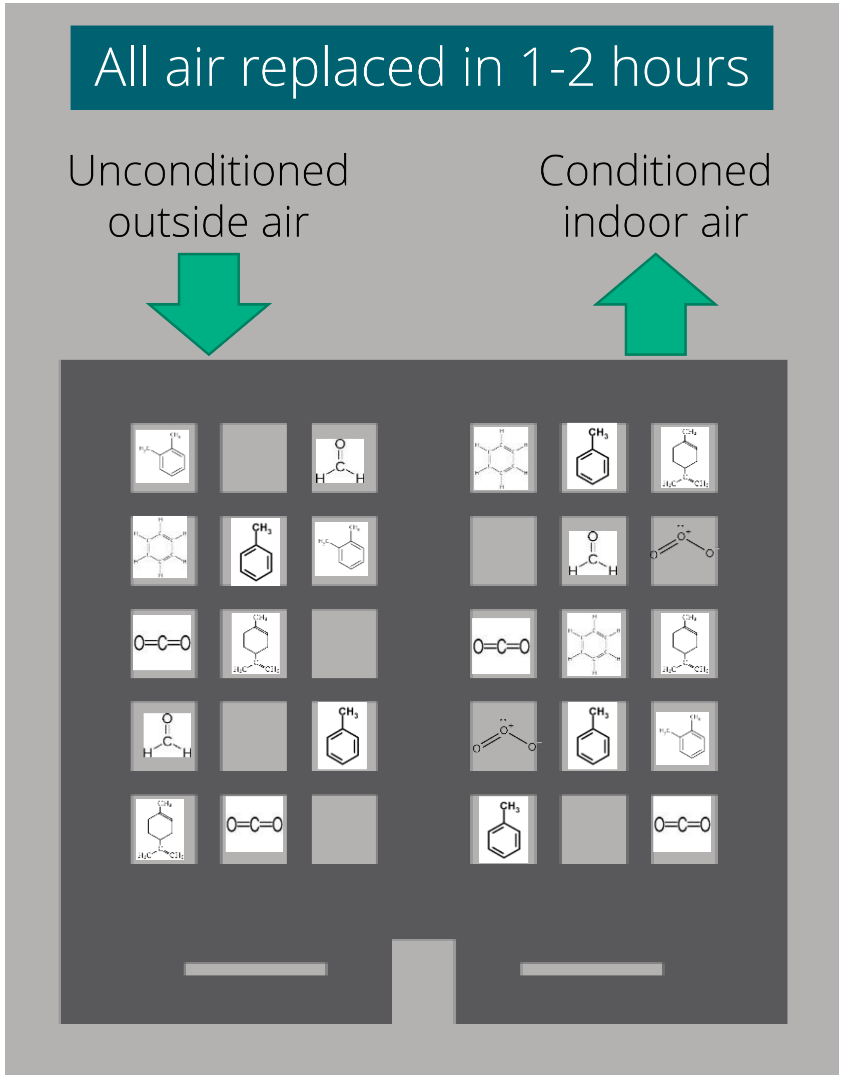
Conventional Approach to IAQ

Dilution to Avoid Pollution

Ventilation leads to higher energy costs:

- Outside air is replaced 1-2 time per hour
- Outside air conditioning represents 30-50% of the total load on HVAC systems in most climates

- HVAC capacity
- Energy usage
- Water consumption
- Maintenance



Outdoor Air as a Source of Contaminants

~~Fresh~~, Hot & Polluted Air

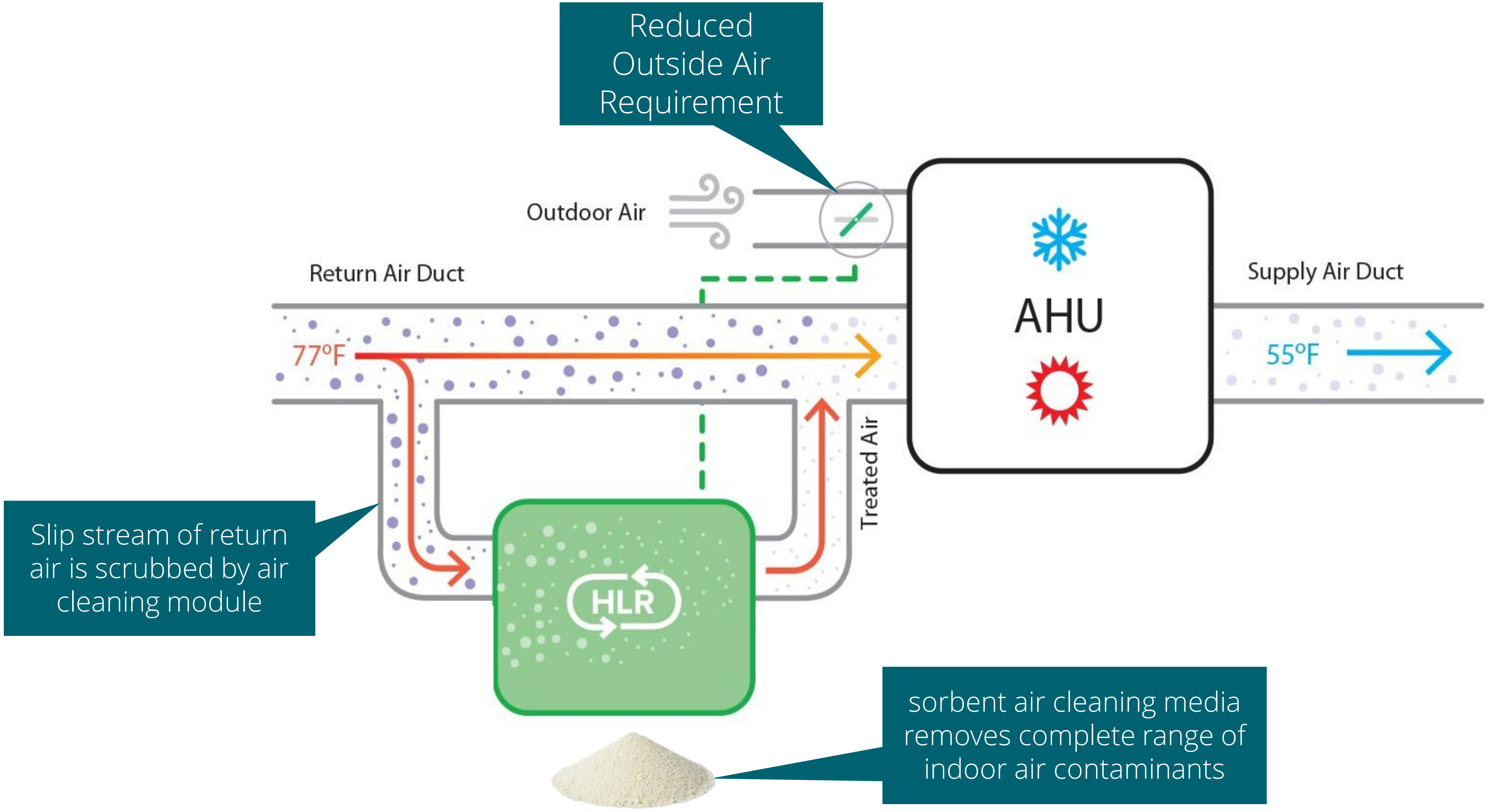
Ventilation leads to increase of outdoor generated pollutants indoors, $PM_{2.5}$ - Ozone - CO - NOx - SOx

	American Lung Association		EPA
Outside air ratings	**24-Hour Particle Pollution**	**Ozone Grade**	**8-Hr Ozone Classification**
Boston-Worcester-Providence, MA-RI-NH-CT	B	F	
Chicago-Naperville, IL-IN-WI	F	F	Nonattainment
Dallas-Fort Worth, TX-OK	B	F	Nonattainment
Houston-The Woodlands, TX	C	F	Nonattainment
New York-Newark, NY-NJ-CT-PA	F	F	Nonattainment
Miami-Fort Lauderdale-Port St. Lucie, FL	B	C	
Washington-Baltimore-Arlington, DC-MD-VA-WV-PA	C	F	Nonattainment
Kansas City, MO	C	D	
Cleveland, OH	C	F	Nonattainment
Cincinnati, OH	A	F	Nonattainment

“Fresh” air, anybody?

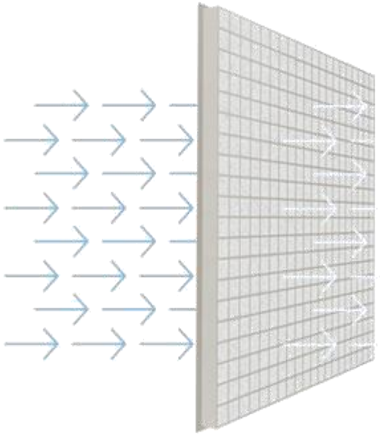
Air Cleaning +
HVAC Load Reduction (HLR)

Maintaining IAQ with Molecular Air Cleaning



Multiple breakthroughs in sorbent materials.

- Proprietary amine polymers
  - Low-cost CO_2 capture *and* release
  - Exceptional formaldehyde removal
  - Multiple other air-cleaning functionalities
- Mineral – polymer synthetics
  - Formation of high surface solid sorbents and catalysts
  - Reduced thermal mass for low-energy temperature swing
  - Modular form factors for diverse applications
- Capabilities that span all contaminants (Over 250+)
  - BTX / aromatics, aldehydes, polyols
  - VOCs and VVOCs
  - Inorganics: NOx, SOx, H_2S, ozone, radon



Massachusetts Institute of Technology

USC

Berkeley Lab

Challenge Gas	Efficiency Measured by RTI Lab[1]
Ozone	70%
Hexane	74%
Xylene	60%
Isopropanol	77%
Toluene	52%
Benzene	87%
Formaldehyde	55%
Carbon dioxide	57%

The HLR family (indoor and outdoor units)

HLR 1000E - 10M

HLR 1000E - 10R

Generating value for global clients

Google
TESLA
GSA
CISCO
HARVARD
Morgan Stanley
bxp Boston Properties
The DIPLOMAT BEACH RESORT
U MIAMI
THE UNIVERSITY OF TENNESSEE CHATTANOOGA
Hines
ArcBest
Air Liquide creative oxygen
CBRE

RMF Engineering Reliability. Efficiency. Integrity.
TLC ENGINEERING FOR ARCHITECTURE
GIRARD ENGINEERING
Southland Engineering
GHT LIMITED CONSULTING ENGINEERS
MJT THOMPSON Consulting Engineers
SETTY
Gipe Associates, Inc. CONSULTING ENGINEERS Mechanical | Electrical | Plumbing
MATERN

enVerid in the News

FOR IMMEDIATE RELEASE

enVerid HLR Technology Ranked as Top Energy Saving Opportunity in Department of Energy Study

Prioritized in top 3 of over 300 technologies for commercial buildings

Boston, MA—February 27, 2018— enVerid Systems, Inc. announced today that its HVAC Load Reduction® (HLR®) technology has been listed as one of the top three priorities for commercial HVAC energy efficiency in a study commissioned by the U.S. Department of Energy (DOE) – providing potential energy savings of 250,000 billion BTU per year in the US. The study evaluated over 300 technologies and determined a final set of 18 high priority technologies.

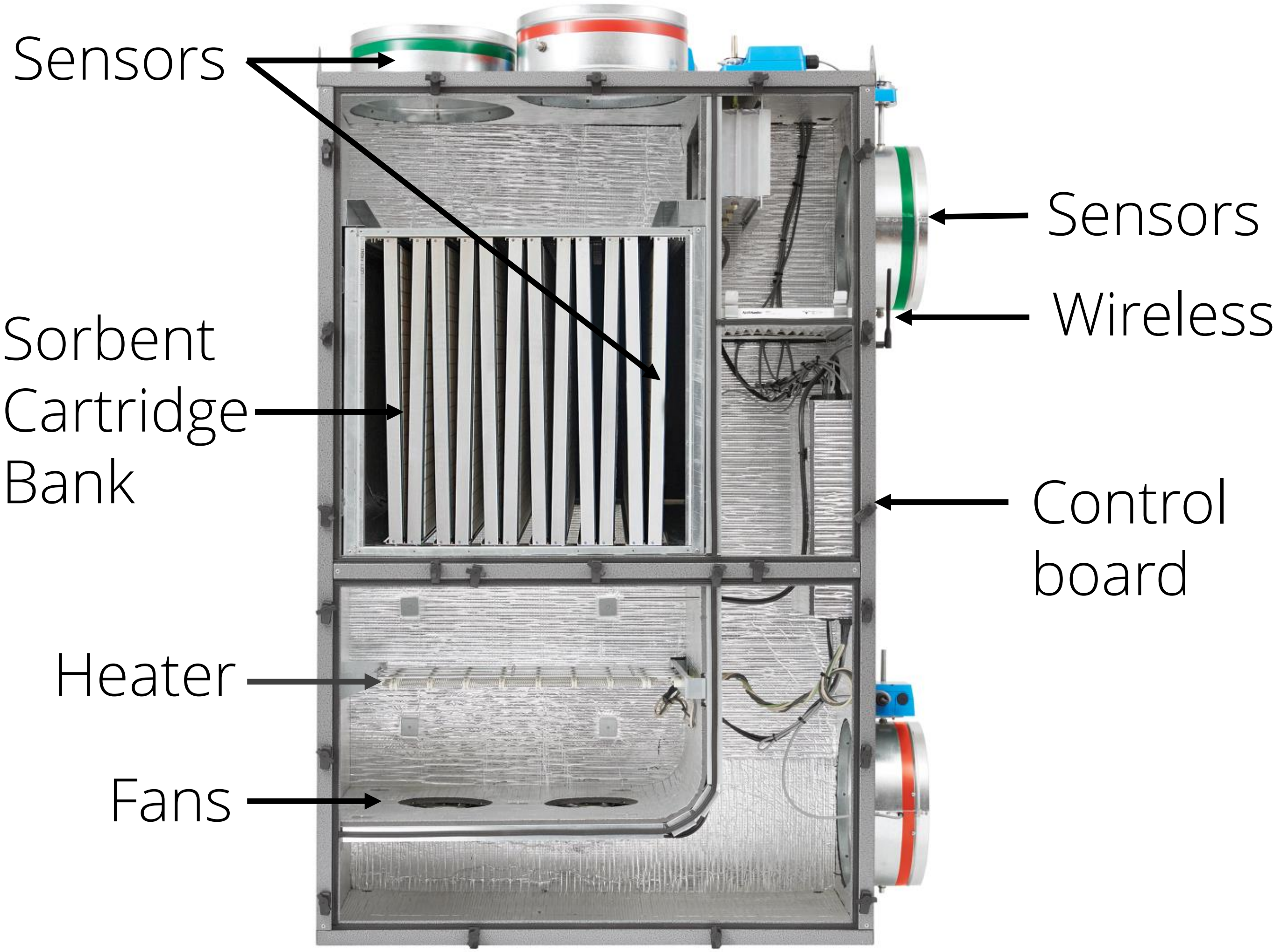
Energy Savings

Demonstrations with the DOE and GSA field studies suggest 20-35% HVAC energy savings for the advanced filtration technology:

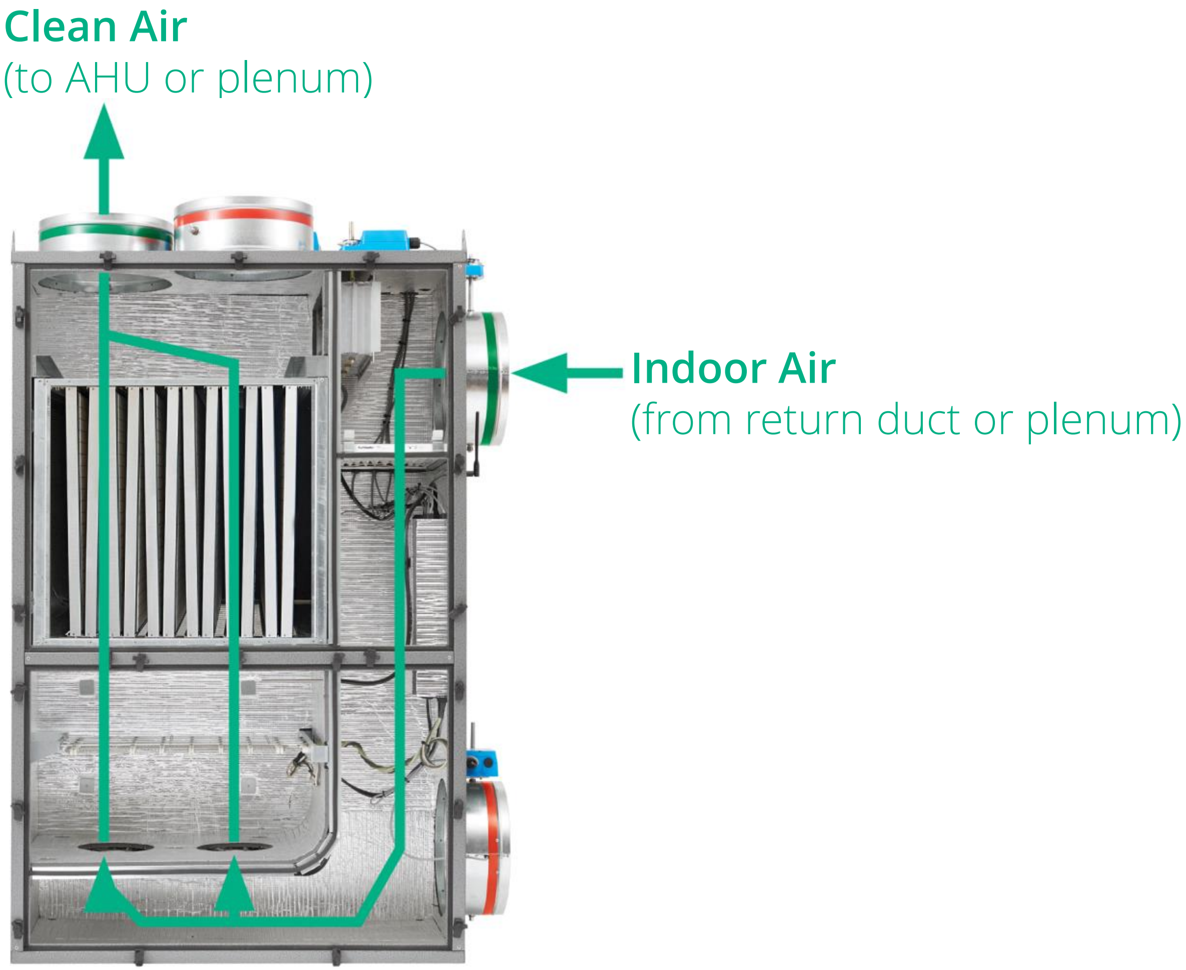
- A 2015 field study at a University of Miami (FL) wellness center found a 28% reduction in total HVAC energy consumption by reducing outside airflow by 75%.[43]
- A 2016 field study at a large office building in Arkansas found a 36% decrease in peak HVAC loads by reducing outside airflow by 65%.[44]
- Other case studies show 22-35% energy savings.[45]

enVerid HLR Technology wins AHR / ASHRAE 2019 Product of the Year

What's Inside



Adsorption Mode: Adsorption of Contaminants

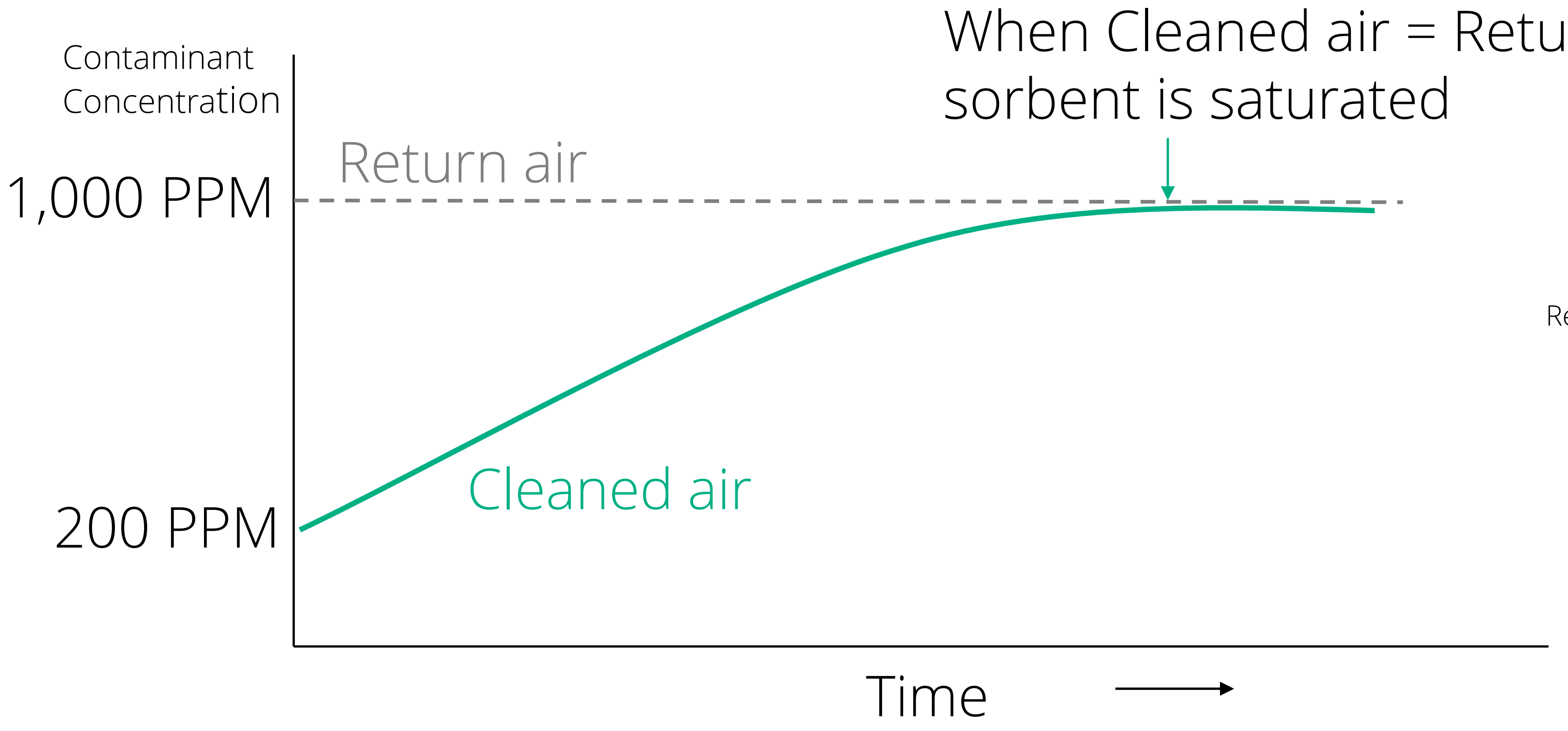


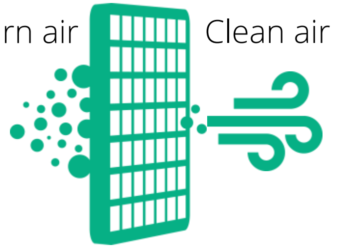
1,000 CFM

- Captures:
  - Carbon Dioxide
  - VOCs
  - Formaldehyde
  - Ozone
- Zero by-products

Each HLR 1000E module typically addresses 15,000 – 25,000 ft^2 of occupied space

Over Time, Sorbents Saturate

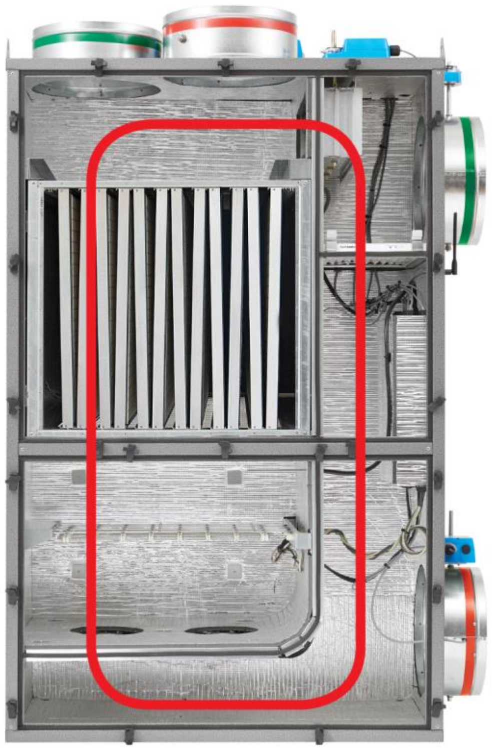




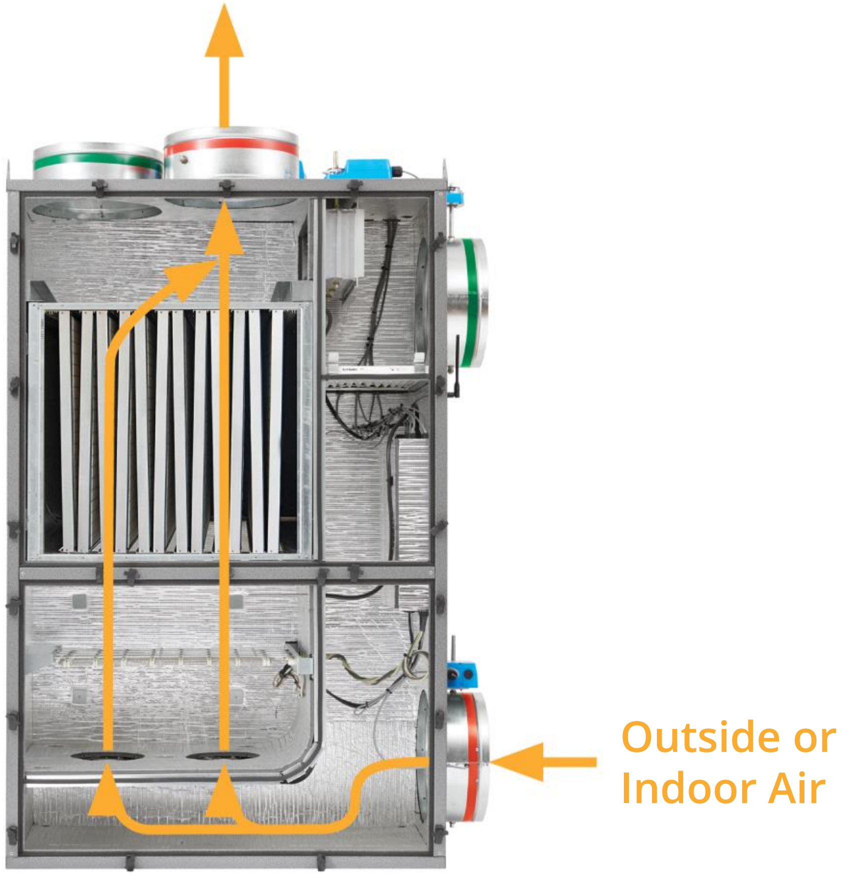
“Regeneration” is performed when sorbents saturate

Regeneration Mode: Heat and Release

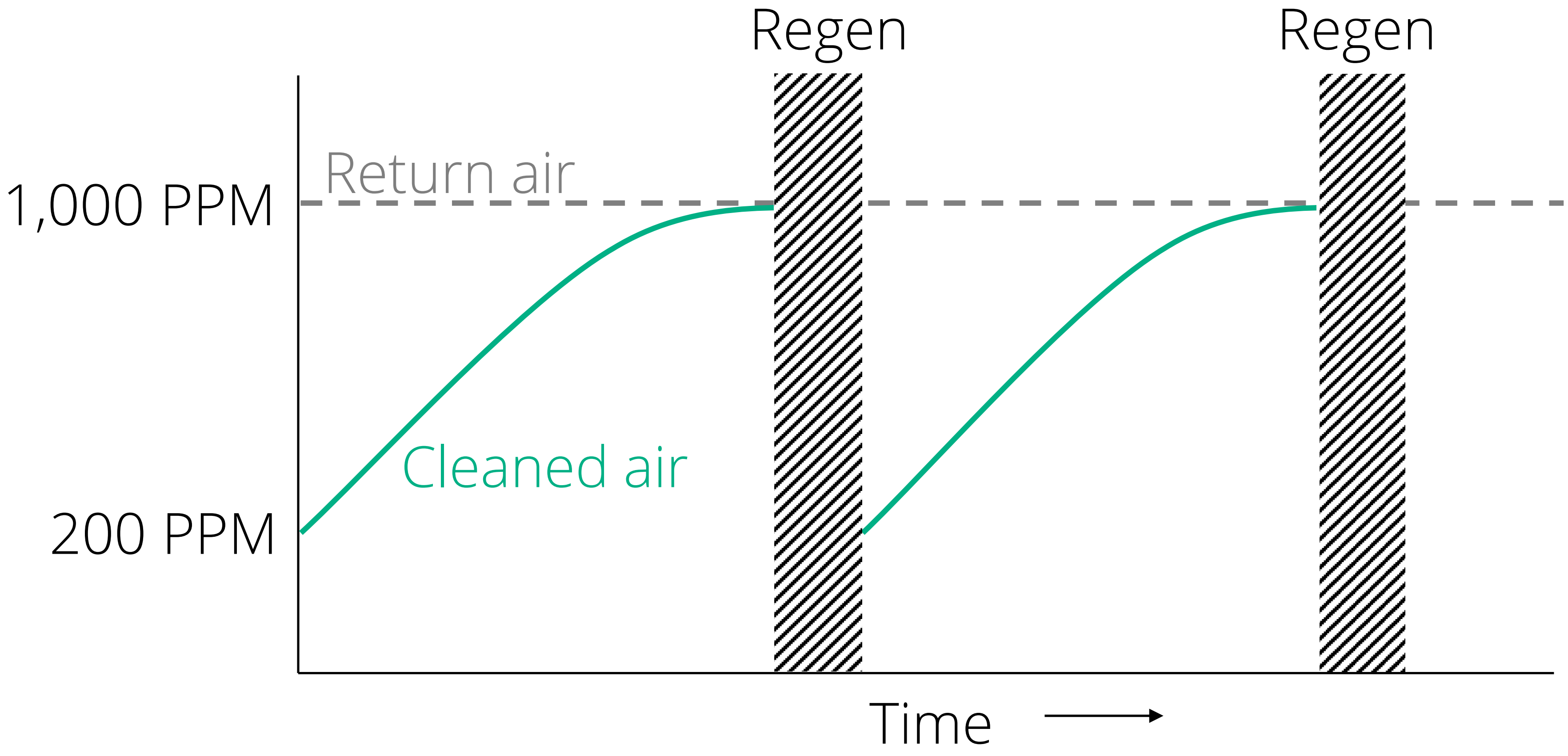
Step 1: Closed Loop Heating
- All dampers closed
- Air heated to 130-150 ˚F



Step 2: Vent Contaminants Outside
- Regeneration dampers opened



Adsorption/Regeneration Cycles

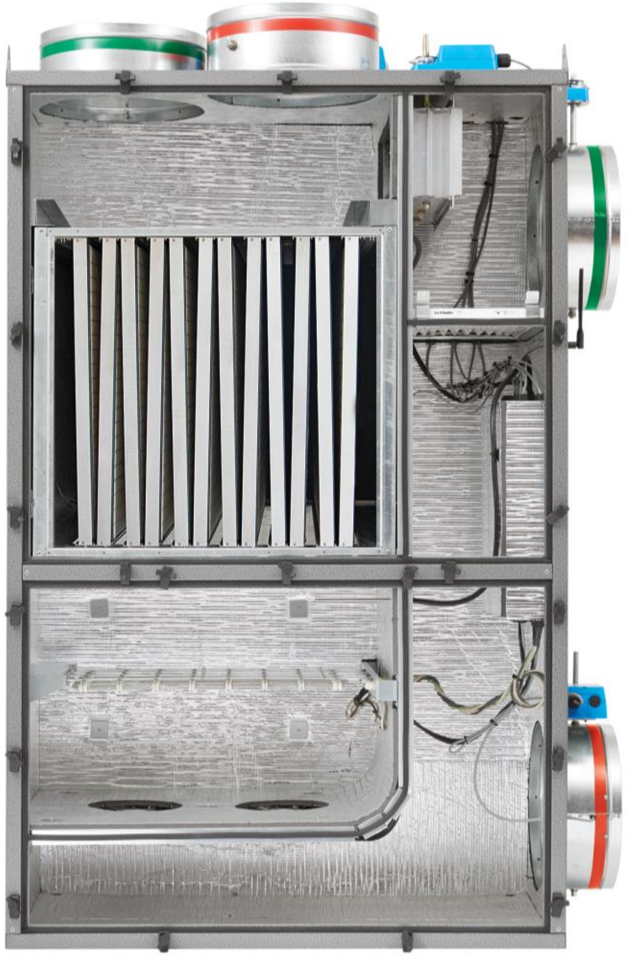


Regeneration brings sorbent efficiency back to baseline

Comprehensive Sensing

Clean Air Sensor
- Temperature
- Humidity
- CO_2

Cartridge Bank Sensor
- Temperature
- Pressure



Indoor Air Inlet Sensor
- Temperature
- Humidity
- CO_2
- Total VOC (TVOC)

Connections (direct or via BMS):
- Outside air (OA) damper control
- OA damper position monitoring
- Air handling unit (AHU) status

Fire signal dry contact

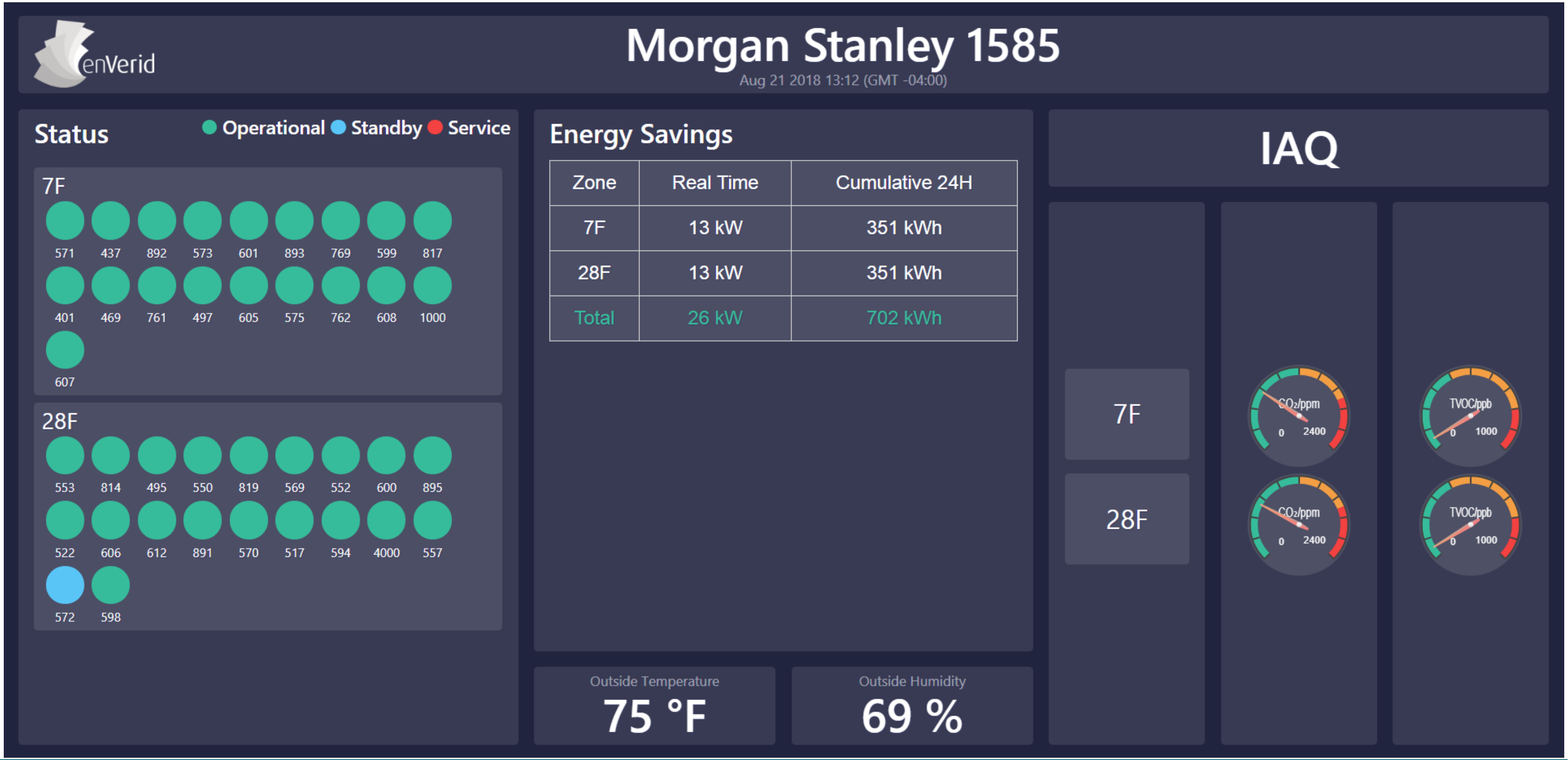
AHU Supply duct sensor (optional)
- Temperature
- Humidity

Outside Air Sensor (optional)
- Temperature
- Humidity

Note: BACnet integration to BMS eliminates need for optional sensors & connections

Advanced algorithms use sensor data to optimize energy savings & IAQ

enVerid Cloud: 24/7 Monitoring and Management of IAQ



Know the quality of the air inside the building anytime, anywhere

HLR Technology Reduces HVAC Capital Expenditures

Savings Per HLR module:

Capacity Savings	Equipment Savings	CapEx Savings
10-20 tons of cooling*	• Eliminate / reduce ERV • Eliminate DCV • Eliminate DOAS • Reduce RTU and/or AHU capacity • Downsize chiller & cooling tower • Reduce piping size • Reduce OA and exhaust duct sizes	$20,000 - $40,000
100K – 200K BTU of heating*	• Downsize boiler or electric heat	$2,500 - $5,000

*Varies based on climate zone, building, and ventilation design

Utility rebates further reduce CapEx

- As high as $12,000/HLR module

Higher energy efficiency usually means higher cost. HLR turns this upside down.

HLR Technology Reduces HVAC Operating Expenses

Annual energy & operational savings per HLR module:

Operating Expense Reductions	Annual OpEx Savings
• Cooling / heating energy usage • Electric peak "demand" charges • Pump and fans energy consumption • Water consumption • DCV and ERV maintenance • Filter costs	\$3,000 - \$10,000

Combination of rebates + annual savings produces >25% IRR in retrofit-only deployments

The Target Application

High occupancy, low exhaust

- Office buildings: High rise, or medium/large low rise
- Colleges / universities / libraries
- Malls, big box stores
- Common areas/Conference rooms
- Green / LEED buildings

Generally ***not*** good candidates:

- Hotel guestrooms, Hospitals (ASHRAE 170), Kitchens

Compliance

enVerid
Energy savings. Air quality.

International Mechanical Code

odor migration to or from a space and is, therefore, not prohibited. In the context of the code, negative and positive air pressures refer to pressures that are below or above atmospheric pressure or a reference pressure in another room or space.

Mechanical ventilation systems are air distribution systems, and the components of mechanical ventilation systems are subject to the requirements of Chapter 6, which regulates air distribution systems.

Mechanical ventilation systems involve electrical components and controls that must comply with Section 301.10. See Section 403.3 which makes a distinction between Group R-2, R-3 and R-4 occupancies and all other occupancies.

403.2 Outdoor air required. The minimum outdoor airflow rate shall be determined in accordance with Section 403.3.

Exception: Where the *registered design professional* demonstrates that an engineered ventilation system design will prevent the maximum concentration of contaminants from exceeding that obtainable by the rate of outdoor air ventilation determined in accordance with Section 403.3, the minimum required rate of outdoor air shall be reduced in accordance with such engineered system design.

❖ Section 403 represents an indirect method of controlling air quality by diluting contaminants (ventilation rate procedure) to an acceptable level by introducing outdoor air. Although an engineered ventilation system may be approved by the code official as an alternative design in accordance with Section 105, the exception to this section provides a direct reference to such an alternative design in this section. An engineered ventilation system is more of a direct method of controlling air quality and would be classified as an "Indoor Air Quality Procedure" in ASHRAE 62.1. ASHRAE 62.1, as a whole, is not a referenced standard in the code (with the exception of a limited reference in Section 403.3.1.1.2.3.2), but, the exception to this section could certainly be viewed as allowing the indoor air quality (IAQ) method of that standard as one of the possible means of complying with the exception. The design professional is responsible for demonstrating to the code official that a proposed engineered system will result in air quality at least equivalent to that achievable by the ventilation rate method of Section 403. A demonstration of equivalence would involve detailed analysis of at least the following: the anticipated contaminants of concern in the space to be ventilated; the anticipated sources and concentrations of the contaminants of concern; the acceptable occupant exposure limits or concentration levels for those contaminants; and the means and methods to control the contaminants. The design documentation should include all criteria and assumptions regarding occupancy conditions, equipment/system performance and contaminants. An engineered ventilation system would be allowed to supply outdoor air at any rate essential to the performance of the design.

403.2.1 Recirculation of air. The outdoor air required by Section 403.3 shall not be recirculated. Air in excess of that required by Section 403.3 shall not be prohibited from being recirculated as a component of supply air to building spaces, except that:

1. Ventilation air shall not be recirculated from one *dwelling* to another or to dissimilar occupancies.
2. Supply air to a swimming pool and associated deck areas shall not be recirculated unless such air is dehumidified to maintain the relative humidity of the area at 60 percent or less. Air from this area shall not be recirculated to other spaces where more than 10 percent of the resulting supply airstream consists of air recirculated from these spaces.

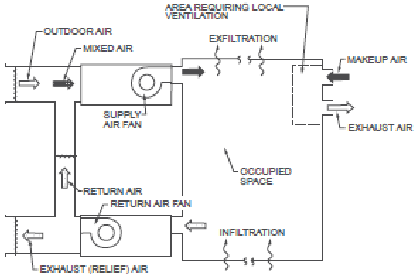


Figure 403.1(2)
TYPICAL HVAC SYSTEM

Exception: Where a registered design professional demonstrates than an *engineered ventilation system design* will prevent the maximum concentration of containments from exceeding the obtainable by the rate of outdoor air ventilation determined in accordance with Section 403.3, the *minimum required rate of outdoor air shall be reduced* in accordance with such engineered system design.

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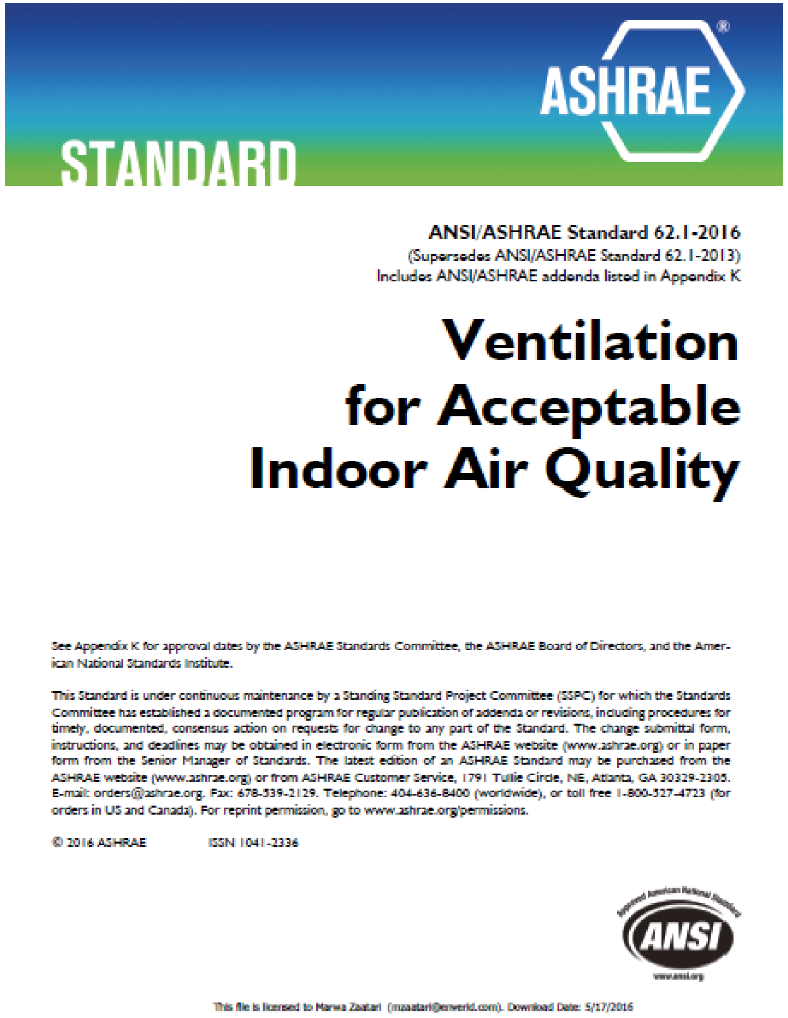
ASHRAE Standard 62.1 Overview

- ASHRAE Std. 62.1: Ventilation Rate Procedure (VRP)
  - *PRESCRIPTIVE*
- ASHRAE Std. 62.1: Indoor Air Quality Procedure (IAQP) – since 1979*
  - *PERFORMANCE-BASED*
  - Pollutant control ventilation (PCV)
  - Cleaning efficiency
  - Compliance report
  - Occupant survey

* Since 2006, the International Mechanical Code (IMC) allows for an engineered solution showing control of contaminant concentrations (IAQP).


STANDARD

ASHRAE

ANSI/ASHRAE Standard 62.1-2016
(Supersedes ANSI/ASHRAE Standard 62.1-2013)
Includes ANSI/ASHRAE addenda listed in Appendix K

Ventilation for Acceptable Indoor Air Quality

See Appendix K for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

 ISSN 1041-2336

ANSI

www.ansi.org

ASHRAE Standard 62.1–2016

Ventilation Rate Procedure (VRP)

- Breathing zone outdoor airflow: use Table 6.2.2.1 rates (pages 12-15)

Breathing Zone Outdoor Airflow CFM

People Component

Building Component

$$V_{bz} = R_p P_z + R_a A_z$$

Minimum CFM/Person (R_p)

Zone Population (P_z)

Minimum CFM/ft^2 (R_a)

Zone Floor Area (A_z)

Definition: Breathing zone is the region within an occupied space between planes 3-72 in. above the floor and more than 2 feet from the walls.

ASHRAE Standard 62.1–2016

VRP + Demand-Controlled Ventilation (DCV)

- Based on CO_2 concentrations as a surrogate for human occupancy

$$V_{bz} = R_p P_z + R_a A_z$$

Minimum CFM/Person (R_p)

Actual Zone Population (P_z)

Minimum CFM/ft^2 (R_a)

Zone Floor Area Constant (A_z)

Example Calculation of Outside Air Requirement using VRP and DCV

Office Building

Area = 20,000 ft^2

People/1,000 ft^2 = 5

People = 100

Supply/Return Location = Ceiling

Zone Air Distribution Effectiveness = 0.8

People Outside Rate = 5 CFM/person

Area Outside Rate = 0.06 CFM/ft^2

Example Calculation of Outdoor Air Requirement using VRP and DCV

VRP	Outdoor Air Area (CFM)	Outdoor Air People (CFM)	Total Outdoor Air
# People = 100	1,500	625*	2,125

DCV	Outside Air Area (CFM)	Outside Air People (CFM)	Total Outside Air (CFM)
# People = 80	1,500	500	2,000
# People = 50	1,500	312	1,812
# People = 20	1,500	120	1,625

***For office buildings, DCV can save a maximum of 29% of total Design Outside Air intake.**

VRP and DCV Drawbacks

- VRP
  - Leads to unnecessary energy consumption (prone to over-ventilation)
  - Does not control outdoor-generated pollutants
- DCV
  - Does not control outdoor-generated pollutants
  - Does not account for pollutants generated indoors that are independent of human activities
    - Nine literature studies* documented the above statements by testing formaldehyde, total volatile organic compounds (TVOC), and radon
  - Requires CO_2 sensor for each ventilation zone; sensors must be calibrated every ~6 months for proper operation.
  - For certain spaces, such as offices, portion of ventilation related to ”people” component is low (29% in case of offices), leaving little margin to save energy using this methodology

*(Gabel et al., 1986; Donnini et al., 1991; Carpenter, 1996; Enermodal, 1995; Persily et al., 2003; Chao & Hu, 2004; Jeong et al., 2010; Mui & Chan, 2006; Herberger & Ulmer 2012)

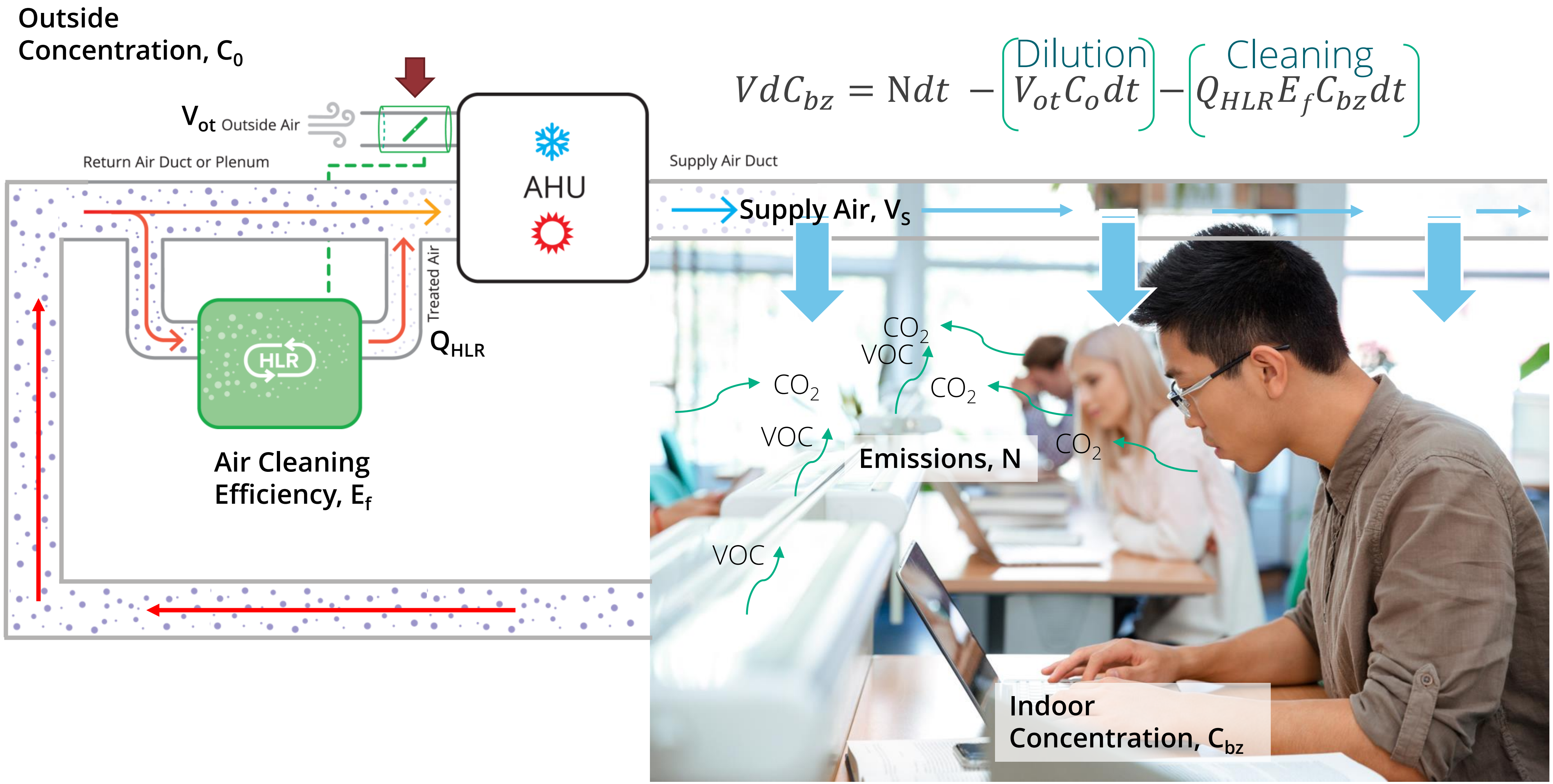
IAQP Methodology

enVerid
Energy savings. Air quality.

IAQP: Objective Evaluation Steps

Mass Balance Analysis

$$V dC_{bz} = N dt - \underbrace{\left(V_{ot} C_o dt \right)}_{\text{Dilution}} - \underbrace{\left(Q_{HLR} E_f C_{bz} dt \right)}_{\text{Cleaning}}$$



Example Calculation of Outside Air Requirement using VRP, DCV, IAQP

<u>Office Building</u>

Area = 20,000 ft^2

People/1,000 ft^2 = 5

    # People = 100

Supply/Return Location = Ceiling

Zone Air Distribution Effectiveness = 0.8

Comparison Outside Air Requirements

ASHRAE Standard 62.1-2016

Method	Office
VRP (CFM)	2,125
DCV (CFM) - # People = 80	2,000
DCV (CFM) - # People = 50	1,812
DCV (CFM) - # People = 20	1,625
IAQP (CFM)	652
Design Outside Air Savings (CFM)	1,473

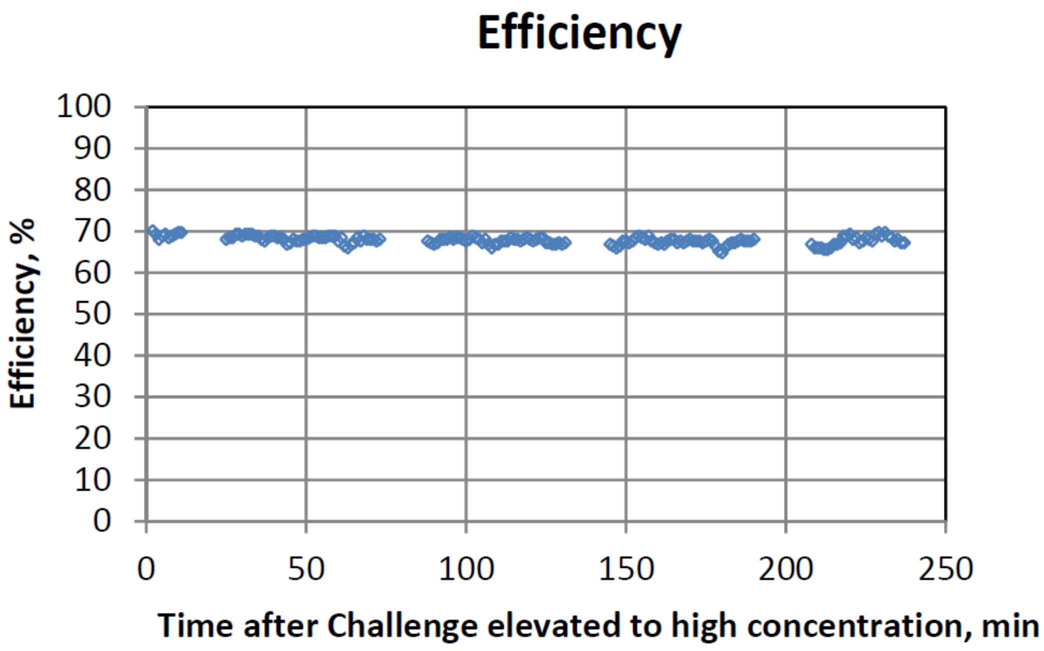
*Both Outside Air CFM figures above are compliant with ASHRAE Standard 62.1-2016 and thus **equivalent** with respect to satisfying the requirements of the Standard*

HLR Air Cleaning Performance

- Air cleaning certification data according to ASHRAE Standards is needed to apply the Indoor Air Quality Procedure (IAQP) and LEED IAQP
- enVerid obtained certifications according to ASHRAE Standard 145.2 and 52.2 for the sorbent cartridge in the HLR module from Research Triangle Institute (RTI)

Example: Ozone test data from RTI:

- Efficiency = 70%
- By-product VOCs and ozone concentrations = 0 ppb



LEED + WELL Impact

LEED

Pilot Credit PC124

Intent & Overview

Published in April 2018:

https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-healthc-148

1. Contribute to the comfort and well-being of building occupants by minimizing indoor air quality problems associated with construction and renovation.

2. Establish minimum standards for indoor air quality (IAQ).

3. Provide awareness of baseline indoor air contaminant levels to support indoor air quality management.

Pilot Credit PC124

Earning Points

PC124, New construction

- + 6 points → IEQ
- 4 - 8 points → Energy

(depends on energy model outcome)

Total = +12 points

0	**5**	**0**	**Indoor Environmental Quality**		**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
			Prereq	Environmental Tobacco Smoke Control	Required
Y	1		Credit	Enhanced Indoor Air Quality Strategies	2
Y	1		Credit	Low-Emitting Materials	3
Y	1		Credit	Construction Indoor Air Quality Management Plan	1
Y	2		Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1
0	**1**	**0**	**Innovation**		**6**
Y	1		Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	**0**	**0**	**Energy and Atmosphere**		**33**
Y	?		Credit	Optimize Energy Performance	18

WELL

- Feature A01: Fundamental Air Quality
  - Part 3: Meet Thresholds for Inorganic Gases
    - Carbon Monoxide less than 9 ppm
    - Ozone less than 51 ppb

PRECONDITION

Verification

On-site Assessment
- Performance Test

- Feature A03: Ventilation Effectiveness
  - Part 1: Ensure Adequate Ventilation
    - *For mechanically ventilated spaces (non-dwelling units):*
      - ASHRAE 62.1-2010 or any more recent versions (Ventilation Rate Procedure or IAQ Procedure)

PRECONDITION

Verification

Letters of Assurance
- MEP

- Feature A05: Enhanced Air Quality (Max 4 pts.)
  - Part 2: Meet Enhanced Thresholds for Organic Gases (1 pt.)
    - Formaldehyde less than 13.4 ppb
    - Benzene less than 3μg/m^3
  - Part 3: Meet Enhanced Thresholds for Inorganic Gases (1 pt.)
    - Carbon monoxide less than 6 ppm
    - Ozone less than 25 ppb
    - Nitrogen dioxide less than 21 ppb

OPTIMIZATION

Verification

On-site Assessment

- Performance Test

Case Studies

The Building

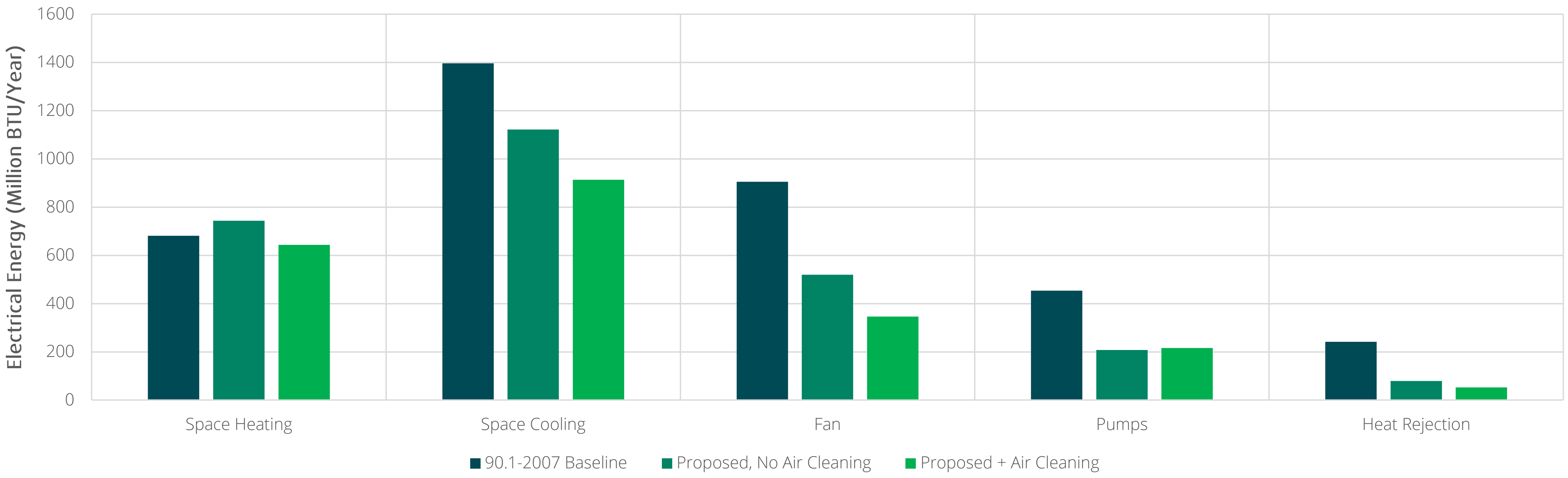
Overview

Client: Technology Company
Floor Area: 108,000 ft^2 of labs, dining room, open office spaces, and conference rooms
Design Occupancy: 800
HVAC: Two (2) Designated Outside Air Systems (DOAS) at 15,000 CFM each serving downstream Fan Coil Units (FCUs). Hot water and chilled water serving DOAS and FCUs.
# of Floors: 7

The Building

Energy Modeling Results

	ASHRAE 90.1 Baseline Building	Proposed Building – No Air Cleaning	Proposed Building – With Air Cleaning
Savings	-	27.3%	40.9%
LEED EA Optimize Energy Performance Points	-	5	10

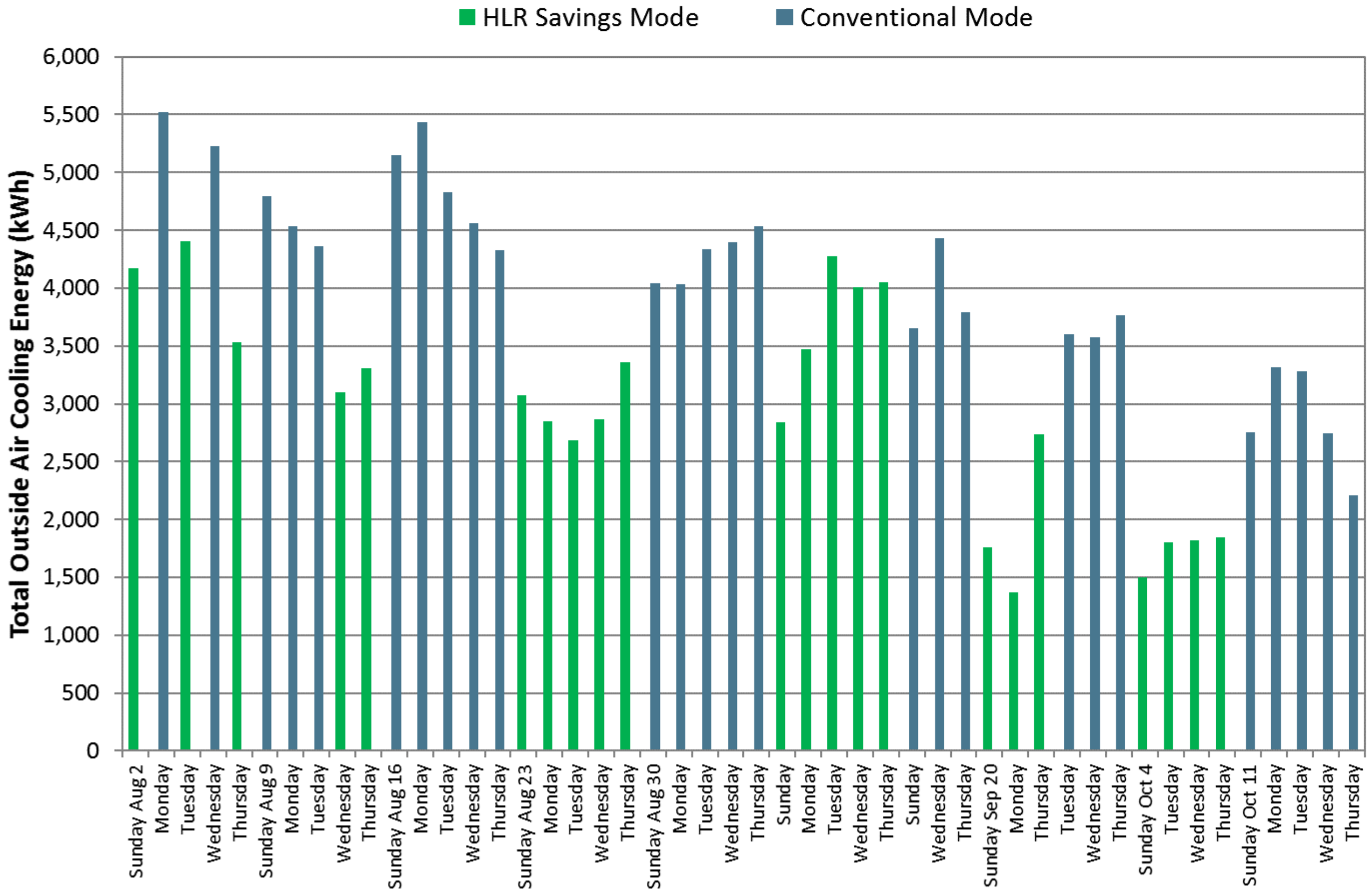


The Building

Measurement & Verification Results – Energy

Summary:

- **33%** Reduction in Cooling Energy
- **57%** Reduction in Minimum Outside Air Flow
- **$14,720** annual energy cost savings
- **17-ton** reduction in HVAC cooling peak load
- **60 metric ton** annual reduction in GHG emissions

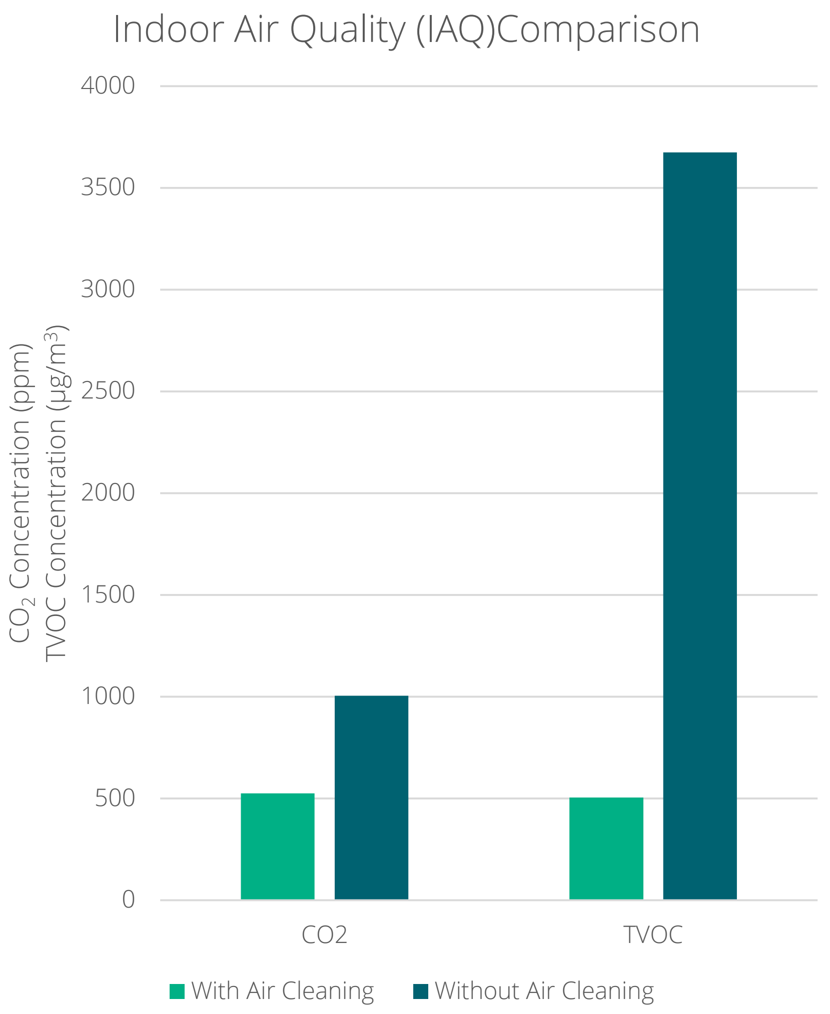


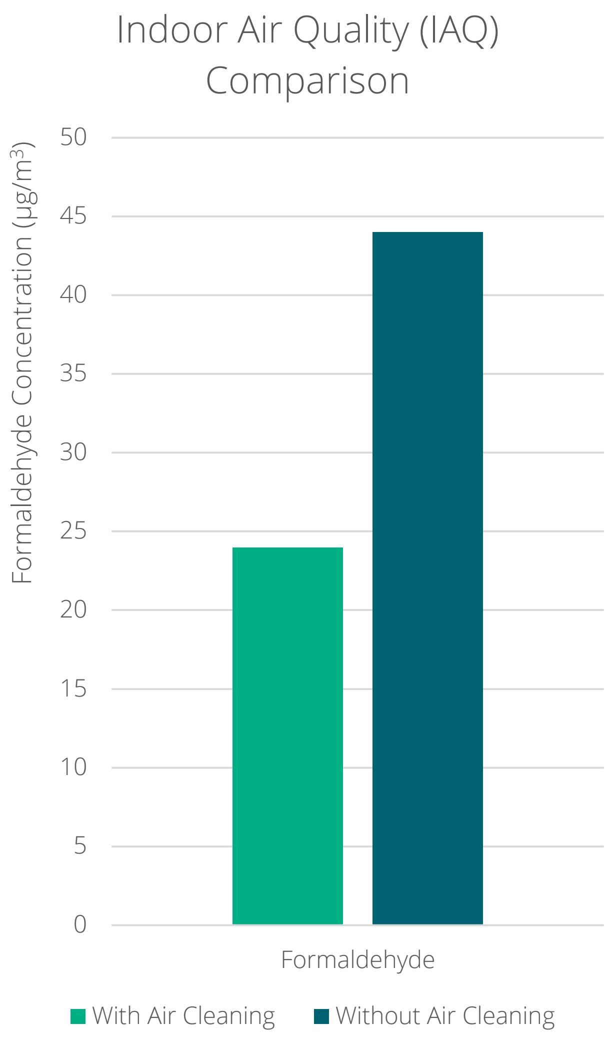
The Building

Measurement & Verification Results – Indoor Air Quality

Summary:

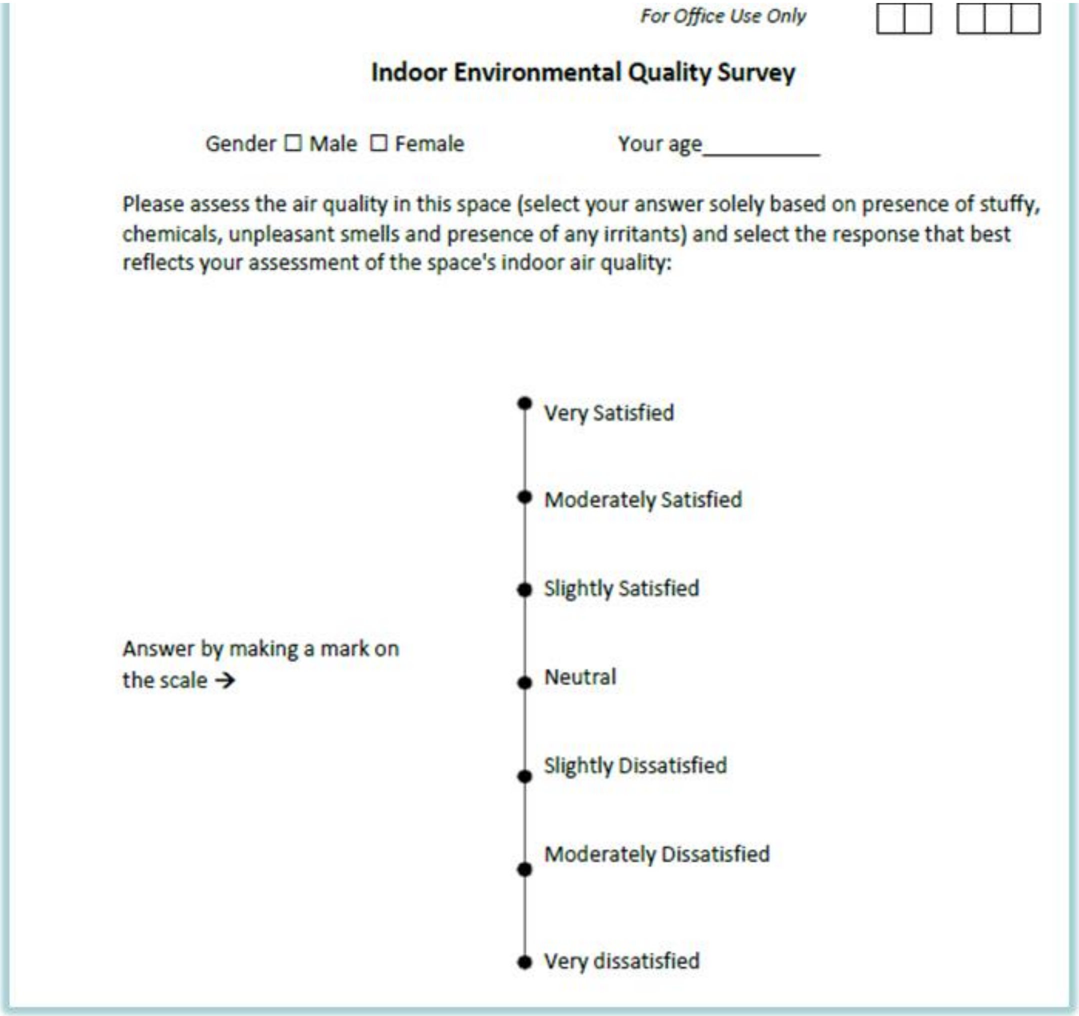
- All contaminants of concern maintained at a healthy level and below allowable LEED pc124 concentration limits
- Better indoor air comfort
- Reduced amount of outdoor-generated contaminants (i.e. Ozone)





The Building

Post Occupancy Survey Results



For Office Use Only

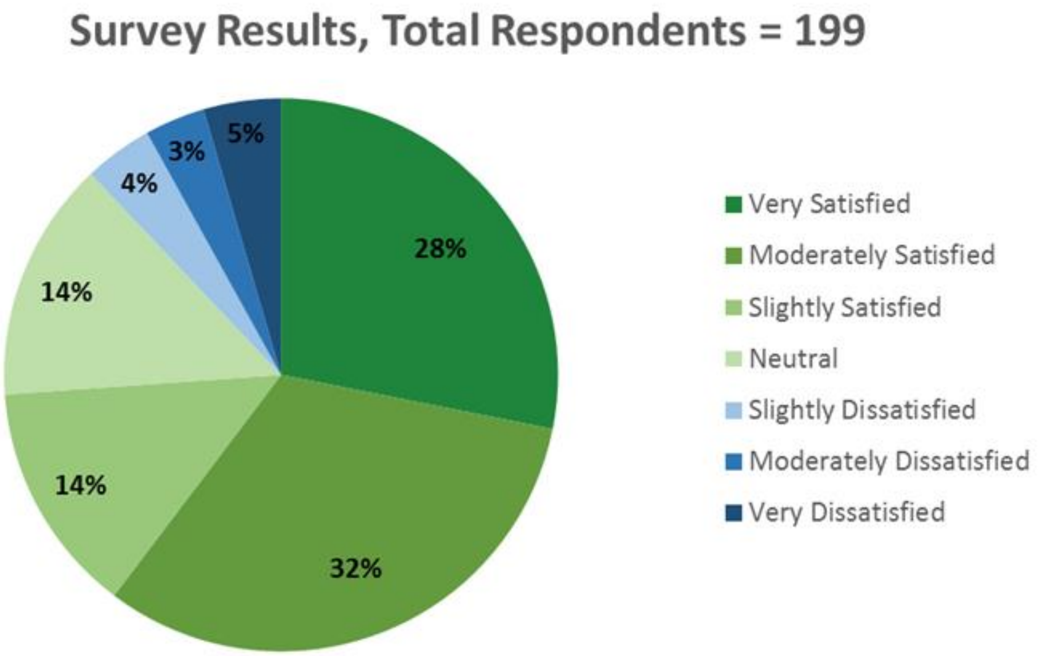
Indoor Environmental Quality Survey

Gender ☐ Male ☐ Female Your age__________

Please assess the air quality in this space (select your answer solely based on presence of stuffy, chemicals, unpleasant smells and presence of any irritants) and select the response that best reflects your assessment of the space's indoor air quality:

Answer by making a mark on the scale →

- Very Satisfied
- Moderately Satisfied
- Slightly Satisfied
- Neutral
- Slightly Dissatisfied
- Moderately Dissatisfied
- Very dissatisfied



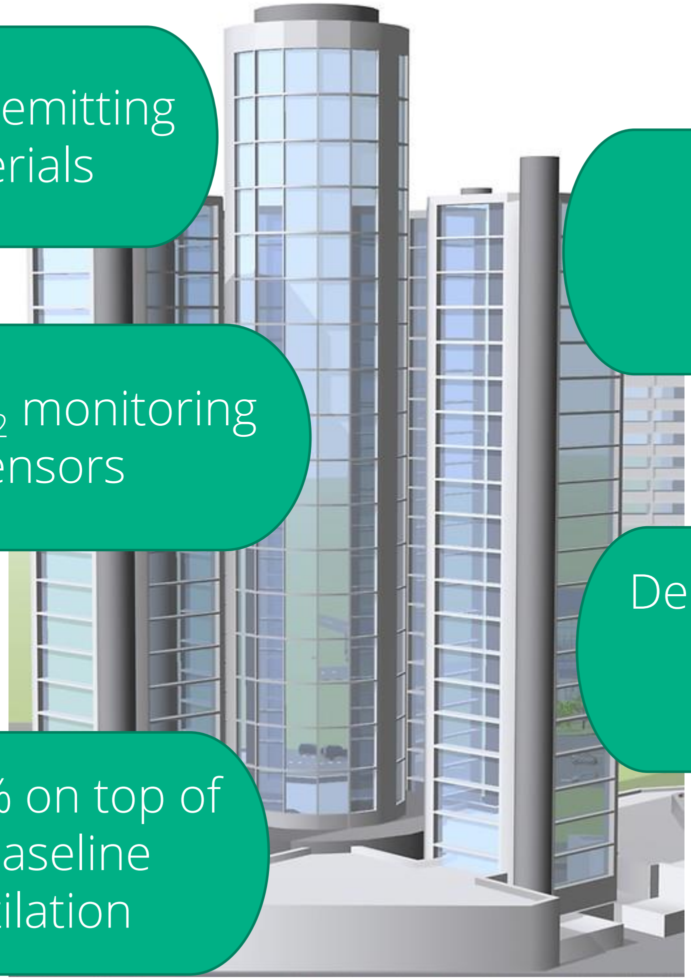
7 floors , mid-rise office building
LEED Status = Gold, 62 points
Client requirements = Gold

Traditional Credits

+3 points = add significantly to the project cost

+1 point = install 60 CO2 sensors = increase of $90,000
+ $9,000 yearly calibration

+1 point = increase 45 tons cooling = $90,000
+ increase $25,000 operational cost



Add low emitting materials

Add CO_2 monitoring sensors

Add 30% on top of the baseline ventilation

Install Air Cleaning Modules

Decrease OA by 60% + air cleaning

Pilot Credit + Air Cleaning

+6 points = increase of $50,000
+ increase $4,000 yearly in cartridge costs

+5 points = Decrease 17 tons cooling = $34,000 + downsize energy recovery = $80,000
+ decrease $15,000 in operational cost

Traditional Approach

7 floors , mid-rise office building
LEED Status = Gold, 62 points
Client requirements = Gold

Pilot Credit+ Air Cleaning

+5 points

Installation Cost =
- $180,000

Yearly cost =
- $34,000

+11 points

Installation Cost =
- (-$54,000)

Yearly cost =
- (-$11,000)

Elevated the status of the building from LEED Silver to LEED Gold

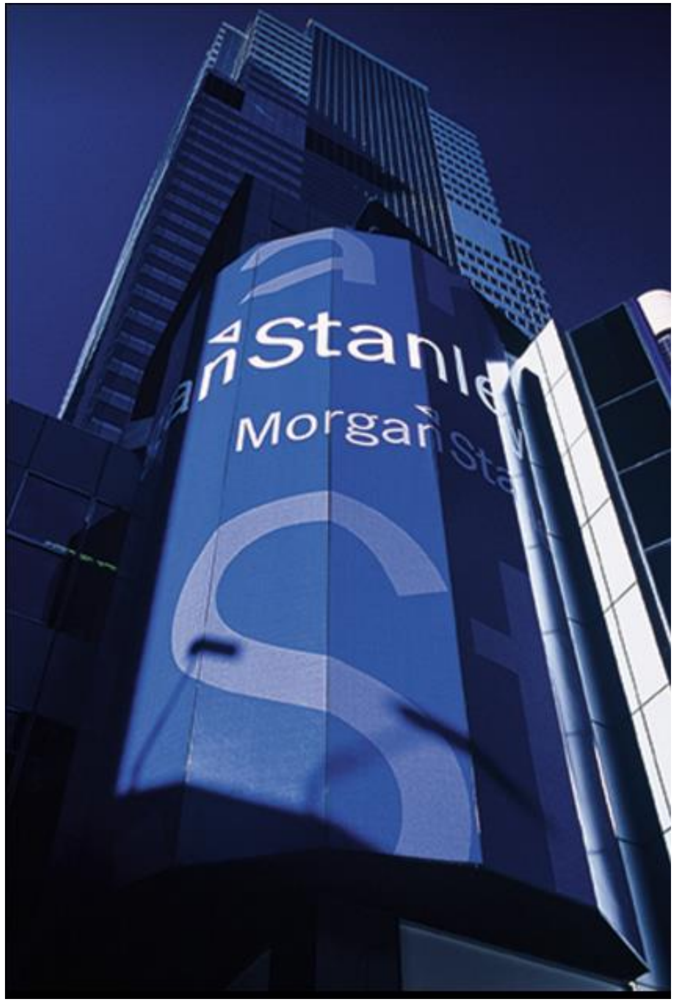
Case Study 1

Morgan Stanley 1585 Broadway

Building Parameters			
Occupancy	Building Sq. Ft.	# of Floors	Operating Hours
Max Occupancy = 6,863	1,346,148	44	24 hours/day

HVAC Parameters		
Outside Air (CFM)	Total Supply (CFM)	Existing Outside Air (CFM)
Mon-Fri (From 0:00-5:00)	225,000	56,250
Mon-Fri (From 5:00-19:00)	750,000	190,000 – 217,742
Mon-Fri (From 19:00-24:00)	225,000	63,086
Sat-Sun (From 0:00-24:00)	225,000	56,250

AHU	Serving
ACS 1 to 6; ACS 16, 17	Basement to 6
ACS 1 to 6; ACS 16, 17	8 to 14
ACS 8 to 15	15 to 27
ACS 8 to 15	29 to 42



IAQP Results

- 40 HLRs
- Outside air reduction =
  Existing Outside Air – max (IAQP, exhaust/overpressure)

  =190,000 – max (58,000,70,000)

  =190,000 – 70,000

  =120,000 CFM

  Outside air needed when HLR is ON

  = 70,000 CFM

Summary Results

Previous

Ventilation Zone 1 **Office buildings**

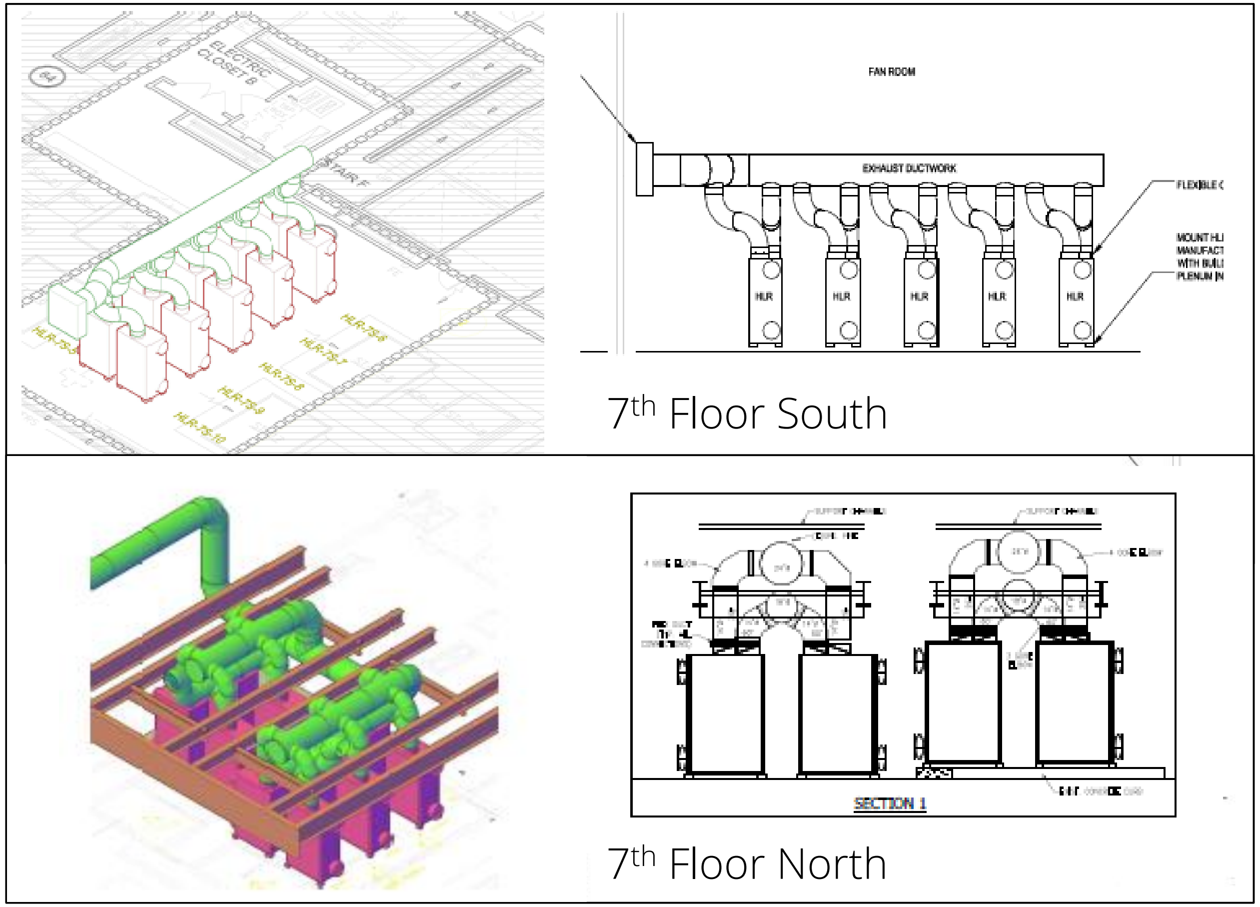
Square Footage	1346148
Occupancy	6863

	# HLRs	IAQP Outside Air (m3/hr)	Outside Air Reduced ((m3/hr)	% Outside Air Reduction
Option 1	**40.00**	**99781**	**204000**	**63%**

Option 1

COC	**Voa m3/hr**	**Indoor Emissions**	**Selected Limit Standard**
1,4-DCB	Not a COC	0.13 ug/m^2.h (Wu et al., 2011)	CA OEHHA (800.0 µg/m^3)
2-butoxyethanol	Not a COC	7.19 ug/m^2.h (Wu et al., 2011)	ATSDR MRL (966.2 µg/m^3)
acetaldehyde	Not a COC	17.45 ug/m^2.h (Wu et al., 2011; Hodgson and Levin, 2003)	LEED IAQP (140.0 µg/m^3)
acetone	Not a COC	37.70 ug/m^2.h (Wu et al., 2011; Hodgson et al., 2012)	ATSDR MRL (3087.9 µg/m^3)
benzene	Not a COC	0.21 ug/m^2.h (Wu et al., 2011)	CA OEHHA REL (110.0 µg/m^3)
carbon tet.	Not a COC	0.31 ug/m^2.h (Wu et al., 2011)	ATSDR MRL (188.7 µg/m^3)
chloroform	Not a COC	0.10 ug/m^2.h (Wu et al., 2011)	CA OEHHA; LEED IAQP (300.0 µg/m^3)
CO2	87987	22500000.00 ug/ppl.hr (ASHRAE Standard 62.1-2013)	LEED IAQP (1100ppm) (2131800.0 µg/m^3)
decanal	Not a COC	16.00 ug/m^2.h (Wu et al., 2011)	EU-LCI value (920.3 µg/m^3)
diethylphthalate	Not a COC	0.58 ug/m^2.h (Wu et al., 2011)	ATSDR: NIOSH; OSHA (5000.0 µg/m^3)
d-limonene	Not a COC	11.30 ug/m^2.h (Wu et al., 2011)	IARC guideline (150000.0 µg/m^3)
ethylbenzene	Not a COC	0.77 ug/m^2.h (Wu et al., 2011; Hodgson et al., 2012)	CA OEHHA; LEED IAQP (2000.0 µg/m^3)
formaldehyde	99781	37.50 ug/m^2.h (Wu et al., 2011; Hodgson and Levin, 2003)	CARB; LEED IAQP (33.0 µg/m^3)
hexanal	Not a COC	6.39 ug/m^2.h (Wu et al., 2011)	EU-LCI value (920.3 µg/m^3)
methylene chloride	Not a COC	1.18 ug/m^2.h (Wu et al., 2011)	CA OEHHA REL (400.0 µg/m^3)
naphthalene	Not a COC	0.38 ug/m^2.h (Wu et al., 2011)	ATSDR MRL (3.7 µg/m^3)
n-hexane	Not a COC	1.35 ug/m^2.h (Wu et al., 2011)	CA OEHHA REL; LEED IAQP (7000.0 µg/m^3)
nonanal	Not a COC	8.57 ug/m^2.h (Wu et al., 2011)	EU-LCI value (920.3 µg/m^3)
octanal	Not a COC	2.93 ug/m^2.h (Wu et al., 2011)	EU-LCI value (920.3 µg/m^3)
PCE	Not a COC	0.14 ug/m^2.h (Wu et al., 2011)	ATSDR MRL (272.1 µg/m^3)
phenol	Not a COC	6.25 ug/m^2.h (Wu et al., 2011)	CA OEHHA REL; LEED IAQP (200.0 µg/m^3)
PM2.5	Not a COC	6.00 ug/m^2.h (Wu et al., 2011)	NAAQS, LEED IAQP (15.0 µg/m^3)
styrene	Not a COC	1.06 ug/m^2.h (Wu et al., 2011)	ATSDR MRL (851.1 µg/m^3)
TCE	Not a COC	0.12 ug/m^2.h (Wu et al., 2011)	ATSDR MRL (537.6 µg/m^3)
toluene	Not a COC	5.55 ug/m^2.h (Wu et al., 2011; Hodgson and Levin, 2003; Hodgson et al., 2012)	China Code GBT 18883 Hong Kong IAQ Guideline - Good Class (200.0 µg/m^3)
α-terpineol	Not a COC	0.40 ug/m^2.h (Wu et al., 2011)	µg/m^3)

Precise layouts were designed for each of the MER floors - 7th



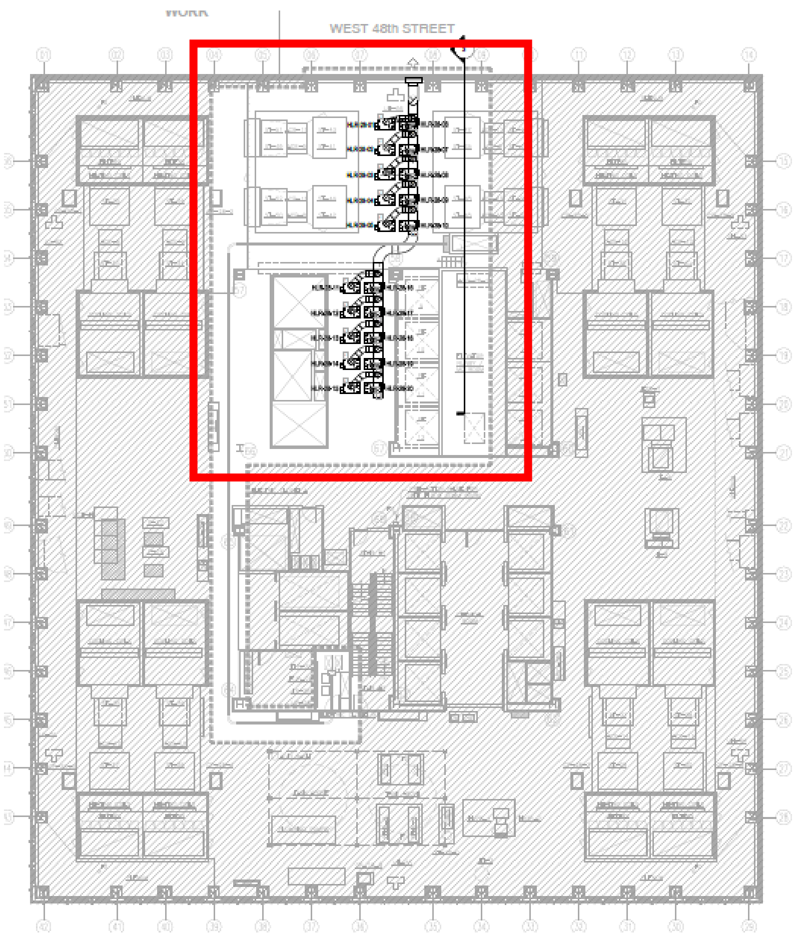
7th Floor South

7th Floor North

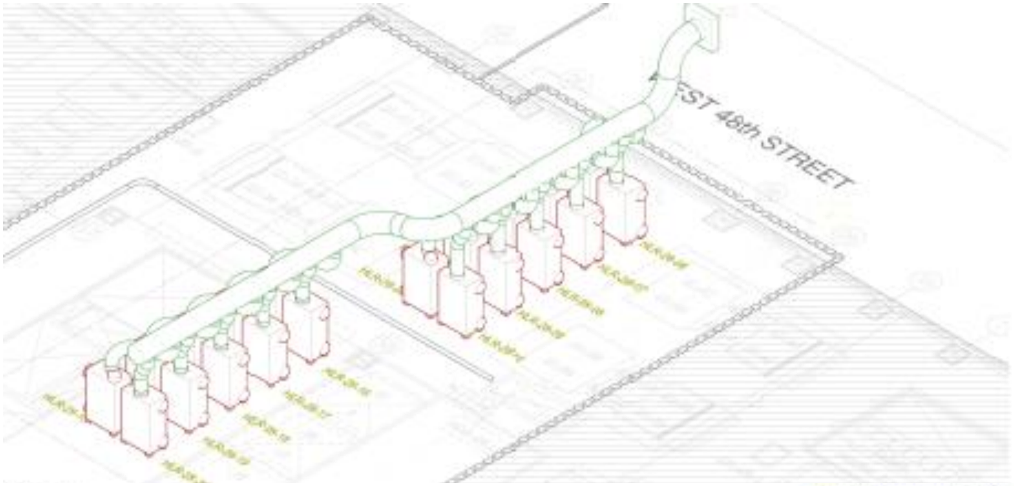
7th Floor Mechanical Room

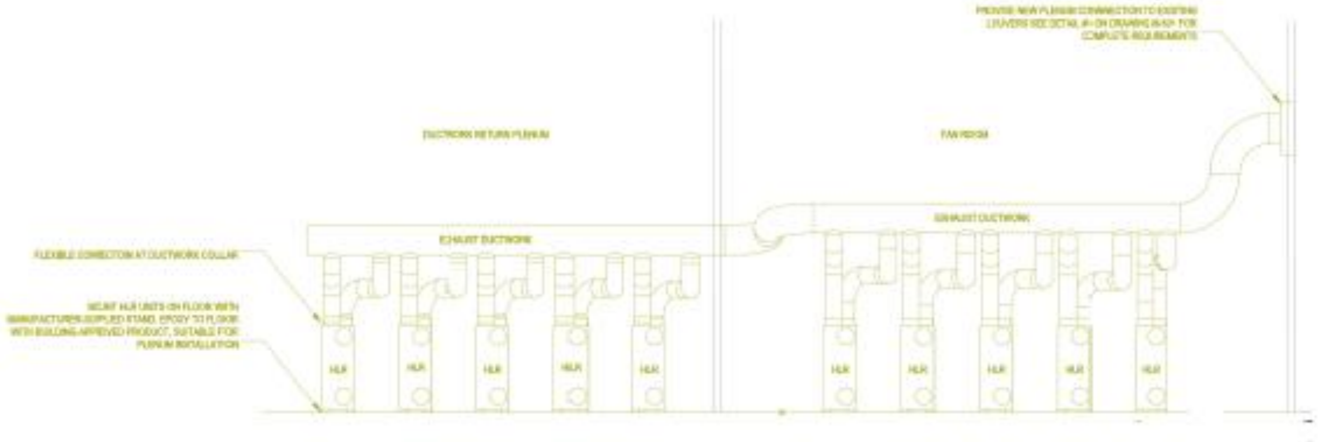
7th Floor Implementation

MER 28th



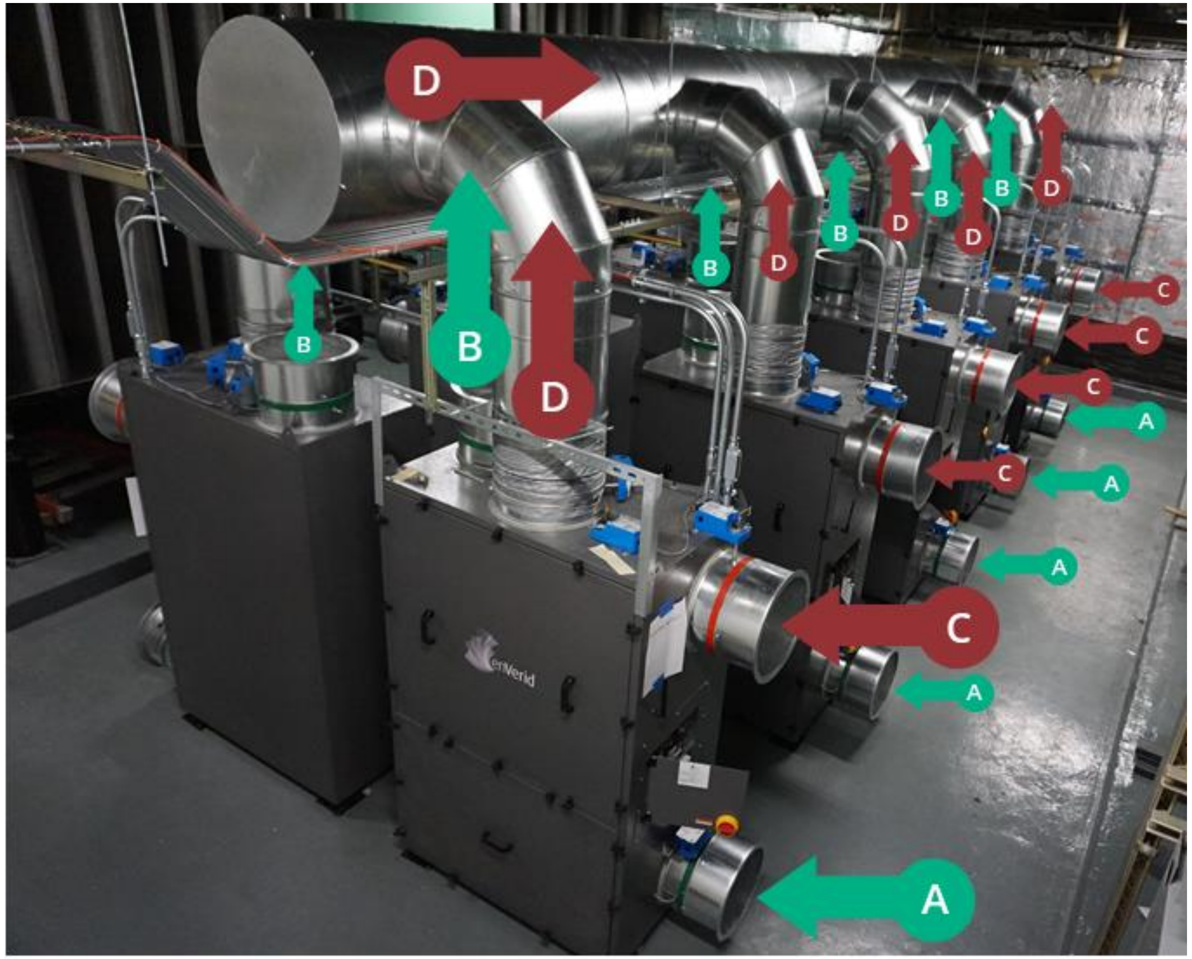
28th Floor Mechanical Room





28th Floor Implementation

HLR modules are grouped in clusters of 10, each with a shared exhaust duct.



A Return air from Plenum
B Clean air from HLR returned to Plenum
C Plenum air for regeneration
D Regeneration exhaust from HLR

Case Study 2

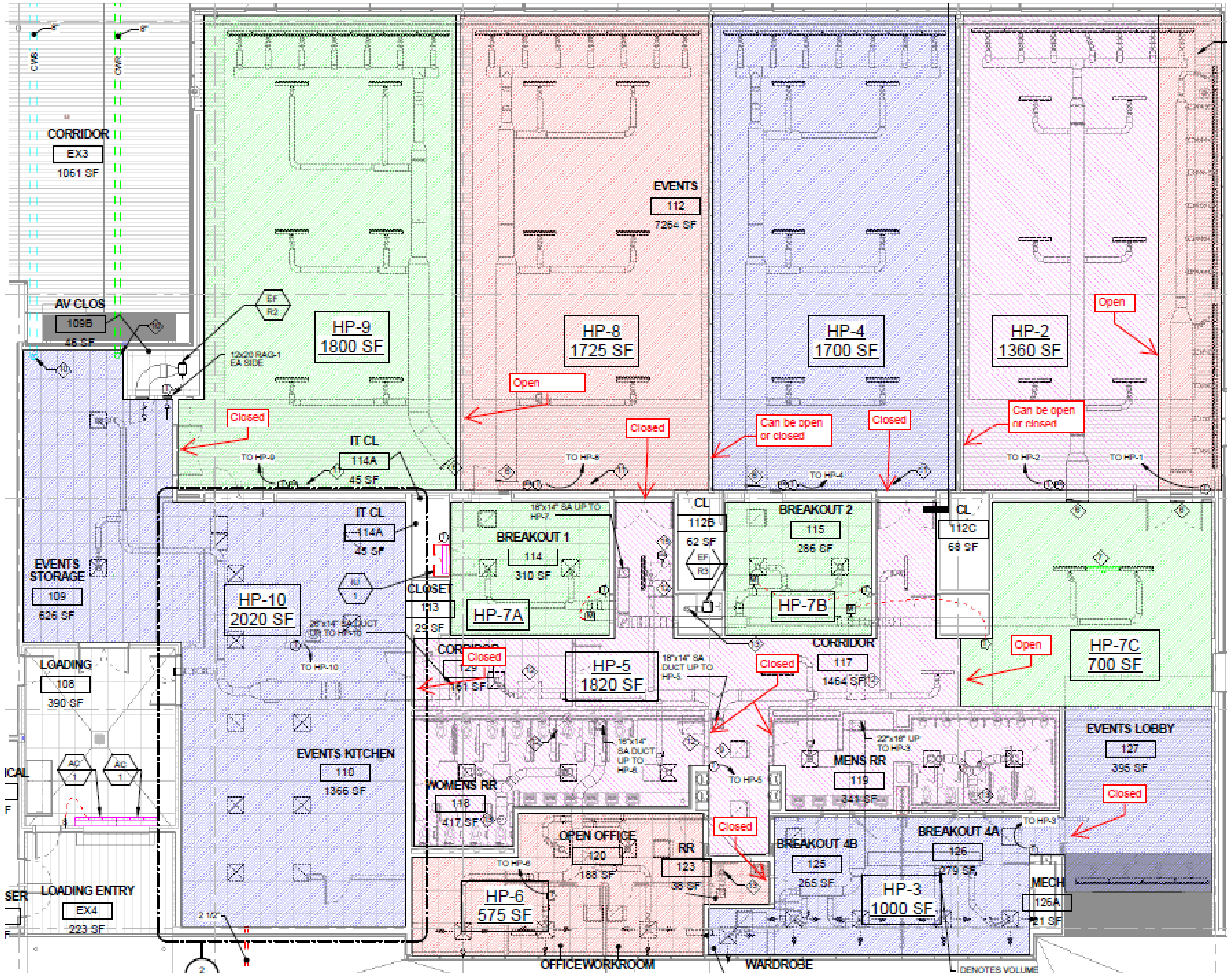
Built in 2016, the one-story, 10,000 ft^2 Event Center includes events spaces, offices, breakout rooms, a lobby, a storage room and a signature restaurant.

This is the **first** structure in Shelby County, TN, to be heated and cooled by geothermal energy.

The Center pursued LEED Certification.

The Design

- 10 heat pumps (HP) providing heating, cooling, and ventilation for the retreat center which are each zoned individually.
- The zones for HP-2, 4, 8, and 9 are the ones that experience the largest loads due periodic high occupancy levels.
- The mechanical system for the center features a geothermal loop that runs horizontally across the bottom of the adjacent lake bed.



The Problem

- Original plans called for the use of geothermal wells for heating and cooling of the building
  - Well field was to be sized to handle the cooling and heating load for the building.
  - Problem: Cost of the wells was prohibitive within the construction budget, threatening the completion of the project and meeting the goal of a state-of-the-art sustainable event center for the community.

Space	ft^2	Outside air CFM	Area
HP-9	1800	916	Event area
HP-8	1725	911	Event area
HP-7(A,B,C)	1296	347	Breakout area
HP-4	1700	909	Event area
HP-2	1810	917	Event area

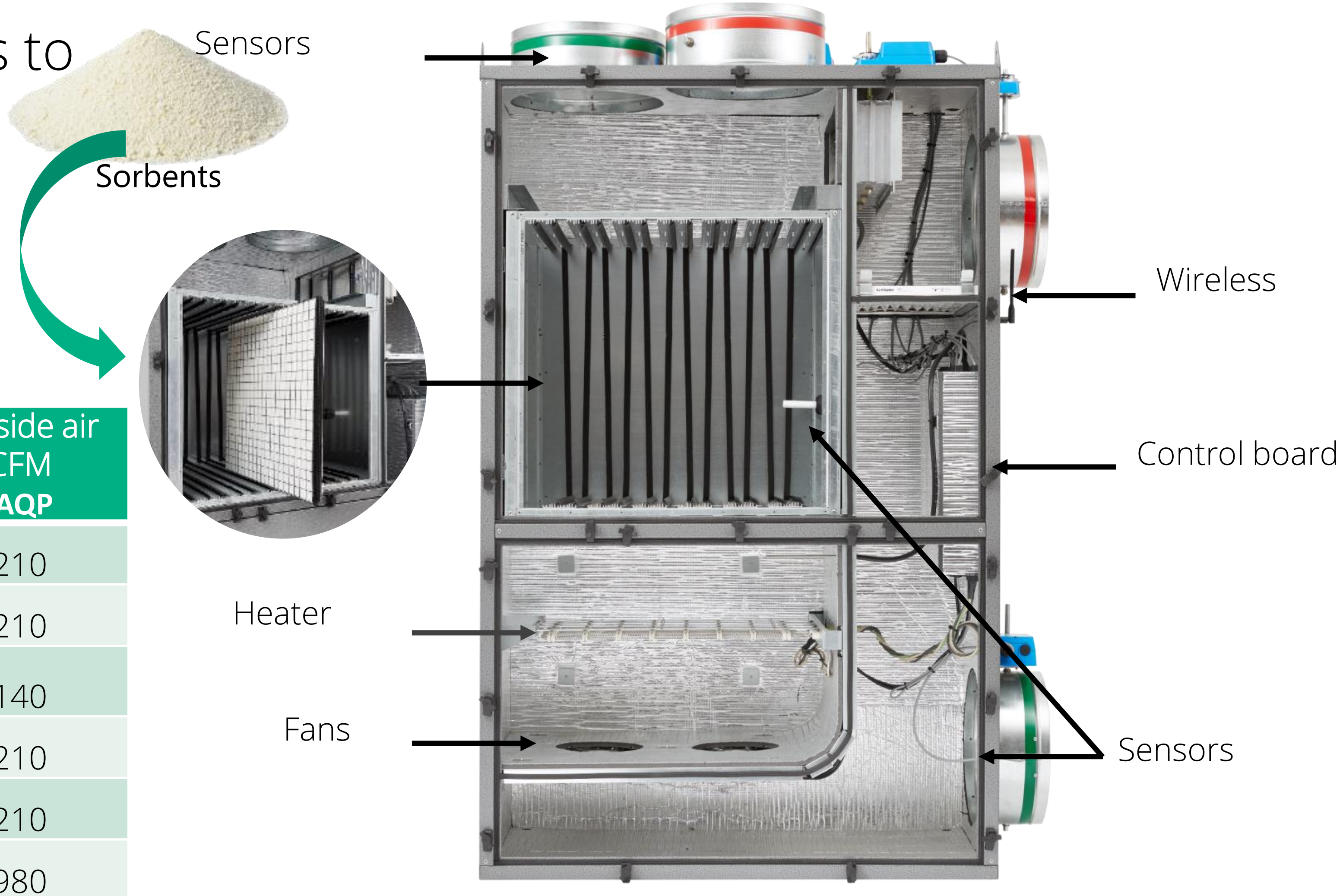
The Solution

- *ASHRAE Std. 62.1: Indoor Air Quality Procedure (IAQP) – since 1979**

- Use of 4 air cleaning modules to decrease outside air requirements
- Self-regenerating sorbent

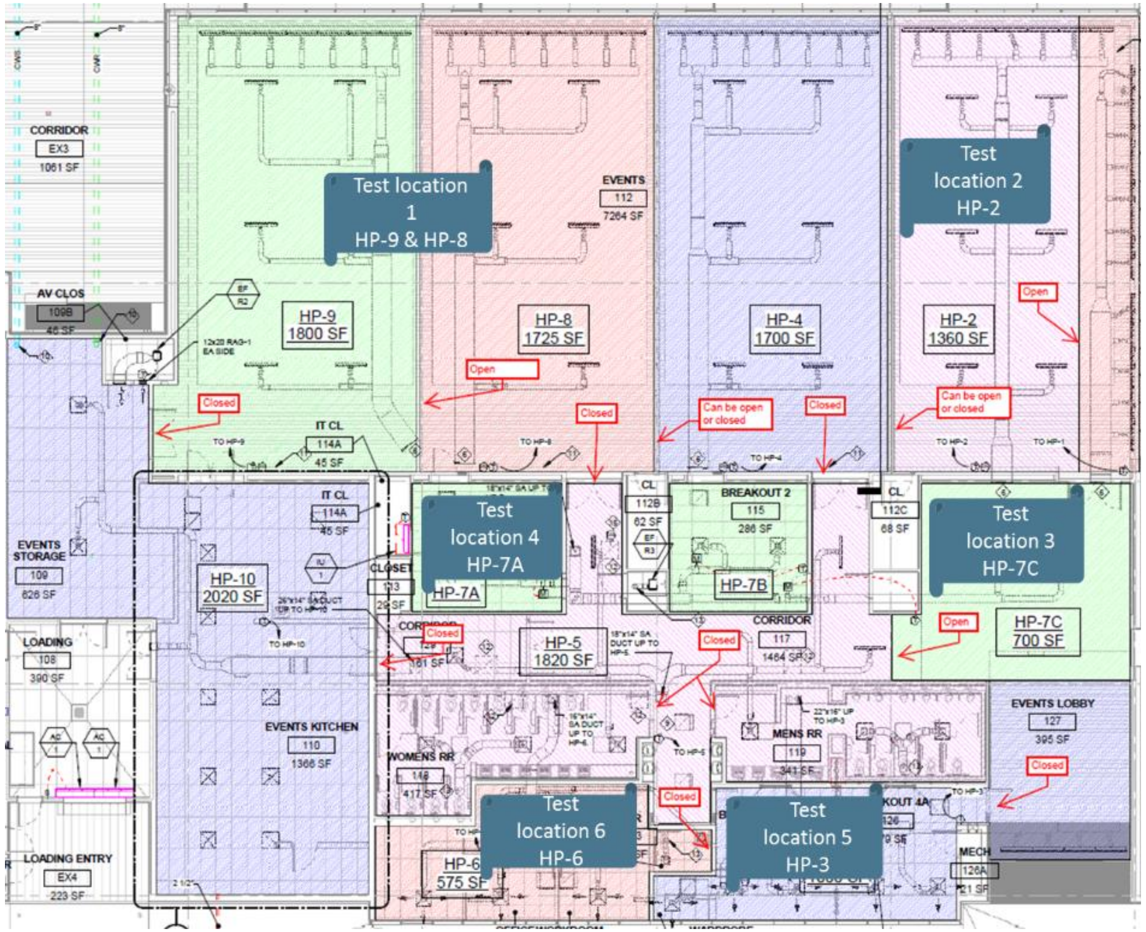
(0 by-products)

Space	ft²	Outside air CFM **VRP**	Outside air CFM **IAQP**
HP-9	1800	916	210
HP-8	1725	911	210
HP-7(A,B,C)	1296	347	140
HP-4	1700	909	210
HP-2	1810	917	210
Total		4,000	980



Design Verification: IAQ Test after Occupancy

- Comprehensive IAQ sampling following EPA methods, Objective evaluation; measurements of:
  - VOCs
  - Aldehydes
  - CO
  - O_3
  - CO_2
  - PM_1, $PM_{2.5}$, PM_{10}



The Results – Energy Impact

- Outside air reduction to the building and resulted in the following cost savings:
  - Geothermal Heating / Cooling
    - Geothermal well savings of $90,000
  - HVAC Equipment
    - 19 tons of cooling
    - Equipment cost savings: $17,000
    - Downsizing the outside air and relief air duct sizes
  - Operational Savings

BUILDING INFORMATION

Project	Shelby Farms	
City	Nashville	
Tariff	Fixed	
Outside Air Reduced	CFM	3020
Operating Hours	from	6:00
	to	24:00
Weekly Schedule		7 Day
Heating System	**Electric ($/kWh)**	

ANNUAL SAVINGS SUMMARY

Energy Savings		
Cooling	26,371 kWh	
Heating	38,283 kWh	0 kBTU
Total	**64,654 kWh**	**0 kBTU**
	kW *(power)*	TR *(energy)*
Cooling Peak Load Reduction	22 kW	19 TR
Cost Savings		
Electricity (Usage)	$ 9,698	
Electricity (Demand)	$ 5,480	
Non-Electric Heating	$ -	
Total	**$ 15,178**	

Thank you.

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