Welcome to Webinar Wednesday

Varitec Technical Institute - 2023

Presenter: Dan Hahne
(Varitec: Director of High-Performance HVAC Solutions)

Program Coordinator: Kellie Huff
(Varitec: Marketing Manager)

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SHAPING THE FUTURE OF HVAC

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Mission:

(New Horizons Launch, January 9, 2006)

To provide an educational platform for continued learning in the HVAC industry with a focus on high performance buildings and innovative technologies for a better built environment.

Varitec Technical Institute

November 8th: Thermally Stratified Environments

December 6th: Underfloor Air Systems

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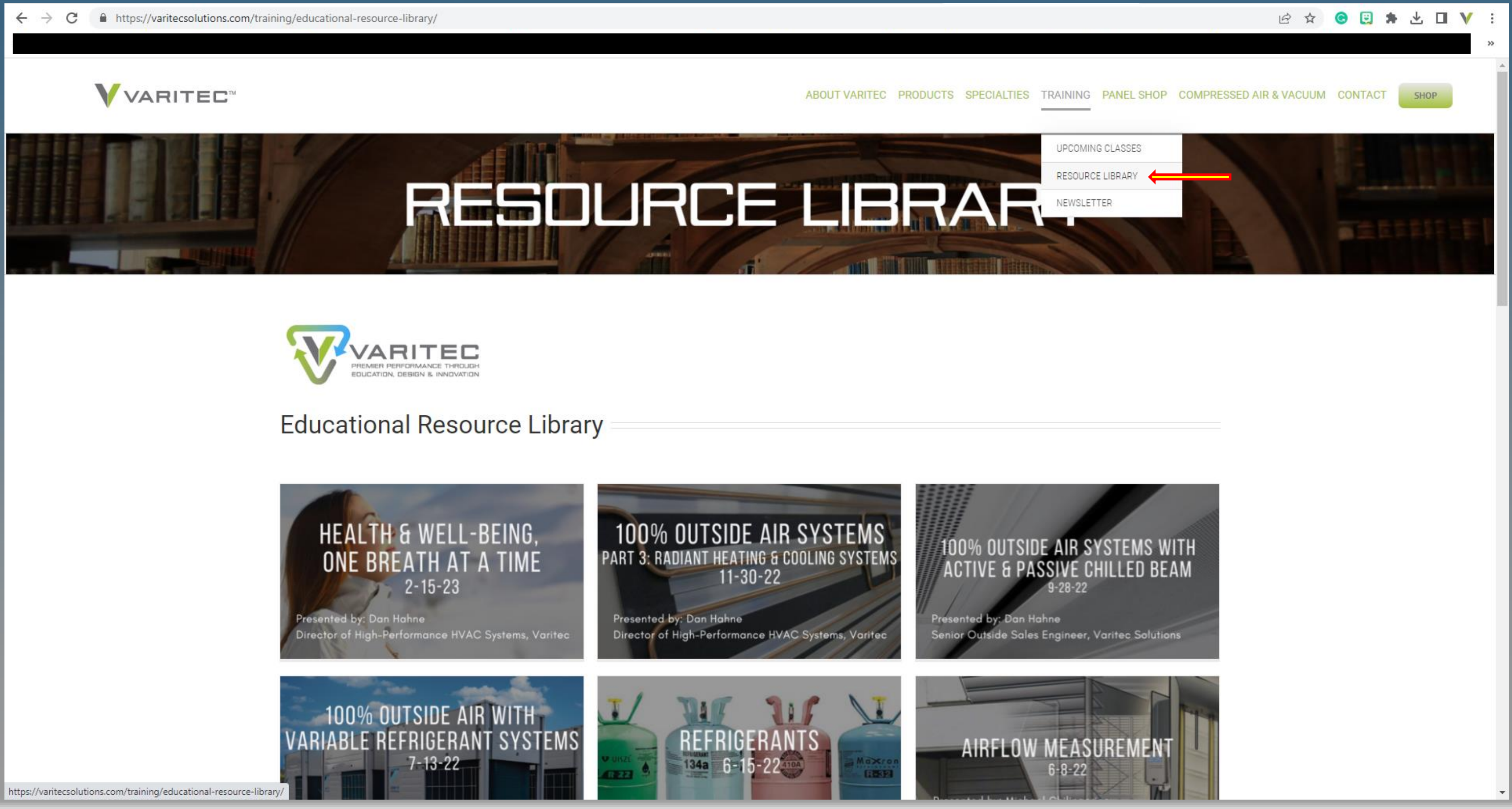

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Housekeeping Items:

- **We are recording this session**
- **Please ask questions in the chat**
- **If you need PDH or AIA credit, make sure your name is displayed correctly. If you are calling in, send me an email to let me know you attended.**

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Introduction

Education:

- University of Arizona – Chemical Engineering
  - 1974 thru 1976
- University College London – BFA Degree (Sculpture)
  - 1978 thru 1983
- Boston University – MFA Degree (Sculpture)
  - 1983 thru 1985

Industry:

- **Norman S. Wright SW:** Estimator/Sales
  - 1985 thru 1999
- **Air Specialty Products/ThermAir Systems:** Outside Sales
  - 2000 thru 2008
- **Air Specialty Products/ThermAir Systems:** Engineering Sales
  - 2009 thru 2016
- **Varitec Solutions:**
  - Senior Sales Engineer
    - 2016 - 2022
  - Director of High-Performance HVAC Solutions/Educator
    - 2022 thru present

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Introduction
Publications:

- **July 2022: 100% Outside Air VRF Systems: A Sustainable, Hybrid Approach for Superior IEQ**
  - Dan Hahne
- **October 2021: Health Care Design: Beyond Code Minimum – Creating Healthier, More Efficient Environments**
  - (Co-Authored with Fletcher Clarcq P.E.)
- **June 2021: Health Care Design: ANSI/ASHRAE/ASHE Standard 170, and Beyond**
  - (Co-Authored with Fletcher Clarcq P.E.)
- **November 2019: Debunking the Myths of Active Chilled Beams: What You Thought You Knew But Were Wrong**
  - (Co-Authored with Eric Martin P.E., Fletcher Clarcq P.E. Steven Lamica, Engineer (Dadanco))
- **October 2019: Debunking the Myths of Active Chilled Beams: The Drip Test**
  - (Co-Authored with Eric Martin P.E., Fletcher Clarcq P.E.
Steven Lamica, Engineer (Dadanco))

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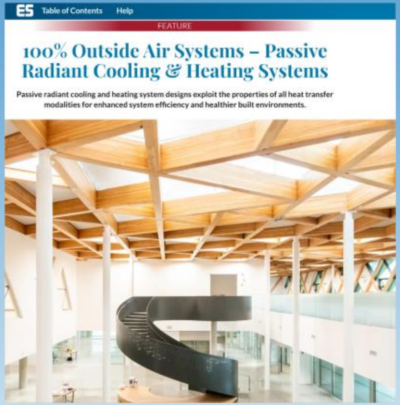
Latest Publication

Engineered Systems Magazine: December 2022 Edition

- *100% Outside Air Systems – Passive Radiant Cooling and Heating Systems*
- **(Co-Author: Darren Alexander, P.E. (Twa Panel Systems, Inc.)**


ES Table of Contents Help
FEATURE
100% Outside Air Systems – Passive Radiant Cooling & Heating Systems
Passive radiant cooling and heating system designs exploit the properties of all heat transfer modalities for enhanced system efficiency and healthier built environments.


ES Table of Contents Help
FEATURE
Creating an Innovative Building Design through Creative, Adaptive Architecture, Engineering and Collaboration
Meeting developing building standards, codes and assuming best practices to support high-performance buildings, will require architects and engineers to collaborate holistically.
By Dan Hahne, Conrad Brown, P.E. and Matthew Peairs, P.E.

ES Magazine August 2023 Edition

- **Co-Authors:**
  - Dan Hahne (Varitec)
  - Conrad Brown P.E. (PAE)
  - Matthew Peairs P.E. (PAE)

Innovative active chilled beam design approach for building humidity control

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Session #6: 100% OSA Systems & The Importance of Ventilation

Presented by: Dan Hahne
Varitec: Director of High-Performance HVAC Solutions

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100% OSA Systems & The Importance of Ventilation

AGENDA:

- EPA, CDC and ASHRAE Ventilation Rate Statements
- What is a 100% OSA System?
- Indoor Air Contaminants and Human Health
- ASHRAE Standard 241-2023: Control of Infectious Aerosols
- ASHRAE Position Document on CO_2
- 100% OSA Systems: System Type Review
  - Active Chilled Beam Systems
  - Passive Radiant Cooling & Heating Systems
  - Variable Refrigerant Systems

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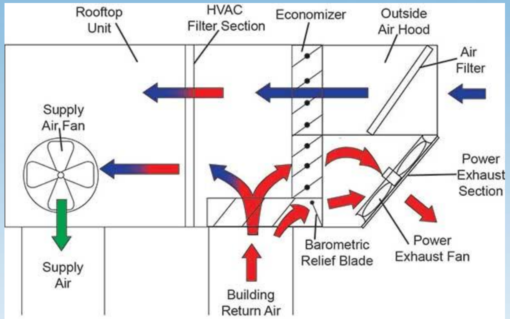
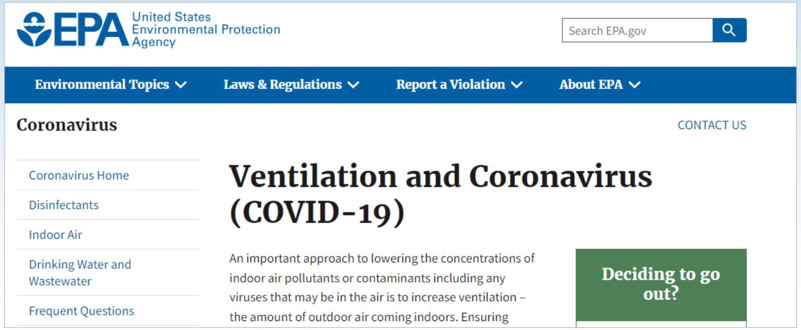
EPA, CDC and ASHRAE: Ventilation Rate Statements

EPA, CDC & ASHRAE: Ventilation Rate Statements

Environmental Protection Agency (EPA):

- ***Ventilation and Coronavirus (COVID-19):***
  - *"An important approach to **lowering the concentrations of indoor air pollutants** or **contaminants including any viruses** that may be in the air is to **increase ventilation – the amount of outdoor air coming indoors**.."*




EPA United States Environmental Protection Agency

Search EPA.gov

Environmental Topics | Laws & Regulations | Report a Violation | About EPA

Coronavirus

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- Coronavirus Home
- Disinfectants
- Indoor Air
- Drinking Water and Wastewater
- Frequent Questions

Ventilation and Coronavirus (COVID-19)

An important approach to lowering the concentrations of indoor air pollutants or contaminants including any viruses that may be in the air is to increase ventilation – the amount of outdoor air coming indoors. Ensuring

Deciding to go out?

- *"**Ensuring proper ventilation with outside air** can help reduce the concentration of airborne contaminants, including viruses, indoors."*

EPA, CDC & ASHRAE: Ventilation Rate Statements

EPA: Clean Air in Buildings Challenge

- **Section #2: Optimize Fresh Air Ventilation…:**
  - “**Ensure outdoor air is acceptably clean** or is adequately filtered as it is brought into the building


EPA United States Environmental Protection Agency

Environmental Topics | Laws & Regulations | Report a Violation | About EPA

Indoor Air Quality (IAQ)

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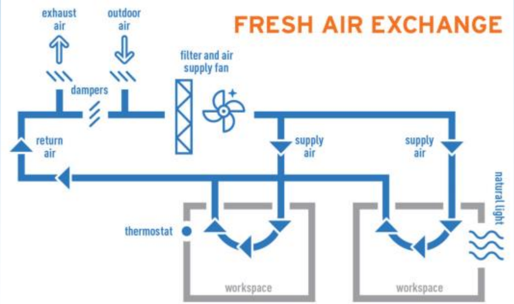
Clean Air in Buildings Challenge

Guidance to Help Building Owners and Operators Improve Indoor Air Quality and Protect Public Health

Fact Sheet Guidelines:

- **“Increase volume of clean, outdoor air at times of higher risk. (e.g. at times of elevated risk of COVID-19)”**
- “Run HVAC systems during all occupied hours to ensure clean air enters and is distributed throughout the building.”
- “Consider running the HVAC system to refresh air before arrival and/or remove remaining particles at the end of the day (e.g., 1-2 hours before/after the building is occupied,) as needed.”



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EPA, CDC & ASHRAE: Ventilation Rate Statements

Center for Disease Control (CDC):

- *May 7, 2021: "…**SARS-CoV-2 is transmitted by exposure to infectious respiratory fluids**."*
- *"…Infectious exposures to respiratory fluids carrying SARS-C0V-2 occur in three principle ways…deposition, touching, and **inhalation of air carrying very small droplets and aerosol particles that contain infectious virus**."*

CDC Website Subsequent Statement

- *"When indoors, **ventilation mitigation strategies** can help reduce viral particle concentration."*
- *"Open outdoor air damper beyond minimum settings to reduce or **eliminate HVAC air recirculation**."*

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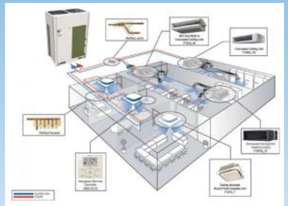
EPA, CDC & ASHRAE: Ventilation Rate Statements

Increasing HVAC System Outdoor: Air Challenge

- **ASHRAE** is advocating for **more energy efficient systems** (Standard 90.1 and 189) and **Decarbonization** (Position Document on Building Decarbonization)
- Increasing ventilation alone is less efficient than designing to minimum ventilation in accordance to Standard 62.1 and 62.2



100% Outside Air Systems: An Efficient, Healthy HVAC System Design Approach

- Proven to be **25 to 30% or more efficient** than conventional medium pressure VAV
- No return air path to the building, all building air is exhausted
- Energy recovery applied for heightened system efficiency
- Measurable outside air supplied to each zone
- Multiple approaches depending on building type and design
- Innovative technologies available

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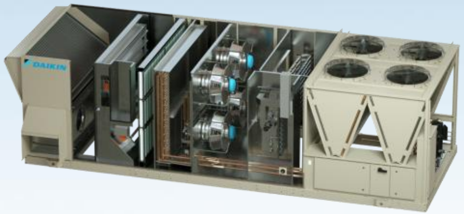
What are 100% OSA Systems?

What are 100% Outside Air Systems?

100% Outside Air (OSA) Systems: Design Intent

- **Outside air (ventilation load) is designed independently from and parallel to** the primary HVAC system
- Building airflow reduced by 60 to 70%
- **Reduced airflow = less duct work = reduced architectural space**

Decouple Total Load: Sensible (Heat) & Latent (Humidity)



(Courtesy: Daikin Applied)

- **Water & refrigerant: denser heat transfer mediums**
- Building **sensible load shifted to water or refrigerant** heat transfer mediums
- Building **humidity controlled by the 100% OSA unit**
- **Less energy** to move denser heat transfer mediums than fan energy for all air systems

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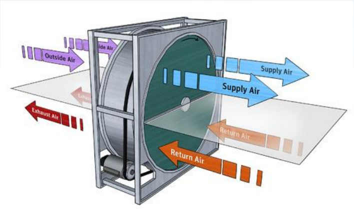
What are 100% Outside Air Systems?

100% Outside Air (OSA) Systems: Design Intent

- **Control OSA (ventilation) rates to each zone:**
  - Option: **Increase OSA air change rates** to levels as desired: **BEYOND CODE MINIMUM?.**
- Building **CO_2 concentrations** controlled to 1,000 PPM or below
- Improved **humidity control** through **lower dew point supply air**

100% Outside Air Unit (DOAS) Layout: Dual Tunnel Supply/Exhaust Units

- **Heat Recovery:** Building **exhaust air** used to **pre-condition OSA (summer or winter)**
  - **Sensible:** Plate & Frame, Heat-Pipe Technology, Sensible Wheel, Run-Around Coil Loop
  - **Enthalpy:** Enthalpy Wheel (Sensible and Latent Exchange), Plate & Frame Technology



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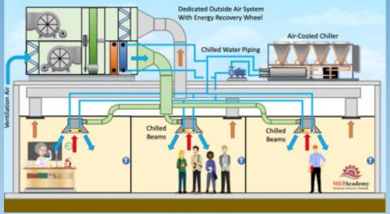
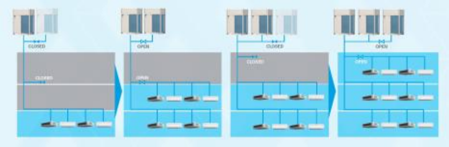
What are 100% Outside Air Systems?

Heat Transfer Medium and Efficiency

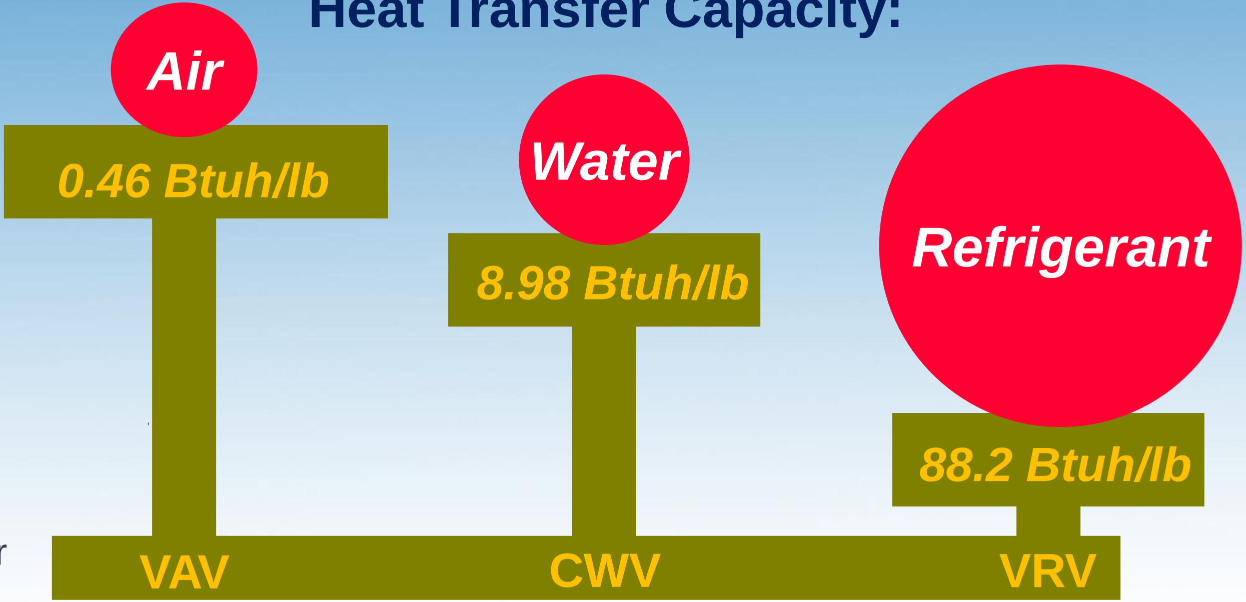
(Active Chilled Beam System)



(Variable Refrigerant System)



Heat Transfer Capacity:



Water & Refrigerant:

- More Dense Than Air
- More Efficient Heat Transfer Medium

Airside Systems:

- **More horsepower (energy)** to remove heat & moisture loads in lieu of water or refrigerant.

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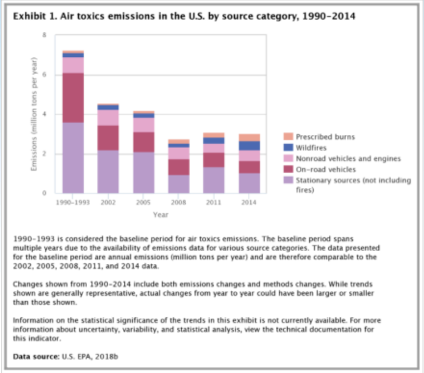
Indoor Air Contaminants and Human Health

Indoor Air Contaminants and Human Health

Outdoor Air Pollution: The Good News

- **Environmental Protection Agency: Report on the Environment**
  - “According to **NEI (National Emissions Inventory)** data, estimated annual emissions for the 187 **air toxics*** combined **decreased by 58 percent** from 72 million tons per year in the baseline period (1990-1993) to **3.0 million tons** per year in 2014 **(Exhibit 1)**.”

(Exhibit 1)



- “Examples of air toxics include benzene, found in gasoline; perchloroethylene, emitted from some dry cleaning facilities; and methylene chloride, used as a solvent by a number of industries.”
- “Most air toxics originate from anthropogenic sources, including mobile sources (e.g., cars, trucks, construction equipment), and stationary sources (e.g., factories, refineries, power plants…”

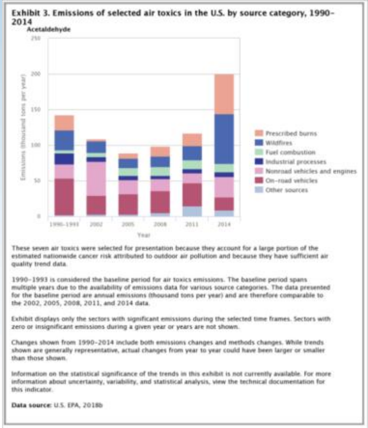
* Toxic Air Pollutants or hazardous air pollutants

Indoor Air Contaminants and Human Health

Outdoor Air Pollution: The Good News

- **Environmental Protection Agency: Report on the Environment**
  - "**Exhibit 3** shows emissions trends for seven pollutants believed to be among the pollutants that contribute to the greatest cancer and non-cancer risks that are attributed to air toxics according to an EPA assessment (U.S. EPA, 2018c)"

(Exhibit 3)



- "Estimated emissions decreased between the baseline period (1990-1993) and 2014 for five of the seven air toxics; **acrolein** (7%), **benzene** (58 %), **1,3-butadiene** (45%), **carbon tetrachloride** (98%) and **tetrachloroethylene** (97%)."
- **Acetaldehyde** increased by 40% and **formaldehyde** emissions increased by 6%...driven both by methodological changes and contributions from **wildfires and proscribed burns**."

* Toxic Air Pollutants or hazardous air pollutants

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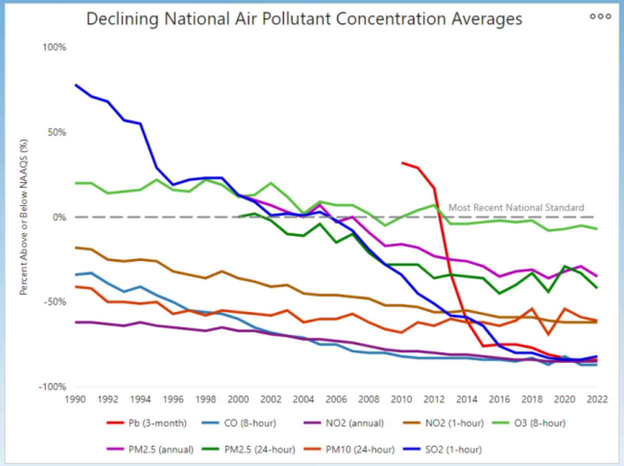
Indoor Air Contaminants and Human Health

Outdoor Air Pollution: The Good News

- **EPA: Air Quality Trends**
  - "**Carbon Monoxide (CO):** -81%
  - **Lead (Pb):** (3)- Month Average: -88%
  - **Nitrogen Dioxide (NO2):** -60%
  - **Ozone (O3):** -22%
  - **Particulate Matter PM10**: -34%
  - **Particulate Matter PM2.5**: -42%
  - **Sulfur Dioxide (SO2):** -90%



Percent Change in Air Quality

	1980 vs 2022	1990 vs 2022	2000 vs 2022	2010 vs 2022
Carbon Monoxide	-88	-81	-67	-27
Lead	---	---	---	-88
Nitrogen Dioxide (annual)	-66	-60	-52	-27
Nitrogen Dioxide (1-hour)	-65	-54	-38	-21
Ozone (8-hour)	-29	-22	-17	-7
PM_{10} (24-hour)	---	-34	-30	+21
$PM_{2.5}$ (annual)	---	---	-42	-21
$PM_{2.5}$ (24-hour)	---	---	-42	-16
Sulfur Dioxide (1-hour)	-94	-90	-85	-75

- "Despite increases in air concentrations of pollutants associated with fires, carbon monoxide and particle pollution, national **average air quality concentrations remain below the current, national standards**."

Downward Pollution Trends? What Happened?

Indoor Air Contaminants and Human Health

Outdoor Air Pollution: Government Standards

NRDC
NATURAL RESOURCES DEFENSE COUNCIL

- **October 26, 1948: The Donora, Pennsylvania Incident**
- A thick cloud of smog composed of carbon monoxide, sulfur dioxide, and metal dust produced by the towns zinc plant and steel mill descended on the town. 20 people killed and 14,000 fell sick
- **Response: The Air Pollution Control Act of 1955**

(Donora, PA. October 26, 1948 (National Geographic))

(Donora Wire Mills 1910 (Library of Congress))


Air Pollution Control Act of 1955

This law specifically states that:
"the prevention and control of air pollution at its source is the primary responsibility of State and local governments."

Consequent Legislation:

- **The Clean Air Act of 1963**
- **The Air Quality Act of 1967**
- **The Clean Air Act of 1970**

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Indoor Air Contaminants and Human Health

Outdoor Air Pollution: The Clean Air Act

- **Clean Air Act: Bi-Partisan Legislation became Law in 1970**
- **Unanimously passed by U.S. Senate and 374-to-1 in the House of Representatives** as a significant amendment to earlier laws

Signed into law by Richard Nixon on December 31st, 1970

Clean Air Act (1970)

- One of the most complex laws ever written;
- Identifies 6 criteria pollutants (CO, O_3, SO_2, NO_x, Pb, PM)
- Major revisions in 1977, 1985, 1990, 1995 to deal with toxic chemicals, stratospheric ozone, etc; (now CO_2)
- Considered by many to be a model environmental legislation and has been used as the basis for Clean Air Acts in many other countries.

http://www.epa.gov/air/criteria.html

- "In this law, Congress recognized **a right to healthful air quality**"
- "**The EPA** – which Richard Nixon established on December 2nd, 1970 – **was tasked with overseeing its implementation**.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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Indoor Air Contaminants and Human Health

Outdoor Air Pollution: The Clean Air Act

- **National Ambient Air Quality Standards: Contaminant Limits**
  - Lead
  - Ozone
  - Sulfur Dioxide
  - Nitrogen Dioxide
  - Carbon Monoxide
  - **Particulate Matter ($PM_{2.5}$, PM_{10})…**

Pollutant	Time Weighted Average	Concentration in Ambient Air: Industrial, Residential, Rural, and Other Areas	Concentration in Ambient Air: Ecologically Sensitive Area (notified by Central Government)
Sulphur dioxide (SO_2), µg/m³	Annual 24 hours	50 80	20 80
Nitrogen dioxide (NO_2), µg/m³	Annual 24 hours	40 80	30 80
Particulate matter (< 10 µm) or PM_{10}, µg/m³	Annual 24 hours	60 100	60 100
Particulate matter (< 2.5 µm) or $PM_{2.5}$, µg/m³	Annual 24 hours	40 60	40 60
Ozone (O_3), µg/m³	8 hours 1 hour	100 180	100 180
Lead (Pb), µg/m³	Annual 24 hours	0.50 1.0	0.50 1.0
Carbon monoxide (CO), mg/m³	8 hours 1 hour	02 04	02 04
Ammonia (NH_3), µg/m³	Annual 24 hours	100 400	100 400
Benzene (C_6H_6), µg/m³	Annual	05	05
Benzo(α)Pyrene (BaP) – particulate phase only, ng/m³	Annual	01	01
Arsenic (As), ng/m³	Annual	06	06
Nickel (Ni), ng/m³	Annual	20	20

- **Has The Clean Air Act Been Successful?**
  - Since 1990, **fine particulate matter pollution** – the deadliest form of air pollution has **declined 41 percent**
  - **Ozone has declined 22 percent**
  - An **NRDC 2020** report found that annual benefits of the Clean Air Act programs will prevent 370,000 premature deaths in 2020 and 457,000 deaths avoided by 2030. *
  - In 2018, a "documented" 30% death reduction since 2005 *

NRDC NATURAL RESOURCES DEFENSE COUNCIL

*** MIT News Office, February 12, 2020**

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Indoor Air Contaminants and Human Health

What About Indoor Environment Air Quality?

Which Indoor Air Quality Standards Are Written Into Law for Healthier Building Environments?

Indoor Air Contaminants and Human Health

EPA: Indoor Air Contamination Levels

- "EPA studies of human exposure to air pollutants indicate the **indoor levels of pollutants may be two to five times –** and occasionally more than 100 times **– higher than outdoor levels."**

Environmental Research and Public Health:

International Journal of *Environmental Research and Public Health*

- "According to the World Health Organization (WHO), indoor air pollution is responsible for the **deaths of 3.8 million people annually**."
- "Harmful pollutants inside buildings include carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter (PM) aerosol, biological pollutants and others**."** *

** Indoor Air Pollution, Related Human Diseases, and Recent Trends …(April 23, 2020)*

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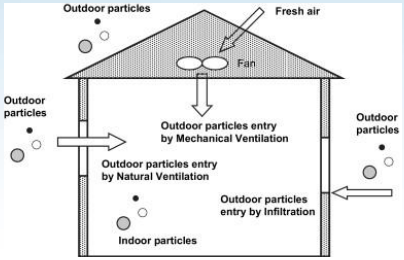
Indoor Air Contaminants and Human Health

Contamination Levels & CO_2:

Outdoor and Indoor Air Contaminants: Comparison

Indoor Air Pollutant

- Asbestos
- Biological Pollutants
- Carbon Monoxide
- Cook Stoves
- Formaldehyde/Pressed Wood Products
- Lead
- Nitrogen Dioxide
- Pesticides
- Radon
- Particulate Matter (PM)
- Volatile Organic Compounds
- Wood Smoke



Outdoor Air Pollutant

- Carbon Monoxide
- Lead
- Nitrogen Dioxide
- Ozone
- Particulate Matter (PM):Various Sizes
- Sulfur Dioxide)

(Note: Outdoor air contains other pollutants not regularly monitored by the EPA under The Clean Air Act)

Indoor Air Includes Outdoor Air Contaminants!

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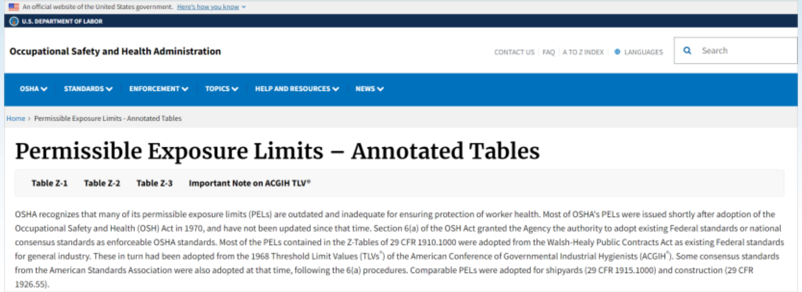
Indoor Air Contaminants and Human Health

WHAT ABOUT INDOOR AIR QUALITY STANDARDS?

Occupational Health and Safety Administration (OHSA)

- **OHSA created legally enforceable limits for exposure to pollutants indoors in 1970 for many chemicals based on a report created in 1968.**
- However, from OHSA's own website statement: **"OHSA recognizes many of its permissible exposure limits (PELs) are outdated and inadequate for ensuring protection of worker health."** *



An official website of the United States government. Here's how you know

U.S. DEPARTMENT OF LABOR

Occupational Safety and Health Administration

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Home › Permissible Exposure Limits - Annotated Tables

Permissible Exposure Limits – Annotated Tables

Table Z-1 | Table Z-2 | Table Z-3 | Important Note on ACGIH TLV®

OSHA recognizes that many of its permissible exposure limits (PELs) are outdated and inadequate for ensuring protection of worker health. Most of OSHA's PELs were issued shortly after adoption of the Occupational Safety and Health (OSH) Act in 1970, and have not been updated since that time. Section 6(a) of the OSH Act granted the Agency the authority to adopt existing Federal standards or national consensus standards as enforceable OSHA standards. Most of the PELs contained in the Z-Tables of 29 CFR 1910.1000 were adopted from the Walsh-Healy Public Contracts Act as existing Federal standards for general industry. These in turn had been adopted from the 1968 Threshold Limit Values (TLVs®) of the American Conference of Governmental Industrial Hygienists (ACGIH®). Some consensus standards from the American Standards Association were also adopted at that time, following the 6(a) procedures. Comparable PELs were adopted for shipyards (29 CFR 1915.1000) and construction (29 CFR 1926.55).

OSHA®

(Occupational Health and Safety Administration)

* Healthy Buildings: Dr. Joseph Allen, Dr. John Macomber

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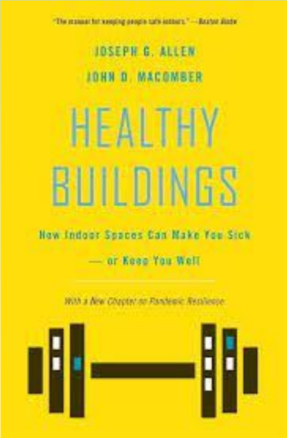
Indoor Air Contaminants and Human Health

WHAT ABOUT INDOOR AIR QUALITY STANDARDS?

Healthy Buildings: How Indoor Spaces Can Make you Sick – or Keep You Well (2022 Edition)

- **Dr. Joseph Allen** (Director of Harvard's Healthy Buildings Program)
- **Dr. John Macomber** (Lecturer at Harvard Business School)



Built Environment Statistics: *Global Mega Changes Shaping Our World, Our Buildings, and Us*

- **"Buildings represent the largest consumer of materials of all industries in the world."**
- "Approximately 80% of global energy comes from fossil fuel combustion, and as consumers of 40% of that energy, **buildings influence our health indirectly** by contributing to…the amount of air pollutants and greenhouse gases produced by our energy generation." *

*** Healthy Buildings: Dr. Joseph Allen, Dr. John Macomber**

Indoor Air Contaminants and Human Health

WHAT ABOUT INDOOR AIR QUALITY STANDARDS?

- **"…we tend to focus much more on outdoor air quality than on indoor air quality."***
- Is there an **Indoor Air Quality Standard**? **"NO SUCH THING."***

1970's Energy Crisis: Sealing of Buildings

- Building minimum outside air rates reduced to **5 cfm/person**
- **Sick Building Syndrome**: *"A set of symptoms (such as headache, fatigue and eye irritation) typically affecting workers in airtight office buildings that is believed to be caused by indoor air pollutants (such as formaldehyde, fumes and microorganisms.* (Merriam-Webster)
- **Sick Building Syndrome can occur in any building**
- **Airtight buildings** are often the culprit
- Fumes, technically particles suspended in the air such as wildfire smoke, impact indoor air quality (IAQ)

* Healthy Buildings: Dr. Joseph Allen, Dr. John Macomber

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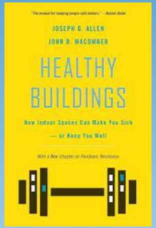
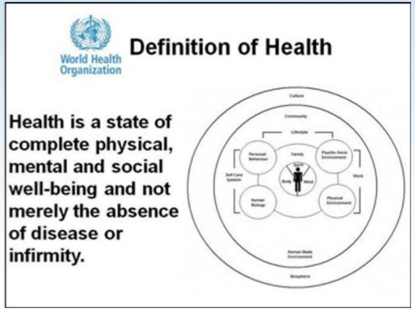
Indoor Air Contaminants and Human Health

Healthy Buildings: The Sixth Mega Change



Changing Definition of Health

- Old Definition of Health: ***"The Absence of Disease"***
- Replaced by the **World Health Organization (WHO)** new definition: **"State of Complete Physical, Mental and Social Well-Being"**
- "Companies are recognizing that there is value in not just a disease avoidance strategy for their employees but also **a health promotion strategy.**"*



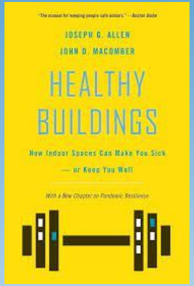
WHO Constitution:

- "The health of all peoples is fundamental to the attainment of peace and security and is dependent on the fullest co-operation of individuals and States…"
- "Informed opinion and active co-operation on the part of the public are of the utmost importance in the improvement of the health of the people."

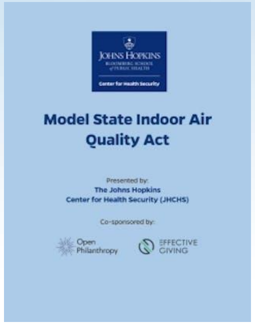
* **Healthy Buildings: Dr. Joseph Allen, Dr. John Macomber**

Indoor Air Contaminants and Human Health

Why Are We Ignoring the 90 Percent?



- **“North America and Europe: 90% or more of our time is spent indoors**
- By the time one is 40 they will have spent **36 years indoors**, by the time they are 80, **72 years indoors**
- For kids…by the time they graduate from high school, they will have spent **15,600 hours inside a school**.”
- “Heck, we spend **a third of our lifetime in one little box** on our planet – **our bedrooms**.” *



Outdoors vs. Indoors:

- The United States regulatory system is geared to outdoor air quality.
- The **Clean Air Act** set the **National Ambient Air Quality Standards** and have successfully reduced outdoor air pollution
- **Is an Indoor Air Quality Act in our future?**

*** Healthy Buildings: Dr. Joseph Allen, Dr. John Macomber**

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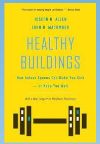
Indoor Air Contaminants and Human Health

Indoor Air Quality (IAQ) and Human Health

- ***"The Dirty Little Secret of Outdoor Air-Pollution"***



COUNTER INTUITIVE

- "Because we spend 90 percent of our time indoors…**we spend 21 hours a day inside and less than 3 hours outside**…the math is very straight forward,…**the majority of outdoor air pollution occurs indoors."**

(Los Angeles, Callfornia (2022)

Los Angeles-North Main Street Air Pollution: Real-time Air Quality Index (AQI)

	Current	Max
PM2.5 AQI	16	64
PM10 AQI	30	39
O3 AQI	49	54
NO2 AQI	11	37

6 more rows

(Global Cities, 2022)

Rank	City	2022
1	**Lahore, Pakistan**	97.4
2	Hotan, China	94.3
3	Bhiwadi, India	92.7
4	Delhi (NCT), India	92.6

Adult Breathing Rates & Outdoor Air Pollution Breathed per Day

- Average Adult Breathing Rate: **1,000 breathes per hour**
- Each breath is approximately, 0.625 m³ (22.1 ft³) or 15 m³ (~529.1 ft³) per day
- **Total Outdoor Air Pollution Breathed 2.4 hours = 30 µg/day**
- **Total Outdoor Air Pollution Breathed Indoors in 21.6 hours = 135 µg/day**

44 HEALTHY BUILDINGS

TABLE 3.1 The dirty secret of outdoor air pollution.

	Outdoor Air Pollution	Breathing Rate	Time Spent Indoors	Total *Outdoor* Air Pollution Breathed per Day
Outdoors	20 µg/m³	0.625 m³/hour	2.4 hours (10% of 24 hours)	30 µg/day
Indoors	10 µg/m³	0.625 m³/hour	21.6 hours (90% of 24 hours)	135 µg/day

* Healthy Buildings: Dr. Joseph Allen, Dr. John Macomber

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Indoor Air Contaminants and Human Health

Indoor Air Quality (IAQ) and Human Health

- **Intl. Journal of *Environmental Research and Public Health***
  - Report: ***Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality***
  - Indoor pollutants: **Particulate Matter (PM)**, Volatile Organic Compounds (VOCs), Nitrogen Dioxide (NO_2), Ozone (O_3), Carbon Monoxide (CO), Sulfur Dioxide (SO_2), Toxic Metals, Aerosols, Radon, Pesticides, Biological Pollutants

- **Particulate Matter ($PM_{2.5}$, PM_{10}):**
  - "**PM** is defined as carbonaceous particles in association with absorbed organic chemicals and reactive metals"* **(Q. Di et al., "Air Pollution and Mortality in the Medicare Population," *New England Journal of Medicin 376, No 26 (2017)*)**
  - **Indoor PM** sources include (i) particles that migrate from outdoors, (II) particles generated by indoor activities; cooking, fossil fuel combustion, smoking, machine operation, and residential hobbies …etc."


Int. J. Environ. Res. Public Health 2020, 17, 2927 — 7 of 27

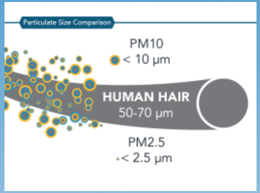
Table 1. Common indoor pollutants and their effects on human health.

Pollutants	Sources	Health Impacts	Refs
PM	Outdoor environment, cooking, combustion activities (burning of candles, use of fireplaces, heaters, stoves, fireplaces and chimneys, cigarette smoking), cleaning activities	Premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, increased respiratory symptoms	[illegible]
VOCs	Paints, stains, varnishes, solvents, pesticides, adhesives, wood preservatives, waxes, polishes, cleansers, lubricants, sealants, dyes, air fresheners, fuels, plastics, copy machines, printers, tobacco products, perfumes, dry-cleaned clothing, building materials and furnishings	- Eye, nose and throat irritation - Headaches, loss of coordination and nausea - Damage to liver, kidney and central nervous system - Some organics can cause cancer	[illegible]
NO_2	Gas-fueled cooking and heating appliances	- Enhanced asthmatic reactions - Respiratory damage leading to respiratory symptoms	[illegible]
O_3	Outdoor sources, photocopying, air purifying, disinfecting devices	DNA damage, lung damage, asthma, decreased respiratory functions	[illegible]
SO_2	Cooking stoves, fireplaces, outdoor air	- Impairment of respiratory function - Asthma, chronic obstructive pulmonary disease (COPD), and cardiovascular diseases	[illegible]
CO	Cooking stoves, tobacco smoking, fireplaces, generators and other gasoline powered equipment, outdoor air	Fatigue, chest pain, impaired vision, reduced brain function	[illegible]
Heavy metals	Pb, Cd, Zn, Cu, Cr, As, Ni, Hg, Mn, Fe Outdoor sources, fuel-consumption products, incense burning, smoking and building materials	- Cancers, brain damage - Mutagenic and carcinogenic effects, respiratory illnesses, cardiovascular deaths	[illegible]
Aerosols	Tobacco smoke, building materials, consumer products, incense burning, cleaning and cooking	Cardiovascular diseases, respiratory diseases, allergies, lung cancer, irritation and discomfort	[illegible]
Radon (Rn)	Soil gas, building materials, and tap water Outdoor air	Lung cancer	[illegible]
Pesticides	- Termiticides, insecticides, rodenticides, fungicides, disinfectants and herbicides - Building materials: carpet, textiles, and cushioned furniture - Outdoor environment	Irritation to eye, nose and throat; Damage to central nervous system and kidney; Increased risk of cancer	[illegible]
Biological allergens	House dust, pets, cockroaches, mold/dampness, pollens originating from animals, insects, mites, and plants	Asthma and allergies Respiratory infections, sensitization, respiratory allergic diseases and wheezing	[illegible]
Microorganism	Bacteria, viruses, and fungi are carried by people, animals, and soil and plants	Fever, digestive problems, infectious diseases, chronic respiratory illness	[illegible]

(Table 1. Common indoor pollutants and their effects on human health)

Indoor Air Contaminants and Human Health

Indoor Air Quality (IAQ) and Human Health



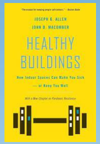
- **Particulate Matter ($PM_{2.5}$, PM_{10}):**
  - "$PM_{2.5}$ particulate matter: **2.5 micrometers (µm) or smaller**
  - (1) micrometer = 0.001 meters or 0.000039 inches
  - "PM is especially concerning, as it is sometimes inhalable, affecting the lungs and heart and causing serious health effects"
  - "…**particles less than 2.5 micrometers in diameter**…**pose the greatest health risk**"

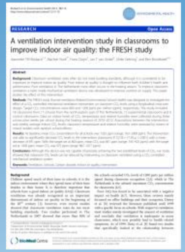
- **Global $PM_{2.5}$ Contaminant Levels:**
  - PubMed lists over **7,000 scientific papers on PM 2.5** health effects
  - **"Mortality rates increase by 7 percent for every 10 µg/m³ of $PM_{2.5}$**
  - "Hospital admissions increase by over 4 percent for every **10 µg/m** long term increase in $PM_{2.5}$*
  - "5 percent of lung cancer deaths globally are attributable to particulate matter (PM)"

* Healthy Buildings: Dr. Joseph Allen, Dr. John Macomber

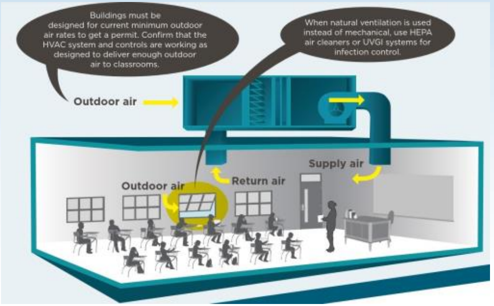
Indoor Air Contaminants and Human Health

Indoor Air Quality (IAQ) and Human Health





- **Classroom IAQ and Student Performance: Statistics**
  - “There are over **200 scientific studies** documenting how the **school *building* influences student health, student thinking, and student performance.”***
  - Cognitive testing of students shows a **5 percent decrease in “power of attention” in poorly ventilated classrooms**.
  - Researchers equate this to a student’s missing breakfast”*



- “In a study of over 4,000 sixth graders, **lower ventilation rates**, moisture and dampness…were all independently associated with a **higher incidence of respiratory symptoms**
- **Inadequate ventilation** was also associated with more missed school days” *

* Healthy Buildings: (Chapter 3 Note 1) Dr. Joseph Allen, Dr. John Macomber

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Indoor Air Contaminants and Human Health

Indoor Air Quality (IAQ) and Human Health

- **Classroom IAQ and Student Performance: Statistics**
  - A study of over 3,000 fifth-grade students showed that they had **higher math, reading, and science scores in classrooms with higher ventilation rates.***

American Lung Association.

Is Thermal Comfort a Factor?:

- "In a study of exam records for nearly one million school students in New York City, the likelihood of failing an exam taken on a 90°F day versus a 75°F day is 14 percent greater"*

National Lung Association: *From Absences to Aces…*

- **Reduce Absenteeism:** poor indoor air quality can lead to higher rates of respiratory infections, allergic responses and adverse reactions to chemicals **
- **Asthma** is one of the leading causes of school absenteeism causing **an estimated 13.8 million lost school days** in children ages 5-17. **

* Healthy Buildings: (Chapter 3 Note 1) Dr. Joseph Allen, Dr. John Macomber
** American Lung Association: *From Absences to Aces*

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Indoor Air Contaminants and Human Health

IAQ and Human Health: Short & Long Term Impact

- **National Institute of Environmental Health Sciences: Indoor Air Quality**
  - "Studies suggest that indoor concentrations of air pollutants are increasing, driven by factors such as types of chemicals in home products, inadequate ventilation, hotter temperatures and humidity" *

- **Cardiovascular Disease:** A study partially supported by NIEHS found that markers of cardiovascular disease risk appear when ozone levels are even lower than current EPA air quality standards…in healthy adults, exposure to short-term indoor and outdoor ozone was linked to increased blood platelets, a risk factor for clotting and increased blood pressure.
- **Cognitive Effects:** Indoor exposures to air pollutants, including particulate matter, allergens, oxides of nitrogen, endotoxin, and mold have been associated with impaired health and performance in children and adults…
  - **The air quality within an office:** affect employees' cognitive function, including response times and ability to focus, and it may also affect their productivity…*

* National Institute of Environmental Health Sciences: Indoor Air Quality

Indoor Air Contaminants and Human Health

IAQ and Human Health: Short & Long Term Impact

- **National Institute of Environmental Health Sciences: Indoor Air Quality**
  - **Cancer:** Long-term exposure to radon or other indoor air substances that increase the chances of developing lunch cancer; secondhand smoke, asbestos, arsenic, and some forms of silica and chromium
    - **Indoor air contaminants, such as the carcinogen formaldehyde, exceed acceptable levels in some early childhood leaning centers***

TECHNICAL FEATURE

Revisiting the 1,000 ppm CO_2 Limit

ROBERT E. STUMM P.E.

The 1989 revision of ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality*, states that "comfort (odor) criteria are likely to be satisfied if the ventila-

- **ASHRAE Carbon Dioxide (CO_2) Limits Revisited:**
  - **ASHRAE Standard 62-1999** replaced the original (CO_2) limit (1,000 ppm)…stating that **indoor CO_2 should not be 700 ppm or less above the ambient outdoor concentration**…"
  - "…several studies providing substantial evidence of **acute exposure to CO_2 at levels as low as 1,000 ppm** inducing significant reductions in cognition and decision-making abilities…"**

* National Institute of Environmental Health Sciences: Indoor Air Quality

** *"Revisiting the 1,000 ppm CO_2 Limit"*, (ASHRAE Journal, June 2022)

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Indoor Air Contaminants and Human Health

IAQ and Human Health: Short & Long Term Impact

- **Healthy Buildings (Macomber & Allen): *The Impacts of Higher Ventilation on Your Income Statement”* ***
  - Does increasing a building’s ventilation rate improve a companies productivity and profitability?*
  - Sample Business (consulting firm) of 40 employees, average salary $75,000/year
  - Business overhead: $3,000,000 payroll, $300,000 rent, $30,000 energy cost

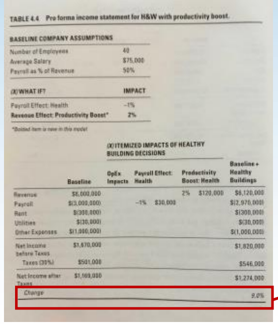

TABLE 4.4 Pro forma income statement for H&W with productivity boost.

BASELINE COMPANY ASSUMPTIONS	
Number of Employees	40
Average Salary	$75,000
Payroll as % of Revenue	50%

(X) WHAT IF?	IMPACT
Payroll Effect: Health	–1%
Revenue Effect: Productivity Boost*	**2%**

*Bolded item is new in this model

	Baseline	(X) ITEMIZED IMPACTS OF HEALTHY BUILDING DECISIONS: OpEx Impacts	Payroll Effect: Health		Productivity Boost: Health		Baseline + Healthy Buildings
Revenue	$6,000,000				2%	$120,000	$6,120,000
Payroll	$(3,000,000)		–1%	$30,000			$(2,970,000)
Rent	$(300,000)						$(300,000)
Utilities	$(30,000)						$(30,000)
Other Expenses	$(1,000,000)						$(1,000,000)
Net Income before Taxes	$1,670,000						$1,820,000
Taxes (30%)	$501,000						$546,000
Net Income after Taxes	$1,169,000						$1,274,000
Change							9.0%

Action: Double Ventilation from 20 to 40 cfm/person

- “Documented **improvements in thinking…like focused activity, information usage, and strategy**
- More billable hours, more client assignments and more engagements sold
- **Revenue productivity boost 2% or more = 9% bottom line increase****

*** P. Wargocki et. al., *“The Effects of Outdoor Air Supply Rate in an Office on Perceived Air Quality, Sick Building Syndrum (SBS) Symptoms and Productivity,”*** *Indoor Air 10 No. 4 (2000)*

**** Healthy Buildings: (Chapter 4, Ventilation and Cognitive Function) Dr. Joseph Allen, Dr. John Macomber**

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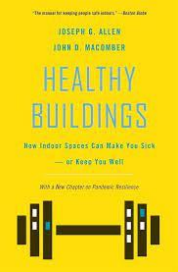
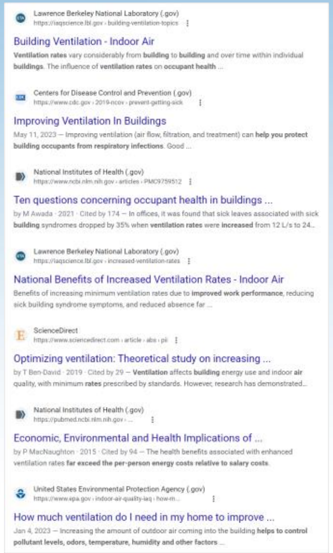
Indoor Air Contaminants and Human Health

IAQ and Human Health: Major Points of Interest



- Numerous studies and research more than suggest one way **to improve in indoor air quality and occupant health** is to **increase the ventilation rate**.



Lawrence Berkeley National Laboratory (.gov)
https://iaqscience.lbl.gov › building-ventilation-topics

Building Ventilation - Indoor Air

Ventilation rates vary considerably from **building** to **building** and over time within individual **buildings**. The influence of **ventilation rates** on **occupant health** ...

Centers for Disease Control and Prevention (.gov)
https://www.cdc.gov › 2019-ncov › prevent-getting-sick

Improving Ventilation In Buildings

May 11, 2023 — Improving ventilation (air flow, filtration, and treatment) can **help you protect building occupants from respiratory infections**. Good ...

National Institutes of Health (.gov)
https://www.ncbi.nlm.nih.gov › articles › PMC9759512

Ten questions concerning occupant health in buildings ...

by M Awada · 2021 · Cited by 174 — In offices, it was found that sick leaves associated with sick **building** syndromes dropped by 35% when **ventilation rates** were **increased** from 12 L/s to 24...

Lawrence Berkeley National Laboratory (.gov)
https://iaqscience.lbl.gov › increased-ventilation-rates

National Benefits of Increased Ventilation Rates - Indoor Air

Benefits of increasing minimum ventilation rates due to **improved work performance**, reducing sick building syndrome symptoms, and reduced absence far ...

ScienceDirect
https://www.sciencedirect.com › article › abs › pii

Optimizing ventilation: Theoretical study on increasing ...

by T Ben-David · 2019 · Cited by 29 — **Ventilation** affects **building** energy use and indoor **air** quality, with minimum **rates** prescribed by standards. However, research has demonstrated...

National Institutes of Health (.gov)
https://pubmed.ncbi.nlm.nih.gov › ...

Economic, Environmental and Health Implications of ...

by P MacNaughton · 2015 · Cited by 94 — The health benefits associated with enhanced ventilation rates **far exceed the per-person energy costs relative to salary costs**.

United States Environmental Protection Agency (.gov)
https://www.epa.gov › indoor-air-quality-iaq › how-m...

How much ventilation do I need in my home to improve ...

Jan 4, 2023 — Increasing the amount of outdoor air coming into the building **helps to control pollutant levels, odors, temperature, humidity and other factors** ...

- Data is available to demonstrate **improving IAQ** is one good way **to boost employee productivity** and to **increase a company's bottom line**
- Will insurance companies lobby congress to address building IAQ?
- Remember, consuming more energy to increase ventilation is not necessary when an appropriate HVAC system is designed, **100% Outside Air Systems**

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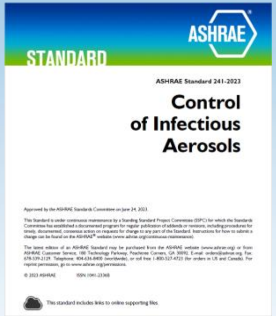
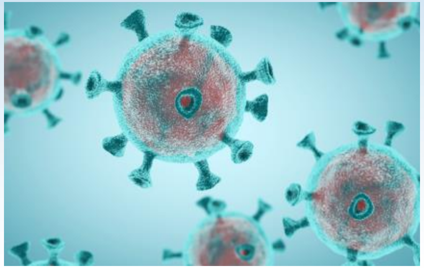
ASHRAE Standard 241-2003:
Control of Infectious Aerosols

ASHRAE Standard 241-2023

Standard 241: Purpose

- *“The purpose of this standard is to establish minimum requirements for control of infectious aerosols to reduce risk of disease transmission in the occupiable space in new buildings, existing buildings and major renovations including requirements for outdoor air system and air cleaning system design…”*





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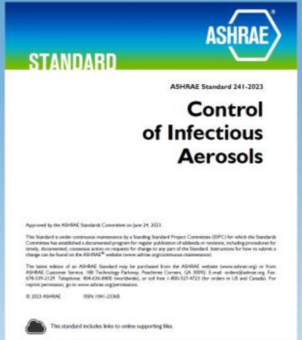
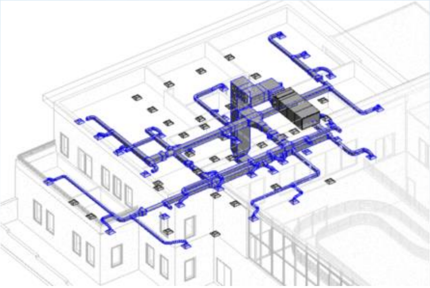
ASHRAE Standard 241-2023

ASHRAE Standard 241-2023:

Standard 241 Foreward:

- *“The catalyst for the development of Standard 241 was* ***discussion between ASHRAE and the White House*** *COVID-19 Response Team about* ***the need for new and better IAQ standards****.”*
- “Engineering controls – dilution ventilation, filtration, and air disinfection – can reduce the concentration of active pathogens in the air”*





ASHRAE Standards Committee Approved Standard 241 June 24, 2023

- *“Airborne transmission of communicable diseases occurs when a susceptible person inhales a sufficient number of active pathogens to cause an infection, i.e. an infectious dose.”**
- *Standard addresses long-range airborne transmission*

* Standard 241-2023: Foreward

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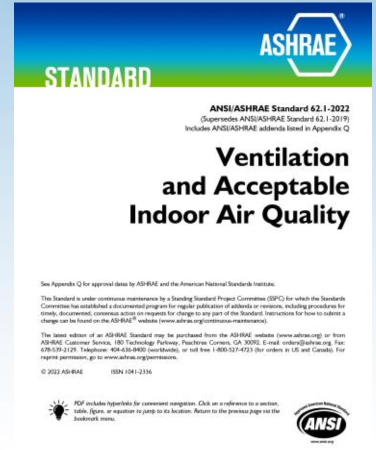
ASHRAE Standard 241-2023

Standard 241 Scope: “ASHRAE Standard 62.1 & 62.2”

- *“The project scope…stated the intention to work to* ***incorporate similar provisions into existing ASHRAE IAQ standards, specifically ANSI/ASHRAE Standards 62.1 and 62.2****, perhaps as optional requirements.”*


STANDARD

ANSI/ASHRAE Standard 62.1-2022
(Supersedes ANSI/ASHRAE Standard 62.1-2019)
Includes ANSI/ASHRAE addenda listed in Appendix Q

Ventilation and Acceptable Indoor Air Quality

See Appendix Q for approval dates by ASHRAE 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. Instructions for how to submit a change can be found on the ASHRAE® website (www.ashrae.org/continuous-maintenance).

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PDF includes hyperlinks for convenient navigation. Click on a reference to a section, table, figure, or equation to jump to its location. Return to the previous page via the bookmark menu.

Standard 241 Foreward “*Requirements*”

- *“A requirement that systems comply with the requirements of the applicable ventilation and indoor air quality standards (e.g.* ***ANSI/ASHRAE Standards 62.1 and 62.2****…*
- *Standard 241 provides additional requirements for an* ***infection risk management mode of operation (IRMM)*** *that applies during periods when higher levels of infection risk mitigation* ***are desired (e.g. building owners) or are required by authorities****…”*

**** Authority Having Jurisdiction (AHJ)***

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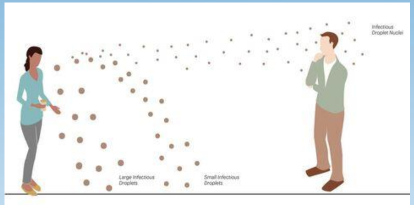
ASHRAE Standard 241-2023

Standard 241 Foreward: Definitions

- *"**Infection Risk Management Mode (IRMM)**: the mode of operation in which measures to reduce infectious aerosol exposure in documented building readiness plan are active…"*



Standard 241 Foreward: "Equivalent Clean Air (ECAi)"

- *"Requirements for **infection risk management** given in terms of **equivalent clean airflow** rate in units of **flow per occupant** in a space **(ECAi)**."*
- **ECAi Definition**: *"the theoretical flow rate of pathogen-free air that, if distributed uniformly within the breathing zone, would have the same effect on infectious aerosol concentration as **the sum of actual outdoor airflow, filtered airflow, and inactivation of infectious aerosols**."*

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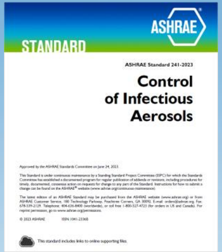
ASHRAE Standard 241-2023

Standard 241 Foreward: “Equivalent Clean Air (ECAi)”

- *“The **equivalent clean airflow requirement** for a space or system can be met **not only by outdoor air** but also by **filtered recirculated air and air disinfected by various other technologies**.”*
- *“Requirements for **air distribution** in mechanically ventilated, naturally ventilated, and mixed-mode buildings, and requirements for application of in-room air cleaners” are addressed in Par. 7 under “Air Cleaning”*



Equivalent Clean Air (ECAi): Calculation

- The **minimum ECAi airflow rate** can be met either by **outdoor air meeting the minimum ECAi requirement per person** per Table 5-1, or any combination of OSA**, providing minimum OSA per Standard 62.1 is met**, and **supplemental return air treated by filtration or other air disinfecting technology** that meets the standards product testing requirements

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ASHRAE Standard 241-2023

Standard 241 Par. 5: Equivalent Clean Airflow for Infection Risk Mitigation

- **ECAi Calculation:**
  - $V_{ECAi} = ECAi \times P_{z,IRMM}$

V_{ECAi} = minimum *equivalent clean airflow* rate required in the breathing zone to mitigate *long-range transmission* risk in *IRMM*, cfm (L/s)

ECA_i = *equivalent clean airflow* rate required per person in *IRMM* from Table 5-1, cfm (L/s) per person

$P_{Z,IRMM}$ = number of people in the breathing zone in *IRMM*. $P_{Z,IRMM}$ shall default to the number of occupants used to calculate the ventilation rate per the applicable standard (see Section 4.1.1) or design occupancy or lower number of occupants during *IRMM* accepted by the owner.

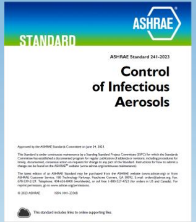

Table 5-1 Minimum Equivalent Clean Airflow per Person in Breathing Zone in IRMM

Occupancy Category	ECAi cfm/person	ECAi L/s/person
Correctional Facilities		
Cell	30	15
Dayroom	40	20
Commercial/Retail		
Food and beverage facilities	60	30
Gym	80	40
Office	30	15
Retail	40	20
Transportation waiting	60	30
Educational Facilities		
Classroom	40	20
Lecture hall	50	25
Industrial		
Manufacturing	50	25
Sorting, packing, light assembly	20	10
Warehouse	20	10
Health Care		
Exam room	40	20
Group treatment area	70	35
Patient room	70	35
Resident room	50	25
Waiting room	90	45
Public Assembly/Sports and Entertainment		
Auditorium	50	25
Place of religious worship	50	25
Museum	60	30
Convention	60	30
Spectator area	50	25
Lobbies	50	25
Residential		
Common space	50	25
Dwelling unit	30	15

Standard 241: Table 5.1 *Minimum ECAi…*

- **Minimum ECAi rates taken from Table 5.1:**
  - Commercial / Retail:
    - Food & Beverage Facilities: 60 cfm / person
    - Gym: 80 cfm / person
    - Office: 30 cfm / person
  - Public Assembly / Sports and Entertainment:
    - Auditorium: 50 cfm / person
    - Place of Religious Worship: 50 cfm / person
    - Lobbies: 50 cfm / person

(Table 5-1: Minimum Clean Airflow per Person in Breathing Zone in IRMM)

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ASHRAE Standard 241-2023

Standard 241: Section 7. Air Cleaning

- **Par. 7.1 Testing Requirements**
- **Par. 7.2 Calculated Effectiveness of Air Cleaning Systems**
  - Par. 7.2.1 In-Duct Air Cleaning Systems that Clean Air in the Air-Handling Unit, Ductwork, or Plenum
  - Par. 7.2.2 In-Duct Air Cleaning Systems that Clean Air in the Occupied Zone
  - Par. 7.2.3 In-Room Air Cleaning Systems
- **Par. 7.3 Mechanical Fibrous Air Cleaning Systems**
  - Par. 7.3.1 Infectious Aerosol Removal Efficiency for Mechanical Fibrous Filters Installed In-Duct
  - Par. 7.3.2 Equivalent Clean Airflow Rate for In-Room Air Cleaning Systems Using only Mechanical Fibrous Filters
- **Par. 7.4 Air Cleaning Systems that Inactivate Infectious Aerosols**
  - Par. 7.4.1 In-Duct Air Cleaning Systems
    - Par. 7.4.1.1 In-Duct Ultraviolet Germicidal Irradiation
  - Par. 7.4.2 In-Room Air Cleaning Systems
    - Par. 7.4.2.1 Upper in-room ultraviolet germicidal irradiation
    - Par. 7.4.2.2 Other In-Room Air Cleaning Systems

Table 7-1 Infectious Aerosol Removal Efficiency (ε_{PR}) for Mechanical Fibrous Filters

ANSI/ASHRAE Standard 52.2 MERV (Prior to 1/1/2025) MERV-A (After 1/1/2025)	ISO 16890 ePM	Weighted ε_{PR}
<11		0%
11	ePM2.5 50%	60%
12	ePM2.5 65%	71%
13	ePM1 50%	77%
14	ePM1 70%	88%
15	ePM1 85%	91%
16	ePM1 95%	95%
HEPA [a]	ISO 20E [b]	99%

a. High-efficiency particulate air (HEPA) filters are not tested under ANSI/ASHRAE Standard 52.2 or ISO 16890-1. However, HEPA filters are included here for completeness.
b. Tested in accordance with ISO 29463 [7].

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ASHRAE Position Document on Indoor Carbon Dioxide

Air Quality, Contaminants & CO_2

Contamination Levels and CO_2:

- “EPA studies of human exposure to air pollutants indicate the **indoor levels of pollutants may be two to five times** – and occasionally more than 100 times – **higher than outdoor levels.”**

ASHRAE Journal: June 2022

- “CO_2 is a stoichiometric by-product of both hydrocarbon fuel combustion and biological metabolism…”
- **“…measuring CO_2 concentration offers an easy … way to gage the concentration of the other pollutants.”**

(*Revisiting the CO_2 Limit:* By Robert Stumm, P.E.)

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Air Quality, Contaminants & CO_2

Contamination Levels and CO_2:

- **Robert Stumm, P.E.:** "Suggested here is that some **statistical correlation may exist between the concentration of CO_2 and that of the aggregate of other by-product pollutants** affecting human comfort and wellness."


IEQ APPLICATIONS
Column

ASHRAE Position Document on Indoor CO_2

(By: Robert E. Stumm, P.E.)

ResearchGate

Phoenix: Research Gate 2013 Report

- "…the presence of an **"urban CO_2 dome" that reaches 555 ppm** in the city center and decreases to…~370 ppm on the outskirts."

ASHRAE Standard 62.1-1999: Indoor Air CO_2 Levels

- **Satisfactory Indoor CO_2 Limit of 700 ppm above outdoor CO_2 Concentrations** (Based on Outdoor CO_2 Concentrations in the 1980's of ~350 ppm.)
- **Urban Phoenix: 555 ppm + 700 = 1255 ppm indoor CO_2**

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Air Quality, Contaminants & CO_2

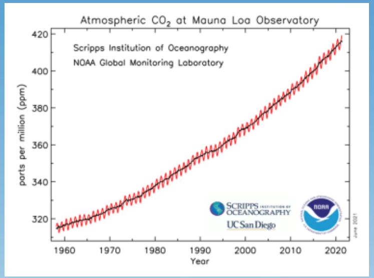
Contamination Levels and CO_2: ASHRAE Journal: June 2022

- Phoenix CO_2 Urban Dome in 2021?

TABLE 1 Nominal daily maximum CO_2 levels (ppm) at select urban sites compared with Mauna Loa values.

SITE	DATA YEAR	MAUNA LOA	URBAN	DIFFERENCE
Phoenix, Ariz.	2000	369	575[12]	206
Baltimore	2006	382	488[13]	106
Evanston, Ill.	2011	392	440[14]	48
Los Angeles	2015	400	622[15]	222

Mauna Loa Data from Reference 8. Data current as of July 2021.



(Scripts Institute of Oceanography: NOAA Global Monitoring Laboratory)

Phoenix CO_2 Dome July 2021 = 575 ppm

Boston University Study: Between 1990 to 2017:

CO_2 Increase of 291%

CO_2 [ppm]	Air Quality
2100	BAD Heavily contaminated indoor air Ventilation required
2000	
1900	
1800	
1700	
1600	
1500	MEDIOCRE Contaminated indoor air Ventilation recommended
1400	
1300	
1200	
1100	
1000	FAIR
900	
800	GOOD
700	
600	EXCELLENT
500	
400	

(Indoor Quality CO_2 Website)

Robert Stumm Article: Conclusions

- "…substantial evidence of **acute exposure to CO_2 at levels as low as 1,000 ppm** inducing significant **reductions in cognition and decision-making abilities**."
- "Considering the recent studies showing CO_2 directly impacting human health, in particular cognition and decision-making, the **indoor CO_2 level of 1,000 ppm reappears as a sensible, time-honored upper limit**…

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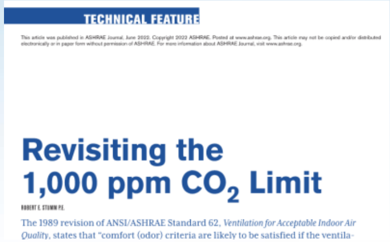
Indoor Air Contaminants and Human Health

IAQ and Human Health: Short & Long Term Impact

- **National Institute of Environmental Health Sciences: Indoor Air Quality**


TECHNICAL FEATURE

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Revisiting the 1,000 ppm CO_2 Limit

ROBERT E. STUMM P.E.

The 1989 revision of ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality*, states that "comfort (odor) criteria are likely to be satisfied if the ventila-

- **ASHRAE Carbon Dioxide (CO_2) Limits Revisited:**
  - **ASHRAE Standard 62-1999** replaced the original (CO_2) limit (1,000 ppm)…stating that **indoor CO_2 should not be 700 ppm or less above the ambient outdoor concentration**…"
  - "…several studies providing substantial evidence of **acute exposure to CO_2 at levels as low as 1,000 ppm** inducing significant reductions in cognition and decision-making abilities…"**

* National Institute of Environmental Health Sciences: Indoor Air Quality
** *"Revisiting the 1,000 ppm CO_2 Limit"*, (ASHRAE Journal, June 2022*)*

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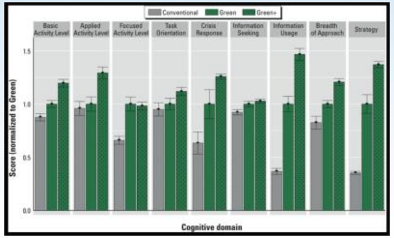
Indoor Air Contaminants and Human Health

IAQ and Human Health: Short & Long Term Impact

- **Healthy Buildings (Macomber & Allen): *The False Choice of "Energy and Health"* ***
  - "Indoor CO_2 is mostly from indoor human respiration"*
  - "In one study of 100 non-problem buildings in the United States, **the 95th percentile CO_2 concentration was about 1,500 ppm**"
  - "…**Lawrence Berkeley National Laboratory studied 162 classrooms across 28 elementary schools in California** and found that **the average CO_2 concentration was above 1,500 ppm**."
  - "In Texas, **one in five schools tested** had **peak CO_2 concentrations above 3,000 ppm**."*



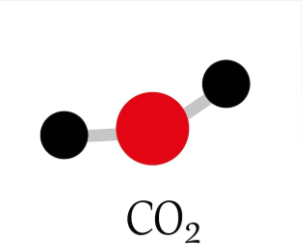
- **One Solution: Increase Ventilation ****
  - Three different factors tested for cognitive function; ventilation, volatile organic compounds, carbon dioxide (CO_2)
  - Ventilation rate doubled from 20 cfm/person to 40 cfm/person
  - "…VOC's and carbon dioxide can largely be controlled…through higher ventilation rates." **

* National Institute of Environmental Health Sciences: Indoor Air Quality
** Healthy Buildings: (Chapter 4, Ventilation and Cognitive Function) Dr. Joseph Allen, Dr. John Macomber

ASHRAE Position Document on Carbon Dioxide

Position Document Abstract:

- *"…This position document discusses the role of indoor CO_2 in the context of building ventilation and IAQ based on ASHRAE's long involvement with those topics…"*
- *"…The positions state within address the use of CO_2 as a metric of IAQ and ventilation, the impacts of CO_2 on building occupants, the measurement of CO2 concentrations, the use of CO_2 to evaluate and control outdoor air ventilation and the relationship of indoor CO_2 to airborne infectious disease transmission."*



Abstract (continued):

- This document recommends research into the impacts of CO_2 on occupant health, comfort, and performance and on the application of indoor CO_2 concentrations in building operation, as well as guidance on the measurement and practical application of CO_2 concentrations

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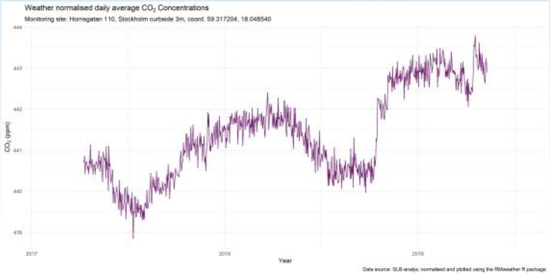
ASHRAE Position Document on Carbon Dioxide

Position Document: ASHRAE takes the following positions

- *“Indoor CO_2 concentrations do not provide an overall indication of IAQ, but they can be a useful tool in IAQ assessments if uses understand the limitations in these applications.”*
- *“Existing evidence for direct impacts of CO_2 on health, well-being, learning outcomes, and work performance at commonly observed indoor concentrations is inconsistent, and therefore does not currently justify changes to ventilation and IAQ standards, regulations or guidelines*



ASHRAE takes the following positions:

- “Differences between indoor and outdoor *CO_2 concentrations can be used to evaluate ventilation rates and air distribution using established tracer gas measurement methods, but accurate results require the validity of several assumptions and accurate input values.”*

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ASHRAE Position Document on Carbon Dioxide

ASHRAE Recommends Research on the Following Topics

- *"Health and performance impacts of indoor CO_2 in concentration ranges typical of non-industrial indoor environments in both laboratory and field settings covering a diverse range of subjects, including variations in age, gender, and health status."*
- *"Physiological impacts of elevated CO_2 concentrations, such as changes in blood chemistry and respiration, including those associates with increasing outdoor CO_2 concentrations."*

ASHRAE Recommends Research…:

- "Indoor *CO_2 concentration measurement, including sensor performance and sensor locations for different applications and the performance and application of low-cost CO_2 sensors*
- *"Indoor CO_2 concentrations, ventilation rates, and occupancy in different building types in building and system designs…*

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ASHRAE Position Document on Carbon Dioxide

Section 2.2: Health and Cognitive Effects of CO_2 Exposure

- "Indoor concentrations of CO_2 greater than 1000 ppm, have been associated with increases in self-reported, nonspecific symptoms commonly refered to as *sick-building syndrome (SBS)* symptoms."
- "…However, these observations were not controlled for other contaminants or environmental parameters; therefore, elevated CO_2 concentrations likely served as indicators of inadequate ventilation that increased the concentrations of all contaminants with indoor sources..."

Section 2.4: CO_2 as an Indicator of IAQ and Ventilation

- "An indoor CO_2 concentration below 1000 ppm, has long been considered an indicator of acceptable IAQ, but this concentration is at best an indicator of outdoor air ventilation rate per person."
- "The use of *CO_2 as an indicator of outdoor air ventilation must reflect the fact that outdoor air ventilation requirements depend on space type, occupant density, and occupant charateristics (e.g., age, body mass, and activity lvels)*

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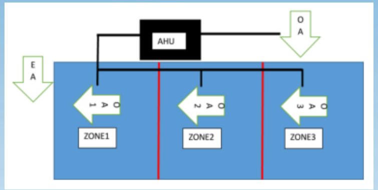
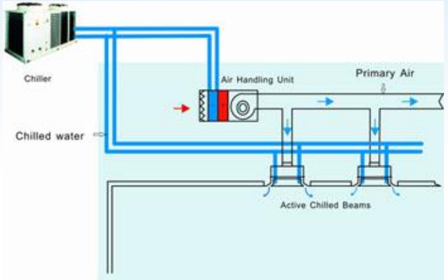
100% OSA Systems: System Type Review

100% OSA Systems: System Type Review

100% OSA Active Chilled Beam Systems

- **Dedicated 100% Outside Air / Decoupled Hydronic Systems**
  - Ventilation air supplied directly to each building zone
  - Greater system efficiency than conventional HVAC





How are decoupled systems more efficient?

- **Water** is more dense than air
- **Water** is a more efficient heat transfer medium than air
  - 4.23x more specific heat capacity **(4-6F vs 20F delta T)** to maintain space setpoint conditions
  - **Less horse power** to move the same amount of energy using water than air

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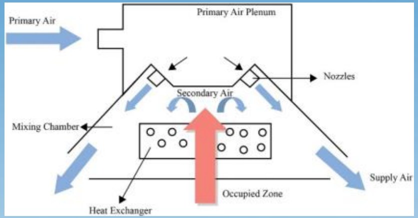
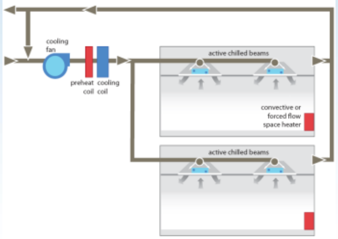
100% OSA Systems: System Type Review

100% OSA Active Chilled Beam Systems



- **DECOUPLE** the **Total Load**
- Chilled and hot water piped locally to each zone
- **Sensible load:** Chilled water loop designed to meet the **sensible energy load in the occupied zone**
- **Latent load:** Latent cooling is achieved by the outside air component. **The lower supply air dew point; greater humidity control**



Ductwork Significantly Reduced

- Design air flow as close to ventilation air requirements
- 50-70% less air flow required compared to mixed air: (e.g. VAV)
- **Reduced System Horsepower = Energy Savings**
- Building air is exhausted from a building to maintain positive building pressure

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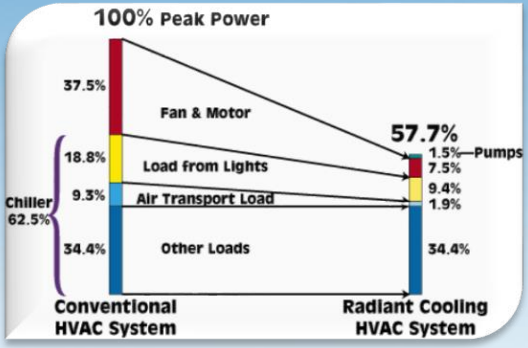
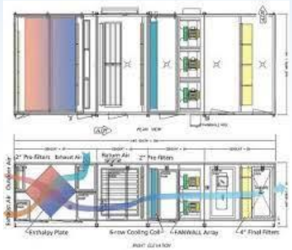
100% OSA Systems: System Type Review

100% OSA Active Chilled Beam Systems

- **Move Sensible Energy to the Chilled Water Loop**
  - **60-70% less airflow than all air systems**
  - Decoupled hydronic systems are 30-40% more efficient due to reduced system horsepower
  - **Passive chilled beam systems:** Potential for enhanced efficiency in dry climates resulting in extended economizer hours





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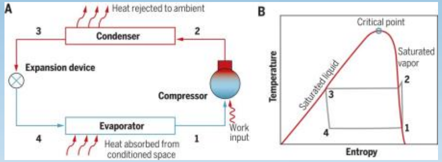
100% OSA Systems: System Type Review

100% OSA Passive Radiant Cooling & Heating Systems

Four Modes of Heat Transfer: Put Physical Laws to Work

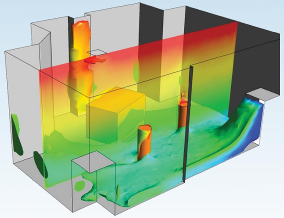
- **Conduction: (Mechanical Force: Fan Energy)**
  - DOAS Cooling & Heating Coils

(Chilled Water Coil)



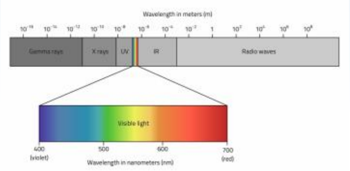
(Vapor-Compression Cycle)

- **Evaporation: (Mechanical Force: Compressor Energy)**
  - Vapor-Compression Cycle: Chillers



(Thermally Stratified Environment)

- **Radiation: (Force of Equilibrium)**
  - Surface **Thermal Asymmetry**: High Energy State moves to Low Energy State



(Electromagnetic Spectrum)

- **Convection: (Force of Equilibrium)**
  - Warm Air Rises, Cold Air Falls

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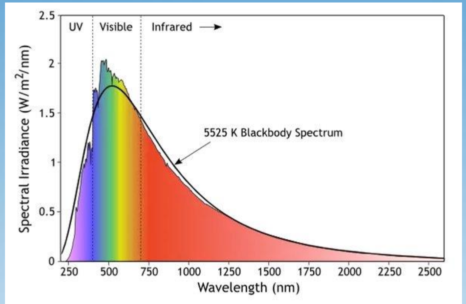
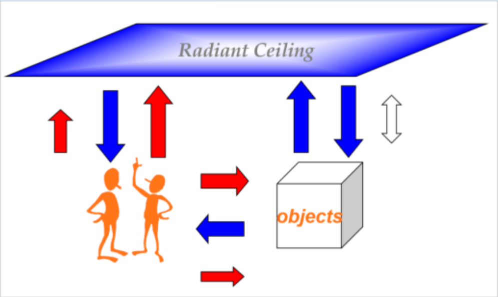
100% OSA Systems: System Type Review

“Passive” Heat Transfer Modes: Radiation

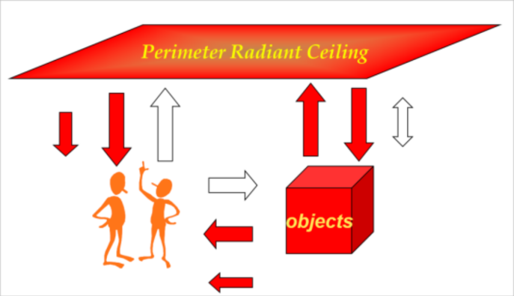
- **Electromagnetic Spectrum = Infrared energy**
- **Surface temperature imbalance:**
  - **Chilled Ceilings** absorb heat energy from warm surfaces
  - **Heated Ceilings** Radiate heat energy to cooler surfaces (e.g. perimeter walls)



(Electromagnetic Spectrum: Infrared Energy)



(Radiant “Cooling”: Chilled Surfaces)



(Radiant Heating: Heated Surfaces)

Fan energy not required for thermal (sensible) energy heat transfer

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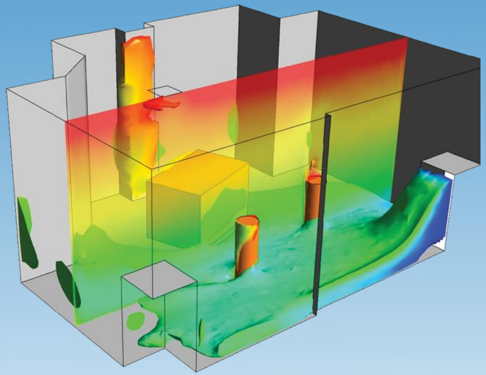
100% OSA Systems: System Type Review

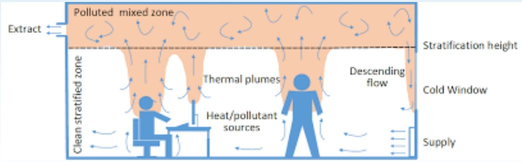
Passive Heat Transfer Modes: Convection



(Thermally Stratified Space)

- **Displacement Ventilation:**
  - Supply air at low velocity: **~40 FPM**
  - Supply air temperature: **62-68°F**

- Stratified: Non-uniform space temperature
- Room thermal profile
  - Floor: **~ 70F**
  - Thermostat: **~75F (set point)**
  - Ceiling: **~78F to 82F (~9ft AFF)**
- Upper level room air temp: **80-85°F**
- **High level return/exhaust grilles**



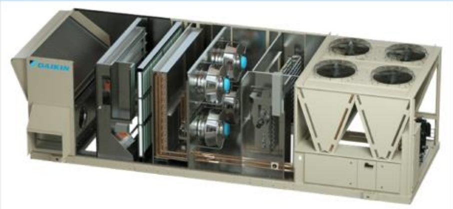
Space Air Movement: Applied buoyancy forces (convection)

- Space heat sources: people, lighting, computers…
- Chilled Surfaces: Panels and Sails

100% OSA Systems: System Type Review

100% OSA Passive Radiant Cooling & Heating Systems

- **System Concept:** Sensible load moved to chilled water loop through radiant panels or sails located in each zone
- **Ventilation and Humidity Control:** 100% Outside Air Unit (DOAS) Parallel to and Decoupled



Air-Side Component: (Outside Air)

- **Dedicated Outside Air Unit (DOAS)**
- Air Flow Volume Significantly Reduced:
  - ~0.3 to 0.8 CFM depending on zone use
- **Building Humidity (LATENT LOAD) Controlled** by supplying low dew point air (~45-48˚F)

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100% OSA Systems: System Type Review

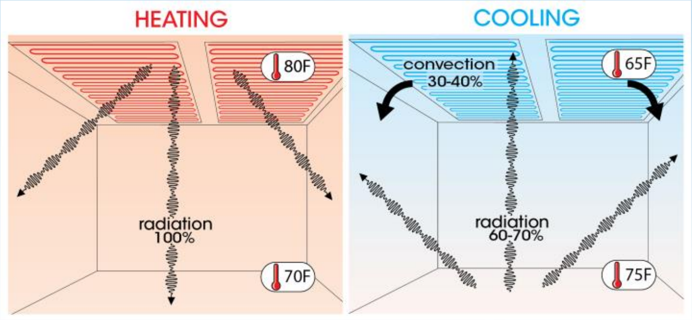
"Passive" Heat Transfer Modes: Radiation & Convection

- **Heat Transfer Terminal Units: Radiant Panels**
- Occupant Radiant Effect: Body temperature of ~98°F
- Occupant surface heat emitted to chilled ceiling or wall

(Radiant Panels)

Improved Thermal Comfort

(Radiant Chilled Ceiling:
Telus Spark World of Science)



(Follow the Heat Energy)

Typical Panel Capacity:

- Cooling: 25-30 Btuh/ft²
- Heating: 100-200 Btu/ft²

Cooling Mode: 30-40% convective effect

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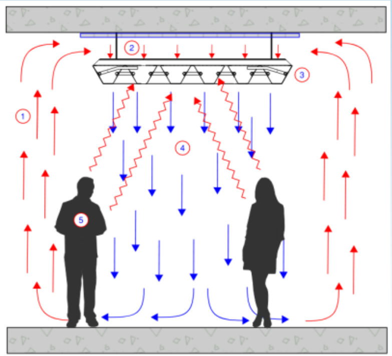
100% OSA Systems: System Type Review

“Passive” Heat Transfer Mode: Radiation & Convection

- **Heat Transfer Terminal Units: Radiant Sails**
- Louvered radiant devices enhance the convective effect, greater cooling capacity **(~50% Radiant / 50% Convective)**



(Passive Radiant & Convective Flow Patterns)

Typical Sail Capacity:

- Cooling: 40-55 Btuh/ft²
- Heating: 80-200 Btu/ft²

- Radiant energy emitted or absorbed by louver blades
- Cool air around chilled sail blades falls via convective forces to the floor
- **Free area between sail & deck** required for free flow of air

(Norquest College, Alberta)

(Custom Sail Cloud)

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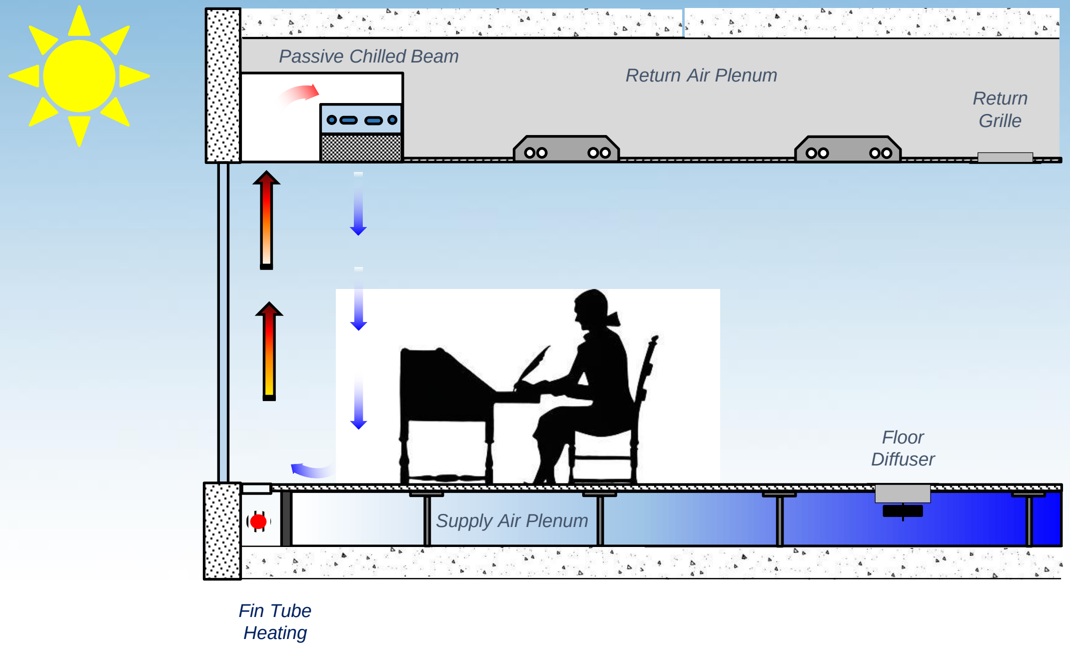
Active & Passive Beams: Two Design Strategies

100% OSA Passive Chilled Beam and Radiant Cooling & Heating Systems Underfloor Air Systems?



Hybrid Systems:

- Passive beams or radiant cooling and heating devices with 100% OSA underfloor air systems
- Single pass of clean conditioned air across the breathing zone

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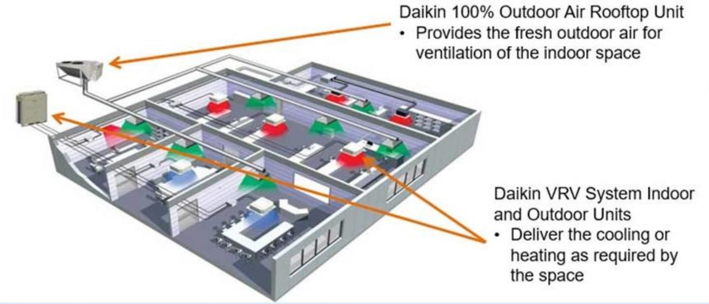
100% OSA Systems: System Type Review

100% OSA Variable Refrigerant Systems

- **100% OSA / VRV Hybrid Approach: Decouple & Condition OSA**



(Courtesy: Daikin Applied)

The Concept:

- 100% Outside Air AHU (**Dedicated Outside Air System (DOAS)**) only conditions and supplies outside air required for building ventilation
- DOAS to control building humidity by assigning OSA supply air the appropriate **DEW POINT**
- **Supply air dry bulb temperature is supplied at between 70-75F (LOAD NEUTRAL)**

Variable Refrigerant System Impact:

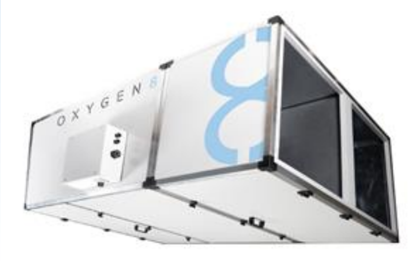
- Reduce VRV System Load
- Reduce latent load at fan coil cooling coils; less condensate

100% OSA Systems: System Type Review

Peak Efficiency at Peak Design Conditions

Outdoor DOAS Units

(Courtesy: Daikin Comfort)



Indoor DOAS Units

(Courtesy: Oxygen 8)

100% OSA / VRV Hybrid Design:

- Outside air treated to load neutral condition
- Lower entering air temperature at fan coil cooling coil
- Improved condenser efficiency
- Lower condenser tonnage for VRV first cost savings
- Smaller VRV dimensional footprint
- Parallel OSA delivery to zones for enhanced system efficiency and assured IAQ is maintained & validated
- Improved system dehumidification (Reduced Risk of Condensation) with **DEPRESSED DEW POINT SUPPLY AIR for true humidity control and increased system efficiency**

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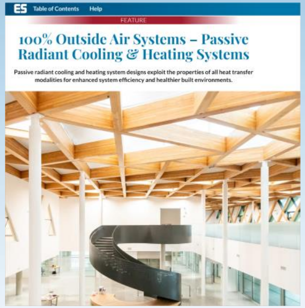
100% OSA Systems: System Type Review


100% Outside Air VRF Systems: A Sustainable, Hybrid Approach for Superior IEQ

Increasing the amount of outside air to the occupied space and increasing ventilation air change rates are effective solutions for reducing concentrations of contaminants and the risk of infection.

- **July 2022 Edition:**
  - 100% Outside Air VRF Systems: A Sustainable, Hybrid Approach for Superior IEQ
  - Dan Hahne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FEATURE

100% Outside Air Systems – Passive Radiant Cooling & Heating Systems

Passive radiant cooling and heating system designs exploit the properties of all heat transfer modalities for enhanced system efficiency and healthier built environments.

December 2022 Edition

- *100% Outside Air Systems – Passive Radiant Cooling and Heating Systems*
  - **(Co-Author: Darren Alexander, P.E. (Twa Panel Systems, Inc.)**


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FEATURE

Creating an Innovative Building Design through Creative, Adaptive Architecture, Engineering and Collaboration

Meeting developing building standards, codes and assuming best practices to support high-performance buildings, will require architects and engineers to collaborate holistically.

By Dan Hahne, Conrad Brown, P.E. and Matthew Peairs, P.E.

August 2023 Edition:

- Creative and Innovative Building Design through Creative, Adaptive Architecture, Engineering and Collaboration
  - **Co-Authors:**
    - Dan Hahne (Varitec)
    - Conrad Brown P.E. (PAE)
    - Matthew Peairs P.E. (PAE)

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Questions?

Thank You

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