Welcome to Webinar Wednesday Varitec Technical Institute - 2024

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







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

May 15th Fundamentals of Controls

June 5th How Can High Performing Buildings Continue to

Perform at Optimal Levels?

Guest Presenter: Janice Means, PE, LEED AP

July 10th ASHRAE 90.1

August 21st Pyschrometrics Deconstructed Part 1

September 18th 100% OSA & VRV

October 23rd Pyschrometrics Deconstructed Part 2

November 20th 100% OSA & Underfloor

Varitec Technical Institute



ABOUT VARITEC PRODUCTS SPECIALTIES TRAINING CONTROLS PANEL SHOP COMPRESSED AIR & VACUUM CONTACT





Educational Resource Library



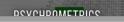


















Housekeeping Items:

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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















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))



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 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

100% OSA Systems & The Importance of Ventilation

Presented by: Dan Hahne

Varitec: Director of High-Performance HVAC Solutions



100% OSA Systems & The Importance of Ventilation

AGENDA:

- EPA, CDC and ASHRAE Ventilation Rate Statements
- What is a 100% OSA System?
- Outdoor Air and Indoor Air: Health Impacts
 - The Clean Air Act, the EPA & OSHA
 - Outdoor Air versus Indoor Air Quality
 - Healthy Buildings, Dr. Joseph Allen & Dr. John Macomber
- ASHRAE Standard 241-2023: Control of Infectious Aerosols
- ASHRAE Position Document on CO2
- 100% OSA Systems: System Type Review
 - Active Chilled Beam Systems
 - Passive Radiant Cooling & Heating Systems
 - Variable Refrigerant Systems

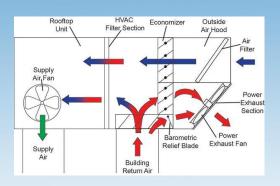




Environmental Protection Agency (EPA):

- 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.."







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



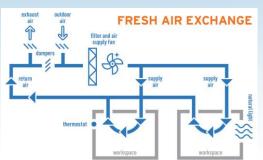
EPA: Clean Air in Buildings Challenge

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









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."



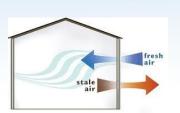
Center for Disease Control (CDC):

- 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."

Increasing HVAC System OSA: The Challenge

- ASHRAE is writing standards for for more energy efficient buildings (Standards 90.1 and 189) and Decarbonization (Position Document on Building Decarbonization)
- The challenge, increasing ventilation rates beyond code minimum for conventional HVAC systems reduces system efficiency





100% Outside Air Systems: An energy efficient HVAC system Design that provides improved indoor air quality

- Proven to be 25 to 40% 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
- Proven and innovative technologies are available





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



(Courtesy: Daikin Applied)

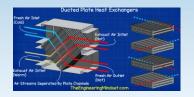
- Control OSA (ventilation) rates to each zone:
 - Design Option: Increase OSA air change rates to levels as desired: BEYOND CODE MINIMUM?.
- Building CO₂ concentrations controlled to 1,000
 PPM or below at each zone
- Improved humidity control through lower dew point supply air

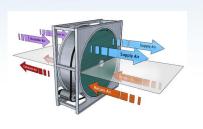
What are 100% Outside Air Systems?

100% Outside Air (OSA) Systems: Design Intent

- 100% OSA Unit Layout: Dual Tunnel Supply/Exhaust Units
 - Design Goal: Design the air side component as closely to building minimum ventilation rates for optimal efficiency, reducing airflow and fan energy







- Heat Recovery: Reduces Building Load
 - Exhaust air pre-conditions 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



What are 100% Outside Air Systems?

100% Outside Air (OSA) Systems: Design Intent

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



(Radiant Panels)



(Radiant Sails)



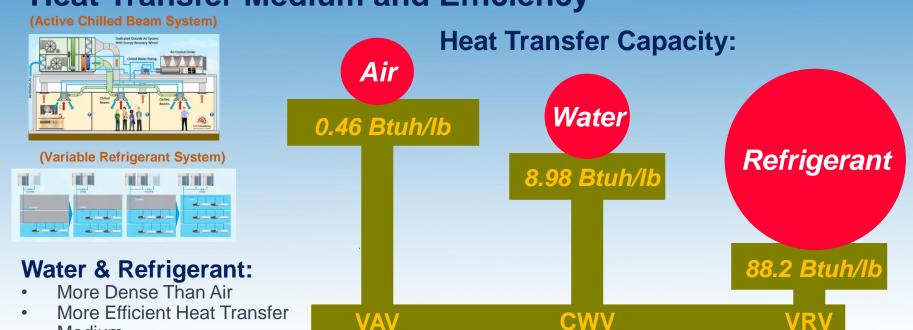
(Variable Refrigerant Systems)



(Active Chilled Beams)

- Sensible load shifted to water or refrigerant locally at each zone
- Why? Water & Refrigerant: Denser Heat Transfer mediums
- Denser heat transfer mediums use less energy (pump HP) than fan energy (fan HP) used in all-air systems
- Building humidity controlled by adequately dehumidified 100% OSA unit supply air

What are 100% Outside Air Systems? Heat Transfer Medium and Efficiency



Airside Systems:

Medium

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



Outdoor and Indoor Air Contaminants: Health Impact



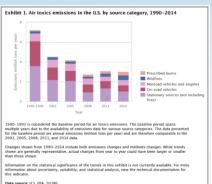
Outdoor Air Pollution: The Good News



- 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 **30 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..."

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^{*} Toxic Air Pollutants or hazardous air pollutants

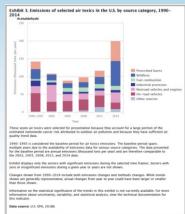
Outdoor Air Pollution: The Good News



- 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."

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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 Droxide (SO2): -90%



Declining National Air Pollutant Concentration Averages °°°
100%
50%
Most Recent National Standard Most Recent National Standard
OS OS
-50%
-100% 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022
— Pb (3-month) — CO (8-hour) — NO2 (annual) — NO2 (1-hour) — O3 (8-hour)
— PM2.5 (annual) — PM2.5 (24-hour) — PM10 (24-hour) — SO2 (1-hour)

	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."



Outdoor Air Pollution: Government Standards

- 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))





Consequent Legislation:

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



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, O₃, SO₂, NO_x, Pb, PM)
- Major revisions in 1977, 1985, 1990, 1995 to deal with toxic chemicals, stratospheric ozone, etc; (now CO₂)
- 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.





Outdoor Air Pollution: The Clean Air Act

- National Ambient Air Quality Standards: Contaminant Limits
 - Lead
 - Ozone
 - Sulfur Dioxide
 - Nitrogen Dioxide
 - Carbon Monoxide
 - Particulate Matter (PM2.5, PM10)...



0-50 GOOD	51-100 MODERATE	101-150 UNHEALTHY FOR SENSITIVE GROUPS	151-200 UNHEALTHY	201-300 VERY UNHEALTH
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Pollutant	Time Weighted Average	Industrial, Residential, Rural, and Other Areas	n in Ambient Air Ecologically Sensitive Area (notified by Central Government)
Sulphur dioxide (SO ₂), μg/m ³	Annual 24 hours	50 80	20 80
Nitrogen dioxide (NO ₂), μg/m ³	Annual 24 hours	40 80	30 80
Particulate matter (< 10 μm) or PM10, μg/m ³	Annual 24 hours	60 100	60 100
Particulate matter (< 2.5 μm) or PM2.5, μg/m ³	Annual 24 hours	40 60	40 60
Ozone (O2), μg/m³	8 hours 1 hour	100 180	100 180
Lead (Pb), μg/m ³	Annual 24 hours	0.50 1.0	0.50 1.0
Carbon monoxide (CO), mg/m ³	8 hours 1 hour	02 04	02 04
Ammonia (NH3), μg/m³	Annual 24 hours	100 400	100 400
Benzene (C ₄ H ₄), µg/m ³	Annual	05	05
Benzo(a)Pyrene (BaP) – particulate phase only, ng/m ³	Annual	01	01
Arsenic (As), ng/m ³	Annual	06	06
Nickel (Ni), ng/m ³	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 *



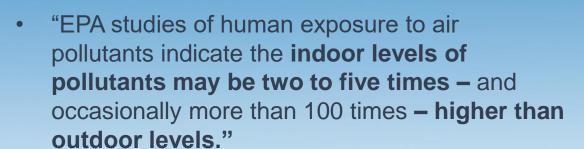
What About Indoor Environment Air Quality?



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



EPA: Indoor Air Contamination Levels









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." *



Contamination Levels & CO₂:



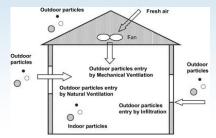
Outdoor and Indoor Air Contaminants: Comparison

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
- Sulfur Dioxide
- Particulate Matter (PM):Various Sizes

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





WHAT ABOUT INDOOR AIR QUALITY STANDARDS?

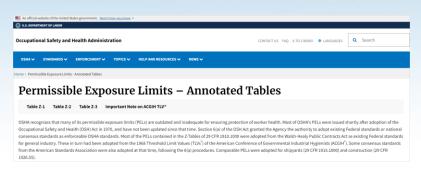
Occupational Health and Safety Administration (OHSA)



 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." *





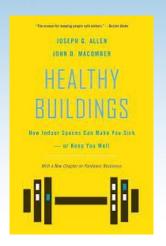
(Occupational Health and Safety Administration)



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." *

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."*







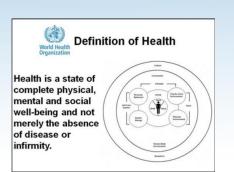
1970's Energy Crisis: Sealing of Buildings

- 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) and occupant 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."*



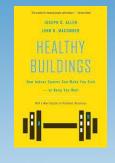
WHO Constitution:

- "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."



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 <u>successfully</u> reduced outdoor air pollution

Is an Indoor Air Quality Act in our future?



Indoor Air Quality (IAQ) and Human Health

"The Dirty Little Secret of Outdoor Air-Pollution"





"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 IS 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

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

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 (NO₂), Ozone (O₃), Carbon Monoxide (CO), Sulfur Dioxide (SO₂), Toxic Metals, Aerosols, Radon, Pesticides, Biological Pollutants

Particulate Matter (PM_{2.5}, PM₁₀):

- "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."

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

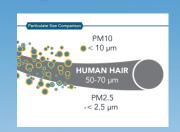
Indoor Air Quality (IAQ) and Human Health

- Particulate Matter (PM_{2.5}, PM₁₀):
 - "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"



- 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)"





IAQ and Human Health: Short & Long Term Impact

- National Institute of Environmental Health Sciences (NIEHS): 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...*







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 learning centers*
 - ASHRAE Carbon Dioxide (CO₂) Limits Revisited:
 - ASHRAE Standard 62-1999 replaced the original (CO₂) limit (1,000 ppm)...stating that "...indoor CO₂ should now be 700 ppm or less above the ambient outdoor concentration..."
 - "...several studies providing substantial evidence of acute exposure to CO₂ at levels as low as 1,000 ppm inducing significant reductions in cognition and decision-making abilities..."**



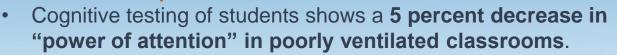


Indoor Air Quality (IAQ) and Human Health

Classroom IAQ and Student Performance: Statistics



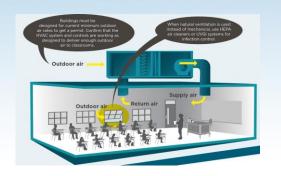
 "There are over 200 scientific studies documenting how the school building influences student health, student thinking, and student performance."*



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" *



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.*"









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. **

VARITECT TECHNICAL INSTITUTE

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

^{**} American Lung Association: From Absences to Aces

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 company's 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



Action: Double Ventilation from 20 to 40 cfm/person

- "Documented improvements in thinking...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

IAQ and Human Health: Major Points of Interest

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





- 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



ASHRAE Standard 241-2003: Control of Infectious Aerosols



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..."



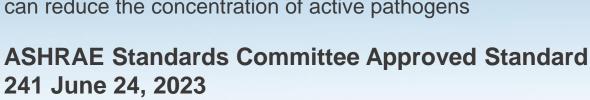






ASHRAE Standard 241-2023: Standard 241 Foreward:

- "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"*





- "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



Contro

of Infectious

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 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*..."



Standard 241 Foreward: What is IRMM?

 "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."



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"











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

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)

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

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.



	EC	Ai
Occupancy Category	cfm/person	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		
Classcoom	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



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



	cy (rpg) for Mechanical Fibrour	
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	cPM2.5 50%	60%
12	cPM2.5 65%	71%
13	cPM1 50%	77%
14	cPM1 70%	88%
1.5	cPM1 85%	91%
16	cPM1 95%	95%
HEPA*	ISO 20E ^b	99%





Contamination Levels and CO₂:

- ASHRAE: Position Document on Indoor Carbon Dioxide
 - History of CO₂
 - Health and Cognitive Effects of CO₂
 - Existing Standards and Regulations for Indoor CO_{2...}
 - CO₂ as an indicator of IAQ and Ventilation...
 - Increases in Outdoor CO₂ Concentrations
 - CO₂ as an indicator of Airborne Infection Risk Transmission



ASHRAE Journal: June 2022

- "CO2 is a stoichiometric by-product of both hydrocarbon fuel combustion and biological metabolism..."
- "...measuring CO₂ concentration offers an easy ... way to gage the concentration of the other pollutants."





Contamination Levels and CO₂:

• Robert Stumm, P.E.: "Suggested here is that some statistical correlation may exist between the concentration of CO₂ and that of the aggregate of other by-product pollutants affecting human comfort and wellness."



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

ResearchGate



Phoenix: Research Gate 2013 Report

"...the presence of an "urban CO2 dome" that reaches
 555 ppm in the city center and decreases to...~370 ppm on the outskirts."

ASHRAE Standard 62.1-1999: Indoor Air CO₂ Levels

- Satisfactory Indoor CO₂ Limit of 700 ppm above outdoor CO₂ Concentrations (Based on Outdoor CO₂ Concentrations in the 1980's of ~350 ppm.)
- Urban Phoenix: 555 ppm + 700 = 1255 ppm indoor CO2

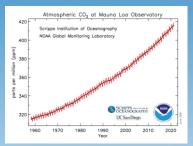




Contamination Levels and CO₂: ASHRAE Journal: June 2022

Phoenix CO₂ Urban Dome in 2021?

with Mauna Loa valu	55.			
SITE	DATA YEAR	MAUNA LOA	URBAN	DIFFERENC
Phoenix, Ariz.	2000	369	57512	206
Baltimore	2006	382	48813	106
Evanston, III.	2011	392	44014	48
Los Angeles	2015	400	62215	222



(Scripts Institute of Oceanography: NOAA Global Monitoring Laboratory)



Phoenix CO₂ Dome July 2021 = 575 ppm
Boston University Study: Between 1990 to 2017:
CO₂ Increase of 291%

CO ₂ [ppm]	Air Quality	
2100	BAD	
2000	Heavily contaminated	
1900	indoor air	
1800	indoor air	
1700	Ventilation required	
1600		
1500	MEDIOCRE	
1400	MEDIOCRE	
1300	Contaminated indoor air	
1200	Ventilation recommended	
1100		
1000	FAIR	
900	FAIR	
800	COOD	
700	GOOD	
600		
500	EXCELLENT	
400	A STATE OF THE STA	

Robert Stumm Article: Conclusions

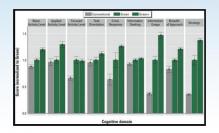
- "...substantial evidence of acute exposure to CO₂ at levels
 as low as 1,000 ppm inducing significant reductions in
 cognition and decision-making abilities."
- "Considering the recent studies showing CO₂ directly impacting human health, in particular cognition and decision-making, the indoor CO₂ level of 1,000 ppm reappears as a sensible, time-honored upper limit...

(Indoor Quality CO₂ Website)

Contamination Levels and CO2



- Healthy Buildings (Macomber & Allen): The False Choice of "Energy and Health" *
 - "Indoor CO₂ is mostly from indoor human respiration"*
 - "In one study of 100 non-problem buildings in the United States, the 95th percentile CO₂ concentration was about 1,500 ppm"
 - "...Lawrence Berkeley National Laboratory studied 162 classrooms across 28 elementary schools in California and found that the average CO₂ concentration was above 1,500 ppm."
 - "In Texas, one in five schools tested had peak CO2 concentrations above 3,000 ppm."*



One Solution: Increase Ventilation **

- Three different factors tested for cognitive function; ventilation, volatile organic compounds, carbon dioxide (CO₂)
- 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

Section 2.2: Health and Cognitive Effects of CO₂ Exposure

- "Indoor concentrations of CO₂ greater than 1000 ppm, have been associated with increases in self-reported, nonspecific symptoms commonly referred to as sick-building syndrome (SBS) symptoms."
- "...However, these observations were not controlled for other contaminants or environmental parameters; therefore, elevated CO₂ concentrations likely served as indicators of inadequate ventilation..."

Section 2.4: CO₂ as an Indicator of IAQ and Ventilation

- "An indoor CO₂ 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 CO₂ as an indicator of outdoor air ventilation must reflect
 the fact that outdoor air ventilation requirements depend on space type,
 occupant density, and occupant characteristics (e.g., age, body mass,
 and activity levels)"

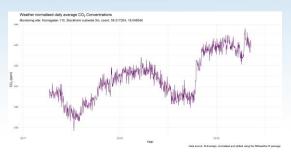


Position Document: ASHRAE takes the following positions

- "Indoor CO2 concentrations do not provide an overall indication of IAQ, but they can be a useful tool in IAQ assessments if users understand the limitations in these applications."
- "Existing evidence for direct impacts of CO₂ 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 CO2
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."



ASHRAE Recommends Research on the Following Topics

- "Health and performance impacts of indoor CO₂ 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 CO₂ concentrations, such as changes in blood chemistry and respiration, including those associates with increasing outdoor CO₂ concentrations."

ASHRAE Recommends Research...:



- "Indoor CO₂ concentration measurement, including sensor performance and sensor locations for different applications and the performance and application of lowcost CO₂ sensors
- "Indoor CO₂ concentrations, ventilation rates, and occupancy in different building types in building and system designs..."







July 2022 Edition:

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

(Author: Dan Hahne)

December 2022 Edition

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



August 2023 Edition:

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

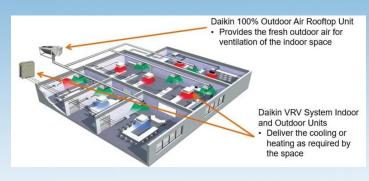


100% Outside Air Systems - Passive Radiant Cooling & Heating Systems



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



Peak Efficiency at Peak Design Conditions



Outdoor DOAS Units

(Courtesy: Daikin Comfort)



Indoor DOAS Units

(Courtesy: Oxygen 8)

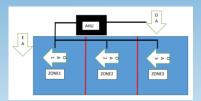
100% OSA / VRV Hybrid Design:

- 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

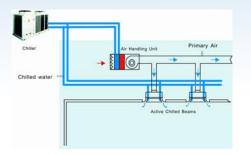


100% OSA Systems: System Type Review 100% OSA Active Chilled Beam Systems

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







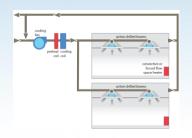
Why are decoupled systems more efficient?

- 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

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. Lower supply air dew point = greater humidity control



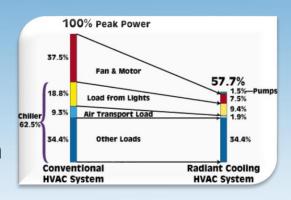


- Design air flow as close to ventilation air requirements
- 50-70% less air flow required compared to mixed air: (e.g. VAV)
- Reduced System Horsepower = Energy Savings
- Building air is exhausted from a building to maintain positive building pressure

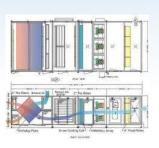
Ductwork Significantly Reduced

100% OSA Active Chilled Beam Systems

- Move Sensible Energy to the Chilled Water Loop
 - Decoupled hydronic systems are 30-40% more efficient due to reduced system horsepower; pump energy in lieu of fan energy
 - Passive chilled beam systems: Potential for enhanced efficiency in dry climates resulting from extended economizer hours











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)

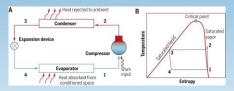
- Dedicated Outside Air Unit (DOAS)
- Air Flow Volume Significantly Reduced:
 - ~0.3 to 0.8 CFM depending on zone use
- Building Humidity (LATENT LOAD) Controlled by supplying low dew point air (~45-48°F)



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



(Vapor-Compression Cycle)

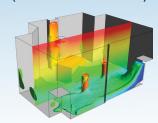
- Evaporation: (Mechanical Force: Compressor Energy)
 - Vapor-Compression Cycle: Chillers



Surface **Thermal Asymmetry**: High Energy State moves to Low Energy State

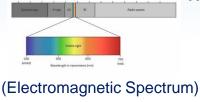


(Chilled Water Coil)



(Thermally Stratified Environment)

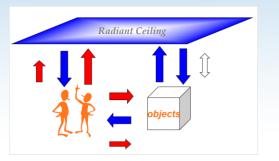
- Convection: (Force of Equilibrium)
 - Warm Air Rises, Cold Air Falls



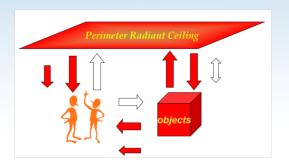


"Passive" Heat Transfer Modes: Radiation

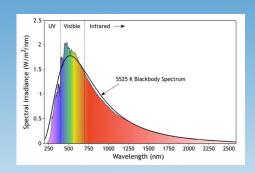
- Electromagnetic Spectrum = Infrared energy
- Surface temperature imbalance:
 - Chilled Ceilings absorb heat energy from warm surfaces
 - Heated Ceilings Radiate heat energy to cooler surfaces (e.g. perimeter walls)



(Radiant "Cooling": Chilled Surfaces)



(Radiant Heating: Heated Surfaces)



(Electromagnetic Spectrum: Infrared Energy)

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



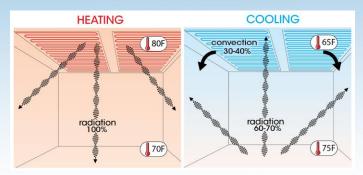
"Passive" Heat Transfer Modes: Radiation & Convection

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

Improved Thermal Comfort



(Radiant Chilled Ceiling: Telus Spark World of Science)



(Follow the Heat Energy)



(Radiant Panels)

Typical Panel Capacity:

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

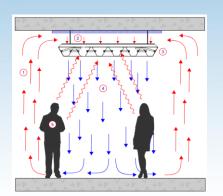
Cooling Mode: 30-40% convective effect



"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)



Passive Heat Transfer Modes: Convection

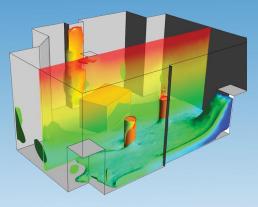
- Ventilation Air: Displacement Ventilation
 - Supply air at low velocity: ~40 FPM
 - Supply air temperature: 62-68°F



- 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



(Thermally Stratified Space)





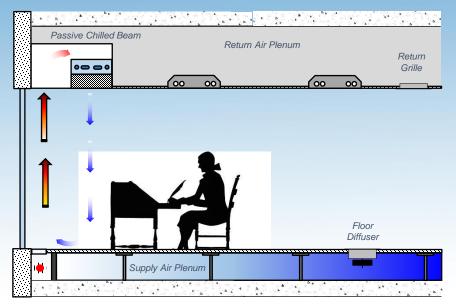


Active & Passive Beams: Two Design Strategies

100% OSA Passive Chilled Beam and Radiant Cooling

& Heating Systems Underfloor Air Systems?





Fin Tube Heating

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



Questions?





Thank You

