Displacement Induction Ventilation:

Delivering School Districts Better IAQ Thru Effective Contaminant Removal and Reduced Shared Exposure

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Agenda – Learn the Classroom Design Method

Follow the Classroom Design Method steps for classroom success!

1 Design Challenges

Understanding the design challenges:

- Constraints
- Demands
- Budgets
- Visibility

2 Critical Concepts

Understanding the building blocks:

- Proper DH Controls
- Ventilation Types
- ACB 101

3 Classroom Delivery

IAQ made better.. IEQ:

- Thermal Comfort
- Quiet Acoustics
- Maintenance
- System Efficiency
- ROI

4 Selection Foundation

Use the tools:

- Selection Software
- Application Guide
- Room Layout
- Smart Submittals

5 Schools Receive

Benefits for all:

- Improved Health
- Lower Absenteeism
- Lower Maintenance & Improved ROI
- Improved Learning
- Environments & Test Scores

Five Key Aspects to Understand

- **Into what type of mechanical system is a displacement induction diffuser typically applied?**
- **Understand the operational characteristics between displacement ventilation and the more commonly applied mixed air systems (overhead VAV, fan coils or UV)**
- **Provide an overview of the displacement induction diffuser operation.**
- **What are the benefits of applying your displacement terminal device over other types?**
- **Who has adopted this technology/where is it applied?**

IEQ: Indoor Environmental Quality
Not just IAQ:

- Proper Ventilation
- Control of Pollutants
    - Contaminant Removal Effectiveness
- Thermal Comfort
    - Temperature Control
    - Proper Humidity Control
- Proper Cleaning / Maintenance
- Low background sound levels

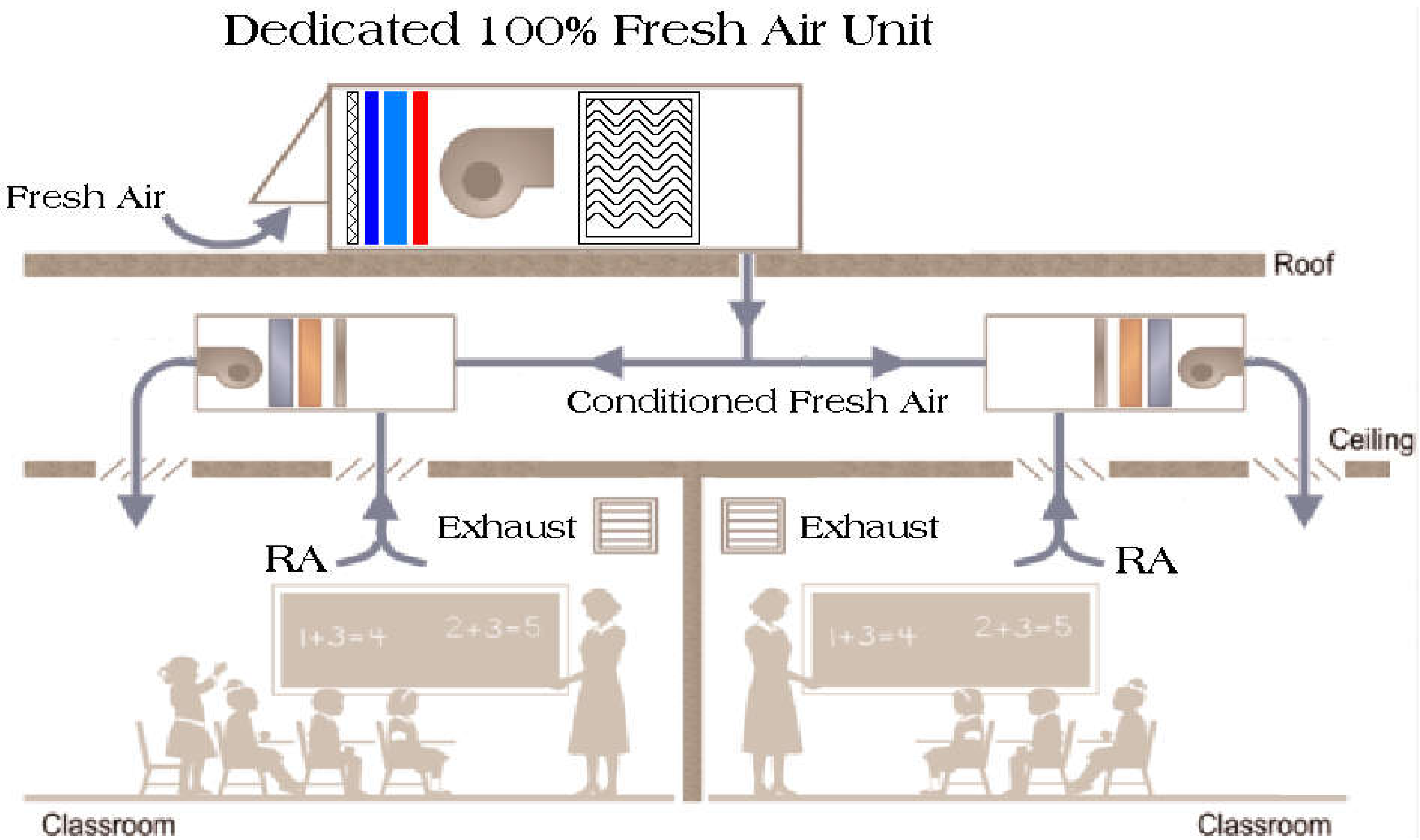
DESIGN ASPECTS IMPORTANT TO SCHOOLS

- Poor Classroom Air Quality
- Increased Demands for Energy Efficiency and Dehumidification Performance
- Poor Classroom Acoustics
- Limited Operating and Maintenance Budgets
- Aging Infrastructure and Rising Maintenance Costs
- Complicated Systems and Limited Technical Maintenance Staff
- Children are rough on classroom equipment
- Classroom Floor and Shelf Space is Valuable
- Existing Building Have Limited Ceiling Space and Mechanical Room Space
- Classrooms must be flexible and uses can be changing

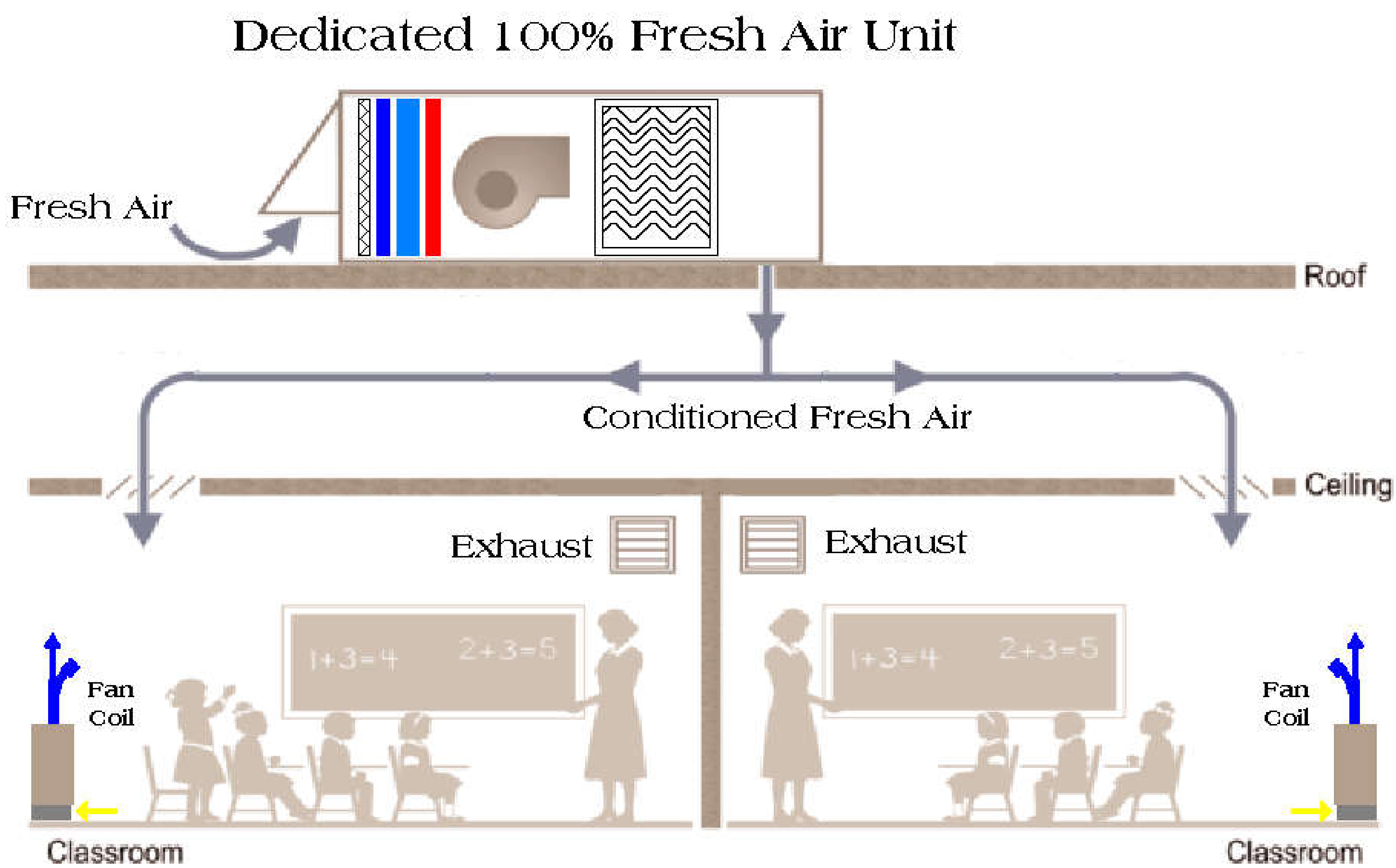
Designing Proper HVAC for Schools is challenging

- Specifically: CLASSROOMS
  - Challenges exist in the unknown and the variability within school spaces
  - Crux of the issue: Failure to control/address both temperature and humidity causes serious issues
  - High levels of OA must be introduced by code…ASHRAE 62.1 established rates for IAQ levels
  - Don't bring in the proper OA:
    - Allergies
    - Mold
    - Sick teachers
    - Sick kids

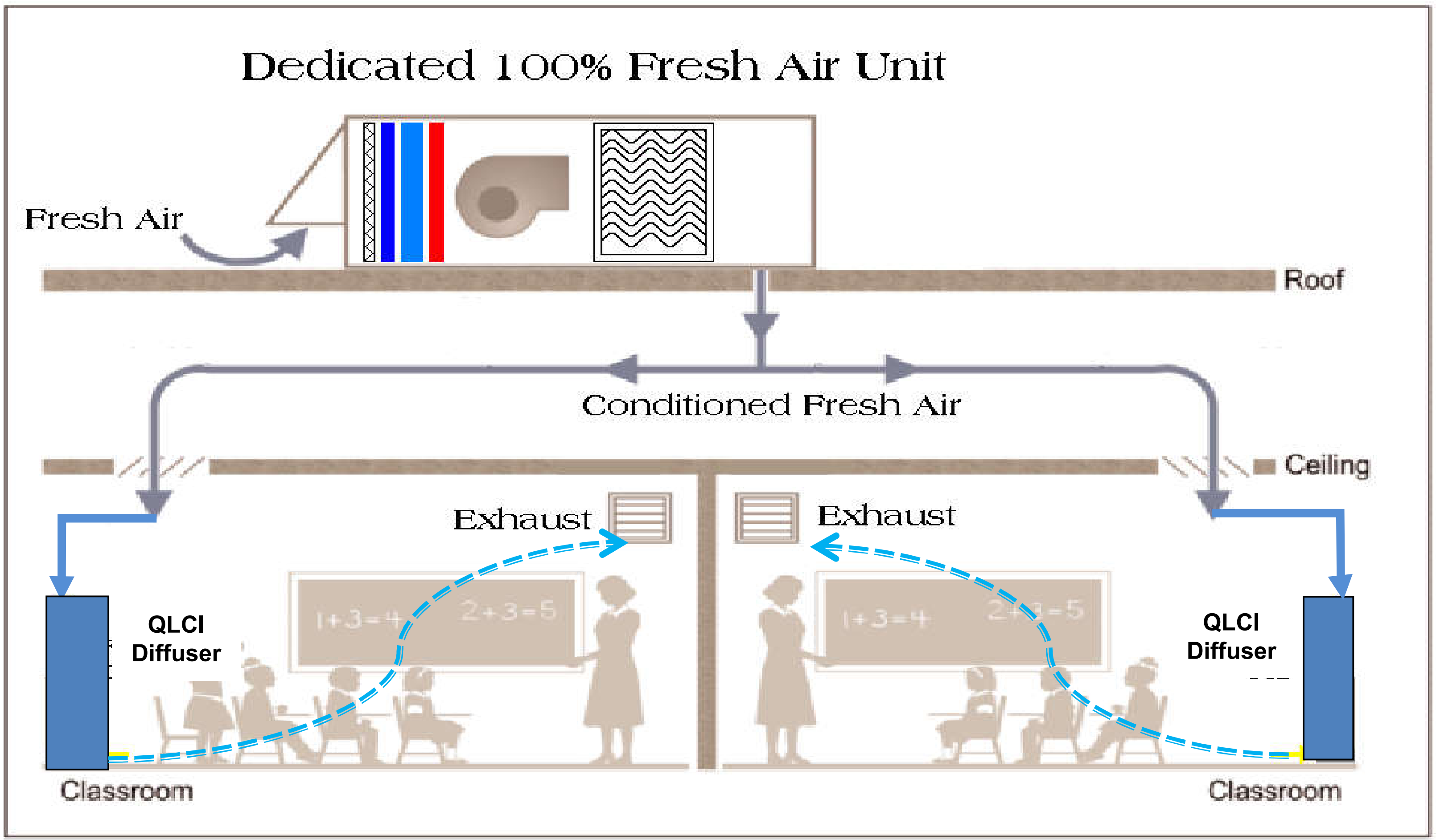
This is DOAS system – Indirect OA to AHU



This is a DOAS system – Direct OA to Zone



This is STILL a DOAS system – Direct OA to diffuser



Start at the RIGHT PEAK

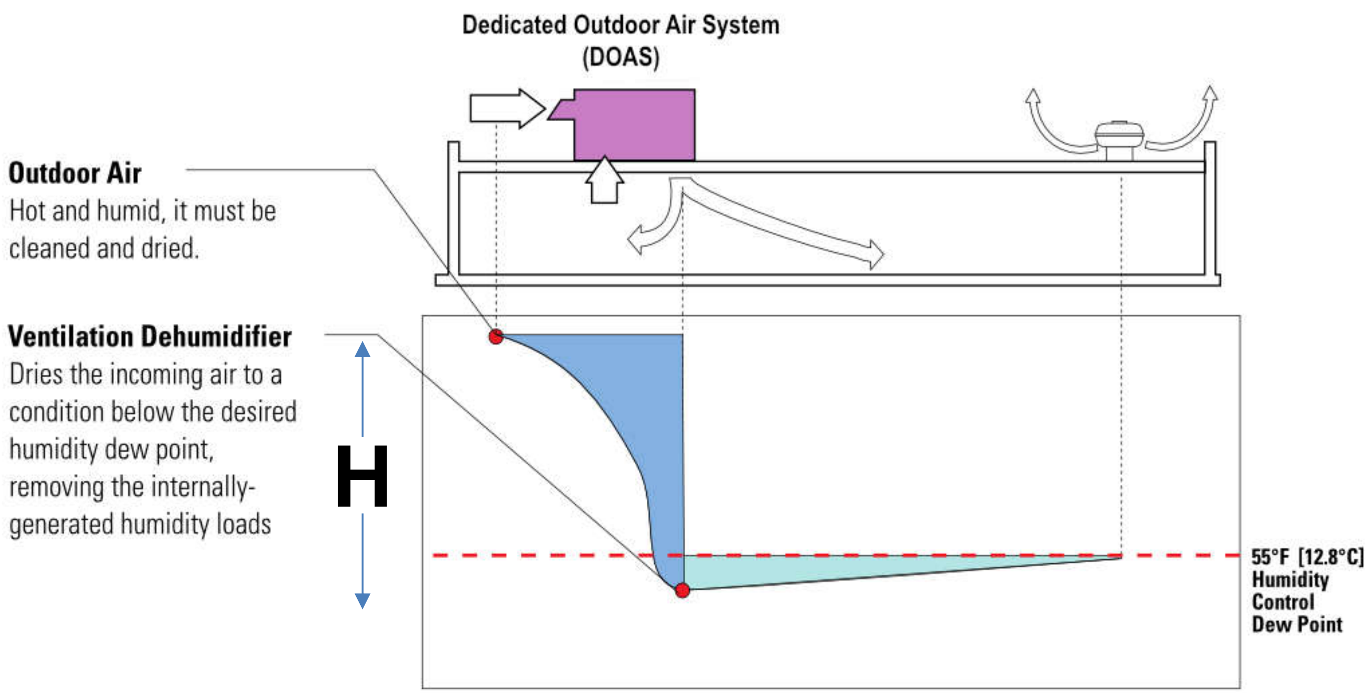
- MSP 0.4% Design Cooling Day:
  - 91°F/74°Fwb => 67°Fdp & 37.5 Btu/lb
- MSP 0.4% Design DH Day:
  - 84°F/76.6°Fwb => 74°Fdp & 40.2 Btu/lb

- CMH 0.4% Design Cooling Day:
  - 91.3°F/73.7°Fwb => 66.3°Fdp & 37.2 Btu/lb
- CMH 0.4% Design DH Day:
  - 81.6°F/75.7°Fwb => 73.5°Fdp & 39.2 Btu/lb

Failure to use the Design DH day:

- MN DOAS capacity potentially undersized by almost 18-20%
- OH DOAS capacity potentially undersized by almost 14-16%

Let the DOAS "do the work"

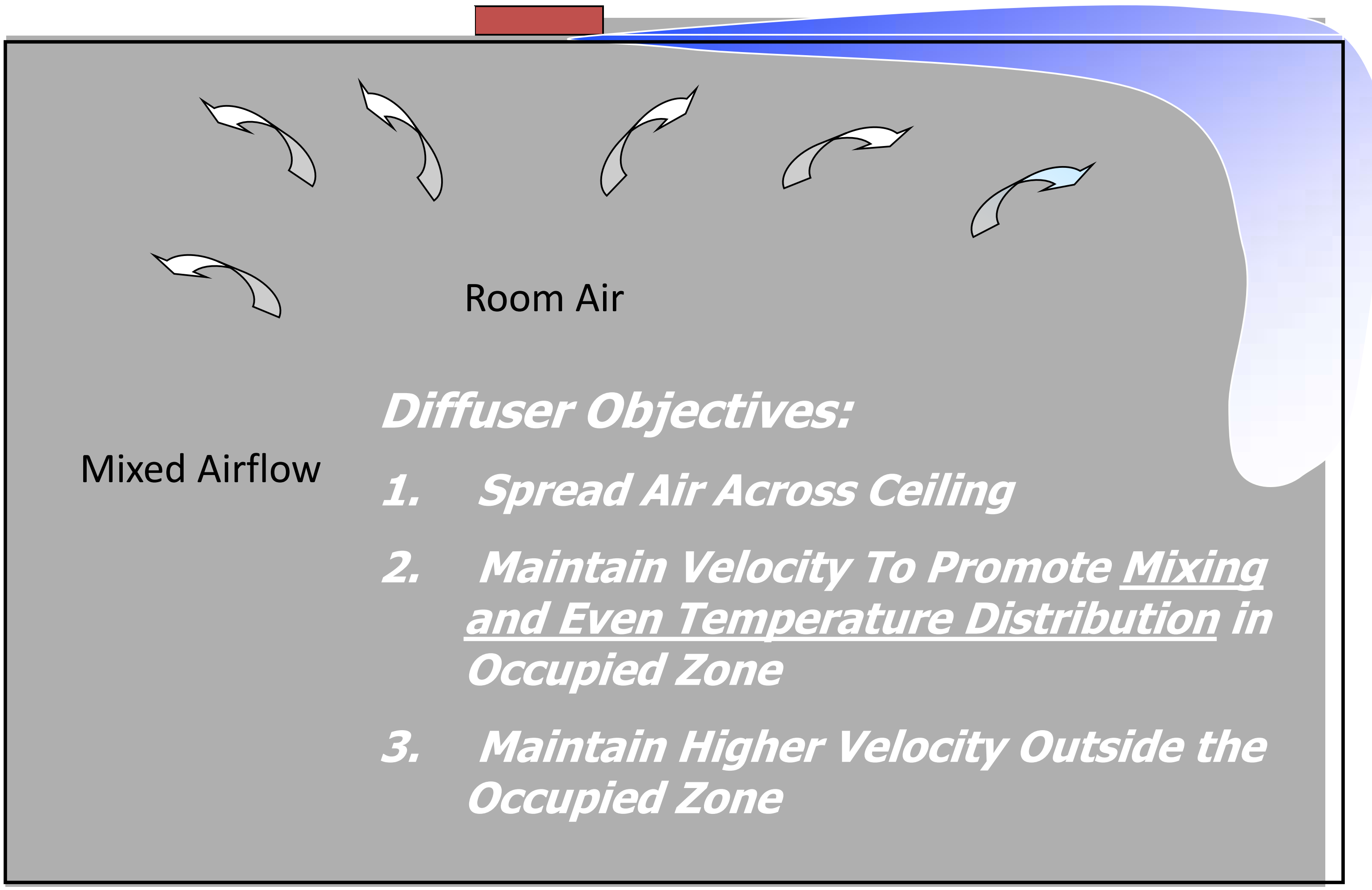


Ventilation Building Blocks

- Breathing Zone
- Ventilation Effectiveness
  - Contaminant Removal Effectiveness
  - Measurable, Calculable, and Distinct
- Mixed Air Ventilation
- Displacement Ventilation

Mixed Air System

Dilution Ventilation



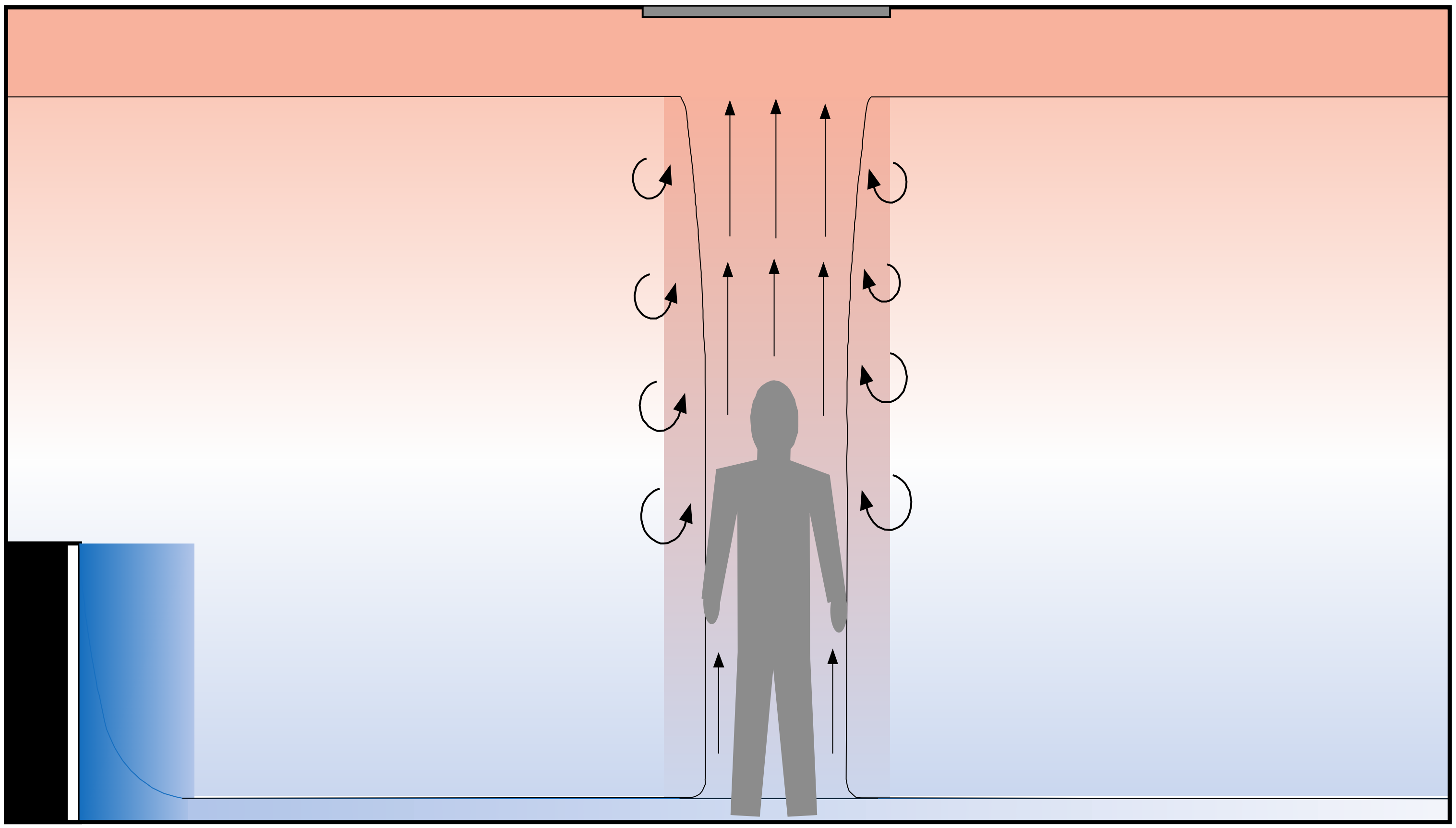
Diffuser Objectives:

1. ***Spread Air Across Ceiling***
2. ***Maintain Velocity To Promote <u>Mixing and Even Temperature Distribution</u> in Occupied Zone***
3. ***Maintain Higher Velocity Outside the Occupied Zone***

Overhead Mixing System

Displacement System

Figure 1: Fundamentals of Displacement Ventilation: thermal plume created



Beaker Analogy: Mixed Air v. Displacement

LinkedIn Post: Hargis Engineering

- **Left Beaker: Mixed Air System**
  - Cool liquid delivered overhead
  - Mixes to maintain constant temperature
  - Excess mixed fluid spills over
  - Dilutes but does NOT effectively purge contaminants
- **Right Beaker: Displacement System**
  - Fresh liquid delivered low
  - Warm, dirty fluid rises, pushed into unoccupied zone
  - Purges contaminants
  - Fresh clean fluid delivered continuously & directly to occupants

EPA website: IAQ for Schools

Tools for Schools Excerpt

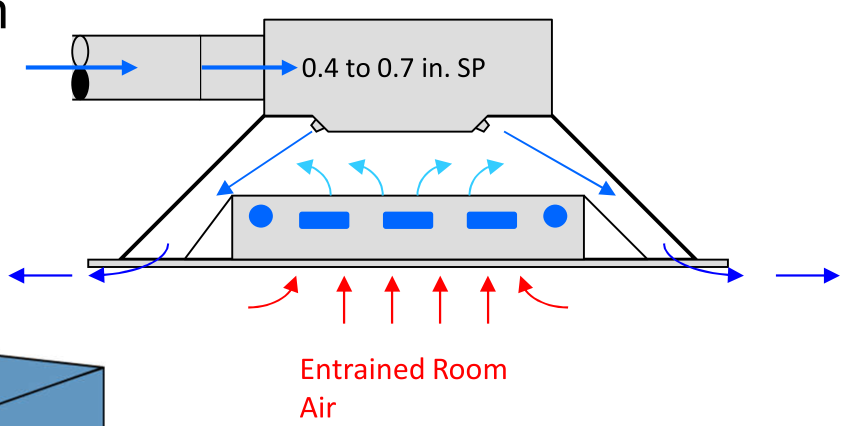
https://www.epa.gov/iaq-schools/heating-ventilation-and-air-conditioning-systems-part-indoor-air-quality-design-tools

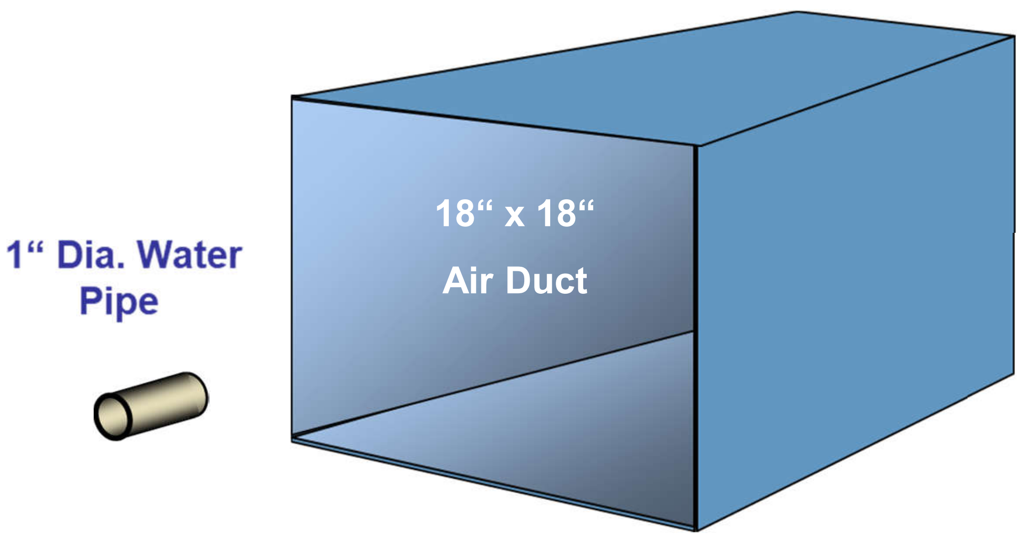
Types of Air Distribution:

i. Nearly all schools currently use the mixed-airflow method for distribution and dilution of the air within the occupied space. Designers should investigate a method called vertical displacement ventilation or thermal displacement ventilation. This approach successfully uses natural convection forces to reduce fan energy and carefully lift air contaminants up and away from the breathing zone.

A Displacement Chilled Beam Combines Active Chilled Beam Efficiencies

- Efficiency gain from fluid transportation savings (Air vs. Water)
- Induction utilizing DOAS 100% OA Units





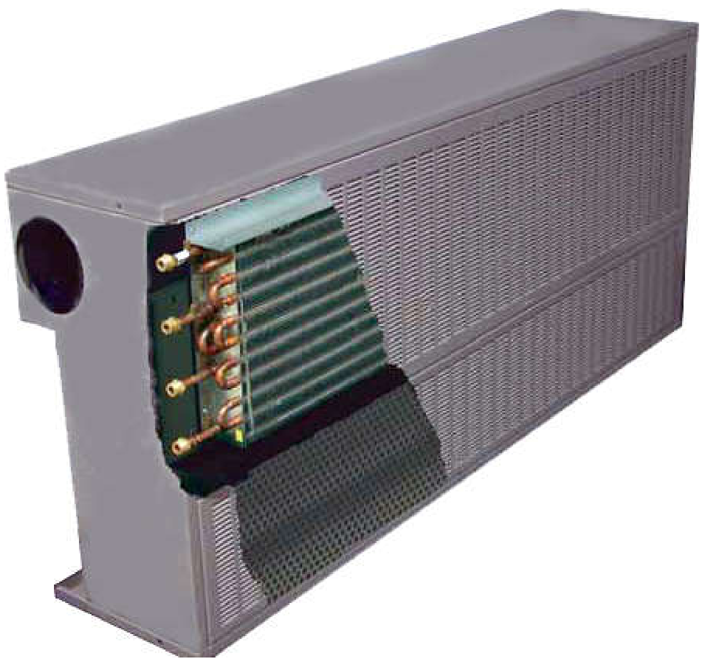
Cost to transport with water

15 to 20% that of air

Displacement Induction Chilled Beam

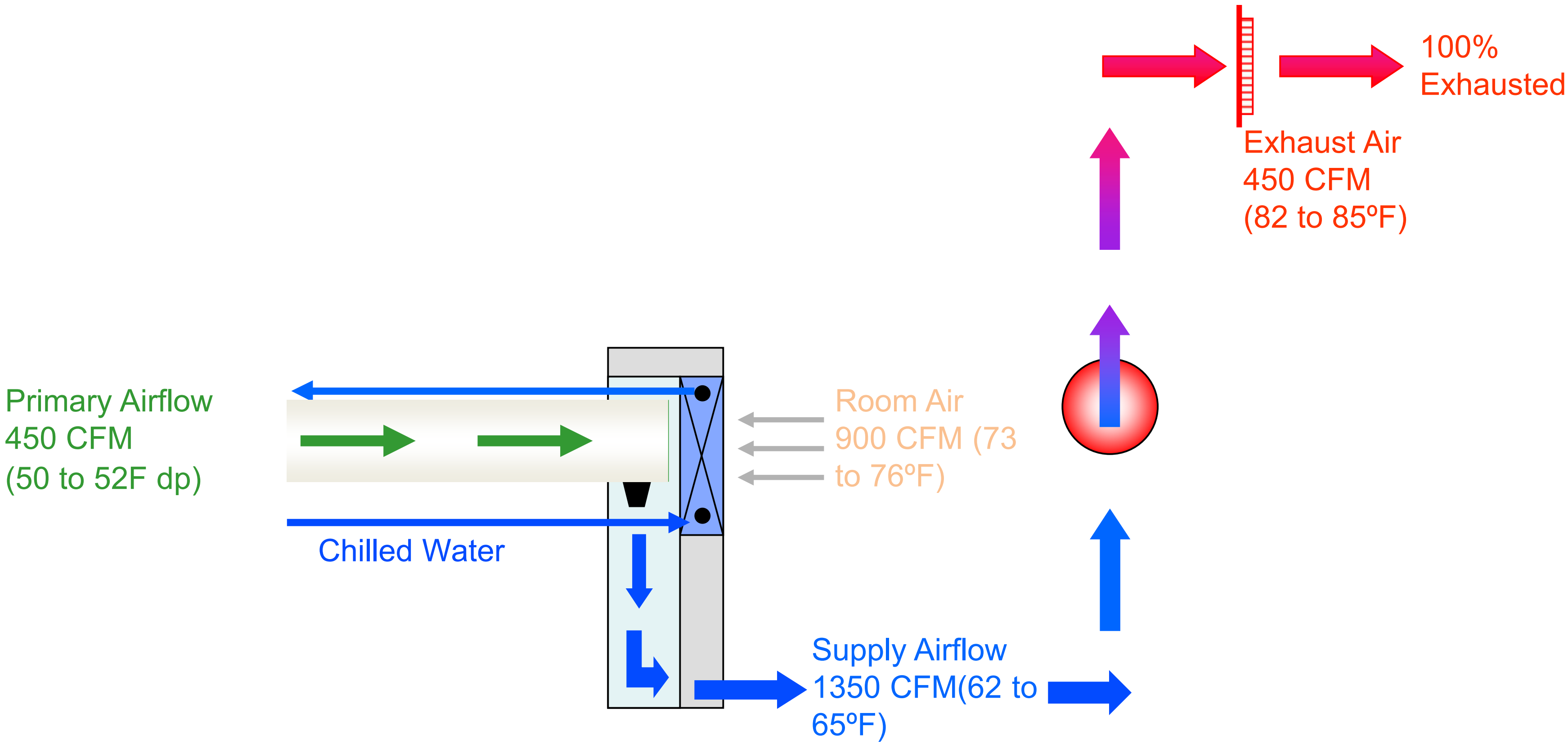
Operation and Benefits for HVAC system design

- Uses primary air from 100% Dedicated Outside Air System (DOAS)
- Combines Displacement Ventilation with Low Pressure Induction
- High Ventilation Effectiveness (Up to 50% better than VAV)
- Exceeds ANSI S12.60 Standard for Noise in Classrooms
- Low sound levels - NC 25 to 30
- Highest Efficiency (Up to 20% greater efficiency than overhead Chilled Beam and 40% better than overhead VAV)



Displacement Induction Chilled Beam

Cooling Mode Operation



Cooling w/ Displacement Chilled Beam

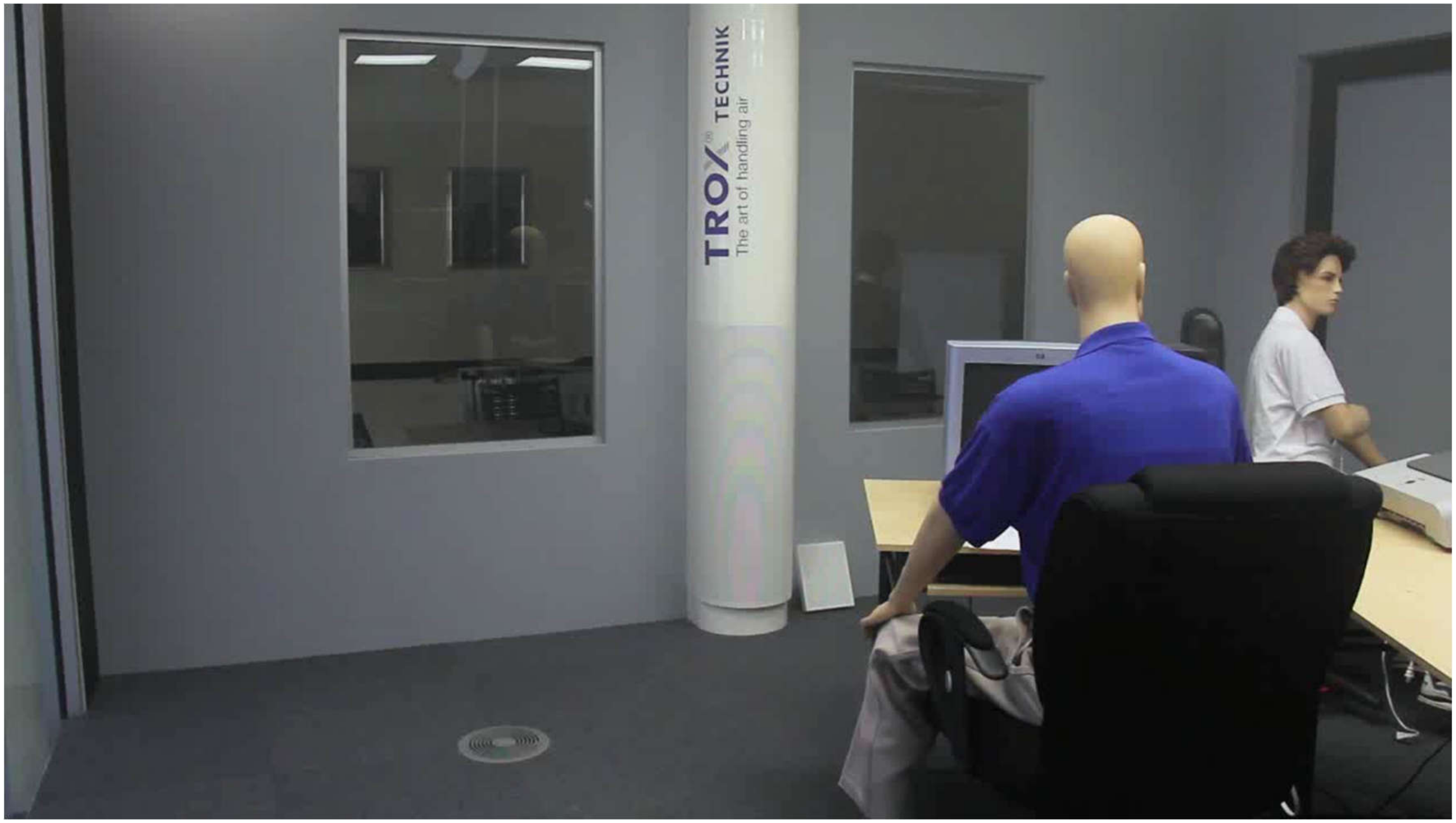
So what about heating with displacement?

Traditional – ALL DISPLACEMENT IS NOT THE SAME

- Typical Displacement decouples heating so you can address the perimeter
- Separate Fin Tube System along perimeter wall
- Vertical Orientation of corner diffusers concentrates heat vertically

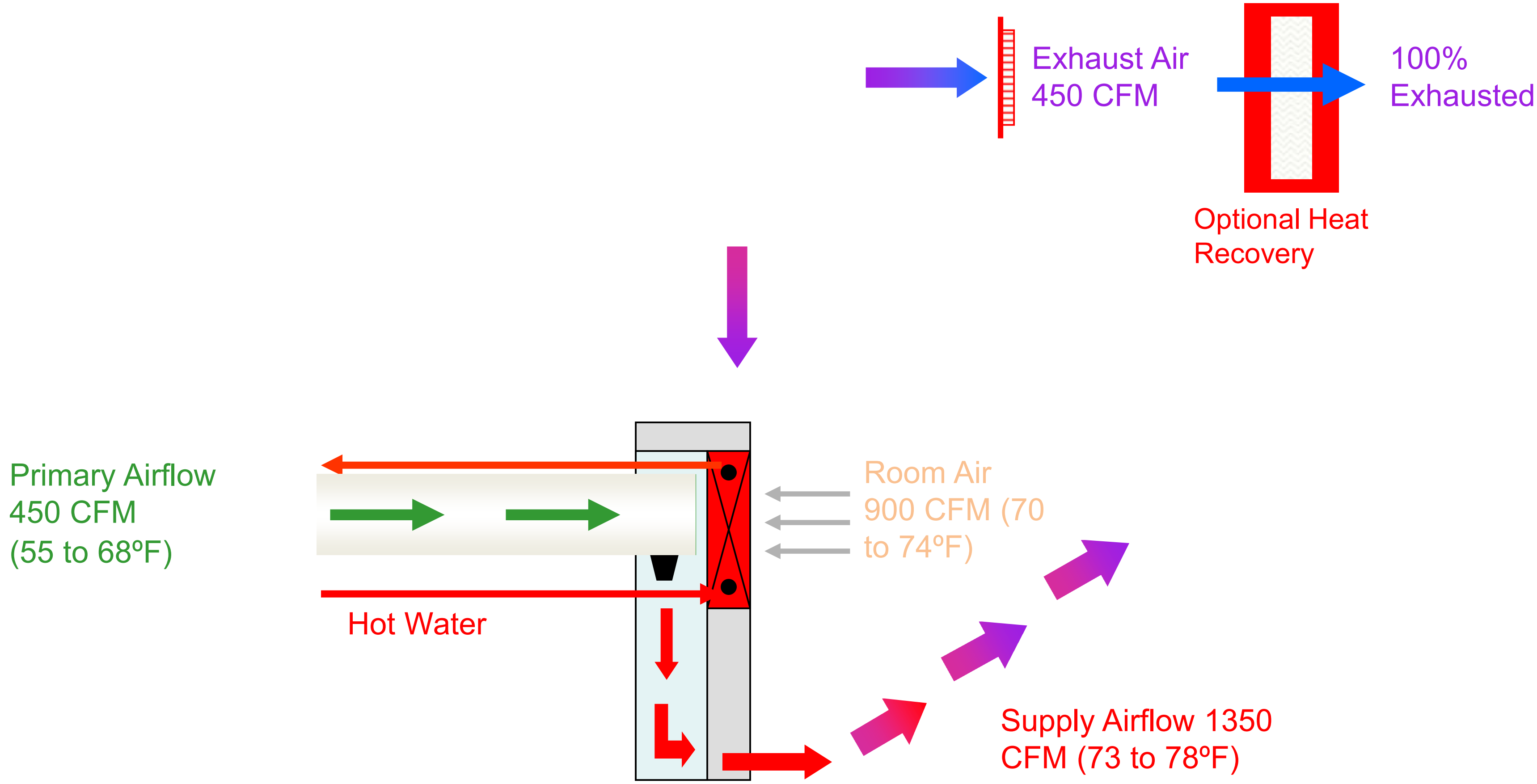
THE CHALLENGE: Heating via Displacement

Traditional Displacement – ALL DISPLACEMENT IS NOT THE SAME



Displacement Induction Chilled Beam

Heating Mode Operation

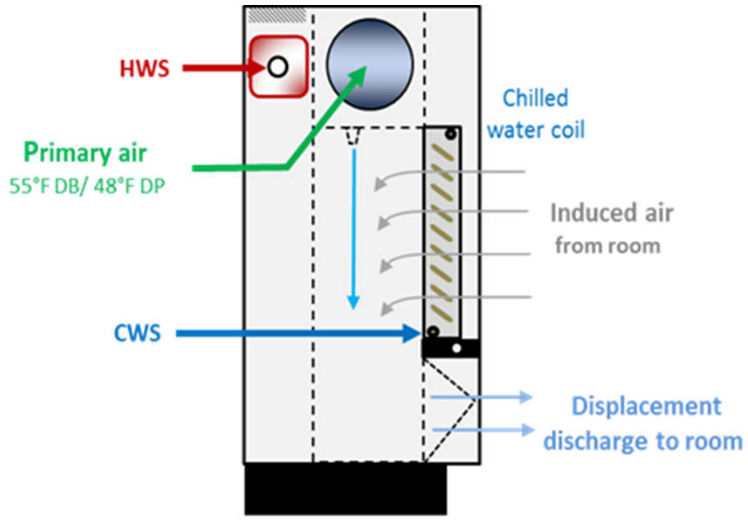


Heating with Induction Displacement Ventilation

Displacement Chilled Beam

Option of Fin Tube Rear Heat

- Decouples heating circuit
- Heat not driven by primary air or induction
- Addresses extreme perimeter heat load requirements
- Can simplify control sequences
- Optimized ventilation air volume

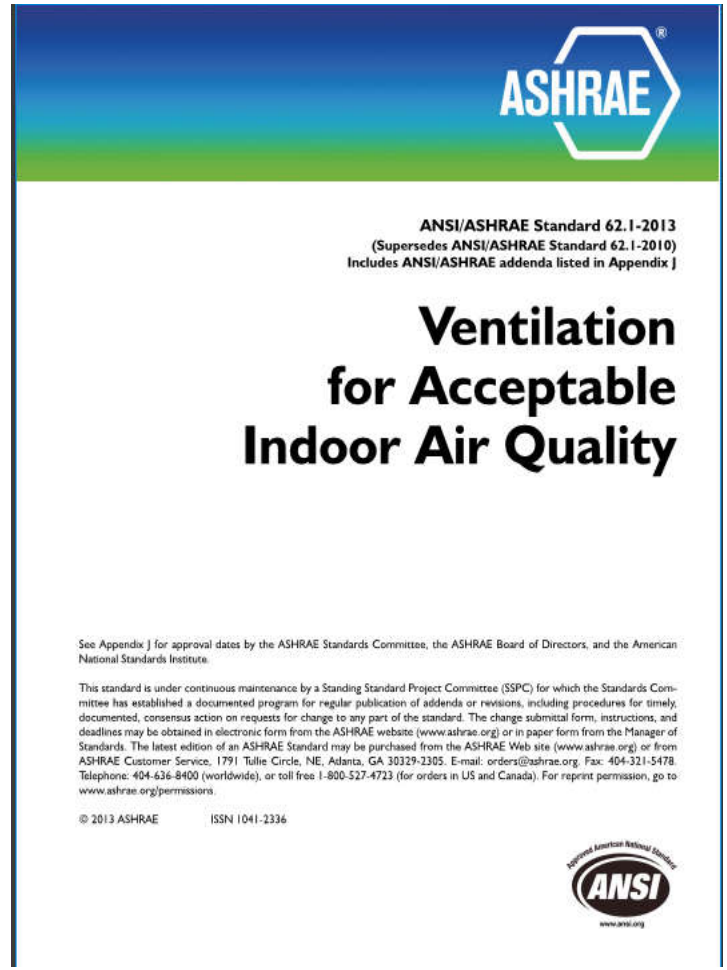


Teachers Utilize Every Square Inch!

Ventilation Rates

(IAQ)

- ASHRAE Standard 62.1 – 2016 Current Standard of Care but every state is different
- The purpose of the standard is to specify minimum ventilation rates and other measures intended to provide indoor air quality that is acceptable to human occupants and minimizes adverse health effects.
- Table 6.2.2.1 establishes minimum ventilation rates in the Breathing Zone
- Table 6.2.2.2 defines the ventilation effectiveness based on air distribution configuration


ASHRAE

ANSI/ASHRAE Standard 62.1-2013
(Supersedes ANSI/ASHRAE Standard 62.1-2010)
Includes ANSI/ASHRAE addenda listed in Appendix J

Ventilation for Acceptable Indoor Air Quality

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

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE Web site (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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Approved American National Standard
ANSI
www.ansi.org

Minimum Ventilation Rates in Breathing Zone

- Table 6.2.2.1 used to apply outdoor air rate to type of occupancy category

- R*p* – cfm/person
- R*a* – cfm/sqft

Table 6-1 Minimum Ventilation Rates in Breathing Zone

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Default Values Occupant Density	Air Class	OS (6.2.6.1.4)
	cfm/person	L/s·person	cfm/ft^2	$L/s \cdot m^2$	$\#/1000\ ft^2$ or $\#/100\ m^2$		
Educational Facilities							
Art classroom	10	5	0.18	0.9	20	2	
Classrooms (ages 5 to 8)	10	5	0.12	0.6	25	1	
Classrooms (age 9 plus)	10	5	0.12	0.6	35	1	
Computer lab	10	5	0.12	0.6	25	1	
Daycare sickroom	10	5	0.18	0.9	25	3	
Daycare (through age 4)	10	5	0.18	0.9	25	2	
Lecture classroom	7.5	3.8	0.06	0.3	65	1	✓
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3	150	1	✓
Libraries	5	2.5	0.12	0.6	10		
Media center	10	5	0.12	0.6	25	1	
Multiuse assembly	7.5	3.8	0.06	0.3	100	1	✓
Music/theater/dance	10	5	0.06	0.3	35	1	✓
Science laboratories	10	5	0.18	0.9	25	2	

Calculating Zone Outdoor Airflow

- Ez - Zone Air Distribution Effectiveness is a measure of the effectiveness of supply air distribution to the breathing zone.
- Breathing Zone is " the region within and occupied space between plane 3" and 72" above the floor and more than 2' from the walls or fixed air-conditioning equipment"
- Breathing Zone Outdoor Airflow
  Vbz = (Rp x Pz) + (Ra x Az)
- Zone **Outdoor Airflow**
  Voz = Vbz/Ez

Table 6-4 Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Well-Mixed Air Distribution Systems	
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above average space temperature where the supply air-jet velocity is less than 150 fpm (0.8 m/s) within 4.5 ft (1.4 m) of the floor and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above average space temperature where the supply air-jet velocity is equal to or greater than 150 fpm (0.8 m/s) within 4.5 ft (1.4 m) of the floor and ceiling return	1.0
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply outlet located more than half the length of the space from the exhaust, return, or both	0.8
Makeup supply outlet located less than half the length of the space from the exhaust, return, or both	0.5
Stratified Air Distribution Systems (Section 6.2.1.2.1)	
Floor supply of cool air where the vertical throw is greater than or equal to 60 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor and ceiling return at a height less than or equal to 18 ft (5.5 m) above the floor	1.05
Floor supply of cool air where the vertical throw is less than or equal to 60 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor and ceiling return at a height less than or equal to 18 ft (5.5 m) above the floor	1.2
Floor supply of cool air where the vertical throw is less than or equal to 60 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor and ceiling return at a height greater than 18 ft (5.5 m) above the floor	1.5

Minimum Outside Air per ASHRAE 62.1

Typical Classroom

- 30' X 30' X 10' – 900 ft^2
- One exposed wall with windows
- 30 Students

Overhead Mixing

900 ft^2 x .12 CFM = 108 CFM
30 students x 10 CFM = 300 CFM

$V_{oz} = V_{bz} / E_z$
V_{bz} = 408 CFM
V_{oz} = 408 CFM/**1.0**

Voz = 408 CFM

Displacement Ventilation

900 ft^2 x .12 CFM = 108 CFM
30 students x 10 CFM = 300 CFM

$V_{oz} = V_{bz} / E_z$
V_{bz} = 408 CFM
V_{oz} = 408 CFM/**1.2**

V_{oz} = 340 CFM ***17% Reduction***

Displacement Induction Ventilation
Energy Efficiency - Real World Proof

South Education Center – ID287

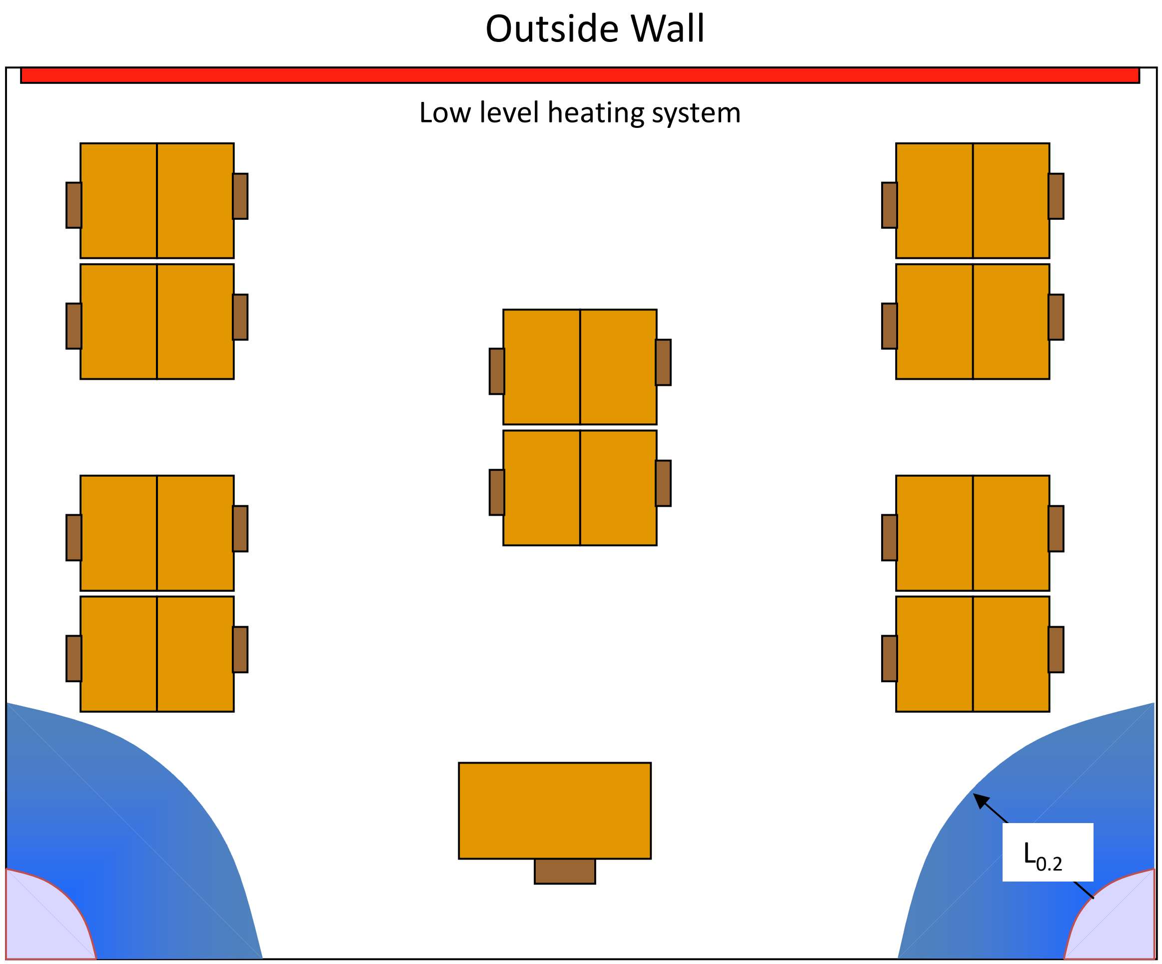
- Location in Richfield Minnesota
- 3 Stories, 108,000 ft^2
- Combined Geothermal with Displacement Induction Chilled Beam In Classrooms
- Overhead Chilled Beam in corridors, offices and conference rooms
- Traditional Displacement in common areas and gym
- ***64% More Efficient*** than energy Benchmark
- Ultra Low 44 kbtu per square foot
- American Council of Engineering Companies (ACEC) Engineering Excellence Award
- LEED Certified
- Xcel Energy's "Most efficient building designed and built for 2009"

20% more efficient than *identical building* with overhead chilled beam!

psst!

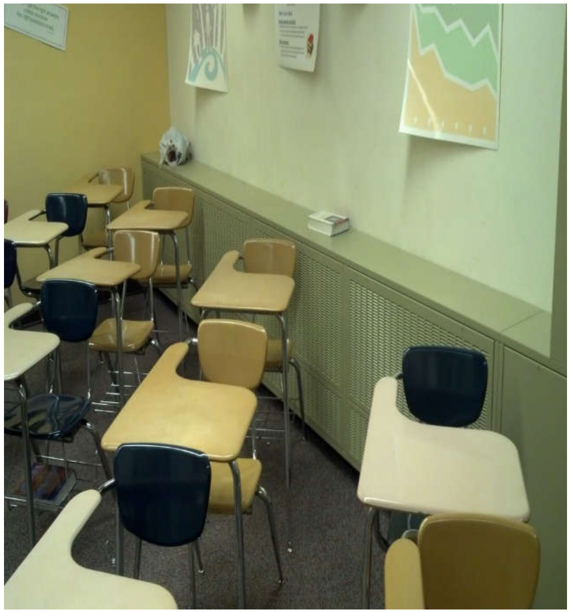
Traditional Displacement challenges in classrooms

Fundamentals of Displacement Ventilation – throw or near zone concerns



Displacement Induction Ventilation
Thermal Comfort

Low velocity => maximized room space



Impact of Poor Classroom Acoustics

Classroom Statistics

Demographics

13-15%	Of students are slightly impaired
10-15%	Of students learning in a language not spoken at home

Poor Classroom Acoustics

3%	Of children need out of classroom support
1%	Of children need outside placement due to acoustics

Annual cost of $6,300 ($7/FT2) per classroom

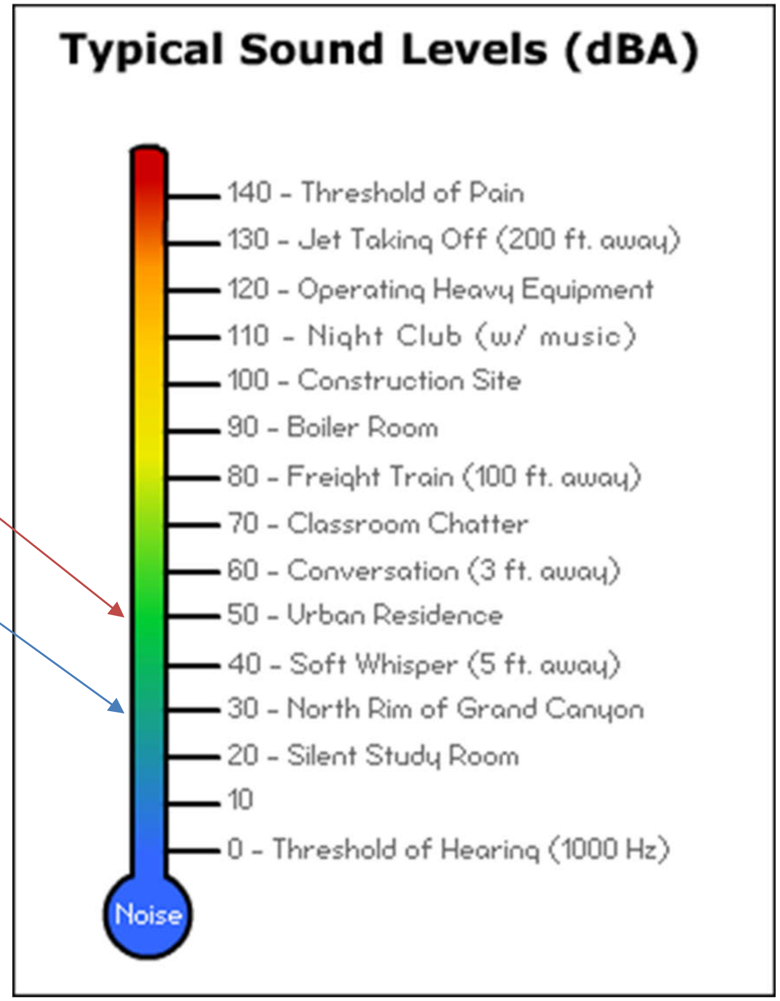
**Based on a 900 ft^2 classroom with 28 students*

Displacement Ventilation
Acoustics – the Quiet Option

- Onsite mockup at Minnesota Elementary School
- Mixed air system (unit ventilator):

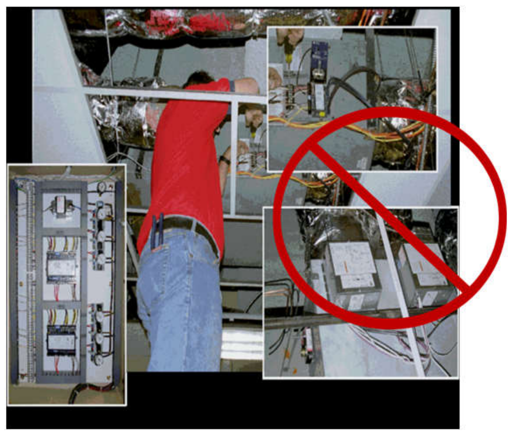
  55 dBA NC50
- Displacement conditioning system:

  35 dBA **NC30**



Displacement Induction Ventilation Chilled Beams *Maintenance* is Minimal

Maintenance: compared to traditional VAV or Unit Vents => MINIMAL



No filtration required

- Low face velocities
- Dry coil surface
- Major expense saved on filter change out
- Easy to clean
  Vacuum coils 1-2 times annually

No blowers or motors

- Blower expected life is 8-10 years
- No performance related issues to deal with
- Cost of blower motor replacement – ECM motors are approaching $450-$500 each plus labor

Low cost of ownership

- Significant energy savings
- Minimal maintenance and repair
- Less classroom downtime

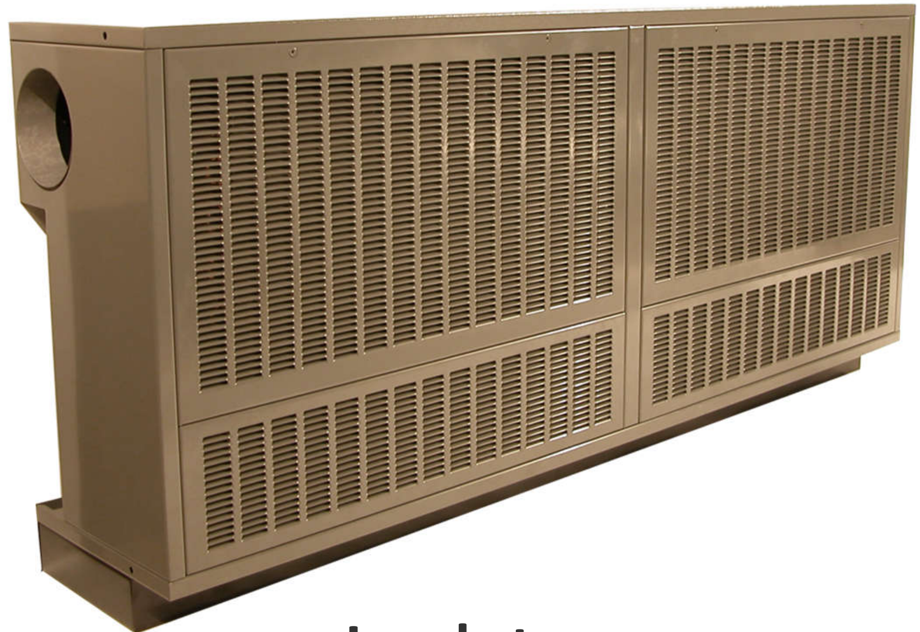
Displacement Induciton Ventilation Benefits

Increased

- IAQ
- Thermal Comfort

Decreased

- Maintenance
- Noise



Leads to…

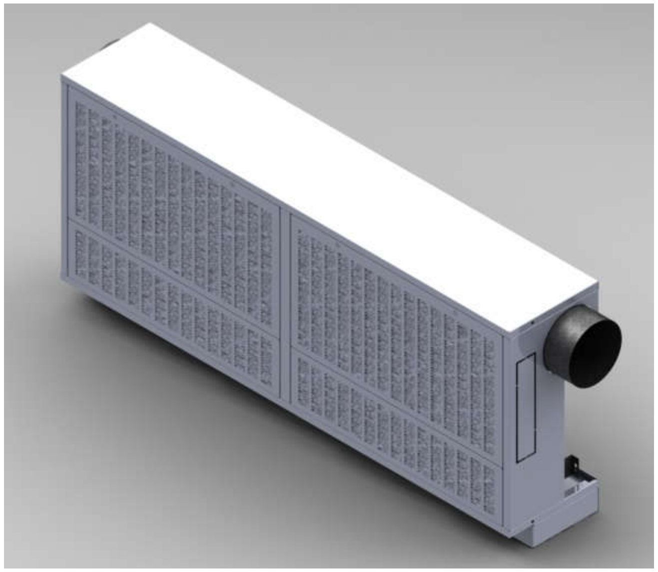
TOTAL IEQ

INDOOR

ENVIRONMENTAL

QUALITY

Displacement Induction Delivers



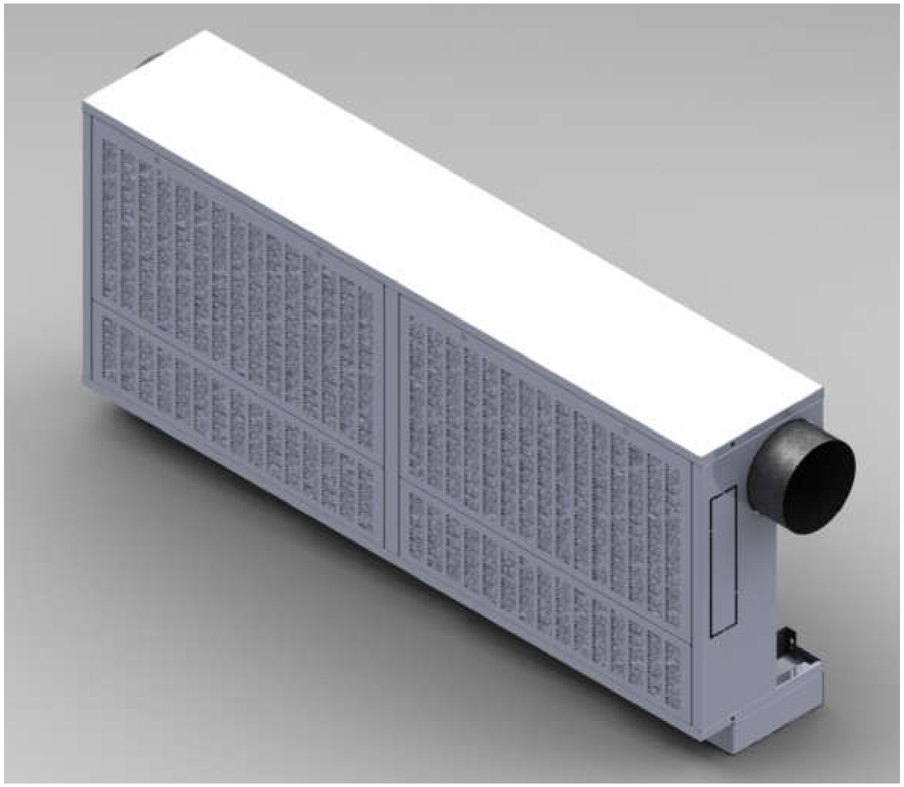
Physical solutions:

- Robust Construction
- Custom cabinetry
- Low maintenance

Application Solutions:

- Thermal Comfort
- Low cost of ownership
- New construction & retrofit solution

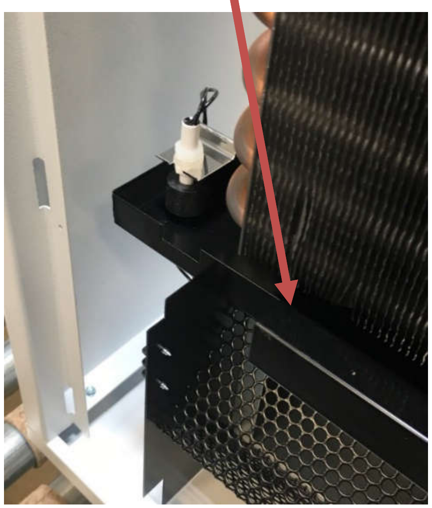
Construction Details Matter in Demanding Spaces



- 16 ga steel casing – framework like
- Designed for 250 lb point load
- Durable powder-coat withstands chipping
- Matte and textured finish withstands fingerprints
- Attaches to wall for safety
- Integral toe kick for maintenance ease

Design Options

- Perforated front access panels
- Internals painted black
- Drain pans with drain connections
  - Integral condensate management



The IEQ Equation:

Improved Student "Health" translates to:

Improved Student Learning

AND

Improved Teaching Environments provides

Enhanced Subject Conveyance

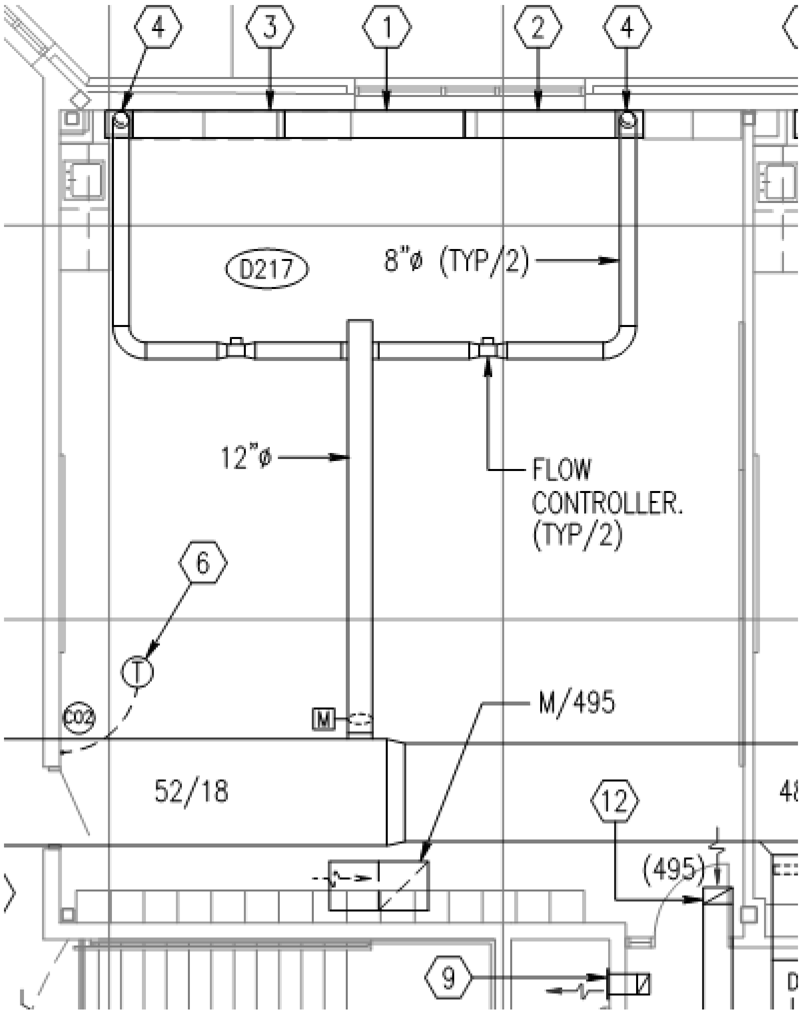
=

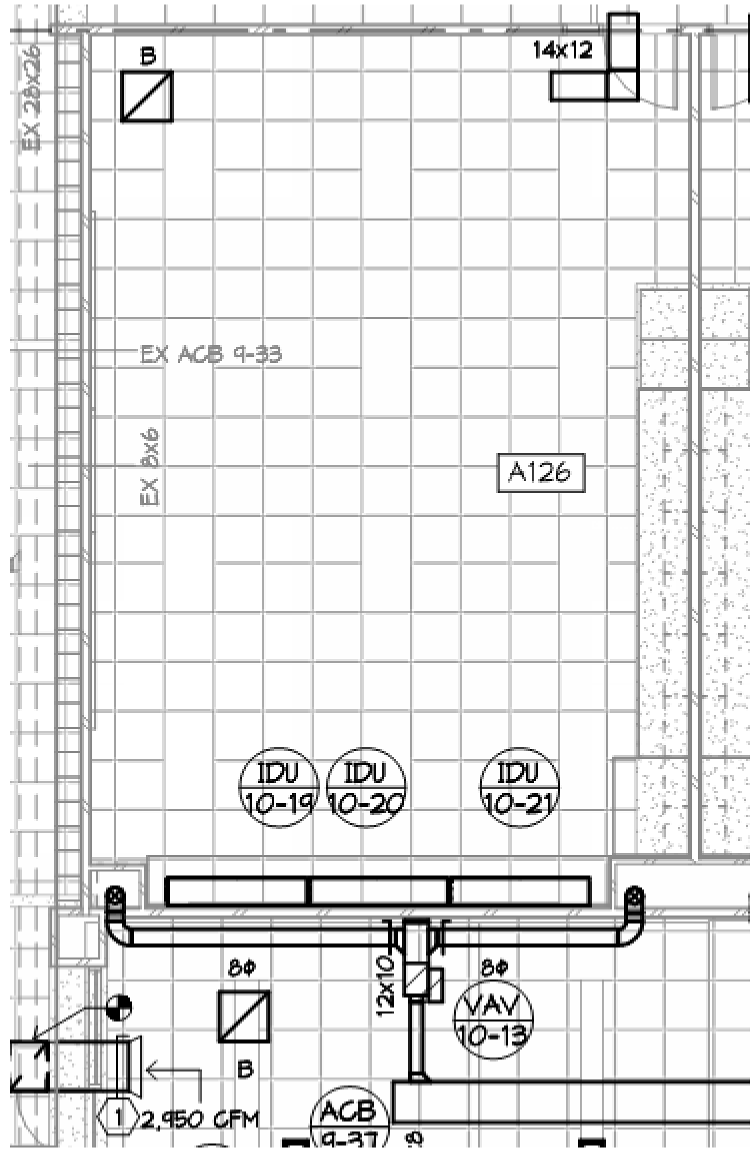
Enhanced Student & District Performance

This SYSTEM checks ALL the important boxes for SCHOOLS

- Guarantee delivery of mandated ventilation air to classroom
- Employ displacement airflow delivery for high IAQ
- Overcome DH issues common to North American climates;
- Comply with ANSI Standard S12.60
- Integrate with systems commonly used for classroom HVAC
- Warmer air temperatures versus traditional OHMV 50 to 55˚F
- Single air handling unit serves 6 to 10 classrooms
- Minimal maintenance and operation complexity
- 20-35 percent more efficient that the energy benchmark is typical
- System first cost comparable to currently used systems

Typical 2 duct drop layouts



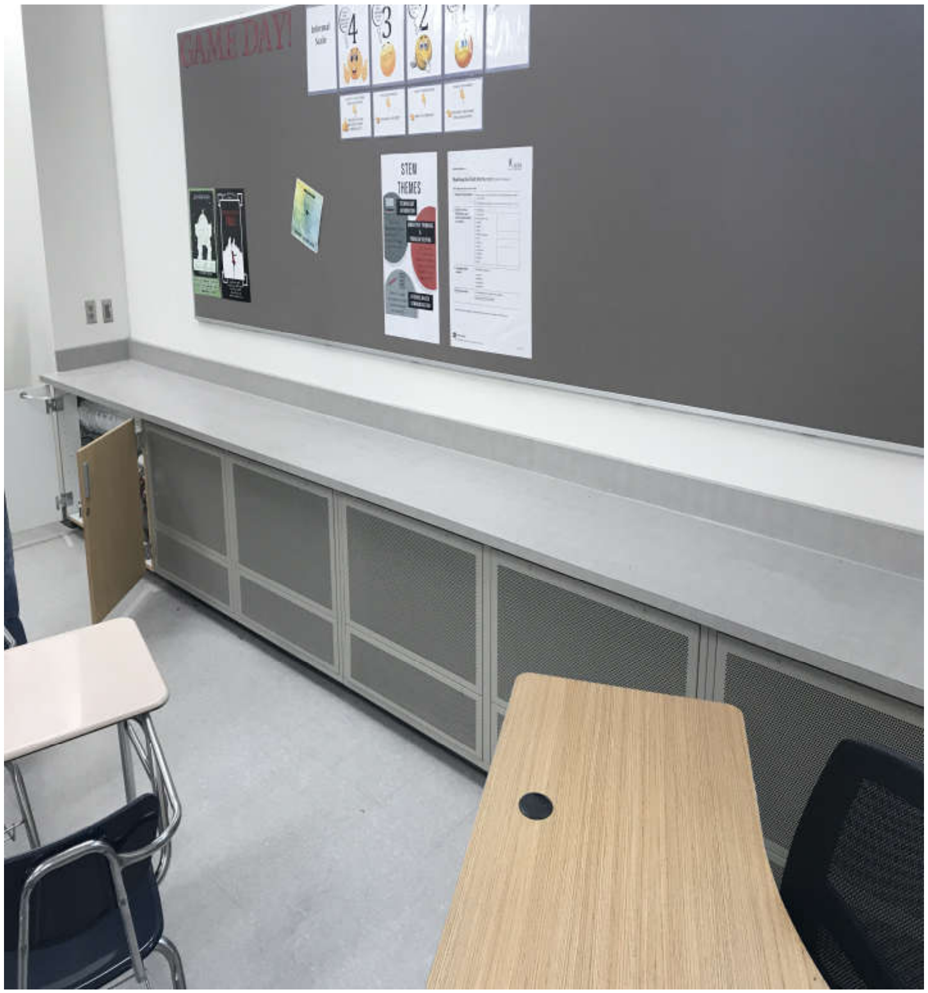


St. Croix ES (St. Croix, WI)

OA duct and water piping into units

Elk River HS (Elk River, MN)

Architectural Counter Tops

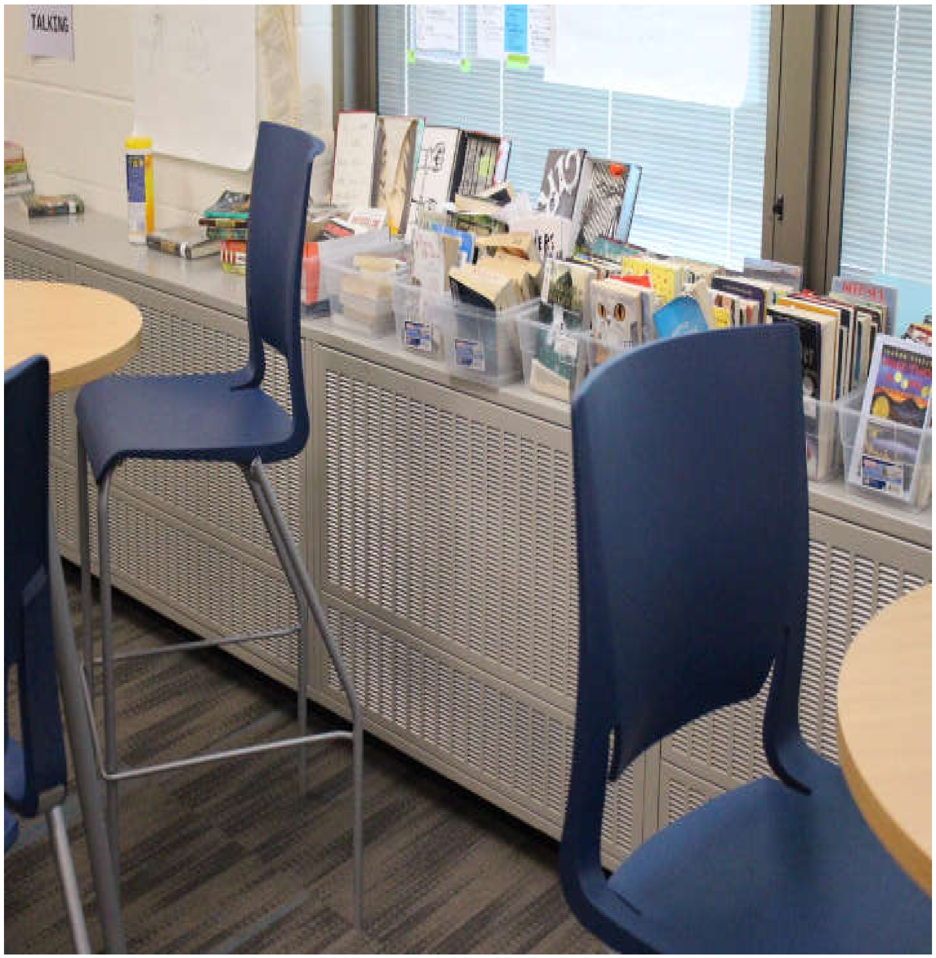


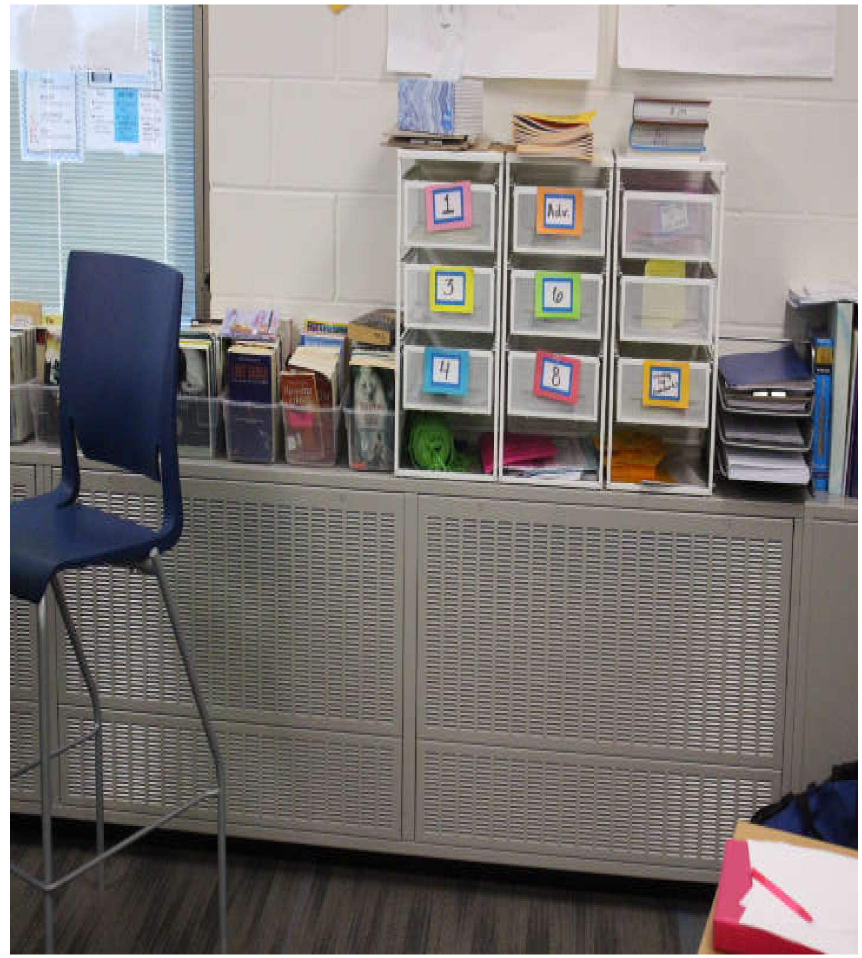
Hudson Valley Community College (Troy, NY)

Fully Recessed Units – Shared via LinkedIn Post

Prairie Winds MS (Mankato, MN)

Usable shelf & no near zone concerns



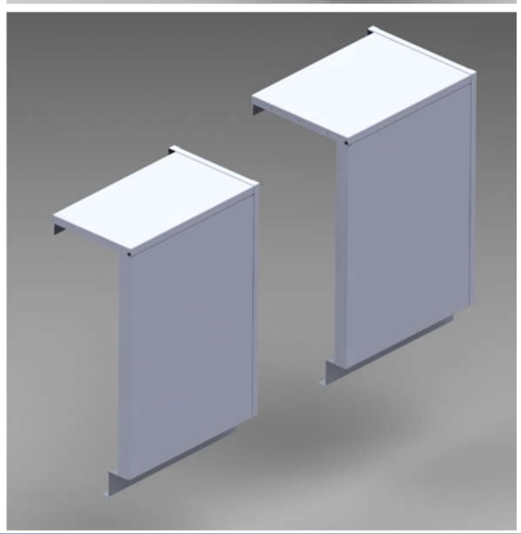


Complete Cabinet Accessories For Room Utility

Standard and Custom Options Available








How you deliver fresh air to a room matters…

Displacement Ventilation:

Better Contaminant Removal = Better Ventilation Effectiveness = Better IAQ

Einar K. Frobom, PE MBA
Carson Solutions
Director of Sales & Marketing

Excerpts from an Expert

Dr. Qingyan Chen, Mechanical Engineering Professor; Purdue University
One of the foremost experts on Indoor Environments
Close collaborator with ASHRAE for many established standards and guidelines
Fastcompany.com, 3/11/20 article - Coronavirus

"I hold a cup of water. I take a drink. Would you drink? You definitely say no. But in a room, I breath out air. We're staying in the same room. Can you hold your breath? No."

If ventilation systems don't properly suck and filter away pathogens before other people breathe them in, a contagion will spread.

It spits out air constantly. That air rises, naturally, as it warms in contact with your body. Then it's sucked inside the ceiling above your head, and largely expelled. This system would largely reduce recirculated pathogens, and it could work, not just in planes, but anywhere with a fixed seat, like buses and even movie theaters.

He suggests that air should come into a room around the floor boards, or even through ventilation in the floor itself. Again, the air would naturally heat in contact with people, and it would rise to the ceiling to be expelled. "You sop up the dirty air from [overhead],"

Ventilation Effectiveness Revisited: Explained

Mixed Air Systems

- The reference *Ez* value of 1 is typical of ideal mixing in the zone.

- Ideal Mixing => uniform C levels throughout zone
- C = Ce

- Ez = (Ce – Cs)/(C – Cs) = (Ce – Cs)/(Ce – Cs) = 1 **AT BEST**

EPA website: IAQ for Schools

ALL displacement ventilation approaches are **NOT** the same

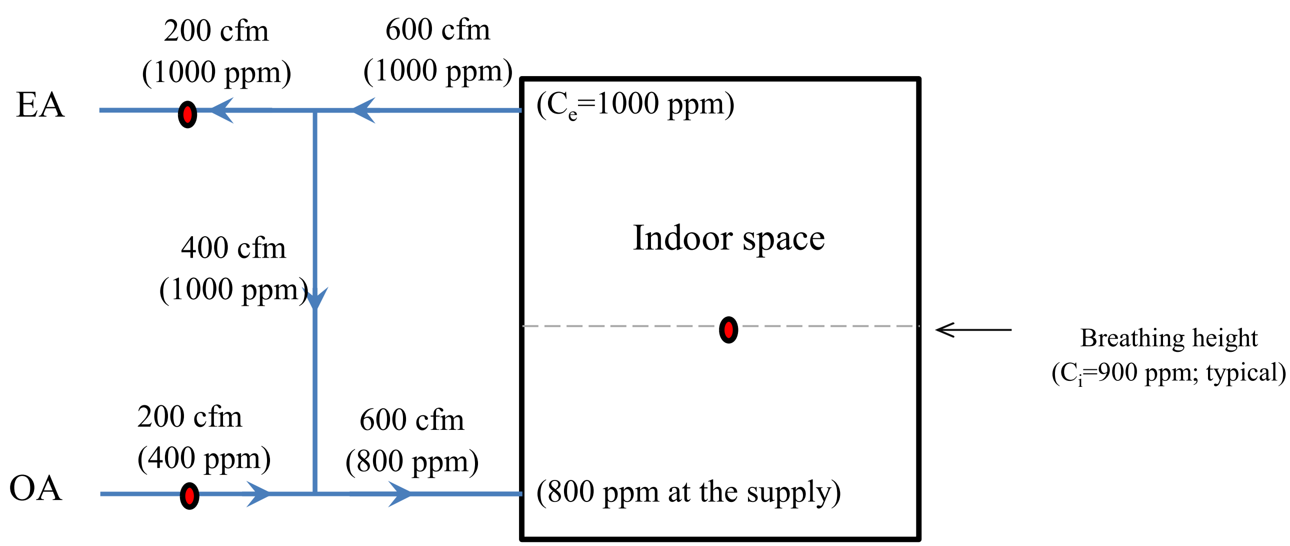
https://www.epa.gov/iaq-schools/heating-ventilation-and-air-conditioning-systems-part-indoor-air-quality-design-tools

Types of Air Distribution:

i. Nearly all schools currently use the mixed-airflow method for distribution and dilution of the air within the occupied space. Designers should investigate a method called vertical displacement ventilation or thermal displacement ventilation. This approach successfully uses natural convection forces to reduce fan energy and carefully lift air contaminants up and away from the breathing zone.

Ventilation Effectiveness Revisited: Explained

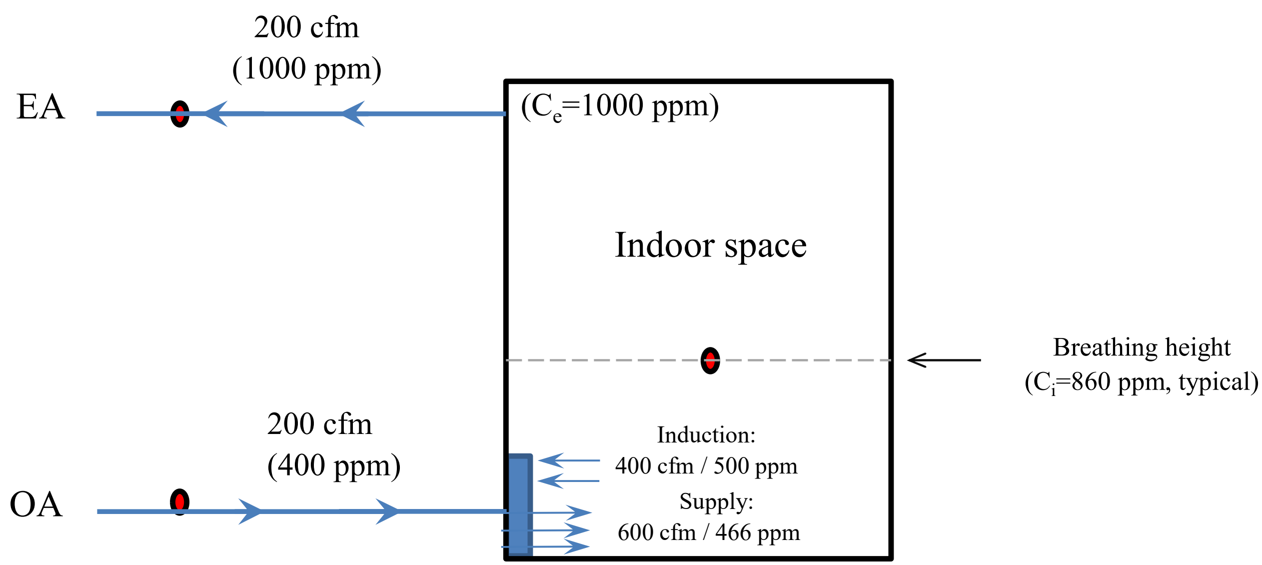
Traditional Displacement Ventilation System



$$Ez = \frac{C_e - C_s}{C_i - C_s} = \frac{1000 - 400}{900 - 400} = 1.2$$

Ventilation Effectiveness Revisited: Explained

Displacement Induction Ventilation – QLCI: cleaner air at Supply=>better IAQ v. TDV



$$Ez = \frac{C_e - C_s}{C_i - C_s} = \frac{1000 - 400}{860 - 400} = 1.3$$

$$Lower\ C\ supplied, lower\ C\ at\ breathing\ height, increased\ Ez\ v. Traditional\ DV$$

Life-size classroom: CFD of DIV v. TDV

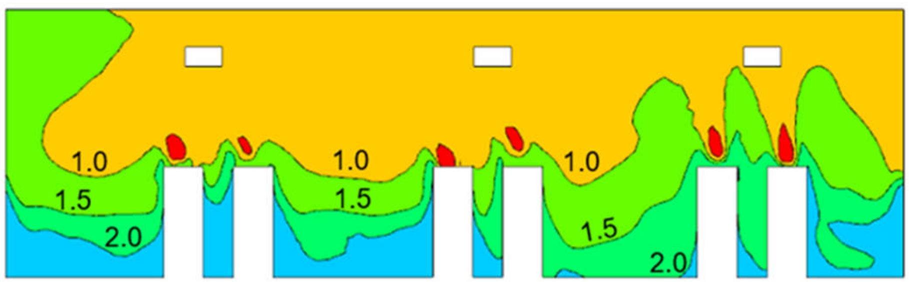
Ray W. Herrick Laboratories

Purdue University
College of Engineering

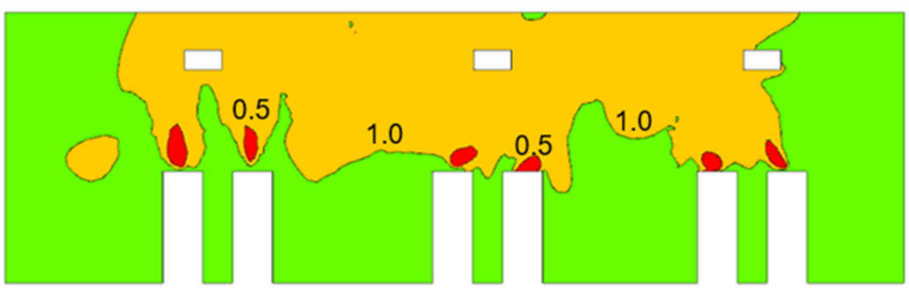
Cooling Mode **(DIV-C)**

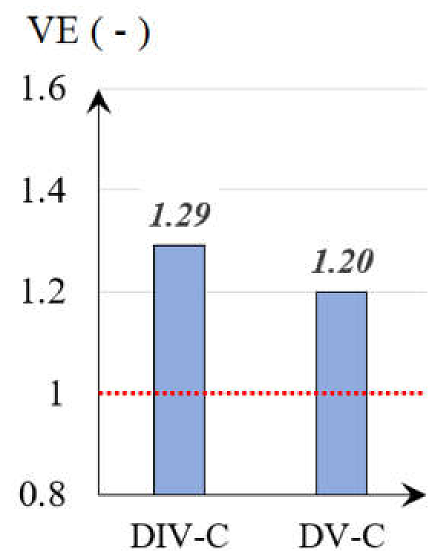
Comparison of DIV to DV (Traditional DV) system in cooling operation

VE distribution with DIV-C



VE distribution with TDV (DV-C)





Life-size classroom: CFD analysis DIV v. TDV

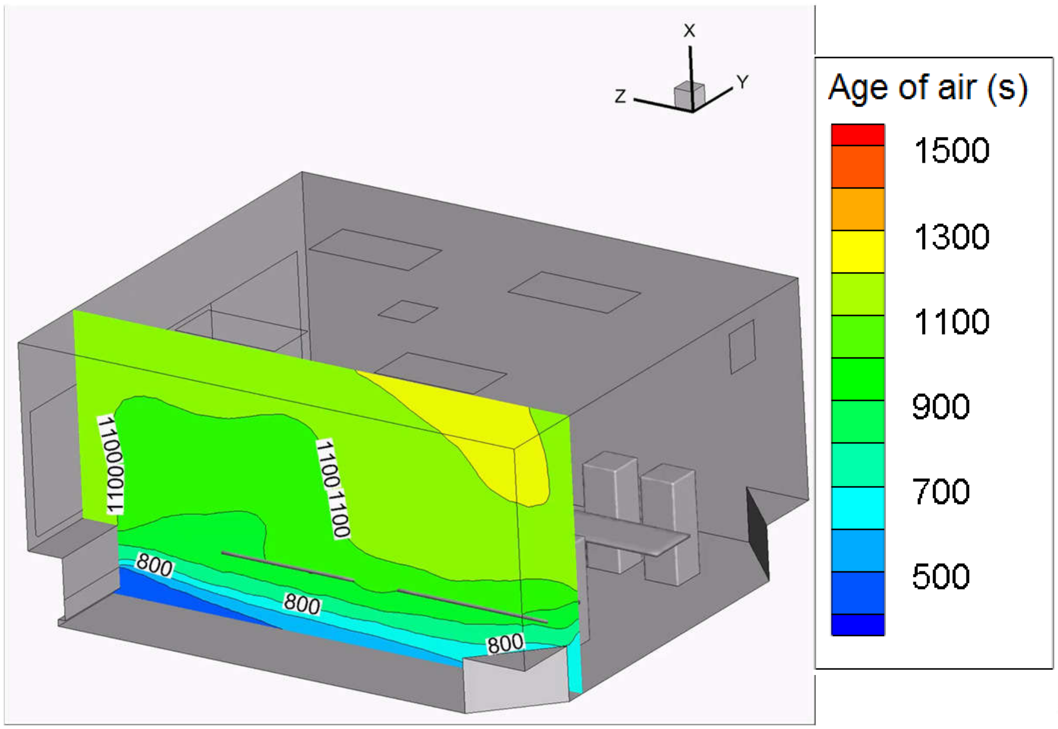
Age of Air – CFD comparison for “newer” air to occupants

RAY W. HERRICK LABORATORIES

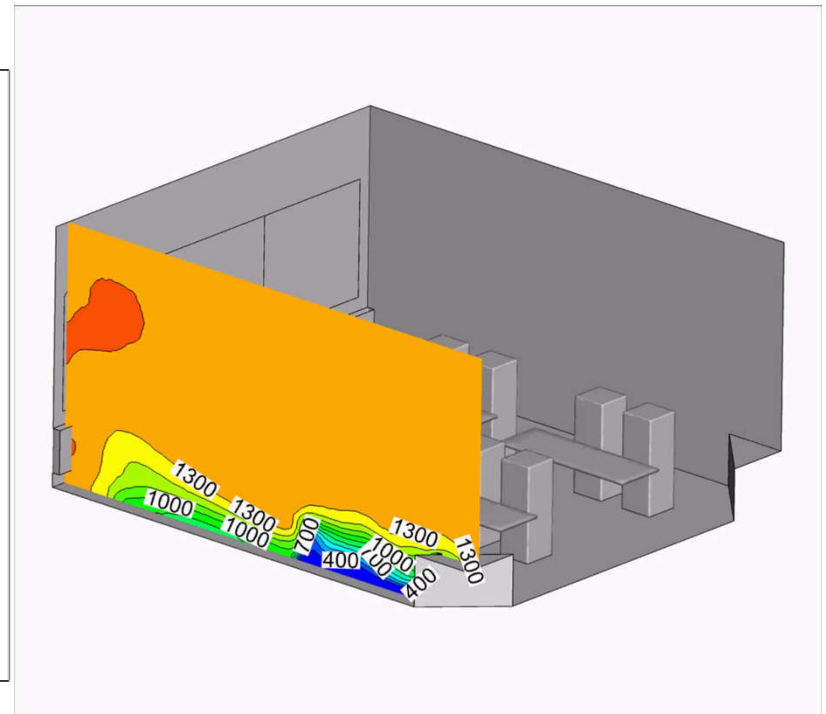
PURDUE UNIVERSITY

College of Engineering

DIV - REAR FIN TUBE HEATING



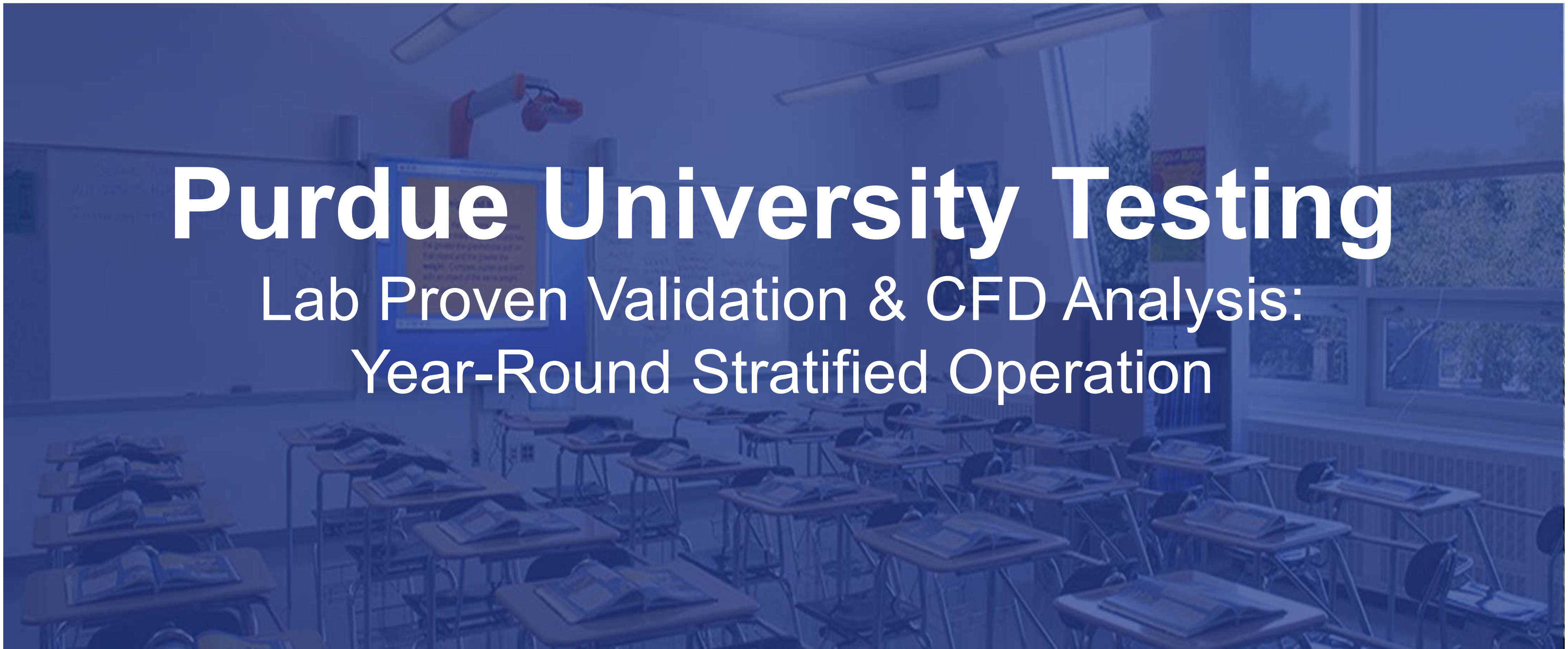
TDV – RADIATED HEATING



Mean age of air of DIV is better/newer than in TDV (w/radiators) in heating mode

Traditional Displacement v. DIV

Interview with Dr. Qingyan Chen, Purdue University – Mechanical Engineering



Purdue University Testing

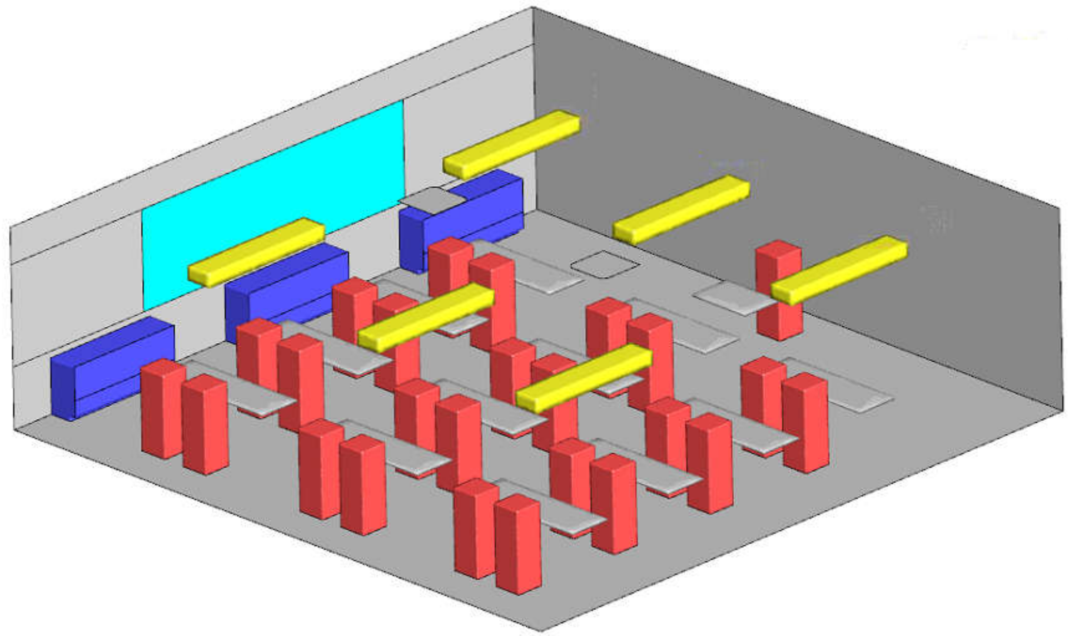
Lab Proven Validation & CFD Analysis: Year-Round Stratified Operation

Einar K. Frobom, PE MBA
Carson Solutions
Director of Sales & Marketing

CFD simulations in a real-size classroom

Lab tested and verified CFD modeling

Input geometry:



Basic conditions:

Room size: 900 sqft (30’ x 30’)

Ceiling height: 9 ft

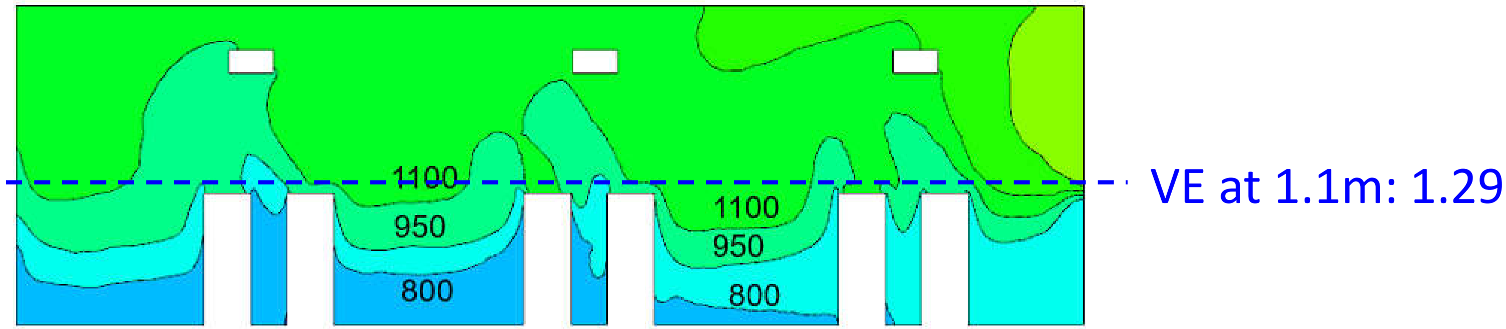
Occupants: 25 students

3 size 1500 (68.75”) QLCI’s

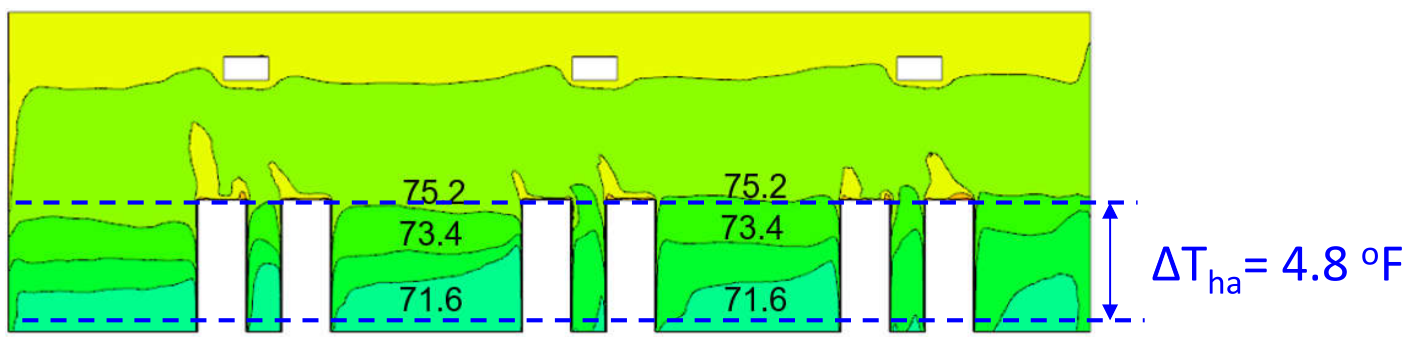
CFD simulations in a real-size classroom

Ray W. Herrick Laboratories | Purdue University College of Engineering

Representative results in classroom: “DIV-C” case; COOLING mode



Age of air in “DIV-C” case: **Stratified**



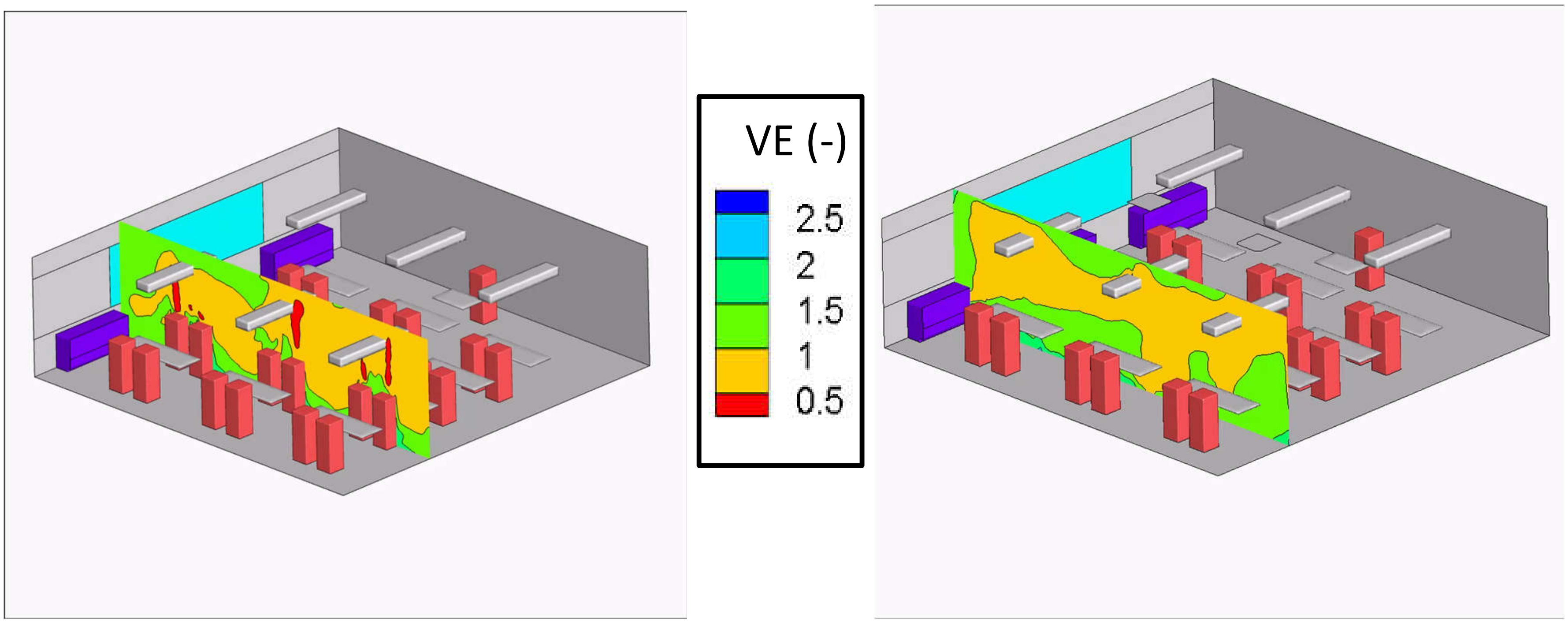
Temperature distribution in “DIV-C” case (unit: °F)

Staged Heating: Complicated Control Strategy

Testing for combined operation of units in both heating and ventilation

DIV-SH1 – 1 unit FACE HEATING

DIV-SH2 – 2 units FACE HEATING



Ave Room VE= 1.20+

Ave Room VE= 1.15-1.2

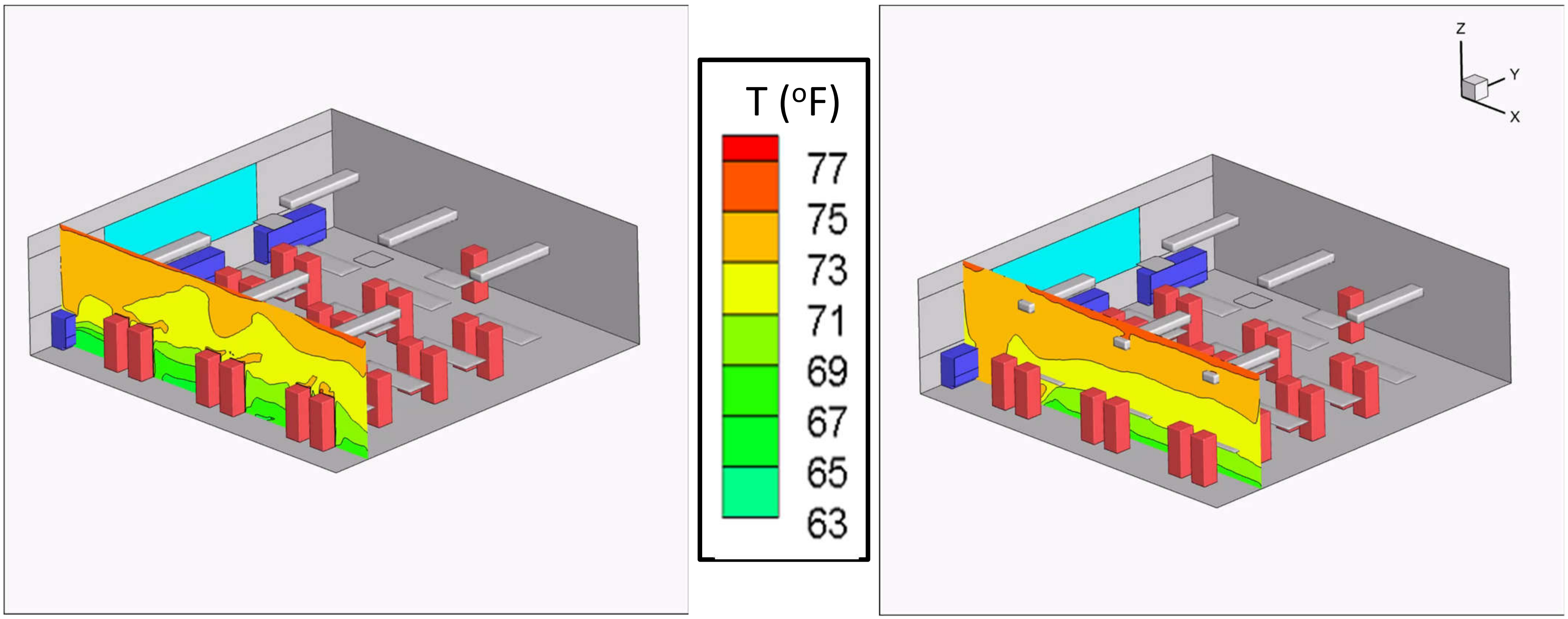
- In these cases, VE is a combined effect resulting from different modes

Staged Heating: Complicated Control Strategy

Testing for combined operation of units in both heating and ventilation

DIV-SH1 – 1 unit FACE HEATING

DIV-SH2 – 2 units FACE HEATING

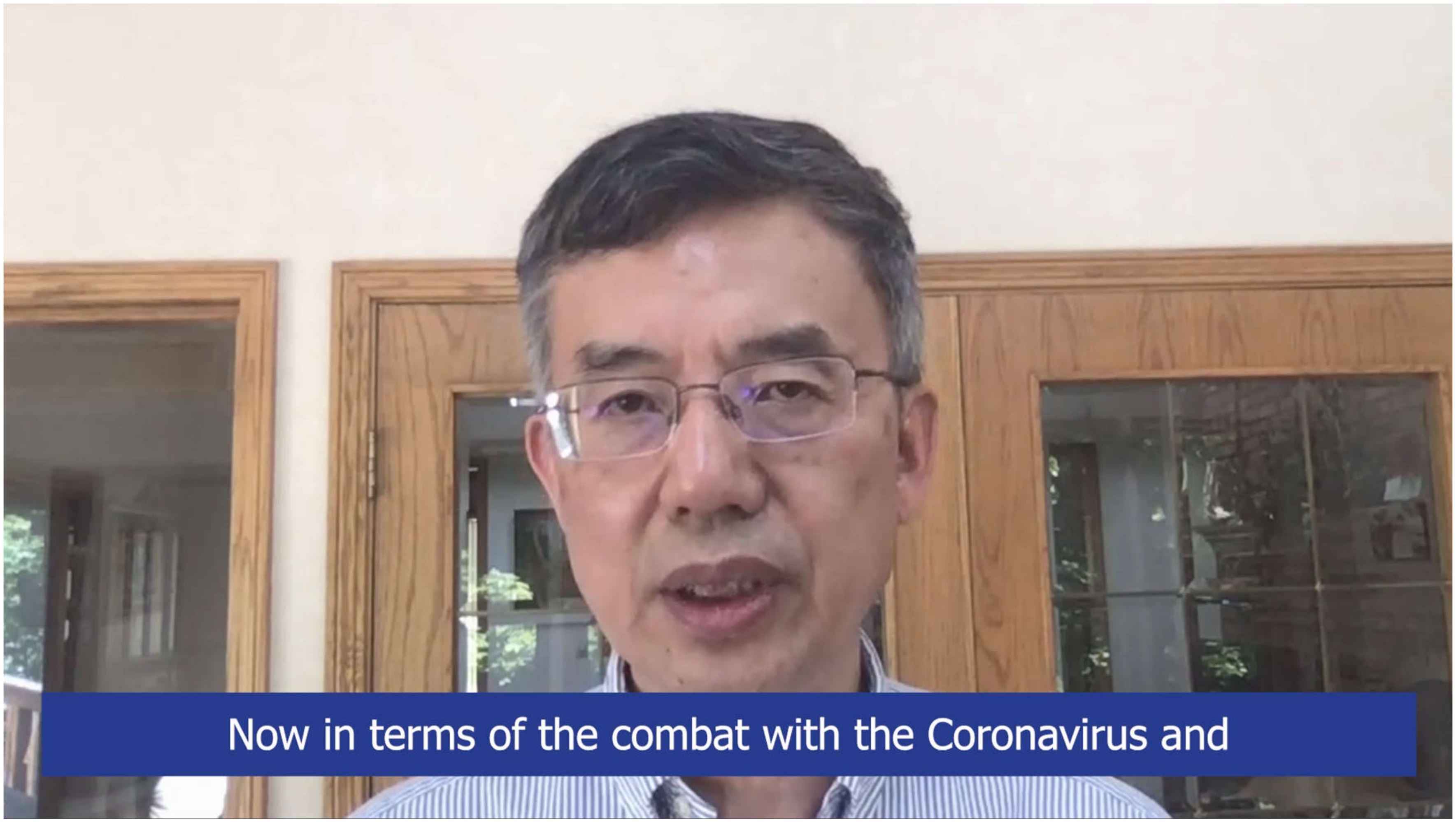


$\Delta T_{ha} = 4.2\ °F$

$\Delta T_{ha} = 3.7\ °F$

Displacement v. Mixed Air Ventilation Contaminant Removal and “Shared” Air

Interview with Dr. Qingyan Chen, Purdue University – Mechanical Engineering



Excerpt from ASHRAE article 5/2020

Guidance for Building Operations During the COVID-19 Pandemic

- ASHRAE HVAC operational suggestions in response to COVID-19 safe building practices:
  - Increase outdoor air ventilation…to increase effective dilution ventilation per person
    - Note the common approach suggested "to dilute" versus "purge" or "remove"
  - Disable demand control ventilation
    - Huge impact for systems specifically designed to promote DCV for savings
  - Increase min OA dampers positioning to 100% open
    - They admit this works during mild seasons
    - Even though the OA damper and fans/motors might be able to accommodate, the cooling or heating components might not be able to perform as needed
  - Increase or improve filtration to MERV-13
    - Increase of system pressure drop potential
  - Run systems longer, 24/7 if possible
  - **ALL SUGGESTED HVAC OPERATIONAL CHANGES INCREASE OPERATIONAL COSTS**

Questions?