Displacement Induction Ventilation: Delivering School Districts Better IAQ Thru Effective Contaminant Removal and Reduced Shared Exposure

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

Dedicated 100% Fresh Air Unit

Fresh Air

Roof

Conditioned Fresh Air

Ceiling

Exhaust

Classroom

Fan Coil

Exhaust

Classroom

Fan Coil

1 + 3 = 4
2 + 3 = 5

1 + 3 = 4
2 + 3 = 5
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”

Outdoor Air
Hot and humid, it must be cleaned and dried.

Ventilation Dehumidifier
Dries the incoming air to a condition below the desired humidity dew point, removing the internally-generated humidity loads.

Dedicated Outdoor Air System (DOAS)

55°F [12.8°C] Humidity Control Dew Point
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 Mixing and Even Temperature Distribution 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


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

Primary Airflow
450 CFM
(50 to 52°F dp)

Chilled Water

Room Air
900 CFM (73 to 76°F)

Supply Airflow
1350 CFM (62 to 65°F)

Exhaust Air
450 CFM
(82 to 85°F)

100% Exhausted
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

Primary Airflow
450 CFM
(55 to 68°F)

Hot Water

Room Air
900 CFM (70 to 74°F)

Supply Airflow 1350 CFM (73 to 78°F)

Exhaust Air
450 CFM

100% Exhausted

Optional Heat Recovery

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
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
  • $Ra$ – cfm/sqft

### Table 6-1 Minimum Ventilation Rates in Breathing Zone

<table>
<thead>
<tr>
<th>Occupancy Category</th>
<th>People Outdoor Air Rate $R_p$ cfm/person</th>
<th>Area Outdoor Air Rate $Ra$ cfm/ft²</th>
<th>Default Values #/1000 ft² or #/#100 m²</th>
<th>Air Class OS (6.2.6.1.4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Art classroom</td>
<td>10</td>
<td>0.18</td>
<td>0.9</td>
<td>20</td>
</tr>
<tr>
<td>Classrooms (ages 5 to 8)</td>
<td>10</td>
<td>0.12</td>
<td>0.6</td>
<td>25</td>
</tr>
<tr>
<td>Classrooms (age 9 plus)</td>
<td>10</td>
<td>0.12</td>
<td>0.6</td>
<td>35</td>
</tr>
<tr>
<td>Computer lab</td>
<td>10</td>
<td>0.12</td>
<td>0.6</td>
<td>25</td>
</tr>
<tr>
<td>Daycare sickness</td>
<td>10</td>
<td>0.18</td>
<td>0.9</td>
<td>25</td>
</tr>
<tr>
<td>Daycare (through age 4)</td>
<td>10</td>
<td>0.18</td>
<td>0.9</td>
<td>25</td>
</tr>
<tr>
<td>Lecture classroom</td>
<td>7.5</td>
<td>3.8</td>
<td>0.06</td>
<td>0.3</td>
</tr>
<tr>
<td>Lecture hall (fixed seats)</td>
<td>7.5</td>
<td>3.8</td>
<td>0.06</td>
<td>0.3</td>
</tr>
<tr>
<td>Libraries</td>
<td>5</td>
<td>2.5</td>
<td>0.12</td>
<td>0.6</td>
</tr>
<tr>
<td>Media center</td>
<td>10</td>
<td>0.12</td>
<td>0.6</td>
<td>25</td>
</tr>
<tr>
<td>Multiuse assembly</td>
<td>7.5</td>
<td>3.8</td>
<td>0.06</td>
<td>0.3</td>
</tr>
<tr>
<td>Music/theater/dance</td>
<td>10</td>
<td>0.06</td>
<td>0.3</td>
<td>35</td>
</tr>
<tr>
<td>Science laboratories</td>
<td>10</td>
<td>0.18</td>
<td>0.9</td>
<td>25</td>
</tr>
</tbody>
</table>
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**
  \[ V_{bz} = (R_p \times P_z) + (R_a \times A_z) \]

- **Zone Outdoor Airflow**
  \[ V_{oz} = \frac{V_{bz}}{E_z} \]

<table>
<thead>
<tr>
<th>Table 6-4 Zone Air Distribution Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Distribution Configuration</td>
</tr>
<tr>
<td>Well-Mixed Air Distribution Systems</td>
</tr>
<tr>
<td>Ceiling supply of cool air</td>
</tr>
<tr>
<td>Ceiling supply of warm air and floor return</td>
</tr>
<tr>
<td>Ceiling supply of warm air 15°F (8°C) or more 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</td>
</tr>
<tr>
<td>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</td>
</tr>
<tr>
<td>Floor supply of warm air and floor return</td>
</tr>
<tr>
<td>Floor supply of warm air and ceiling return</td>
</tr>
<tr>
<td>Makeup supply outlet located more than half the length of the space from the exhaust, return, or both</td>
</tr>
<tr>
<td>Makeup supply outlet located less than half the length of the space from the exhaust, return, or both</td>
</tr>
<tr>
<td>Stratified Air Distribution Systems (Section 6.2.1.2.1)</td>
</tr>
<tr>
<td>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</td>
</tr>
<tr>
<td>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 1.5 ft (0.5 m) above the floor</td>
</tr>
<tr>
<td>Floor supply of cool air where the vertical throw is less than 18 ft (5.5 m) above the floor and ceiling return at a height greater than 18 ft (5.5 m) above the floor</td>
</tr>
</tbody>
</table>
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

\[ V_{oz} = \frac{V_{bz}}{E_z} \]
\[ V_{bz} = 408 \text{ CFM} \]
\[ V_{oz} = 408 \text{ CFM} / 1.0 \]
\[ V_{oz} = 408 \text{ CFM} \]

Displacement Ventilation

\[ V_{oz} = \frac{V_{bz}}{E_z} \]
\[ V_{bz} = 408 \text{ CFM} \]
\[ V_{oz} = 408 \text{ CFM} / 1.2 \]
\[ V_{oz} = 340 \text{ CFM} \quad 17\% \text{ Reduction} \]
Displacement Induction Ventilation
Energy Efficiency - Real World Proof

South Education Center – ID287

- Location in Richfield Minnesota
- 3 Stories, 108,000 ft²
- 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!
Traditional Displacement challenges in classrooms

Fundamentals of Displacement Ventilation – throw or near zone concerns

Outside Wall

Low level heating system
Displacement Induction Ventilation
Thermal Comfort

Low velocity => maximized room space
# Impact of Poor Classroom Acoustics

## Classroom Statistics

### Demographics

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-15%</td>
<td>Of students are slightly impaired</td>
</tr>
<tr>
<td>10-15%</td>
<td>Of students learning in a language not spoken at home</td>
</tr>
</tbody>
</table>

### Poor Classroom Acoustics

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3%</td>
<td>Of children need out of classroom support</td>
</tr>
<tr>
<td>1%</td>
<td>Of children need outside placement due to acoustics</td>
</tr>
</tbody>
</table>

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

*Based on a 900 ft² 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 Induction 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 than 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
“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 $E_z$ value of 1 is typical of ideal mixing in the zone.

• Ideal Mixing => uniform $C$ levels throughout zone
  • $C = C_e$

• $E_z = (C_e - C_s)/(C - C_s) = (C_e - C_s)/(C_e - C_s) = 1$ AT BEST
EPA website: IAQ for Schools

ALL displacement ventilation approaches are NOT the same


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

\[ E_z = \frac{C_e - C_s}{C_i - C_s} = \frac{1000 - 400}{900 - 400} = 1.2 \]
Ventilation Effectiveness Revisited: Explained

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

\[ E_Z = \frac{C_e - C_s}{C_i - C_s} = \frac{1000 - 400}{860 - 400} = 1.3 \]

Lower C supplied, lower C at breathing height, increased Ez v. Traditional DV
Life-size classroom: CFD of DIV v. TDV

**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

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

Yeah, if you read the ASHRAE report on
Purdue University Testing
Lab Proven Validation & CFD Analysis:
Year-Round Stratified Operation

Einar K. Frohomb, 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

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

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

VE at 1.1m: 1.29

$\Delta T_{ha} = 4.8 \degree F$

Temperature distribution in “DIV-C” case (unit: $\degree F$)
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

\[ \text{Ave Room VE} = 1.20+ \]
\[ \text{Ave Room VE} = 1.15-1.2 \]

- 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

$\Delta T_{ha} = 4.2 \, ^{\circ}F$

DIV-SH2 – 2 units FACE HEATING

$\Delta T_{ha} = 3.7 \, ^{\circ}F$
Displacement v. Mixed Air Ventilation
Contaminant Removal and “Shared” Air

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

Now in terms of the combat with the Coronavirus and
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?