Displacement Ventilation System

OVERVIEW

The fundamental approach to displacement ventilation utilizes the natural buoyancy forces created by the convective flows from heat sources in the space. As supply air enters the room at floor level, the interaction between heat sources begins to warm and displace the air into the upper or stratified zone. Over time, the air in a displacement application becomes layered, with the warmest temperatures located near the ceiling. Typically, the warmest layer contains the most contaminants, by placing the return location in or near the ceiling level we are able to maximize the removal of polluted air. This approach not only improves air quality in the occupied zone, it also helps us maintain thermal comfort.

Traditionally, displacement is paired with a Dedicated Outdoor Air System (DOAS), but it may also be used in a variety of other HVAC designs. When analyzing the method for conditioning outside air, it is important to remember that displacement parameters are different than overhead systems. There is an opportunity to decrease energy usage while maximizing IAQ.

DEFINITIONS

Adjacent Zone: The area adjacent to the diffuser where measured velocities exceed 40 fpm measured 4” above the floor.

Displacement Ventilation: A method of conditioning using the buoyancy of warm air combined with floor level, low velocity supply air.

Occupied Zone: A three dimensional area typically defined with a height no more than 6’ above the floor and no less than 24” away from walls.

Stratified Zone: The area above the occupied zone where higher temperature, less dense air becomes layered.

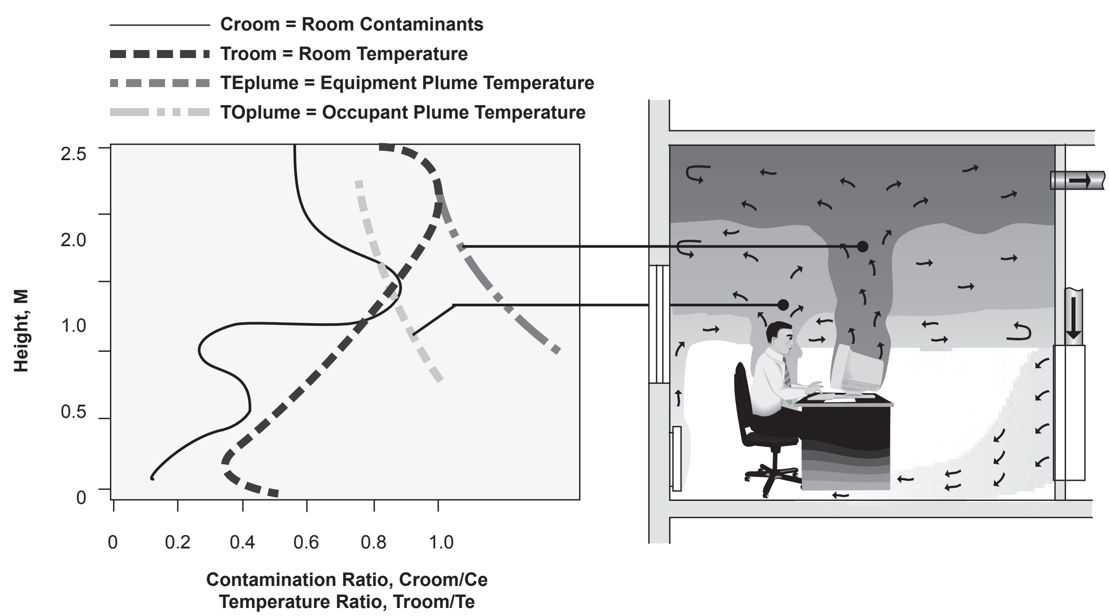
Thermal Plume: Air rising from a heat source.

Ventilation Effectiveness: A ratio between the concentration of particles in the stratified zone compared to the concentration of particles in the occupied zone.

OPERATIONS

Compared to the widely used approach of overhead well mixed air distribution, displacement ventilation presents opportunities to improve IAQ and reduce HVAC energy consumption. In addition to IAQ, we are able to achieve the following:

- Reduce draft in the occupied zone through low velocity supply air.
- Improve IAQ leading to greater occupant productivity.
- Increase the removal of unwanted particulates.
- Capitalize on the air distribution effectiveness thus reducing the required ventilation rate to the space.
- Have an ideal solution for schools and other noise dependent applications.



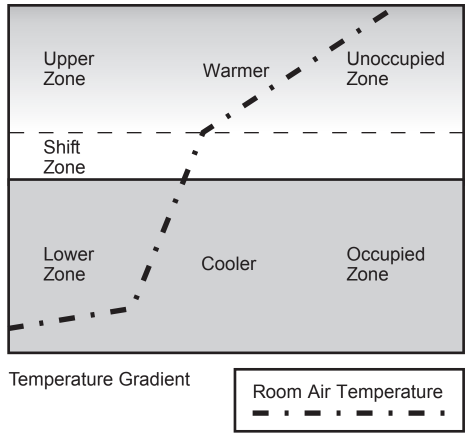
KRUEGER
Excellence in Air Distribution

Displacement Ventilation System

This solution not only has the potential for great thermal comfort, it also enables efficient use of our conditioned air. Unlike overhead air distribution, DV introduces low velocity, higher temperature supply air to the space. Some energy advantages of displacement ventilation over a totally mixed ventilation system include:

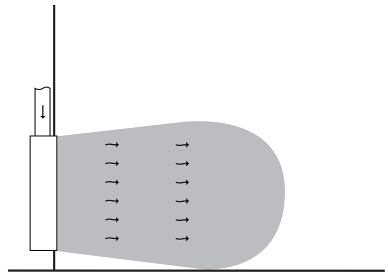
- Lower cooling energy and lower capacity demands will help maintain equal thermal conditions in the occupied zone.
- Higher temperature supply air can maximize the hours of economizer free cooling.
- Improved chiller COP due to higher EWT and higher supply air temperature.

NOTE: In displacement ventilation, the air temperature is actively controlled only in the occupied zone and supply airflow rate is adjusted to a level that makes the airborne contaminants rise above the breathing zone.

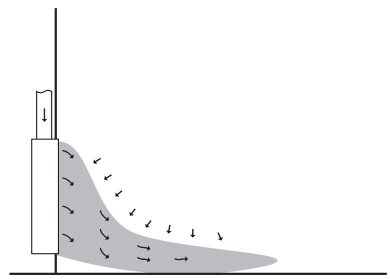


ISOTHERMAL VENTILATION
ASHRAE Standard 62.1-2010 “Ventilation for Acceptable Indoor Air Quality” table 6.2 states the ventilation effectiveness for over head mixed distribution systems is E_z = 1.0. Where fully stratified systems are assigned a value of 1.2, by comparison, 20% more effective than overhead. Better ventilation efficiency means, in addition to energy savings through a reduction in air volume, improved indoor air quality in the occupied zone is attainable.

Where:
E_z = Air Change Effectiveness (Table 6.2)



COOLING
With displacement ventilation, the room air temperature increases with the height in the space. As a result, the thermal conditions and air quality are actively controlled only in the occupied zone. The air temperature and contaminant level are higher in the stratified zone. Depending on the breakdown of heat gains and the height of the space, the temperature difference between the supply and exhaust air is 8 - 18°F. Since cool air is supplied directly to the occupied zone, special attention to the analysis of the adjacent zone should be taken to minimize occupant discomfort.

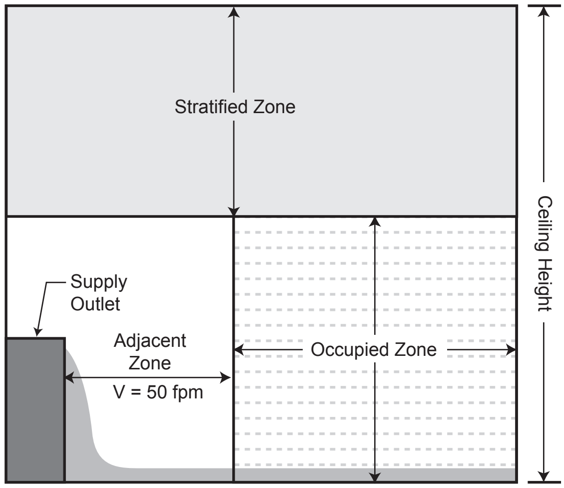


HEATING
A displacement ventilation system can be applied for heating in commercial buildings if the heating demand is low. However, in heating mode a minimal temperature differential must be maintained or the system will create a fully stratified space with cold spots. Careful consideration of the exhaust points should be taking to maintain a minimal amount of supply air short-circuiting. It is also recommended that supplemental systems such as fan coils, radiant floors, or baseboard radiators be used for high demand and perimeter applications. The most typical applications for heating with displacement are industrial or similar buildings, interior spaces and other low demand areas with a minimal delta T.

Application Overview

DESIGN CONDITIONS

In commercial buildings the air quality criteria is often indicated in terms of CO_2 concentrations. In other applications, it is important to determine whether the contaminants are warmer and/or lighter than room air. In both cases where the contaminant loads are high, special attention to the occupied zone height, supply airflow rate, and unit location should be analyzed.



ADJACENT ZONE

The cool supply air creates a zone in front of the supply unit where a draught might be perceived. The size of this adjacent zone depends on the properties of the supply unit, the airflow rate, and the supply air temperature. During the design process, the dimensions of the adjacent zone should be determined, the can later be used when placing objects or occupants in the space.

ENERGY EFFICIENCY

Controlling the temperature gradient in the space is the key to improving the energy-efficiency of the project. The temperature differential between extracted and supply air is typically 8°F - 18°F in commercial applications and 18°F - 22°F for industrial applications. Since the occupied zone is the main focus, our conditioned volume is much less when compared to a traditional overhead distribution. In addition, the relatively high supply temperature can potentially increases the use of free cooling. In spaces where there is no air conditioning and ceilings are high enough, displacement can offer improved IAQ over traditional overhead.

The two charts to the right show the versatility of displacement ventilation. Depending on the application and the activity level of the occupants, the recommended supply air temperature can vary. It is also common for the differential between the supply and return air to vary as a result of the ceiling height and use of the building.

Application	Min Recommended Supply Air °F	Set Point °F
Auditorium	70 - 72°F	75°F
Lobby	64 - 72°F	75°F
Atrium	64 - 75°F	75°F
Classroom	68 - 72°F	75°F
Industry	57 - 64°F	75°F
Hot & Humid Space	61 - 64°F	78°F

Application	Ceiling Height (ft.)	Supply/Return ΔT
Min. Parameters for Comfort	10 ft.	8 - 11°F
Max. Parameters for Comfort	16 ft.	8 - 18°F
Min. Parameters for Commercial	10 ft.	11 - 15°F
Max. Parameters for Commercial	20 ft.	15 - 18°F
Industrial	20 ft.	18 - 36°F

BEST AND LESS SUITED

A displacement ventilation system can be designed to fulfill requirements for sustainable and energy-efficient buildings, promoting a healthy and productive indoor climate. Installations should be evaluated when displacement ventilation is a potential solution because some factors of the project may require the use of another conditioning strategy. Below are typical project parameters shown in a best and less suited comparison.

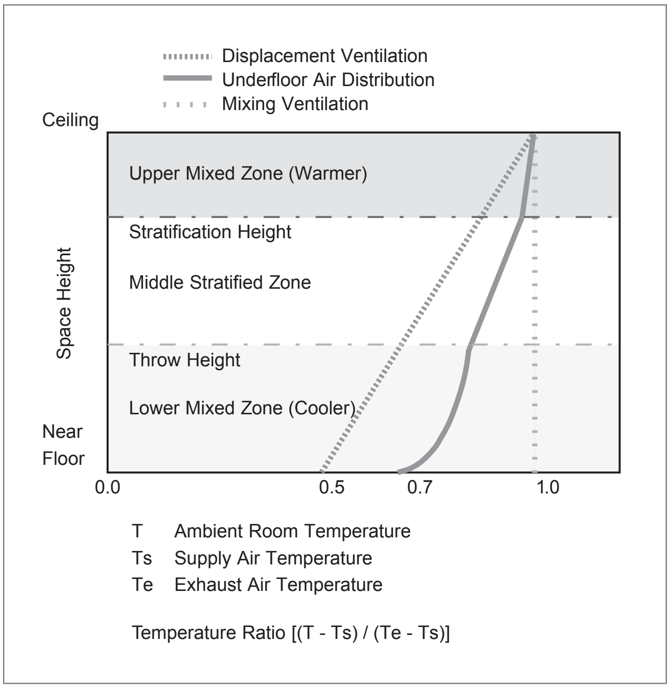
	Best Suited	Less Suited
Ventilation Rate	In spaces where the occupancy rate or contaminant load is high.	Where the specific airflow is low, less than 0.1 cfm/sqft.
Space Height	Ideal for spaces with a height greater than 10 ft.	In low spaces (< 10 ft.), displacement ventilation is not as beneficial due to the minimized height of the stratified zone.
Heat Loads	Ideal where space loads are between 2 - 8 W/ft^2.	In applications where the cooling capacity requirements exceed 8 Btu/h·ft^2.
Supply Air Temperature	Supply air temperatures ranging between 61° - 70° F.	Where the conditioned space requires a low supply air temperature, less than 61° F.
Space Constraints	In many spaces, displacement ventilation can be integrated into walls, columns, or panels. Supply units can add a visual element to the space.	In tight spaces where the adjacent zone limits the placement of other supply units or occupants.

Application Overview

SYSTEM COMPARISON
When determining if a displacement ventilation system is the right choice for the project the following chart may be referenced as a quick comparison between DV, underfloor, and well mixed ventilation. The chart presents the temperature ratio between the ambient room, supply air, and exhaust air temperatures of the systems.

DISPLACEMENT DESIGN PARAMETERS

Room Temperature	73 - 77° F
Supply Air Temperature	61 - 70°F
Pressure Drop	0.04 - 0.16” WG
Sound Pressure Level	25 - 40 dB(A)
Supply Airflow Rate / Floor Area	0.4 - 2 cfm/ft²
Cooling Capacity / Floor Area	2 - 8 W/ft²
Heating Capacity / Floor Area	1.85 - 3.75 W/ft²



System Design

EVALUATION
In the industry today there is no active design standard or criteria practiced when designing displacement systems. However, typical practices include complying with current ASHRAE Standard 55-2010 “Thermal Environment Conditions for Human Occupancy” and guidelines presented in ASHRAE research project RP-949. Temperature gradients in the occupied zone should be no more than 5.4°F. Compliance with these requirements will assure acceptable thermal comfort levels for 95% or more of the occupants.

INDUSTRY RESEARCH
ASHRAE research project RP-949 “System Performance Evaluation and Design Guidelines for Displacement Ventilation” provides and in depth analytical approach to understanding the effects of displacement ventilation. Today, the industry is following much of the information presented by the publication as a form of “standard” when analyzing, selecting, and designing a displacement ventilation system.

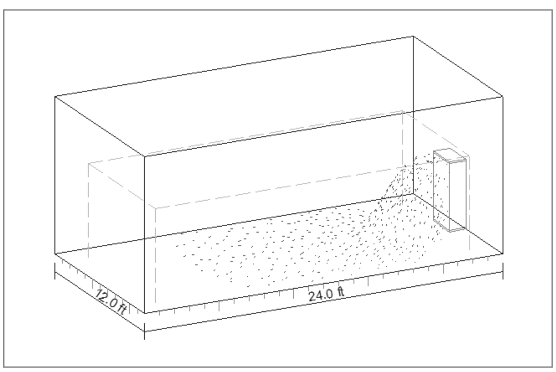
SOFTWARE
Krueger’s selection program is an interactive tool that links complete product data, product selection, and CAD design support for Krueger by Halton Displacement Ventilation products.

The information is comprised of product descriptions, dimensions, and functionality data as well as installation, adjustment, and servicing instructions. The tool enables compilation of product brochures with tailored content.

The software enables products to easily be configured to suit specific design requirements. For the selected product model and size, the software generates a full 3D image and detailed performance data. Product performance is described by data on cooling and heating capacities, pressure drops, sound levels, throw patterns, jet limit velocities, air velocities, and 2D and 3D views describing the performance.

Product performance data can also be applied to a specific design case. The software allows the user to specify space dimensions and characteristics as well as design conditions along with cooling and heating requirements. The software also simulates the interaction of multiple units on the basis of user-provided unit location data.

Our selection program produces CAD objects of the product options configured with the software. The objects may be exported in 2D format directly to an active AutoCAD drawing or to a file.



System Design

Comfort conditioning in the United States is engineered to meet the changing demands over a building life cycle, as a result we expect revisions to continue to be published as more research is completed in the displacement ventilation field. The process below, similar to RP-949, will step you through the required evaluation for a displacement ventilation application. When designing large spaces such as auditoriums or lobbies, it is recommended to utilize CFD analysis to carefully select DV units for optimal performance.

Step 1: Determine the Maximum Cooling Load
Use a load program or the ASHRAE manual to determine the design cooling load of the space in the summer. If possible, assume a 1°F/ft. vertical temperature gradient in the space in the computer simulation as the room air temperature is not uniform with displacement ventilation. Itemize the cooling load:

$$Q_t = Q_{oe} + Q_l + Q_{ex}$$

Where:
Q_{oe} (Btu/h) = Occupants, desk lamps and equipment
Q_l (Btu/h) = Overhead lighting
Q_{ex} (Btu/h) = Heat conduction through the room envelope and transmitted solar radiation

Step 2: Determine the Total Cooling Load CFM, V_h
The flow rate required for design cooling loads using standard air.

$$V_h = 0.076Q_{oe} + 0.034Q_l + 0.048Q_{ex}$$

Step 3: Determine Flow Rate of Fresh Air
Standard 62-2004 Ventilation Rate Procedure includes default values for ventilation effectiveness. From table 6.2: Equation 6-1 is used to determine the Breathing Zone Outdoor Air Flow V_{bz} and Equation 6-2 is used to determine the Zone Outdoor Air Flow V_{oz}.

$$V_{oz} = \frac{V_{bz}}{E_z} = \frac{R_pP_z + R_aA_z}{E_z}$$

Where:
R_p = People outdoor rate from table 6.1 (cfm/person)
P_z = Number of occupants in the zone
R_a = Area outdoor rate from table 6.1 (cfm/ft^2)
A_z = Floor area of the zone (ft^2)
E_z = 1.2 for displacement ventilation per table 62.1

Step 4: Determine Supply Air Flow Rate
The CFM to the zone is determined by selecting the larger of the two values between the total cooling load CFM (V_h) and zone outdoor air flow (V_{oz}).

$$V = \max \{ V_h, V_{oz} \}$$

The percentage (V%) of fresh air require for the zone:

$$V\% = \frac{V_{oz}}{V}$$

Step 5: Determine Supply Air Temperature
The supply air temperature T_s can be determined from the ASHRAE Design Guide equations and simplified to:

$$T_s = T_{sp} - 3.6 - \left(\frac{Q_t}{1.08V}\right)\left(\frac{A}{2.27376V + 1.08A}\right)$$

Where:
T_{sp} = Room set point (°F).

Step 6: Determine Exhaust Air Temperature
The exhaust air temperature T_e can be determined by the following method:

$$T_e = T_s + \frac{Q_t}{1.08V}$$

Step 7: Selection of Diffusers
The goal is to maximize comfort in the space, to achieve this it is recommended that the adjacent zone velocity should be limited to 40 fpm measured 1" above the floor. Krueger's selection software allows users to model the room served by DV diffusers and carefully analyze the air pattern at different velocities, including 40 fpm. Also available through Krueger's partnership with Halton is Halton HDV, another excellent tool to analyze a displacement system and compare the system performance to well mixed systems. Please contact your local Krueger representative for more information.

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