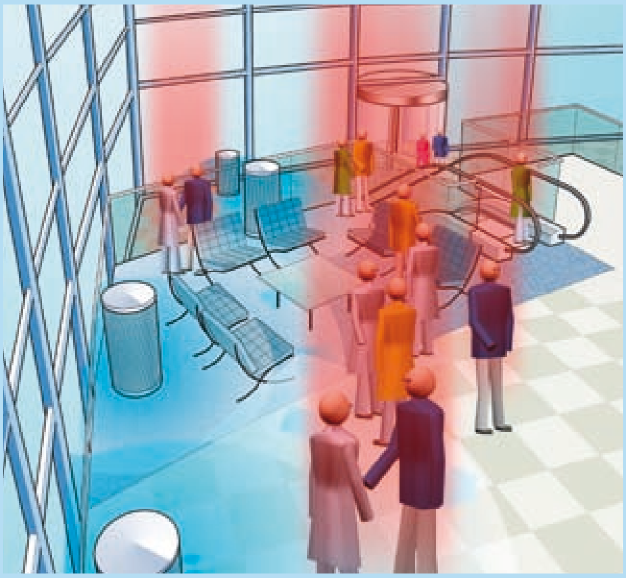


Typical displacement ventilation application

Displacement ventilation system

Description

Thermal displacement ventilation is based on cool air supply at low level and stratification of room air temperature and contaminants as a result of the natural buoyancy forces created by the heat sources. Traditionally the system has been designed as a dedicated outdoor air system.
There are two alternative concepts used in a displacement ventilation system:

- horizontal low-velocity supply
- floor-mounted diffusers.

The extraction point of the exhaust air is located above the occupied zone – preferably close to ceiling level.

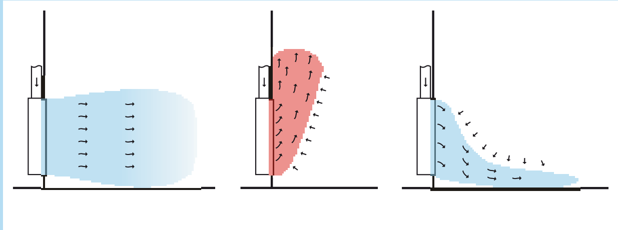
A displacement system is preferable for the following situations:

- the specific airflow rate per unit of floor area is high (as in lobbies, theatres, and conference rooms)
- high contaminant loads exist, as in industry and smoking areas
- the height of the space is more than 3 metres.

Operation

The advantages of displacement ventilation over totally mixing ventilation system are:

- lower cooling energy and capacity demands to maintain equal thermal conditions in the occupied zone.



Isothermal air supply | Warm air supply | Cool air supply

Supply airflow patterns for different supply air temperatures

- a longer period for the use of free cooling
- better air quality in the occupied zon.

Cooling

With displacement ventilation, the room air temperature increases with the height in the space. Thermal conditions and air quality are actively controlled only in the occupied zone. The air temperature and contaminant level are higher in the upper zone.

Depending on the breakdown of heat gains and the height of the space, the temperature difference between the supply and exhaust air is 5 to 12 °C. Since cool air is supplied directly to the occupied zone, special attention should be paid to analysis of the potential draught risk close to the units.

Heating

A displacement ventilation system can be applied also for heating in commercial buildings if the heating demand is low. However, in heating mode the system operates like a mixing ventilation system.
The extraction point should not be located directly above the supply unit, to prevent short-circuiting of warm supply air to exhaust.
The most typical applications for heating integration are industrial or similar buildings and lobby areas where the activity level and clothing differ from, e.g., those of the office environment.

Ventilation

Ventilation efficiency is typically 0.5…0.8 with displacement ventilation, whereas a level of 0.3…0.45 can be reached by using mixing ventilation. Better ventilation efficiency means, in addition to energy savings, improved indoor air quality in the occupied zone and thus improved performance of the workers.

A displacement ventilation system can be designed to fulfil requirements for sustainable and energy-efficient buildings that provide healthy and productive indoor climate conditions.

A displacement system can realise excellent indoor climate conditions in terms of air quality and also thermal and acoustic conditions. The system operates excellently also when airflow rate is controlled according to the demand.

Displacement ventilation application

A few critical issues should be analysed when the suitability of displacement ventilation is studied .The main design characteristics, applicability, and typical operation ranges are presented in the tables below.

Less suited	Best suited
Ventilation rates	
If the specific airflow rate is low, chilled beams are the most recommended solutions for commercial buildings.	A displacement ventilation system is a recommended solution for spaces where the occupancy rate or contaminant load is high.
Space height	
In low spaces (< 3 m), displacement ventilation is not extremely beneficial as compared to a mixing ventilation system.	In high spaces (> 3 m), a displacement ventilation system operates effectively.
Heat loads	
Especially in commercial buildings, a high cooling load (> 90 W/m²) leads to a high airflow rate. Nevertheless, the airflow rate is lower and/or indoor air quality better than with mixed ventilation.	Especially in industrial types of applications, displacement ventilation can cover relatively large cooling capacities and provides significantly better internal conditions than mixing ventilation does.
Supply air temperature	
In comfort air conditioning applications with low supply air temperatures. The draught risk in the near zone increases with low supply air temperatures.	The supply air temperature can be adjusted according to the demand. Displacement ventilation operates satisfactorily even with almost isothermal supply air.
Space constraints for supply units	
The space constraints of supply units should be analysed. The units should be located so that they ensure good indoor air quality throughout the occupied zone. Also, the draft risk in the near zone could limit suitable locations of the wall and floor units.	The units can be integrated into the structure (wall-mounted, covered by a decorative panel) or columns. A supply unit could be a visual element in the room space – e.g., installed in the middle of the floor area.

ROOM CONDITIONS AND SUPPLY UNIT

Room temperature	23..25 °C
Supply air temperature	16..21 °C (14 °C)
Typical pressure drop of units	10 ...40 Pa
Sound pressure level	< 25 ...40 dB(A)

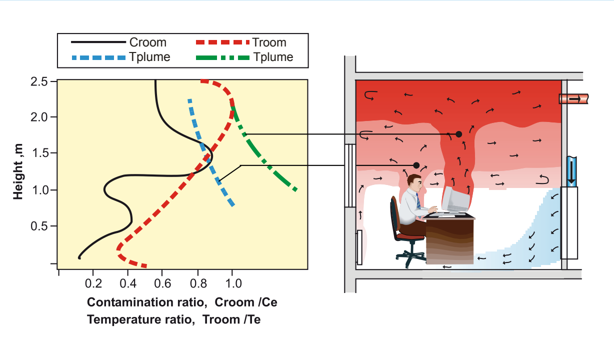
SYSTEM PERFORMANCE

Supply airflow rate / floor area	3 ...10 l/s/m²
Cooling capacity / floor area	25 ...80 (250) W/m²
Heating capacity / floor area	20 ...40 W/m²

Design methods for displacement ventilation

Heat-balance-based design for thermal comfort
A heat-balance-based method is used when excess heat is considered the main indoor climate concern. The temperature profile depends on the output and location of the heat sources and on the airflow rate. A rule of thumb defines the temperature gradient in the space: the air temperature at floor level is halfway between the supply air temperature and exhaust air temperature.

The preferable method for airflow rate estimation is to use a vertical zonal model of two zones. The heat loads are estimated for each zone and the thermal interaction of the zones is taken into account. The airflow rate is based on the heat balance of the occupied zone.

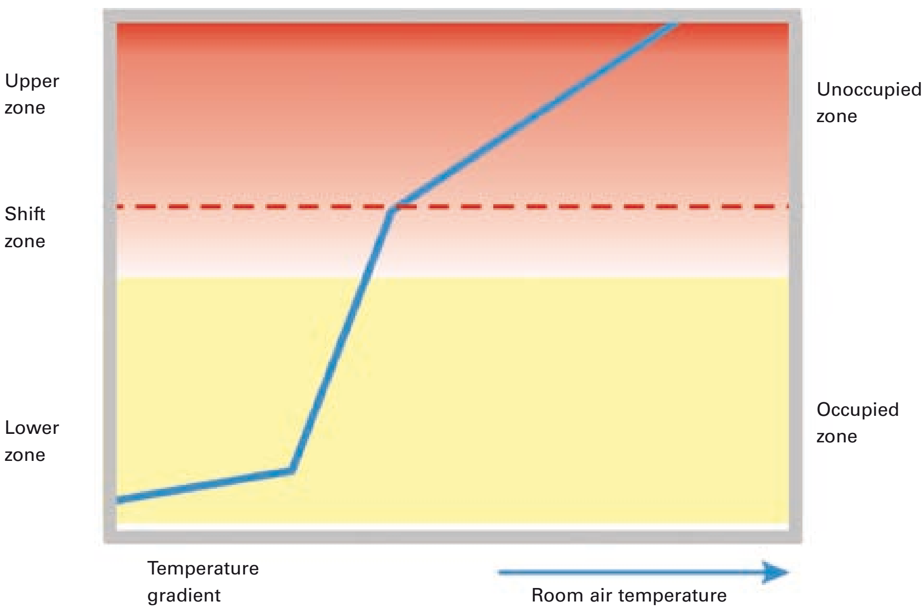


Shift-zone-based design for air quality
Contaminant load is the main design parameter, and the contaminants are warmer and/or lighter than the surrounding air. The contaminants are stratified above the 'shift zone' level.

The shift zone method can be used when the target is to keep the human breathing zone free of contaminants. Typical applications include industrial buildings and smoking rooms, where high contaminant loads exist.

Detailed information about the dimensions and location of heat loads, and how the heat output breaks down into convective and radiant components, are required.

Contaminant concentration and temperature gradient differ from each other: The highest air temperature is typically close to ceiling level and the maximum contaminant concentration is at the height where the sum of the convection flow rates is equal to the supply airflow rate of the space.



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.

Design methods for displacement ventilation – theory

Heat-balance-based design

Derived energy balance for occupied and upper zones

The energy balance is determined for the occupied and upper zone. The breakdown of the loads (persons, lighting, equipment, warm surfaces, and solar load) in the occupied and upper zone is defined. Additionally, the breakdown of heat loads into convective and radiant parts is considered.

The heat balance of the occupied zone is calculated, with the radiant heat transfer from the upper zone surfaces taken into account.
Iteratively, the Halton HIT Design software calculates the required airflow rate and the temperature gradient in the room space.

Shift-zone-based-design

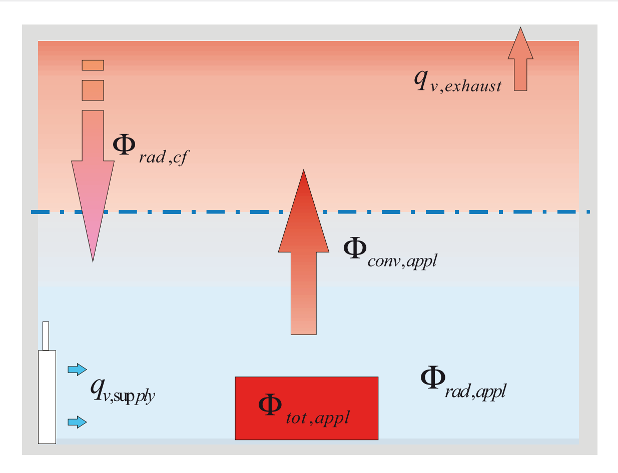
Calculation of the rising convection flow

The shift zone method should be used in cases where heat sources release contaminants into the air and the air quality is the main concern.

The height of different heat sources is defined. The rising convection airflow rate is calculated using theoretical plume equations. The heat loads are assumed to be either point or line sources.

The location of the virtual origin needs to be defined when the shift zone method is used.

Contact your local Halton sales office for further information on the shift zone calculation method.

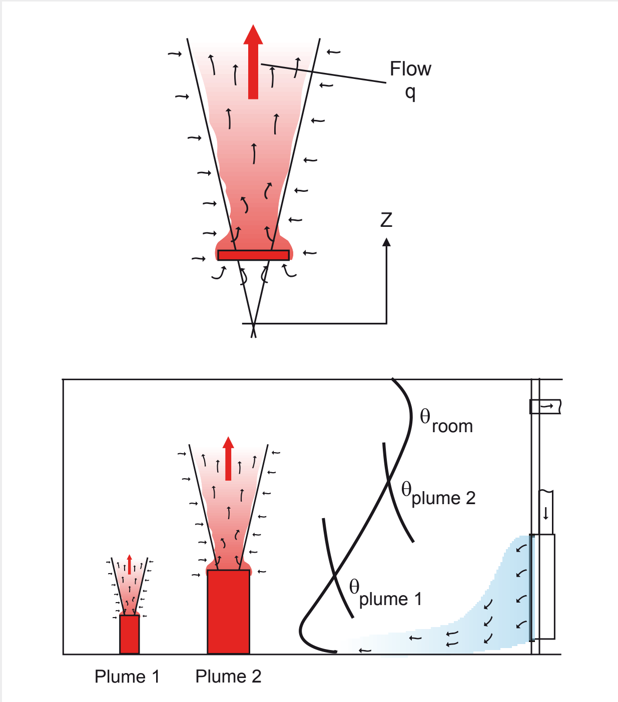


$$\Phi_{oz,tot} = q_{v,supply} * \rho * c_p * (T_{room} - T_{supply})$$

$$\Phi_{tot,oz} = \Phi_{rad,appl} + \Phi_{rad,cf}$$

$$\Phi_{tot} = q_{v,exhaust} * \rho * c_p * (T_{exh} - T_{supply})$$

$$\Phi_{rad,cf} = \sigma * \varphi * \varepsilon * A_f \left(\frac{T_c^4}{100} - \frac{T_f^4}{100} \right)$$



Point source: $q_{v,z} = 0.05 * z^{5/3} * \Phi_{conv}^{1/3}$

Line source: $q_{v,z} = 13 * z * \Phi_{conv}^{1/3}$

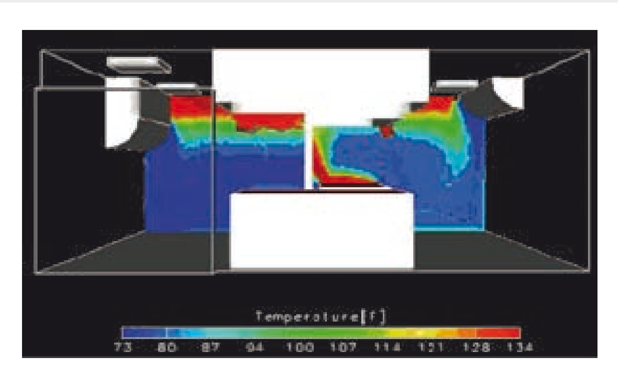
Ventilation and room air conditioning strategy

Displacement ventilation is typically based on low velocity and low induction supply of cool air at low level. The supply air temperature is only slightly (2 … 6 °C) colder than the ambient room air. The airflow rate of typically horizontal air supply equals the airflow rate of rising convective flows. Both thermal comfort and air quality are maintained at a good level.

However, there are cases where it is desirable for air conditioning to be taken care of partly via a water-based system – e.g., with passive chilled beams. On the other hand, situations exist where the supply air is slightly too cold to be discharged directly into the occupied zone. In these cases, floor diffusers with mixing effect can be used in order to minimise the near zone.

In both of these cases, the system operates partly as a mixing system in the occupied zone.

There are also applications where supply units need to be placed in the ceiling, because practical considerations make installation at low level impossible.



Vertical low velocity supply ensures high ventilation efficiency in a kitchen application

In a kitchen, for example, vertical low velocity supply air displaces the excess heat from the appliances into the high level, to the extraction units.

With low-turbulent air supply, the ventilation efficiency is higher than for mixing ventilation, due to beneficial flow conditions near critical extraction points.

Vertical air flow from under-floor air distribution

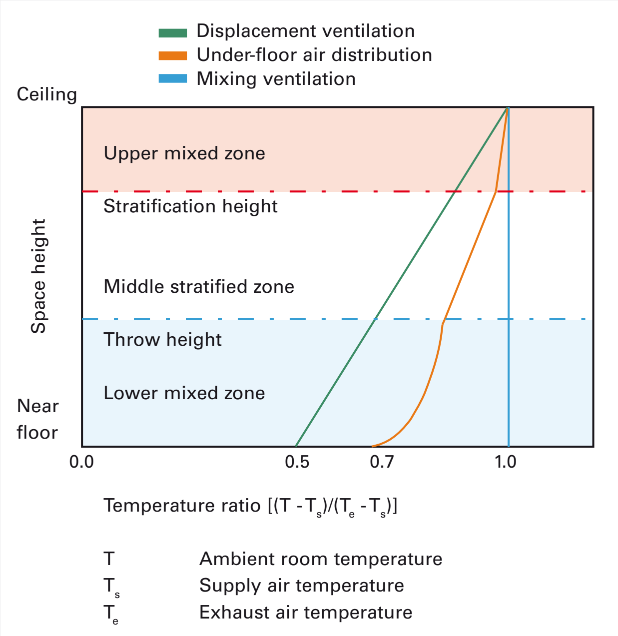
When under-floor supply is used, the introduction of supply air typically occurs with higher momentum than in low velocity supply. Compared to a typical displacement application, the mixing effect in the occupied zone is greater. Consequently, the temperature near the floor is higher and the temperature gradient is lower.

The throw length of the supply unit is the critical factor for the mixing effect. If the diffuser throw extends near the upper zone or even enters the warmer upper zone, the cooler supply air falls back down into the occupied zone and carries warm air downward.

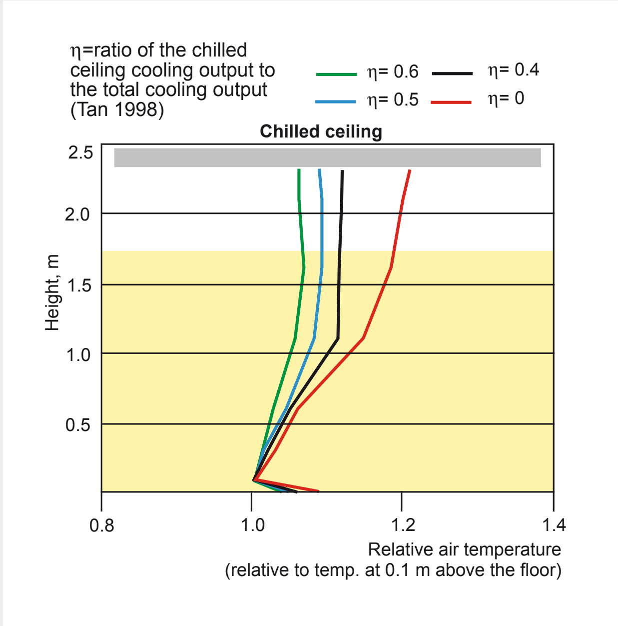
Ceiling cooling elements combined with displacement ventilation

It is necessary to emphasise the difference between the air distribution method and the room air conditioning systems.

Low velocity air supply combined with cooling elements – e.g., passive beams at ceiling level – operates like a mixing system when the cooling elements provide a substantial proportion of the cooling. The temperature gradient decreases gradually as the relative cooling capacity of the ceiling elements increases. Similar behaviour occurs with the contaminant and absolute humidity gradient.



Temperature profile comparison between under-floor air distribution and displacement & mixing ventilation



Displacement ventilation in a hot and humid climate

Description

Thermal displacement ventilation can be adapted to hot and humid climate conditions, for management of excess heat and humidity, taking into account:

- that system operation is based on the use of return air, to minimise energy consumption
- that dehumidification of outdoor air is arranged using a cooling coil and either additional pre-cooling or bypass of return air downflow from the cooling coil
- that supply air temperature may be lower than in temperate climate conditions in comfort applications
- that in spaces with substantial humidity loads, absolute humidity is stratified in a similar way to temperature and contaminant concentrations
- that in cases where outdoor airflow rates are optimised, a displacement ventilation application provides better air quality than a mixing ventilation application does.

1. Definition of targets for a displacement ventilation system

Design conditions

Thermal conditions, minimum primary supply airflow rate (based on occupancy level), and air quality criteria are defined according to national or international standards. However, the system performance may require higher airflow rates, which are specified during system design.

In commercial buildings, air quality criteria are often indicated in terms of CO_2 concentrations. For other applications, it is important to ascertain that all contaminants are warmer and/or lighter than room air. In cases where the contaminant loads are high, the contaminant level close to the breathing zone should be the chief design criterion.

Adjacent zone

The cool supply air creates in front of the unit a zone 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 adjacent zone should be analysed in design conditions, using product-specific information for design conditions.

In commercial buildings, the temperature difference between room air and supply air is typically 2 … 6 °C in a temperate climate. In hot and humid conditions, the temperature difference can be 6 … 8 °C higher. In industrial applications, the temperature difference can be up to 10 °C.

Energy-efficiency

The temperature gradient in the room space improves the energy-efficiency because only the occupied zone is actively controlled. Also, the relatively high supply temperature improves the utilisation ratio of free cooling. The temperature gradient between extracted and supply air is typically 4 … 10 °C in commercial buildings and 10 … 12 °C for industrial applications.

In spaces where there is no air conditioning but the ceiling height is high enough, displacement ventilation provides lower occupied zone temperatures and better energy-efficiency than a mixing system.

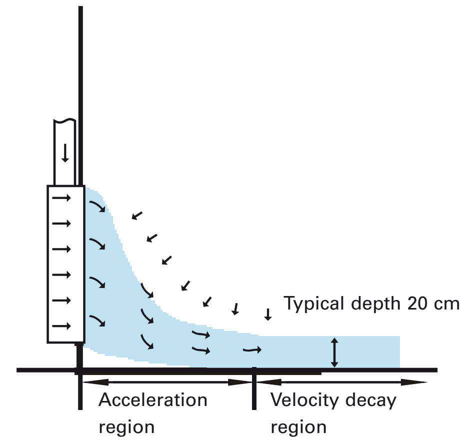
Application	Recommended minimum supply air temperature ˚C	Room air ˚C
Auditorium	21 … 22	24
Lobby	18 … 22	24
Atrium	18 … 24	24
Classroom	20 … 22	24
Industry	14 … 18	24
Hot and humid conditions	16 … 18	26

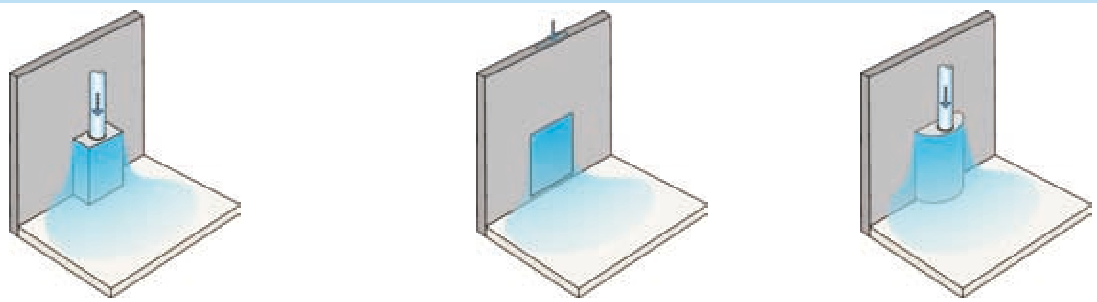
Application	Ceiling height m	Typical temperature difference between exhaust and supply air ˚C
Comfort	< 3	4 … 6
Comfort	3 ... 5	4 … 10
Commercial	< 3	6 … 8
Commercial	3 ... 6	8 … 10
Industrial	> 6	10 … 20

Air distribution principle and supply unit types

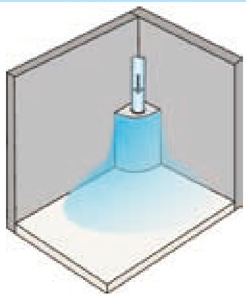
Displacement ventilation requires a low air velocity supply with limited induction. The air supply can be either horizontal or oriented vertically below a low velocity unit. The extraction point needs to be as high as possible but always above the occupied zone.

The low velocity units require a certain wall area, or space in the floor. Typical standard unit types are: wall-mounted, corner-mounted, free-standing, and floor-mounted. Special attention must be paid to the adjacent zone around the supply unit when the unit type and location are determined.

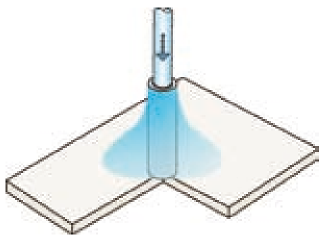




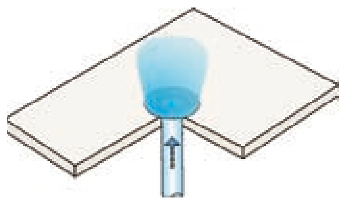
Wall-mounted low velocity unit types.



A corner-mounted low velocity unit.



A free-standing low velocity unit.



A floor-mounted diffuser.

Air distribution in an auditorium

In an auditorium with a typical usage pattern, the room is occupied for 45 minutes, followed by a 15-minute break. In such cases, emissions from persons – not the excess heat load – are the main concern. Typically, a specific airflow rate of 10 ... 15 l/s per person maintains good indoor air quality and thermal conditions in auditoriums.

When people are at different floor levels, air supply beneath the seats through a plenum is a natural solution.

There are several suitable locations for the supply units in auditoriums, such as the floor in front of the people and in risers. In some cases, a combination of floor supply and supply units in front of the audience yields the best conditions.

However, it should be noted that when the units are installed in steps or risers, the seating rows should be closed, to prevent the supply air floating down the stairs and instead let it be captured by the convection currents around the people.

2. Displacement ventilation system design

Cooling load calculations with dynamic energy simulation

Dynamic energy simulation should be conducted in order to estimate cooling load accurately. Simplified steady-state calculations typically overestimate the actual demand.

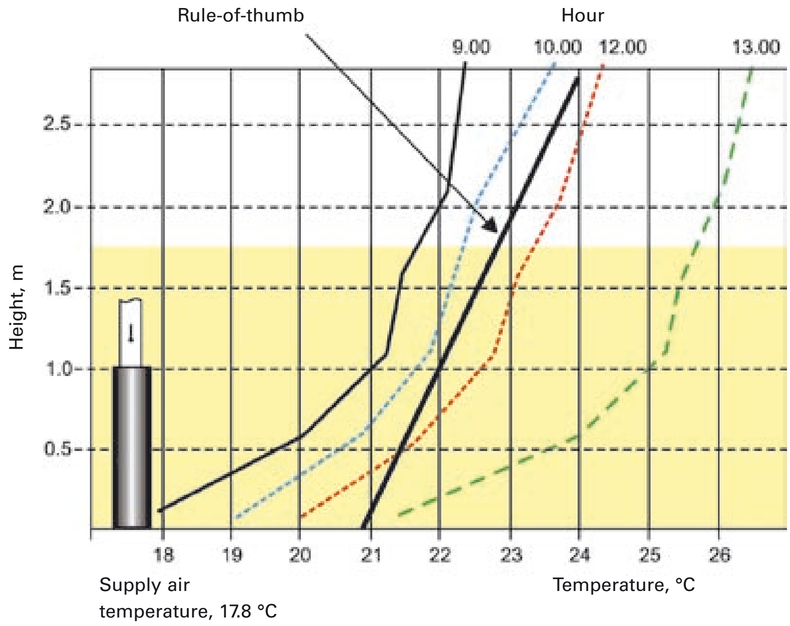
Thermal mass plays an important role when the cooling load is computed. The effect of the thermal mass is even more significant when night-time ventilation or cooling is introduced. In commercial buildings, accurate calculation of the solar load is one of the most important factors. The equipment load is the most crucial in industrial buildings.

It should be noted that commercial energy simulation software do not fully support displacement ventilation system calculations. The cooling load and airflow rate calculation should be carried out sequentially with different tools.

Thermal stratification is affected by thermal radiation between the ceiling and floor. As the vertical temperature gradient increases, the radiation effect balances the temperature difference between the zones and the temperature in the whole space begins to rise.

Where cooling capacity is not intentionally dimensioned to cover the peak load, the room temperature rises slightly while the temperature gradient also increases. As a result, occupied zone conditions remain satisfactory.

CFD is a simulation tool for analysing large, complex spaces. However, special attention should be paid to heat transfer by radiation, boundary conditions of heat and contaminant sources, and supply units. When CFD is used, separate energy simulations are required to determine boundary condition values for, e.g., the surface temperatures.



Diurnal variation of the temperature profile

Ventilation rate calculation

When ventilation rate is calculated, several parallel requirements need to be considered. The minimum primary airflow rate is based on occupancy level. The typical minimum ventilation rate is 10 l/s per person.

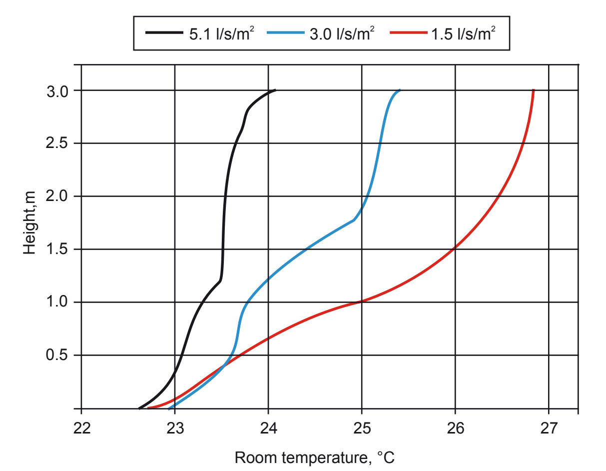
Another calculation criterion is heat-balance-based supply airflow rate. This can be calculated using the Halton HIT Design software. Alternatively, supply and exhaust airflow rates can be roughly estimated from the typical temperature difference between exhaust and supply air. This temperature difference is dependent on the height and use of the space as well as the surface temperature and location of heat sources.

$$qv = P / (1.2 * \Delta T)$$

where,

qv airflow rate, l/s
P heat load capacity, W
ΔT temperature difference between supply and exhaust airflows, K

The third criterion is air quality in the occupied zone. In cases where the contaminant loads are high, the contaminant level close to the breathing zone should be the main design criterion. Detailed design like this is possible only with dedicated design software.



Example of the effect of the airflow rate on system operation.

Halton HIT Design

The Halton HIT Design product catalogue supports product selection when the required airflow rate is known. With HIT Design, the throw pattern, adjacent zone, pressure drop, and noise level can be analysed.

HIT Design also allows fast airflow rate calculation. With the given total heat gain, the type of space, and the dimensions of the room space, the software computes the requested airflow rate. On the basis of the total load, the breakdown of typical heat gain elements for the selected room type is automatically fixed.

3. Low velocity unit selection

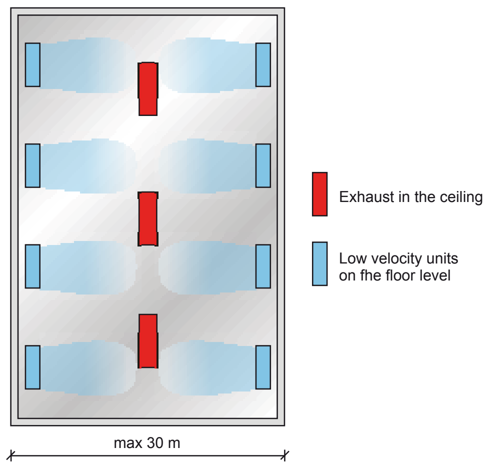
Number of low velocity units and space constraints

In cases where total airflow rate is known, it is possible to estimate the number of supply units required with the selection table. The table presents typical airflow rates and floor areas covered as a function of the nominal size of the supply unit.

Nominal size (mm)	Airflow rate per unit (l/s)	Floor area per supply unit (m^2)
100	... 30	10 ... 15
125	20 ... 30	10 ... 20
160	30 ... 80	10 ... 30
200	70 ... 150	10 ... 50
250	100 ... 200	15 ... 60
315	200 ... 400	20 ... 70
400	250 ... 500	30 ... 100
500	400 ... 800	40 ... 150
630	600 ... 1300	50 ... 170

Air distribution through large spaces is possible using low velocity units. As a rule of thumb, the maximum distance between supply units is 30 m. If the distance between the supply units is more than 30 m, an additional row of supply units between these units is needed.

Halton HIT Displacement Ventilation or HIT Design makes it possible to select the supply units according to the required airflow rate.



Type of low velocity unit

With HIT Design, the final selection of the supply units can be carried out easily, taking into account technical target values and space constraints. Standard units cover a wide range of shapes and flow patterns. A prefabricated installation base and duct cover are available to enable effective installation with elegant interior design.

If there are special requirements for interior design, supply units can be recessed in the structure and covered with a cover plate. When the units are behind a decorative panel, the free supply area should be designed to guarantee the normal performance of the supply units. Also, the units can be painted and serve as a visible element in the interior design.

Pre-selection of unit

qv	l/s m³/h	30 108	40 144	50 180	60 216	80 288	100 360	120 432
AFP-100	LpA	22	31	37				
	ΔPst	6	11	17				
	ΔPtot	15	27	42				
	L0,2 (-3 °C 1.1 m)	< 0.5	< 0.5					
	L0,2 (- 3 °C)	< 0.5	< 0.5	< 0.5				
AFP-125	LpA		22	27	32	41		
	ΔPst		5	8	12	21		
	ΔPtot		12	18	26	46		
	L0,2 (-3 °C 1.1 m)		< 0.5	< 0.5	< 0.5	< 0.5		
	L0,2 (- 3 °C)		0,7	0,9	1,0	1,2		
AFP-160	LpA				19	26	33	39
	ΔPst				3	6	9	12
	ΔPtot				8	15	23	34
	L0,2 (-3 °C 1.1 m)				< 0.5	< 0.5	< 0.5	< 0.5
	L0,2 (- 3 °C)				1,0	1,2	1,3	1,5

Using quick-selection tables as a route map, it is possible to pre-select a suitable size of supply unit for the target airflow rate. The quick-selection table shows the throw length (0.2 m/s; ΔT = -3 °C), the near zone (at 1.1 m level, 0.2 m/s; ΔT = -3 °C) as a function of the airflow rate.

Pressure drop, acoustics, and throw pattern

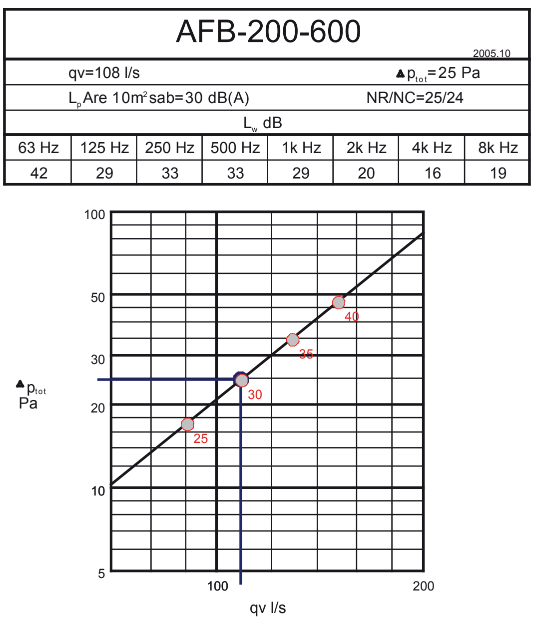
With the HIT Design software, it is possible to analyse the pressure drop and noise generation at given airflow rates. The noise level presented is calculated in a standard room with a total equivalent absorption area of 10 m²- Sab, where the room attenuation is –4 dB in each octave band.

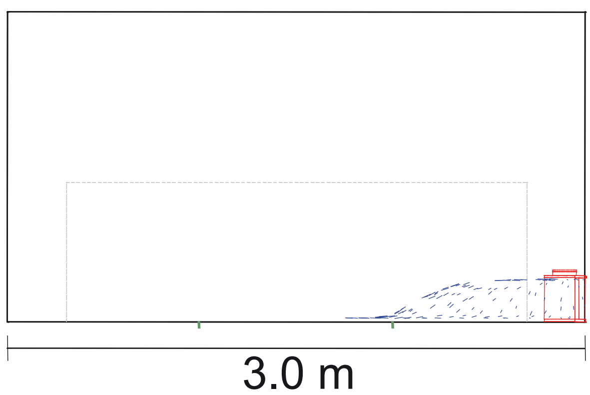
HIT Design presents sound power levels (L_w- values) at different frequency levels, and the attenuation of the supply units.

Throw pattern

Detailed analysis of throw pattern and eventual draft risk can be conducted with HIT Design. In HIT Design, the user can specify the supply air and room temperatures, room dimensions, and the airflow rate.

By using HIT Design, it is possible to analyse the effect of the airflow rate on the velocity profiles close to the near zone.





4. Ducting system

Supply air ducting through the ceiling

The typical location of supply units is close to walls where the units are freely mounted on the floor or embedded in the structure. Ducts are installed either on the wall as a visible element or hidden inside the structure.

Supply units can also be integrated with columns, which creates an ideal ventilation solution for the central part of the large open area. Or the supply units themselves can be designed to look like columns, to suit the interior environment.

Supply air ducting through the floor

When the units are connected to the ductwork through the floor, it is possible to select a suitable location for the supply unit quite flexibly.

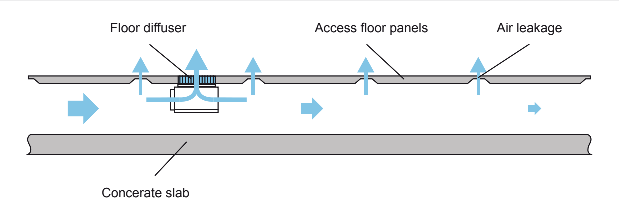
The supply unit can be a visible element in the interior design. The industrial design of the unit can be specially tailored to the special needs of the interior decoration.

Under-floor plenums

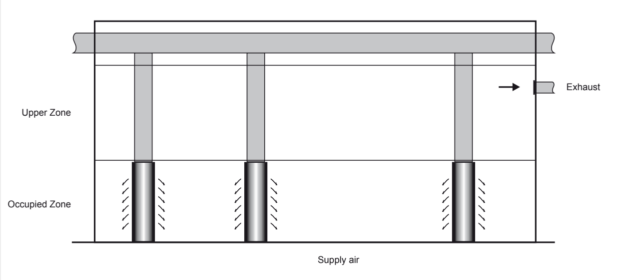
Typically, the height of the raised floor is 0.3 to 0.45 m. To minimise air leakage and enhance the performance of the supply units, the pressure level is kept between 10 and 30 Pa.

As a rule of thumb, the expected leakage of supply air is 10 … 30%, depending on the quality of the structure. The maximum size of the under-floor plenum is about 300 m^2. The maximum distance between air inlet and point of discharge is 15 to 18 metres.

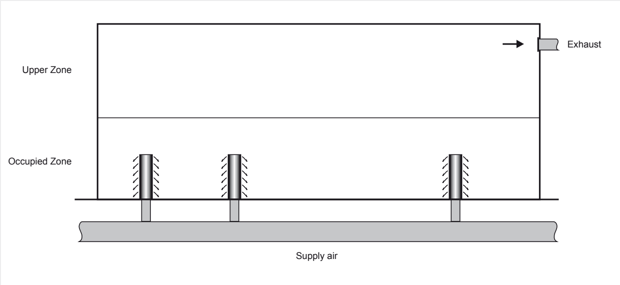
Due to heat transfer between supply air and plenum structure, the supply air is warmed in the plenum. This makes it difficult to adjust room air temperature very rapidly.



Under-floor plenums.



Supply air ducting through the ceiling.



Supply air ducting through the floor.