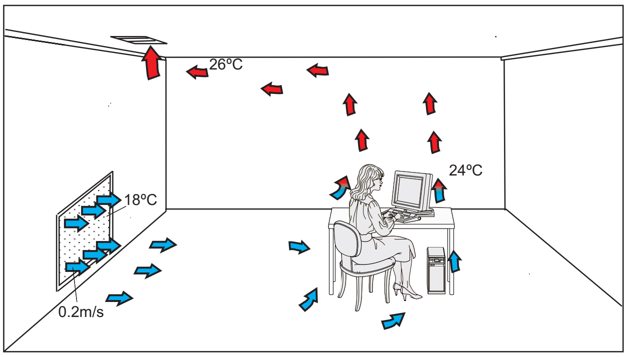
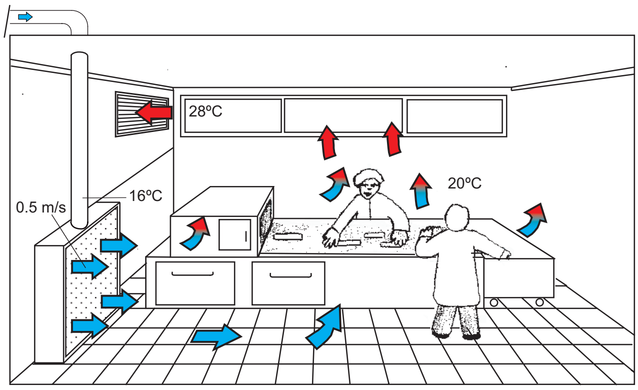
General

The displacement ventilation principle is the oldest form of ventilation and can be achieved without the use of fans. Air movement occurs by means of the density differences between supply air and room air. The driving force in the system are the heat sources (machines, people etc) which transport warm contaminated air and to a higher level. This principle was utilized in old foundries and forges where outside air was allowed to flow through openings at floor level with the warm smoke laden air flowing out through openings in the ceiling. This system operated well as long it was not too windy and the outside temperature was suitable.



It was during the 70's that displacement ventilation started to be used more frequently in the modern way with a balanced fan system. Displacement ventilation is a cost effective means of providing an optimal indoor environment by delivering cool supply air directly to the occupied zone. The air is supplied at least 1ºC cooler than the room air. The fresh air, supplied near the floor at a very low velocity, falls towards the floor due to gravity and spreads across the room until it comes into contact with heat sources. The cool supply air rises as it picks up heat from occupants and other heat sources. The warm stale air ascends to the ceiling where it is exhausted via extract grilles. This vertical air flow near occupants and warm equipment often referred to as a thermal plume, makes it less likely that contamination will spread horizontally across the room. This air distribution system provides for effective ventilation and cooling , since the fresh air is delivered directly in the occupied zone.



To achieve displacement ventilation the following is required:

- air supply at floor level
- air supply with low velocity 0.5-0.15 m/s
- air supply at lower temperature than the room, min 1ºC

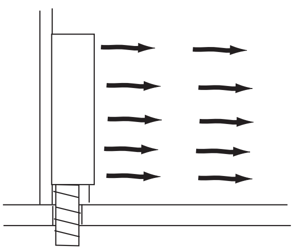
Applications

A displacement system benefits most in the following situations

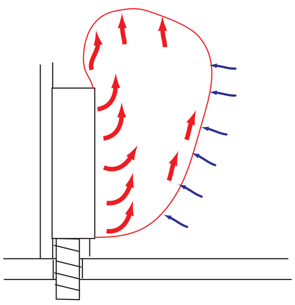
- high heat loads
- high contaminant loads
- high room heights

There are many comfort applications such as theatres, conference rooms, restaurants etc. with both high heat loads and high contaminant loads from occupants. In industry there are many activities that generate heat and/or contaminants from equipment and processes. The benefits also improve when the ceiling heights are increased due to improved stratification.

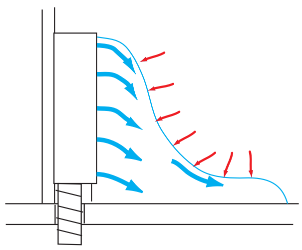
Supply air flow pattern



Isothermal air supply



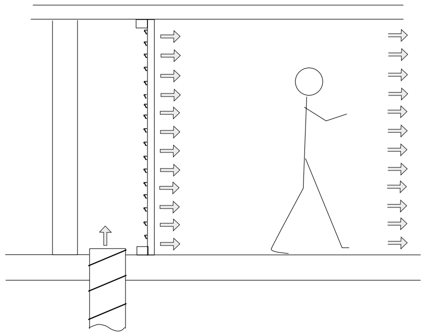
Warm air supply

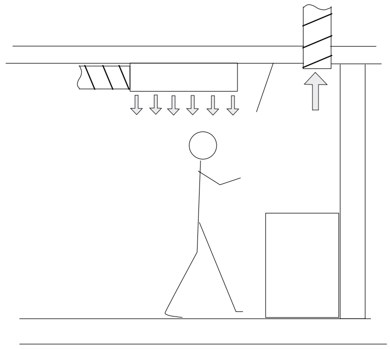


Cool air supply

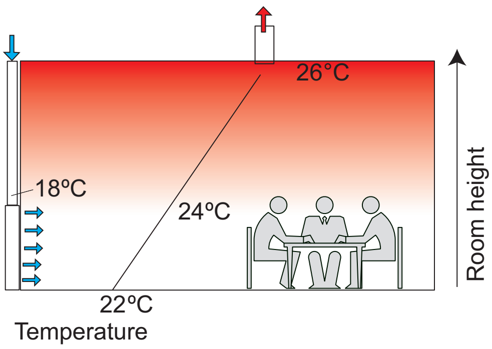
Displacement ventilation

Another type of displacement ventilation piston ventilation. It is frequently utilized in clean rooms, shooting ranges etc. With this form of displacement ventilation the thermal forces from heat sources are not applied. Instead there is an air stream with controlled air velocity and direction, which transports contamination in the air stream away from the breathing zone via extract grilles. In order to get a stable system the air velocity should not be below 0.15 m/s.
Another form of piston ventilation is so called spot ventilation where a low velocity unit is placed horizontally above a working station. This is a very effective way to ventilate fixed working stations. Typical examples are laboratories, printing works, spray booths.

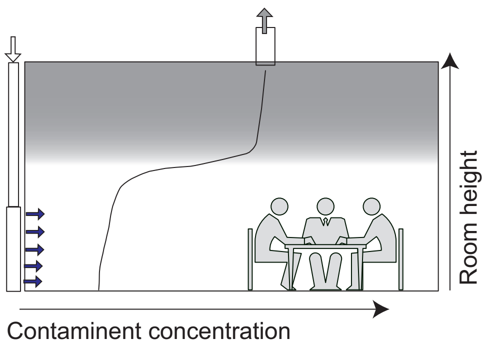




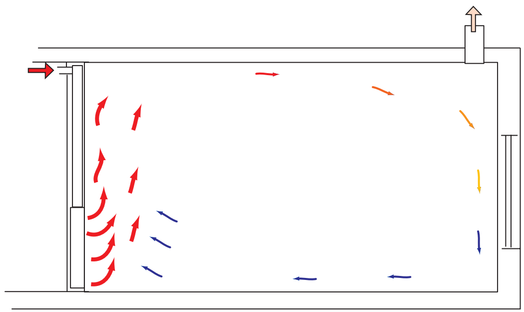
Cooling
With displacement ventilation a temperature gradient is achieved where room temperature increases with the height. A cooler occupied zone can be created compared with mixing ventilation



Ventilation
Contaminant concentrations and temperature gradients differ from each other. With displacement ventilation the indoor air quality in the occupied zone can be improved with lower air flows than for a mixing ventilation system. By using the same air flows as for mixed ventilation displacement ventilation is often used to improve the air quality rather than reducing air flows



Heating
The displacement terminals with low velocity air supply can be applied also for heating the premises.
However, in heating mode a displacement ventilation system rarely achieves the usual benefits you would expect when it is used solely for ventilating or cooling. It is more like a mixing ventilation system.
It can be a useful option to use the terminals for heating when the premises are not in operation during weekends nights etc.



Benefits with displacement ventilation

- lower installed cooling capacity
- longer period for use of free cooling
- improved air quality in the occupied zone
- draught free air supply

Determination of air flow
For a displacement and mixed system the air flow is either decided by the ventilation requirements i.e. air quality or the required cooling loads i.e. temperature control.

Ventilation
1) Experience values
In industrial applications it is often difficult to receive accurate data of machines, processes, production, operating hours etc. This makes it difficult to calculate air flows (independent of dilution or displacement ventilation) to achieve a certain level of air quality. For these industrial applications there are often experience values or recommendations of how much air that should be supplied expressed as air changes per hour or an air flow per m² floor area. By using a more efficient air distribution method -displacement ventilation- the level of contaminations in the occupied zone can be reduced by as much as 50%.

2) Regulations
There are often regulations for public buildings, schools, hospitals etc., which stipulate how much ventilation air must be supplied. In such cases these values are used in the calculation procedure.For unhealthy substances in industry there is often a maximum allowed level of the concentration in the room air or in the occupied zone. The required air flow can be calculated if all factors are known but in practice it is in most cases not possible. In order to get the right air flow the experience value method is used.

Temperature control (Cooling)
The factors to be taken into account when calculation the air flow for cooling with displacement ventilation are:

-Cooling load
-Temperature gradient
-Supply air temperature
-Room air temperature
-Activity/Type of work
-Adjacent zones

Cooling Load
The cooling load is calculated in the normal way but quite often with displacement ventilation this is significantly less than for a dilution system. For example , the lighting load occurs outside the occupied zone at high level and therefore the convective element of the lights can be discounted. Also depending on the hours of use and the accumulation of heat in the building structure significant reductions of heat load arise. It is rather complicated to make a correct heat load calculation or room temperature calculation which considers all factors. In the market there are computer programs which are a big help for these type of calculations.

Temperature gradient
The temperature profile depends on the output and location of the heat sources ,on the air flow rate and the room height. Fig 1 shows a rule of thumb profile, which is used for the calculation of air flows and temperatures. Due to induction of room air into the supply air from the face of the low velocity terminal, the temperature at floor level is not the same as the supply air temperature. The relationship between Δt_2 and Δt depends on the height of the room.

H= Room height
h= Height of working position
t_1= Temperature at height 1m
t_s=Supply air temp
t_e=Exhaust air temp
Δt=Exhaust air temp.-supply air temp
Δ_l= Floor temp-supply air temp
Δt_2=Exhaust air temp-floor temp
Δtu=undertemperature

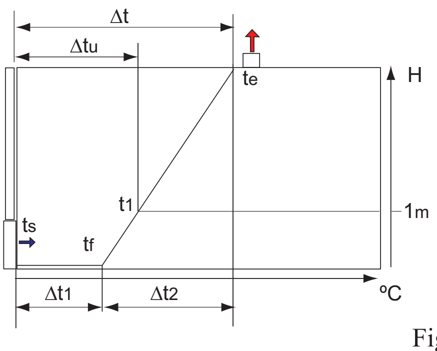


Fig. 1

Temperature gradient = $\Delta t_2/H$ K/m

Rule of thumb

$H \leq 4m$ $\Delta t_l / \Delta t \sim 0.5$ $\Delta tu \sim 0.7 x \Delta t$

$4<H<6m$ $\Delta t_l / \Delta t \sim 0.33$ $\Delta tu \sim 0.5 x \Delta t$

The design air flow is calculated with below formula

$$q=\frac{P}{\delta x Cp x \Delta t} \quad m^3/s$$

P= Cooling load kw
δ= air's density kg/m³ (1.2)
Cp= air's thermal capacity kJ/kgºC (1)
Δt =max possible value is determined by means of table 1 page 4.

The supply air temperature is calculated from:

$t_s = t_1 - \Delta tu$

Supply and room air design temperatures
The maximum Δt that can be used depends on the temperature gradient selected for the space. For sedentary work, for example, a maximum temperature difference between head and feet of 3K is acceptable without giving discomfort. In table 1 the maximum values and also lowest recommended supply air temperature are given. The under temperature (room temp. at lm - supply temperature) is also a design factor. The values in table one should not be exceeded.

Table 1

Activity	Max Temp Gradient	Supply air temp	Under temperature
Sedentary Work	2 K/m	18 ºC	6K
Light work standing	3 K/m	16 ºC	8K
Industry, moving	~3K/m	10-14 ºC	~8K

Adjacent zone L_{02}
Adjacent zone is defined as the area in front of the unit where the air speed at ankle level (100mm above floor) is higher than 0.2 m/s. The adjacent zone varies depending on air flow, type of unit and the under temperature. The adjacent zone is shown in the performance diagrams for all BEMAIR units at 3K and 6k under temperature.

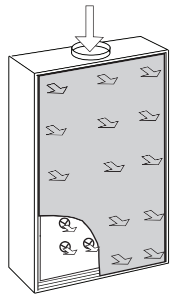
Some guide lines when selecting displacement terminals

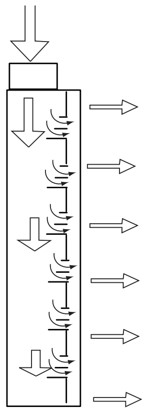
Application	**Supply face velocity**	**Air flow/unit**
Small office rooms	0.15-0.25 m/s	30-70 l/s
Conference rooms	0.15-0.25	70-200
Landscaped office	0.15-0.25	70-300
Theatres, cinemas	0.15-0.20	10-200
Restaurants, Pubs, Bars	0.15-0.25	100-450
Lighter Industry (medium activity) Kitchen, lighter assembly work	0.25-0.35	350-900
Heavier Industry	0.35-0.5	1400-4800

Check that the sound level is at acceptable level for the selected terminal.
If not choose a bigger size.

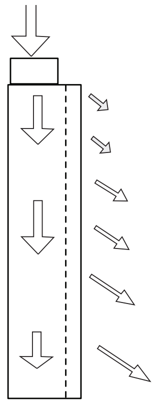
Distribution nozzles

Outlets for displacement ventilation operate with large surfaces in order to get the required low supply air velocity. All BEMAIR low velocity terminals have an internal nozzle plate which distributes the air evenly over a perforated metal sheet. The nozzles do not only distribute the air evenly they also direct the air straight forward against the perforated front. This is done in order to get a short adjacent zone and an even air distribution.





BM terminal with nozzles



Terminal without nozzles

Lay-out of displacement terminals

Industrial installations

Even if the adjacent zones are not critical it is necessary to know the location of the heat sources which "consume" the supply air. Common locations for the terminals are walls or columns at floor level where they are not obstructing the activities in the room.

In applications where it is not possible with a low level air supply ceiling mounted terminals can be considered. Avoid placing the terminal above heat sources such as machines or in an industrial process as the cooler supply air tends to cascade down into the occupied zone bringing with it warm air and contamination. Kitchens are an example where the terminals can placed in the ceiling with the exhaust air going through the hoods above the heat sources.

Comfort installations

In order to find suitable locations of supply units in comfort installations it is necessary to know how the room is going to be furnished. The adjacent zone must be considered as no one can sit permanently in it. There are often areas like corners, besides a door opening or transient areas which can be used for locating air supply terminals.

Terminals with a round shape provide a shorter adjacent zone than a terminal with a flat front.

While a recessed terminal requires less floor space it has a longer adjacent zone. Columns can be enclosed with a special column terminal for air supply. Floor mounted terminals replacing panel in a raised floor system is also an option.

A longer band of floor terminals along a wall or window facade is another used location of terminals.

If ceiling mounted terminals are to be used the avoid installing them above a location where someone is sitting permanently. It will always create a draught problem!

The only option is at a safe distance from the occupants. Above a door is a good example.

In auditoria where people are sitting at different levels air supply beneath the seats through a plenum is a common solution. The terminal can be mounted in the riser or in the floor under the seat. In smaller audtoria it can be sufficient to supply air from the stage in the front of the audience. A combination of both air supply from the stage and under seat terminals is also an alternative.

Example 1
Office with sedentary work
Dimensions H=2.7m W=2.4 L=4.2m
Heat load=380 W
Design room temperature= 24ºC (occupied zone 1m)
Design procedure
Limitations with displacement ventilation?
According to table 1: max temp gradient: 2K/m
lowest supply temp. 18ºC
max Δtu : 6K
Calculate max Δt

$\Delta tu \sim 0.7 x \Delta t$ (page 3)
$\Delta t \sim 6/0.7 \sim 8.5$ºC

Check temp. gradient < 2K/m

$\Delta_2 / \Delta t = 0.5$ (page 3)

Temp gradient= $\Delta t_2/H$ (page 3)=8.5x0.5/2.7~1.6 K/m   ok!

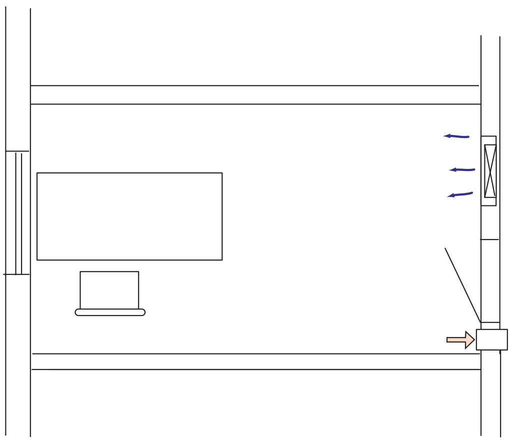
Calculate supply temp. check it is not below 18ºC

$t_s = t_1 - \Delta tu = 24-6 = 18$ºC ok!

Calculate air flow

$$q = \frac{P}{\delta x Cp x \Delta t} \quad m^3/s \text{ (page 3)}$$

$$q = \frac{0.38}{1.2x1x8.5} = 0.037 = 37 l/s$$



Select a suitable displacement terminal considering the adjacent zone and a suitable sound level.
Place the unit where no occupants are sitting permanently. The corner and the wall against the corridor are suitable locations. There are two options, a corner unit or a recessed unit in the wall. According to the guidelines on page 4 the supply velocity for offices should be 0.15-0.25 m/s . Choose type EW for recessed installation with a rectangular connection which is suitable in a double/studded wall.
EWR05-06 con.45x450 is chosen at 37 l/s
$v_0 \sim 0.15$m/s , LwA< 26dB(A) L_{02}=1m Δpt=8 Pa

Example 2
The same data as example 1 but
Design room temperature = 23ºC (occupied zone 1m)

Calculate supply temp. check it is not below 18ºC

$t_s = t_1 - \Delta tu = 23-6 = 17$ºC to low!

Calculate Δtu with t_s=18ºC

$\Delta tu = t_1 - t_s = 23-18 = 5K$

Calculate Δt

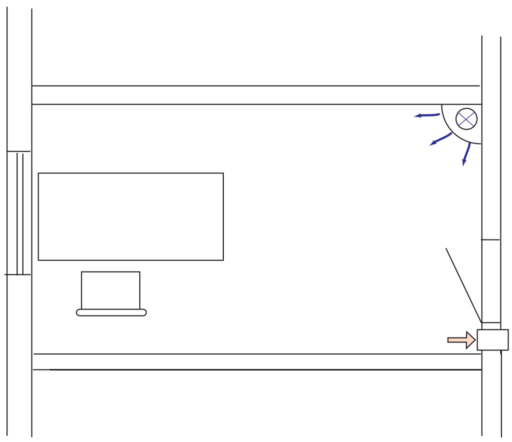
$\Delta t \sim 5/0.7 \sim 7$ºC

temp. gradient is < 2K/m

Calculate air flow

$$q = \frac{0.38}{1.2x1x7} = 0.045 = 45 l/s$$

AVC 125-600 i chosen at 45 l/s
LwA=35 dB(A) L_{02}=1.1m Δpt=17 Pa



Factory- Activity, (light work)
Dimensions H=7m W=30 L=40m
Heat load=120 kw
Ventilation air flow: min 7l/s,m² (recommended for this type of industry)
Only free cooling available
Desired room temperature= 22ºC (occupied zone 1m) when outside temperature allows it.

Calculate total air flow, temp. gradient,,under temp., supply temp.

Design procedure
Limitations with displacement ventilation?
According to table 1: max temp gradient: ~3K/m
lowest supply temp. 10-14ºC
max Δtu :~ 8K
Calculate total min. air flow:
30x40x7=8400 l/s =8.4m³/s

Calculate Δt

$$\Delta t = \frac{P}{\delta x Cp x\ q} = \frac{120}{1.2x1x8.4} \sim 12\ K$$

Calculate Δtu

Δtu~0.5x Δt (page 3)
Δtu~0.5x12~ 6K ok!

Check temp. gradient

$\Delta t_2 / \Delta t \sim$ 0.67 (page 3)

Temp gradient= Δt_2/H (page 3)~12x0.67/6~1.3 K/m ok!

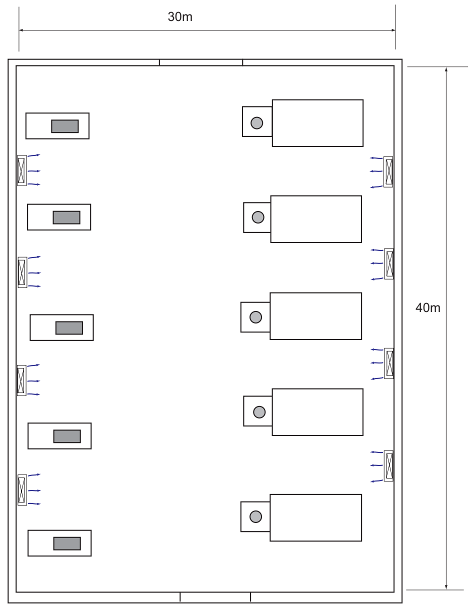
Calculate supply temp.
$t_s = t_1 - \Delta tu$=22-6= 16ºC

As cooling is done with outside air the room temperature will be higher during warmer periods. But the result is always better with displacement ventilation compared to dilution ventilation.

Select suitable BEMAIR units

The sizing and positioning of displacement units will depend on many factors, lay-out of machinery, concentration of personal etc. There are many possible combinations of unit sizes and locations in industrial applications.
The adjacent zone and sound level is mostly not critical which means that the most economical solution is to select big units at about 0.5m/s supply velocity.

Solution 1
Air supply from the two 40m walls.
4pcs ATR 250x800-12 on each side.
Supplying 1050 l/s each.
LwA=48 dB(A) is acceptable for an industrial application and the adjacent zone is of no importance.



Solution 2
Air supply from the two free standing units AKE 800-12 each supplying 4040 l/s at LwA=56 dB(A) which also is acceptable for this type of installation.