Displacement Ventilation

General
The displacement ventilation principle is the oldest form of ventilation and can be achieved without the use of fans. Air movement occurs due to density differences between supply air and room air. The driving force in the system are the heat sources (machines, people etc), which leads to warm contaminated air rising.

This principle was utilised in old foundries and forges where outside air was allowed to flow through openings at floor level, whilst the warm smoke-laden air flowed out through openings in the ceiling. This system operated well as long as 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 way of providing an optimal indoor environment, by delivering cool supply air directly to the occupied zone, at a temperature at least 1°C 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. It then rises as it picks up heat from occupants and other heat sources. The warm stale air ascends to the ceiling where it is extracted via exhaust grilles.

The vertical airflow near occupants and warm equipment, often referred to as a thermal plume, makes contamination less likely to 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 0.15-0.5m/s
- Air supply at lower temperature than the room by at least 1°C

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 and high contaminant loads from occupants. Many industrial activities generate heat and/or contaminants from equipment and processes. The benefits also improve with increased ceiling heights, due to improved stratification.

Supply air flow pattern
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Another type of displacement ventilation is called piston ventilation. It is frequently utilised 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 supply velocity should not be below 0.15 m/s.

Spot ventilation is another form of piston ventilation; in this case, 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 etc.

Cooling

With displacement ventilation, temperature stratification occurs where the room temperature increases with the height of the ceiling. A cooler occupied zone can be achieved with displacement ventilation, when compared to mixing ventilation systems.

Heating

Displacement terminals with low velocity air supply can also be used for heating purposes. In heating mode, a displacement ventilation system operates more like a mixing ventilation system. Using the terminals for heating purposes can be a useful option when the premises are not in operation, i.e. during weekends, nights etc.

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 airflows in comparison to a mixing ventilation system. By using the same airflows as one might for mixing ventilation, displacement ventilation results in an improved air quality.

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 airflow

For displacement and mixing ventilation system, the airflow is decided by either 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 hard to calculate airflows (independently of mixing or displacement ventilation) to achieve a certain level of air quality.

For these industrial applications there are often experience values or recommendations on required airflow, expressed as Air Changes per hour or Airflow per m² floor area. By using a more efficient air distribution method through displacement ventilation, the level of contaminations in the occupied zone can be reduced by as much as 50%.
Displacement Ventilation

2) Regulations

Often regulations for public buildings, schools, hospitals etc. stipulate how much ventilation air should be supplied. When available, these values will be used in the calculation procedure.

For harmful industrial substances, there is often a maximum allowed concentration level in the room air or occupied zone.

The required airflow can be calculated if all factors are known, but in practice, it is impossible in most cases. In order to get the right airflow, the experience value method is then used.

Temperature Control (Cooling)

The factors to be taken into account when calculating the airflow 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, the figure is significantly less in comparison to a mixing ventilation system. For example, the lighting load is produced 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 becomes complicated to make a correct heat load calculation or room temperature calculation taking into account all factors. Computer programs can help with these types of calculations.

Temperature Gradient

The temperature profile depends on heat sources, output, location, airflow rate and room height. Fig 1 shows a rule of thumb profile, which is used for the calculation of airflows 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 \( \Delta t_2 \) and \( \Delta t \) depends on the height of the room.

\[
H = \text{Room height} \\
h = \text{Height of working position} \\
t_1 = \text{Temperature at 1m height} \\
t_s = \text{Supply air temp} \\
t_e = \text{Exhaust air temp} \\
\Delta t = \text{Exhaust air temp} - \text{supply air temp} \\
\Delta t_1 = \text{Floor temp} - \text{supply air temp} \\
\Delta t_2 = \text{Exhaust air temp} - \text{floor temp} \\
\Delta t_u = \text{Under-temperature}
\]

The design airflow (m³/s) is calculated using the following formula

\[
q = \frac{P}{\delta \times C_p \times \Delta t}
\]

\( P = \text{Cooling load kW} \)

\( \delta = \text{air density kg/m}^3 \ (1.2) \)

\( C_p = \text{air thermal capacity kJ/kg/k} \ (1) \)

\( \Delta t = \text{max possible value is determined using table 1 page 50.} \)

The supply air temperature is calculated from:

\[
t_s = t_1 - \Delta t_u
\]

Temperature gradient \( = \Delta t_2 / H \ K/m \)

Rule of Thumb

\[
H \leq 4m \quad \Delta t_1 / \Delta t \sim 0.5 \quad \Delta t_u \sim 0.7 \times \Delta t
\]

\[
4 < H < 6m \quad \Delta t_1 / \Delta t \sim 0.33 \quad \Delta t_u \sim 0.5 \times \Delta t
\]
Displacement Ventilation

Supply and Room Air Design Temperatures
The maximum $\Delta t$ 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 discomfort. In table 1 the maximum values and lowest recommended supply air temperature are also given. The under-temperature (room temp. at 1m - supply temperature) is also a design factor. The values in table 1 should not be exceeded.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Max Temp Gradient</th>
<th>Supply air temp</th>
<th>Under-temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary work</td>
<td>2K/m</td>
<td>18°C</td>
<td>6k</td>
</tr>
<tr>
<td>Light work, standing</td>
<td>3K/m</td>
<td>16°C</td>
<td>8k</td>
</tr>
<tr>
<td>Industry, moving</td>
<td>~3K/m</td>
<td>10-14°C</td>
<td>~8K</td>
</tr>
</tbody>
</table>

Adjacent Zone $L_02$
The Adjacent zone is defined as the area in front of the unit where the air velocity at ankle level (100mm above floor) is higher than 0.2m/s. The adjacent zone varies depending on airflow, type of unit and under-temperature. The adjacent zone is shown in the performance diagrams for all our units at 3K and 6K under-temperature.

Some Guidelines When Selecting Displacement Terminals

<table>
<thead>
<tr>
<th>Application</th>
<th>Face velocity</th>
<th>Airflow/unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small office rooms</td>
<td>0.15-0.25 m/s</td>
<td>30-70 l/s</td>
</tr>
<tr>
<td>Conference rooms</td>
<td>0.15-0.25</td>
<td>70-200</td>
</tr>
<tr>
<td>Landscaped office</td>
<td>0.15-0.25</td>
<td>70-300</td>
</tr>
<tr>
<td>Theatres, cinemas</td>
<td>0.15-0.20</td>
<td>10-200</td>
</tr>
<tr>
<td>Restaurants, Pubs, Bars</td>
<td>0.15-0.25</td>
<td>100-450</td>
</tr>
<tr>
<td>Lighter Industry (medium activity)</td>
<td>0.25-0.35</td>
<td>350-900</td>
</tr>
<tr>
<td>Kitchen, lighter assembly work</td>
<td>0.35-0.50</td>
<td>1400-4800</td>
</tr>
</tbody>
</table>

Check that the sound level is at an 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 our low velocity terminals have an internal air distribution plate with nozzles, which distributes the air evenly over perforated sheet metal. The nozzles not only distribute the air evenly, they also direct the air towards the perforated front. This is done in order to get a short adjacent zone and an even air distribution across the full face of the terminal.
**Displacement Ventilation**

**Layout of Displacement Terminals**

**Industrial Installations**

Even if the adjacent zones are not critical, it is necessary to know the location of the heat sources that "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 to install a low level air supply, ceiling mounted terminals can be considered. Avoid placing the terminal above heat sources such as machines or industrial equipments as the cooler supply air tends to cascade down into the occupied zone, bringing with it warm air and contamination. Kitchens are a prime example where the terminals can be placed in the ceiling with the exhaust air going through the hoods above the heat sources.

**Comfort Installations**

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

Terminals with a round shape provide a shorter adjacent zone, when in comparison to a terminal with a flat front. Whilst 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 a panel in a raised floor system are also an option. A linear assembly of floor terminals along a wall or window facade is another possible solution.

If ceiling mounted terminals are to be used, avoid installing them above a location where someone is sitting permanently; it may generate a draught issue. It is therefore recommended the terminal be installed with the occupants and adjacent zone take into consideration. Above a door is a good example.

In an auditorium, people may be sitting at different levels, under-seat air supply through a plenum is a common solution. The terminal can be mounted in the riser or in the floor under the seat. In smaller auditoria, supplying air from the stage in front of the audience may be preferable. A combination of air supply from the stage and under the seat is also an alternative.

**Example 1**

Office with sedentary work

Dimensions H = 2.7m  W = 2.4m  L = 4.2m

Heat load = 380W

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 Δt,u: 6K

**Calculate max Δt**

\[ \Delta t_u \sim 0.7 \times \Delta t \text{ (page 49)} \]

\[ \Delta t \sim 6 / 0.7 \sim 8.5k \]

**Check temperature gradient < 2K/m**

\[ \Delta t_2 / \Delta t = 0.5 \text{ (page 49)} \]

Temp gradient = \[\Delta t_2 / H \text{ (page 49)} = 8.5 \times 0.5/2.7 \sim 1.6K/m \text{ >> ok!} \]

Calculate supply temperature check it is not below 18ºC

\[ t_s = t_1 - \Delta t_u = 24 - 6 = 18ºC \text{ >> ok!} \]

**Calculate airflow**

\[ q = \frac{P}{\delta \times C_p \times \Delta t} \text{ m³/s (page 49)} \]

\[ q = \frac{0.38}{\delta \times 1 \times 8.5} = 0.037 \text{ m³/s = 37l/s} \]

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 50 the supply velocity for offices should be 0.15-0.25m/s.

Choose type EW for recessed installation with a rectangular connection, which is suitable in a double/studded wall. **EWR05-06 / 45x450** spigot is chosen at 37l/s

\[ v_0 \sim 0.15 \text{m/s, } L_{WA} = 26 \text{dB(A)}, L_{Q2}=1 \text{m} \]
Displacement Ventilation

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

**Calculate supply temp. Check it is not below 18°C.**

\[ t_s = t_1 - \Delta t_u = 23 - 6 = 17°C \]  >>> too low!

**Calculate \( \Delta t_u \) with \( t_s = 18°C \)**

\[ \Delta t_u = t_1 - t_s = 23 - 18 = 5K \]

**Calculate \( \Delta t \)**

\[ \Delta t \sim 5 / 0.7 \sim 7k \]

Temperature gradient is < 2K/m

**Calculate airflow**

\[ q = \frac{0.38}{1.2 \times 1 \times 7} = 0.045m^3/s = 45l/s \]

Select an **AVC/125-600** at 45l/s

\( v_0 \sim 0.2m/s, l_{WA} = 35dB(A), l_{O2}=1.1m \)

Example 3
Factory - Activity (light work)

Dimensions \( H = 7m \quad W = 30m \quad L = 40m \)

Heat load = 120kW

Ventilation airflow: min 7l/s/m² (recommended for this type of industry)

Only free cooling available

Desired room temperature = 22°C (occupied zone 1m) when outside temperature allows it.

Calculate total airflow, temp. gradient, under-temp., supply temp.

**Design procedure**

Limitations with displacement ventilation?

According to table 1:  Max temp. gradient: ~3K/m  Lowest supply temp.: 10-14°C  Max \( \Delta t_u \): ~ 8K

**Calculate total min. airflow:**

\[ 30 \times 40 \times 7 = 8400l/s = 8.4m^3/s \]

**Calculate \( \Delta t \)**

\[ \Delta t = \frac{P}{\delta \times C_p \times q} = \frac{120}{1.2 \times 1 \times 8.4} \sim 12K \]

**Calculate \( \Delta t_u \)**

\( \Delta t_u \sim 0.5 \times \Delta t \) (page 49)

\( \Delta t_u \sim 0.5 \times 12 \sim 6K \)  >>> ok!

**Check temp. gradient**

\( \Delta t_2 / \Delta t \sim 0.67 \) (page 49)

Temp gradient = \( \Delta t_2 / H \) (page 49) \sim 12 \times 0.67 / 6 \sim 1.3K/m  >>> ok!

**Calculate supply temperature**

\[ t_s = t_1 - \Delta t_u = 22 - 6 = 16°C \]

As cooling is achieved using outside air, room temperature may varies dependant on outside temperatures.
Displacement Ventilation

Select Suitable Units

The sizing and positioning of displacement units can depend on many factors: layout of machinery, concentration of personnel etc.; therefore the possible combinations of unit size and location, in industrial applications, is countless. The adjacent zone and sound level is, in many instances, not critical; as such, the most economical solution is to select big units at about 0.5m/s face velocity.

Solution 1

Air supply from the two 40m walls.

4 no. ATR/250x800-12 on each side, each supplying 1050l/s

$L_{WA} = 48$dB(A) is acceptable for an industrial application and the adjacent zone being non-critical.

Solution 2

Air supply from two freestanding units

2 no. AKE/800-12 each supplying 4040l/s

$L_{WA} = 56$dB(A) which also is acceptable for this type of installation.

Technical Information

Definitions and Symbols

$q$ Supply airflow (l/s and m³/h)

$v_0$ Supply air velocity across the unit active front [fig.1]. (m/s)

$\Delta p_t$ Total pressure drop (Pa)

$L_{WA}$ A-weighted sound power level (dB(A))

$L_{02}$ Adjacent zone, defined as the area in front of the unit where the air velocity at ankle level (100mm above floor) is higher than 0.2m/s. The adjacent zone varies depending on airflow, type of unit and Under-temperature (see definition below). The adjacent zone is shown for 3K and 6K under-temperature (m)

$t_s$ Supply air temperature (ºC)

$t_{R1}$ Room air temperature 1m above floor level (ºC)

$\Delta t_u$ Under-temperature, defined as the temperature difference between the room temperature at 1m above floor level and the supply air temperature [fig 2]. (K)

Maintenance

There are no parts in these units that require replacement. If necessary clean front with water and mild detergent.

Any specific maintenance recommendations will be indicated in the relevant product specification.
Waterloo Product Range

GRILLES
A complete range of products suitable for all wall, ceiling and floor applications. Most grilles are made from aluminium, and have a range of fixed or moveable blades designed to give performance whilst remaining aesthetically pleasing to the eye. Grilles are made to customer specified sizes and colours (PPM/G); standard colour is PPM9010 (20% Gloss White). This range is complemented by the Aircell range of polymer Grilles and Diffusers.

DIFFUSERS
A complete range of products designed to be installed in various ceiling systems. Most diffusers are made from aluminium, and can be ordered with or without plenum boxes for easy connection to duct work. Diffusers can be ordered in customer specified (PPM/G) colours; standard colour is PPM 9010 (20% Gloss White). This range is complemented by the Aircell range of polymer Grilles and Diffusers.

ACTIVE AND PASSIVE CHILLED BEAMS
The finest quality range of high output active beams, used for ventilated heating and cooling applications. These units have 4 pipe coils to allow heating and cooling circuits to run simultaneously, giving constant and responsive control. The design allows a large optimum capacity, and also allows the customer to specify the nozzle type and pitch for individual circumstances.
Active beams are made from steel to a large range of customer specified sizes and as such are suitable for various different ceiling systems. Standard finish is PPM 9010, however other (PPM/G) colours are available on request.

AIR VOLUME CONTROL DAMPERS
A complete range of pressure independent Variable Air Volume and Constant air Volume dampers. Most volume dampers are regulated with an electronic motor and sensors, and are calibrated to customer specifications before delivery. The constant air volume damper requires no power source as it is controlled via a mechanical device, it is also calibrated before delivery.
All volume dampers are made from Zintec plate and all units can be ordered with a single or double (with insulation) skin.

EXTERNAL LOUVRES
A quality range of products for external wall applications. Made from aluminium, with birdscreen or insect screen options. All louvres are made to customer specified sizes and (PPM/G) colours; standard colour is PPM 9006

DISPLACEMENT
A complete range of diffusers for displacement air distribution providing high ventilation efficiency with excellent comfort. The very low pressures involved also offer quiet installations. Diffusers are available as wall or floor mounted, or indeed integrated within the architectural design.
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