IMPROVEMENT OF INDOOR AIR QUALITY BY DISPLACEMENT VENTILATION THEORETICALLY AND IN PRACTICE

#6244

Karl-Olov Berglund
Stratos Ventilation Produkt AB,
S-745 81, Enköping, Sweden.
Member of the ABB group.

INTRODUCTION

Displacement ventilation has been used in Sweden for approximately twenty years. The theory for this system has been known for a long time but it was only at the beginning of the seventies that a practical system solution and products for the air distribution were brought to the Swedish market.

The first applications were made in welding halls. There was a growing demand to eliminate smoke particles in the working zone in such premises. With conventional systems this could only be achieved by supplying a greater quantity of air. In order to achieve the desired results, the investment and running costs tended to be higher than what the end-users were willing to pay.

Displacement ventilation spread into most industrial applications and later on also into areas where not only Indoor Air Quality but also temperature control was a vital parameter. Today the situation in Sweden is that displacement ventilation is the natural choice for ventilation of an industrial building and other systems are considered in special cases, for example when no temperature difference between floor and ceiling can be accepted.

THEORY

The function of displacement ventilation is based upon the simple fact that with a temperature difference between supplied air and room air, there is also a difference in density. (Figure 1) The supplied air is slightly cooler than the room air and when supplied with low velocity and at low level, it will first fill the floor area. It will then rise towards the ceiling, partly because it is displaced all the time by more supplied air and partly because of convective airflow created by the heat sources in the room.

The fact that convective airflows are not at their maximum size at floor level, (Figure 2) will guarantee that the supply air flow first will fill the whole floor area and also thereby secure that the whole room will be ventilated. There is no risk for non-ventilated corners etc.

As the size of the convective airflow will increase at higher levels in the room, a larger part of the supplied air will be "consumed" at higher levels. At some level in the room all the supplied air flow is "consumed" by the convective airflow, or the sum of the convective airflows, as we almost always have more than one heat source in the room.

We will find the border line between the lower and the upper zone at this level in the room where we have equalization between the supplied air and the sum of convective airflows . This will always be the case in a room where there are heat sources and displacement ventilation. The height of the border line can, however, be difficult to determine in beforehand as calculation of the size and the growth of convective airflows are quite complex. (Figure 3)

The fact that there is a border line in the room is also interesting from a ventilation efficiency point of view. For example, a room where the border line is established at a level equal to half of the room ceiling height and where the room is ventilated by four airchanges per hour. In this case all of the supplied air will first pass through the lower zone of the room. Thereafter the air will pass the border line and it will remain in the upper zone until it is extracted by the exhaust air opening. That opening should be at ceiling level. This will, in fact, give eight air changes in the lower zone and will double the efficiency in this zone only because of the fact that the system divides the room into two zones. The aim with displacement ventilation is to have the lower zone to be approximately the same as the occupied zone of the room, normally about two meters above the floor.

There is another feature of displacement ventilation that will further influence the ventilation efficiency in the lower zone. In most cases where emission of particles takes place this means that there is a heat source in the room. Welding is a very good example. As there is a heat source there is also the adherent convective airflow. In this case, most of the particles emitted will be captured by the convective airflow and transported up to the upper zone and will then stay in that zone until being extracted. The welding smoke can be seen quite clearly and that is, in fact, the convective airflow.

Compared to traditional ventilation systems, displacement ventilation will not bring the welding smoke back to the occupied zone. Particles not captured by the convective airflow will be displaced to the upper zone. This is done very effectively due to the improved ventilation rate in the lower zone.

Also, with displacement ventilation, horizontal air velocities, outside the zones close to the terminals, are very low. Thereby, there will be no disturbance of the vertical convective airflows. This will further reduce the risk for spread of particles to the occupied zone.

In this example, (Figure 4) the particle concentration in the supplied air is 7 mg/m^3 and the concentration in the exhaust air is 48 mg/m^3 as a result of the ventilation rate and the particle emission in the room. If this premise is ventilated by a perfect mixing system, the average particle concentration at all levels will also be 48 mg/m^3.

If the same premise is ventilated by a displacement ventilation system the average particle concentration in the working zone will instead be 17 mg/m^3. The figures of 17 and 48 mg/m^3 respectively are from measurements in an existing installation.

It shall be added that the concentration in the exhaust air, 48 mg/m^3, is reached in a shorter period of time when a displacement system is used. This is due to the fact that with a displacement system mainly the upper zone in the room is used for dilution of the particles until the concentration in the exhaust air has reached 48 mg/m^3. After that, the system has achieved a steady state function. When the mixing system is used, the particles are diluted in the whole room volume until the exhaust air particle concentration has reached 48 mg/m^3.

In industrial applications, if ventilation efficiency is calculated on the difference between particle concentration in exhaust air and the average value in the occupied zone normally, displacement ventilation will be three to six times more efficient than a traditional mixing system. In the example presented above the relation between the two systems is 1 to 4,1. (Figure 5) This also means that in order to achieve the same result in the working zone with a mixing system, four times the amount of supplied air must be used to get the same result as for the displacement ventilation system.

IN PRACTISE

The example presented hereafter is a Company in Sweden called Medett Produkter. The factory is situated in a town called Borlänge in the center of Sweden. This company manufactures medical equipment as surgical gloves etc. The request for Indoor Air Quality is for a clean room class 100 000. This request is decided by Sweden's Board of Social Welfare and they also carry out tests on the site with production in progress. The aim is of course, to minimize the bacteria concentration in the premises. Bacteria are, however, carried by particles in the air and by reducing the number of particles, the number of bacteria will also be minimized.

The building was designed with a ventilation system where the air was supplied by large grilles at ceiling level and the exhaust air was taken at floor level. The total floor surface was 265 m^2 (ceiling height 3 m) and there were eight supply air grilles each in the 2 x 1 m size. The total airflow was 2,78 m^3/s (10,5 $l/s,m^2$) giving an outlet velocity for the eight grilles of only 0,17 m/s. Theoretically, this should create a vertical air velocity of 0,01 m/s all over the room. This is, of course, a much too low an air velocity to be able to establish an even vertical air distribution all over the room. The heat load in the room was taken care of by a supplied air temperature of 17 °C. The result was a room temperature of 22 °C.

Particle concentration was measured in nine positions and at 1,2 m above the floor just by the production lines. (Figure 6) The average concentration was 154 000 part/ft^3 and there were some readings above 200 000 part/ft^3. This meant that the concentration was about 50% over the accepted value and the company was given a very limited period of time to reduce the particle concentration to below 100 000 part/ft^3.

The Medett company contacted us mainly due to our long experience in displacement ventilation and asked if we could solve their problem. After having analyzed the measuring data and studied the problem on the site, we made a proposal that was accepted and the installation was then rebuilt during a weekend. The changes on site were that the ceiling outlets were closed off with the exception of one that was now used as an exhaust air opening. All exhaust air openings at floor level were also sealed off. The supplied air was brought into the room by five displacement ventilation terminals and the supplied air temperature was raised from 17 to 19 °C. The room temperature at 1,1 m above the floor remained the same 22 °C, as with displacement ventilation there will be a temperature gradient in the room and thereby, also two degrees higher exhaust air temperature.

When the particle concentration was measured in the same positions as before, the difference was quite exceptional. (Figure 7) The average concentration was now down to 19 000 part/ft^3 and all readings were well below the max. allowed value of 100 000 part/ft^3. Max. reading was now 73 000 part/ft^3 whereas in the same position and before the rebuilt , the reading was 201 000 part/ft^3.

The reason for the great change in measured particle concentration is that in the original system, the particles were carried upwards by the convective air streams from machine surfaces with higher temperature than the room's air temperature. These convective air streams have much higher air velocities, 0,5 to 1,0 m/s, than the average, theoretical, vertical airstream from the original supply air grilles, 0,1 m/s. This means that the particles will be transported by the convective airstreams to ceiling level and then brought back to the working zone by the supplied air. The result was not the intended air flow from ceiling to floor but rather a mixing system and thereby, too high particle concentration in the working zone.

Our tests have then been verified by renewed measurement carried out by the authority's staff. The difference in result was insignificant and the Medett company could go along with their production.

SUMMARY

Displacement ventilation creates new possibilities for improvement of Indoor Air Quality. The displacement of the particles in the room, combined with the transport of particles by the convective air flow from heat sources in the room, will improve the results in the occupied zone in the room three to six times compared with traditional mixing systems.

This article gives some of the theories behind this and also results from an installation where the originally designed system could not cope with demand for indoor air quality and was replaced by a displacement ventilation system.

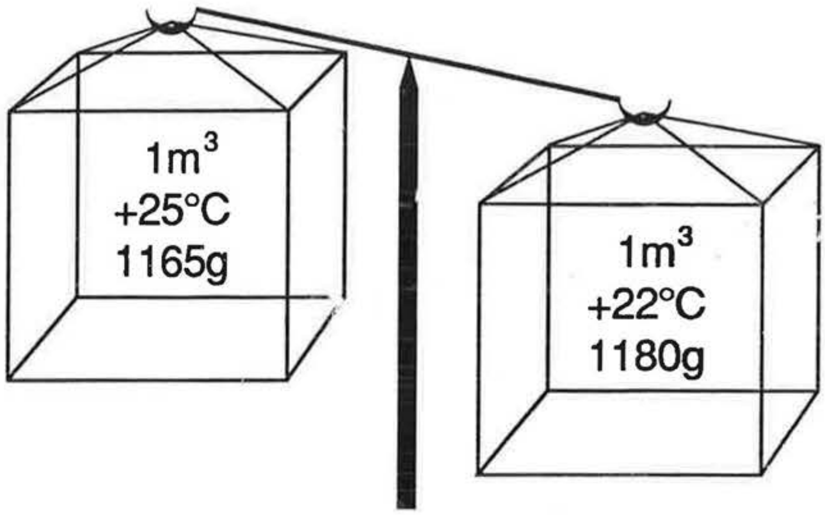

Figure 1

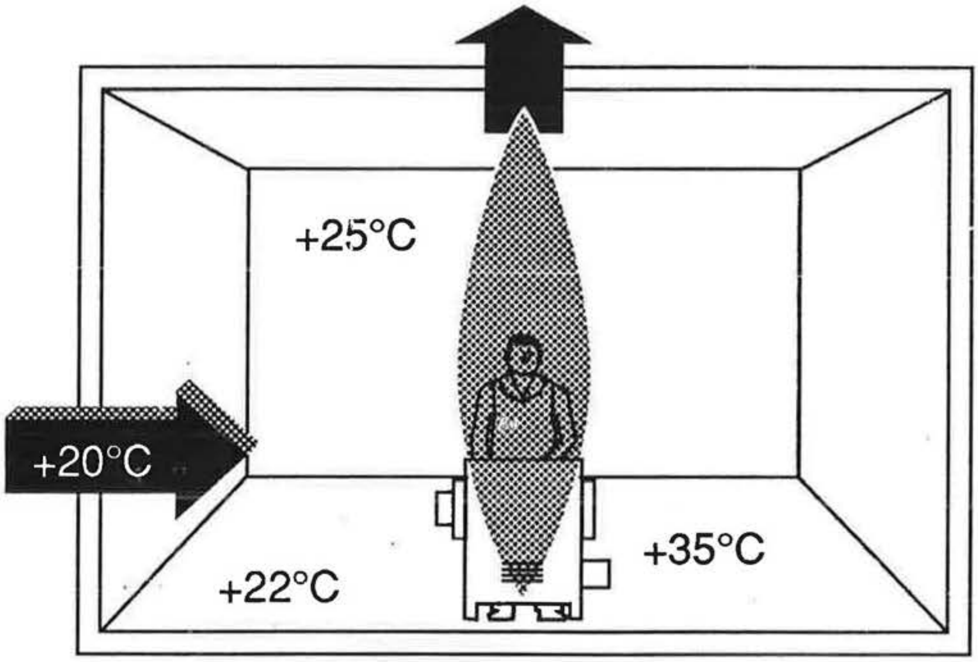

Figure 2

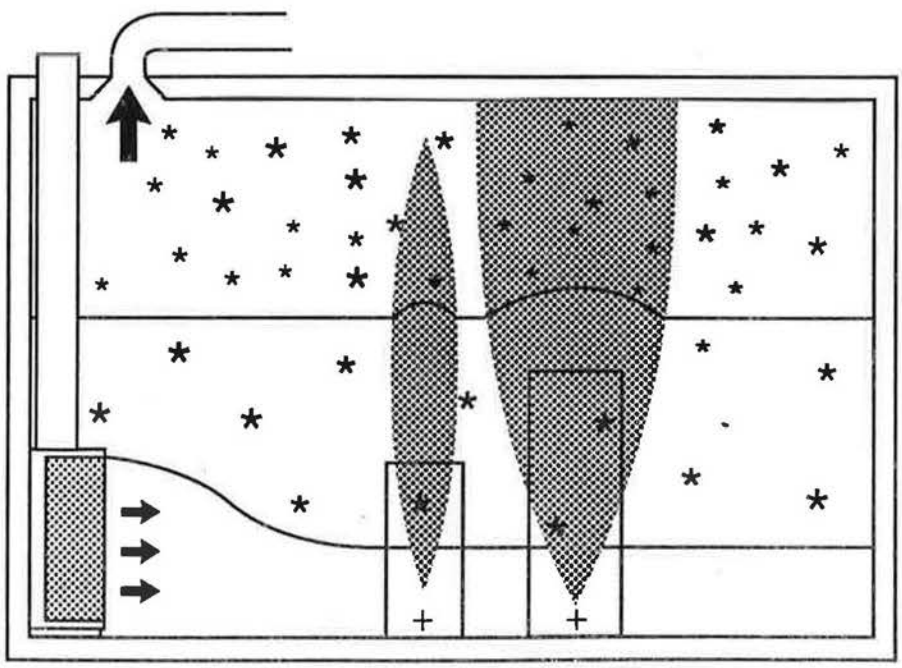

Figure 3

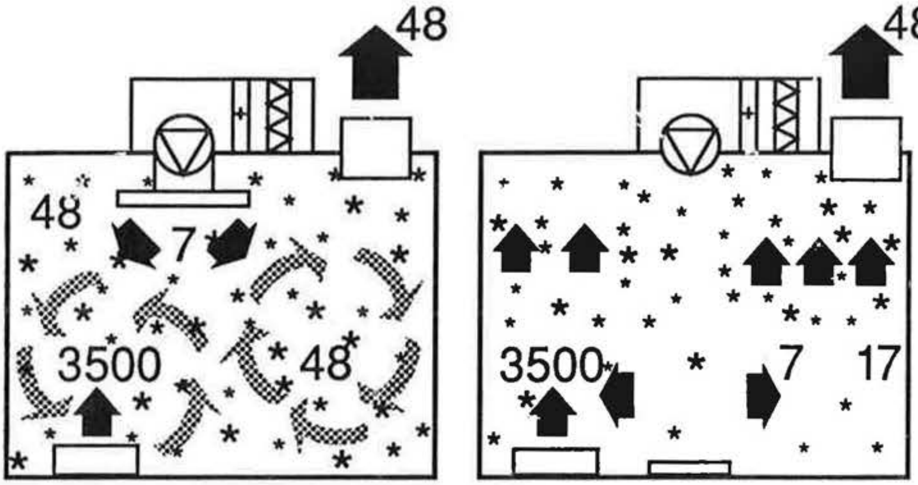

Figure 4

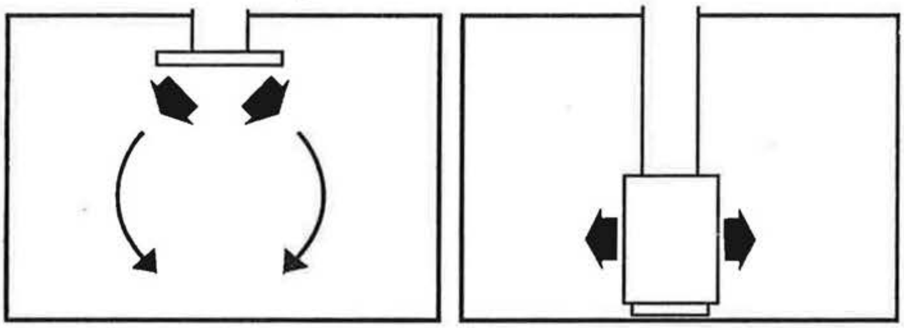

Figure 5

$$\eta_{vent} = \frac{48-7}{48-7} = 1 \qquad \eta_{vent} = \frac{48-7}{17-7} = 4,1$$

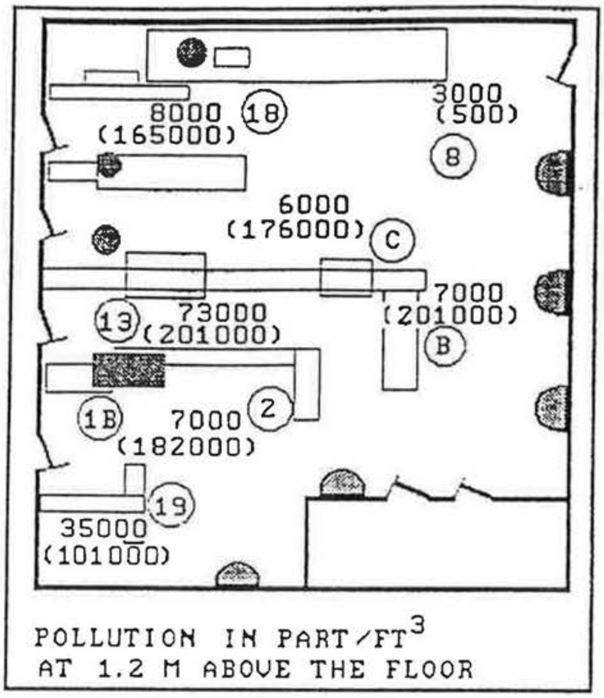

Figure 6

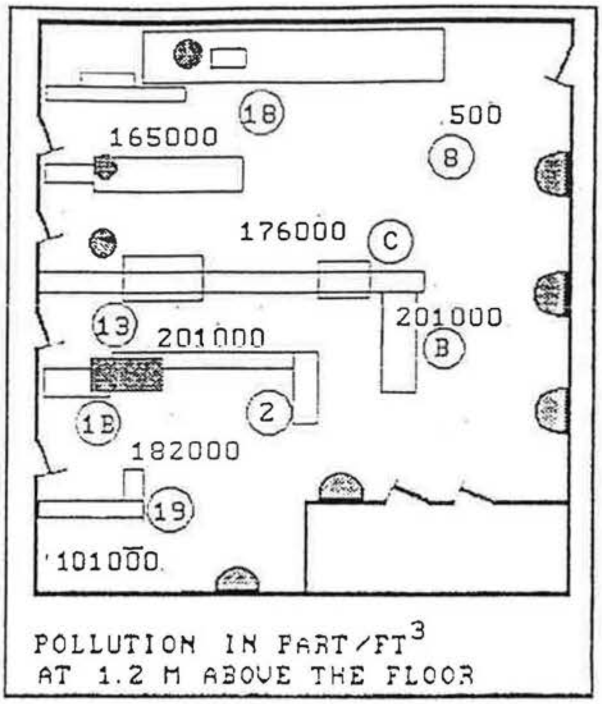

Figure 7