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# LOW-IMPULSE CEILING DIFFUSOR FOR DISPLACEMENT VENTILATION

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## SUMMARY

The past few years have seen a wide-spread use of displacement ventilation for room ventilation. The principle has several advantageous characteristics, of which special attention has been paid to its possibilities of more efficient use of the ventilation air for cooling of workplaces and removal of pollutants. The arguments against the use of displacement ventilation are primarily that the installation of the wall-mounted air outlet devices is expensive; that draught problems may arise close to the outlet; and that the ventilation principle seldomly works when only small air quantities are to be supplied to the room.

We shall examine a system layout where the air is supplied through low-impulse air outlet devices mounted in the ceiling. The philosophy of the this layout is that the cold air is "poured" into the room at a spot not normally used for occupation, e.g. close to the door. On its way to the floor the supply air will be mixed with room air, and as it reaches the floor the amount and temperature of the supply air should be sufficient for ventilation of the rest of the room by the displacement principle. If the examined ventilation system proves to work as described, it will be an inexpensive system for comfort ventilation using the displacement principle.

The tests are carried out as laboratory tests under controlled conditions, with complete recording of all relevant parameters, such as temperature, air velocity, age-of-air in the occupied zone, and air-exchange efficiency in the room. Heated manikins are used to simulate influence of occupants.

## INTRODUCTION

Testing new principles of ventilation is a huge task involving numerous calculations and experiments. The work we have conducted is only to be considered a preliminary investigation with the purpose of getting an impression of the advantages and disadvantages of the low-impulse ceiling supply principle.

We have chosen to conduct the investigation as a comparative investigation with three different air supply principles. Low-impulse ceiling diffusion will be compared to Normal mixing ventilation and Displacement ventilation.

The tests were made in a 33 $m^2$ office room, specially made for this purpose, with four workplaces. A heated manikin (100 W) as well as a heated computer-screen dummy (100 W) were placed at each workplace. Figure 1 shows a plan of the room.

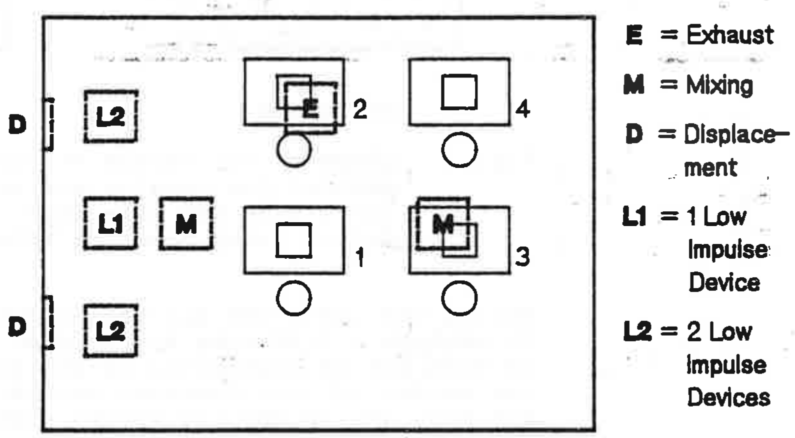
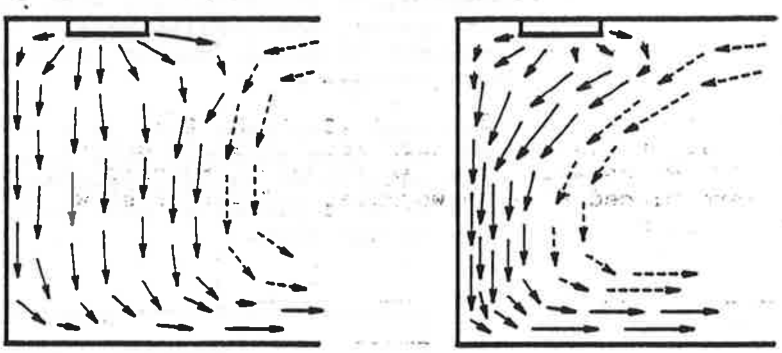



Fig. 1 Plan of test room, showing the location of the four workplaces, and the air inlet and outlet devices. The two devices for displacement ventilation are placed in the side wall at floor level, while the others are built into the ceiling

The height of the test room is 2.6 m. Apart from persons and computer screens there is a slight thermal load (224 W) from the electrical light, and minor heat exchange with the surrounding rooms.

## ADJUSTMENT OF LOW-IMPULSE AIR OUTLET DEVICES

Supply of cold air with low impulse, from a ceiling diffusor may cause some problems, since the air stream from the outlet tends to converge on its way towards the floor. Parameters deciding the shape of the air stream are temperature difference and injection velocity. Figure 2 shows the two shapes of the air stream observed during adjustment of the air outlet diffusors.



Diffusing Converging

Fig. 2 Shape of air stream at supply from ceiling-mounted low-impulse air outlet. The full-drawn lines show the flow from the air outlet and the dotted lines show the movement of the room air.

During the tests the air outlet device has been adjusted to achieve a diffusing air stream. The normal circulation of room air is controlled by the air supply as well as by the convective air currents around the heat sources. In the test set up the two forces work together and create a vortex circulating around a horizontal axis across the room. This vortex will try to press the supply air stream up against the end wall. Therefore, a certain impulse in the supply air is necessary to overcome the vortex forces.

## AIR DISTRIBUTION IN THE ROOM

The air distribution and the air exchange efficiency were measured with tracer gas using the age-of-air method. In short, the method involves measuring the time it takes the air to get from the air supply to a number of measurement points in the room. One way of conducting the measurement is to mark all supply air with tracer gas from the time zero, and then monitor how fast the marked air reaches the measurement points.

We have chosen to measure local mean age-of-air in four points in the room and in the air extraction duct. Furthermore, from the measurement in the air extraction we determine the room-average age-of-air and the air-exchange efficiency. We use the European scale for air-exchange efficiency, where a piston flow gives the value 100%, full mixture gives the value 50%, and short-circuit gives values less than 50%.

Figure 3 shows typical step-up curves for the three principles of ventilation and Table 1 lists the key figures for the three principles, to facilitate comparison.

| Measurement no. | 1-4 | 5-8 | 9-12 | 14-15 | 16-19 | 20-21 |
|---|---|---|---|---|---|---|
| Type | Low 1 | Disp. | Mix. | Low 2 | Mix. | Disp. |
| Local mean age: | | | | | | |
| Desk 2, 0.6 m (4) | 565 | 308 | 634 | 530 | 653 | 402 |
| Desk 2, 1.1 m (6) | 582 | 410 | 643 | 597 | 654 | 477 |
| Desk 2, 1.7 m (5) | 606 | 516 | 624 | 605 | 642 | 731 |
| Desk 3, 1.1 m (1) | 587 | 327 | 677 | 585 | 703 | 358 |
| Exhaust (3) | 628 | 575 | 528 | 603 | 554 | 581 |
| Room-average age-of-air | 607 | 480 | 698 | 573 | 714 | 504 |
| Air-exchange eff. | 51% | 60% | 38% | 53% | 39% | 58% |
| Temp. supply C | 15.2 | 15.2 | 15.0 | 17.0 | 17.1 | 17.1 |
| Temp. extract C | 21.7 | 22.2 | 21.0 | 22.1 | 22.4 | 22.4 |
| Heat removed kW | 1.10 | 1.20 | 1.05 | 0.86 | 0.90 | 0.90 |

Table 1 Results for measurements of age-of-air and thermal load for the three ventilation systems. All age-of-air results are in seconds. "Low 1" indicates that the supply air has been injected through the middle low-impulse ceiling diffuser. "Low 2" indicates that the two outermost low-impulse ceiling diffusers have been used. The air-exchange in the room during measurements was between 540 and 560 m3/h. Leakage from the room to the surroundings constitute 5-10% of the total air-exchange of the room.

Since 2-4 measurements have been conducted for each set up, we have been able to calculate that age-of-air in the above table has an uncertainty of 5%.

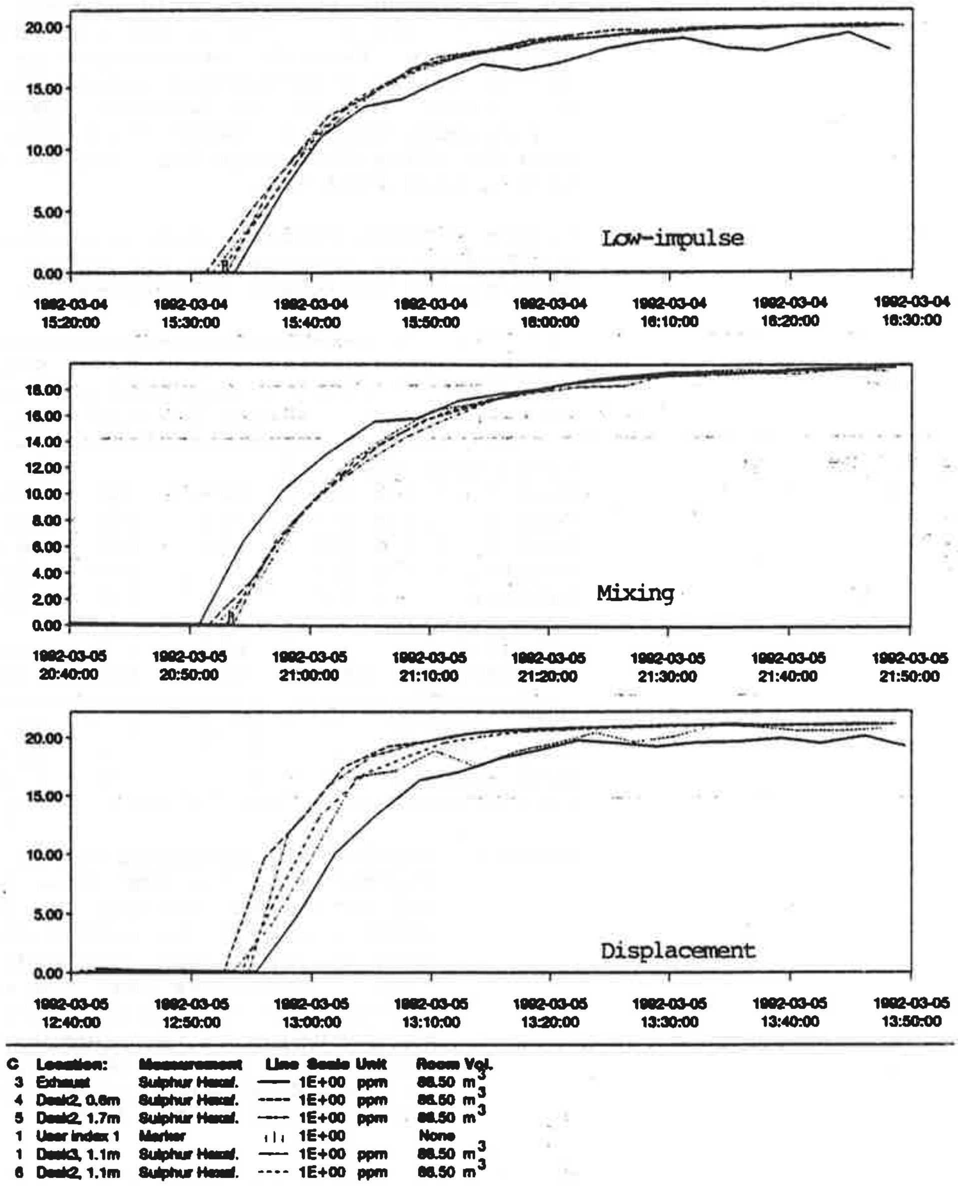



Fig. 3 Step-up curves for measuring age-of-air for low-impulse ceiling diffuser, mixing ventilation, and displacement ventilation. "Marker" indicates the point of time where the tracer-gas dosing started.

## THERMAL COMFORT

In order to evaluate the thermal comfort at the different principles of ventilation, temperature and air velocity were measured at a number of points in the room. Figure 4 shows the isotherms drawn into a sectional elevation across the room, and figure 5 shows the velocities in the same sectional elevation.

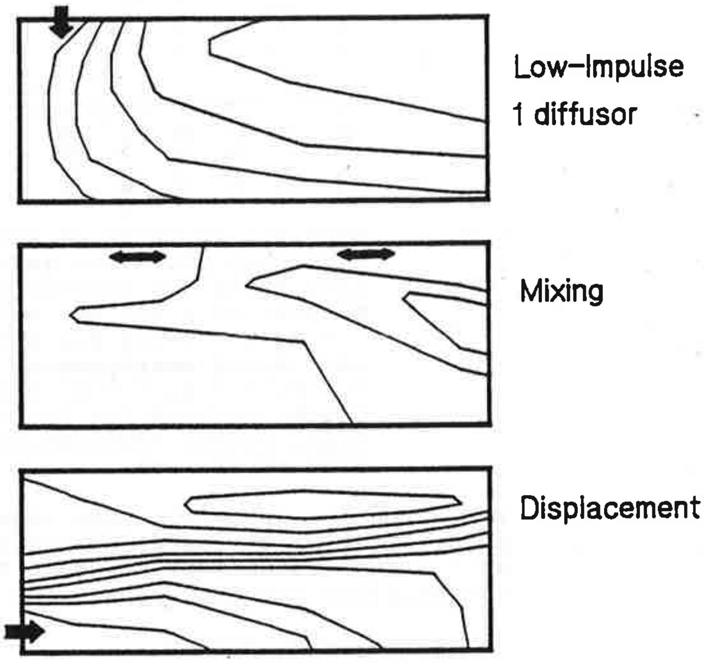



Fig. 4 Isotherms in a sectional elevation across the room for the three different principles of ventilation. The distance between the isotherms is 0.5°C.

Big vertical temperature differences may cause discomfort. In /2/ it is recommended that the vertical air temperature difference between 1.1 m and 0.1 m (head and ankle level) shall be less than 3°C. Figure 4 shows that the displacement ventilation is close to this limit.

The sensation of draught is a function of both mean air velocity, turbulence intensity and air temperature. Therefore, Figure 5 does not show directly the number of persons feeling draught. The percentage of dissatisfied can be calculated by the equations in /1/.

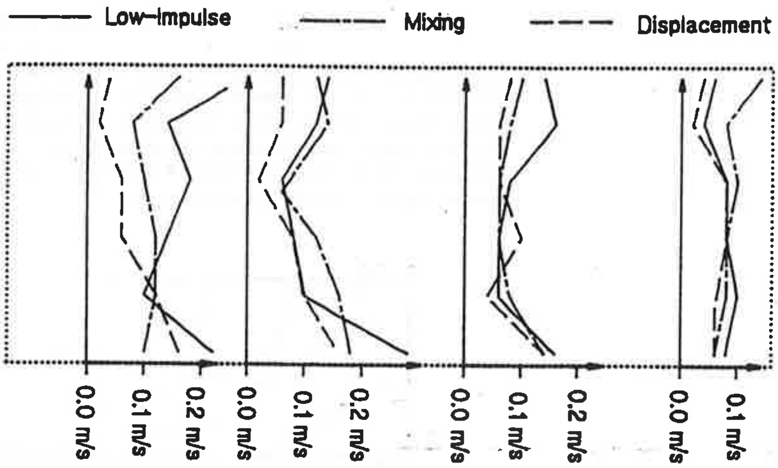



Fig. 5 Mean air velocity in four vertical lines in a sectional elevation across the room. The dotted line shows the contour of the room. The measurements are carried out at distance 0.7 m, 2.0 m, 4.0 m and 6.2 m from the left wall. At each point measurements are done in the heights 0.1 m, 0.6 m, 1.1 m, 1.6 m, 2.1 m and 2.5 m. Outlet devices for low-impulse ceiling supply and displacement ventilation are situated in the left side of the room.

Among the measurement points shown in Figure 5, it is the point 0.1 m above the floor and 2.0 m from the left end wall that creates most draught. The percentage of dissatisfied for that point will be as follows:

| | |
|---|---|
| Mixing ventilation | 16% dissatisfied |
| Displacement ventilation | 15% dissatisfied |
| Low-impulse with 1 diffuser | 26% dissatisfied |
| Low-impulse with 2 diffusers | 19% dissatisfied |

Control measurements at other points in the room did not reveal points with thermal conditions worse than as shown above.

## DISPERSAL OF POLLUTANTS

The key value, air-exchange efficiency, that can be calculated from an age-of-air measurement, indicates how fast an evenly distributed pollution is removed from the room. It does not, however, indicate how pollutants from a point-source are dispersed in the room. In order to investigate this, we placed a source of pollution at one workplace and measured the concentration of the pollutant in the breathing zone at all workplaces in the room, as well as in the air extract.

As source of pollution we chose 10 burning cigarettes, and as pollution component carbon monoxide was registered. Figure 6 shows the result of the measurement.

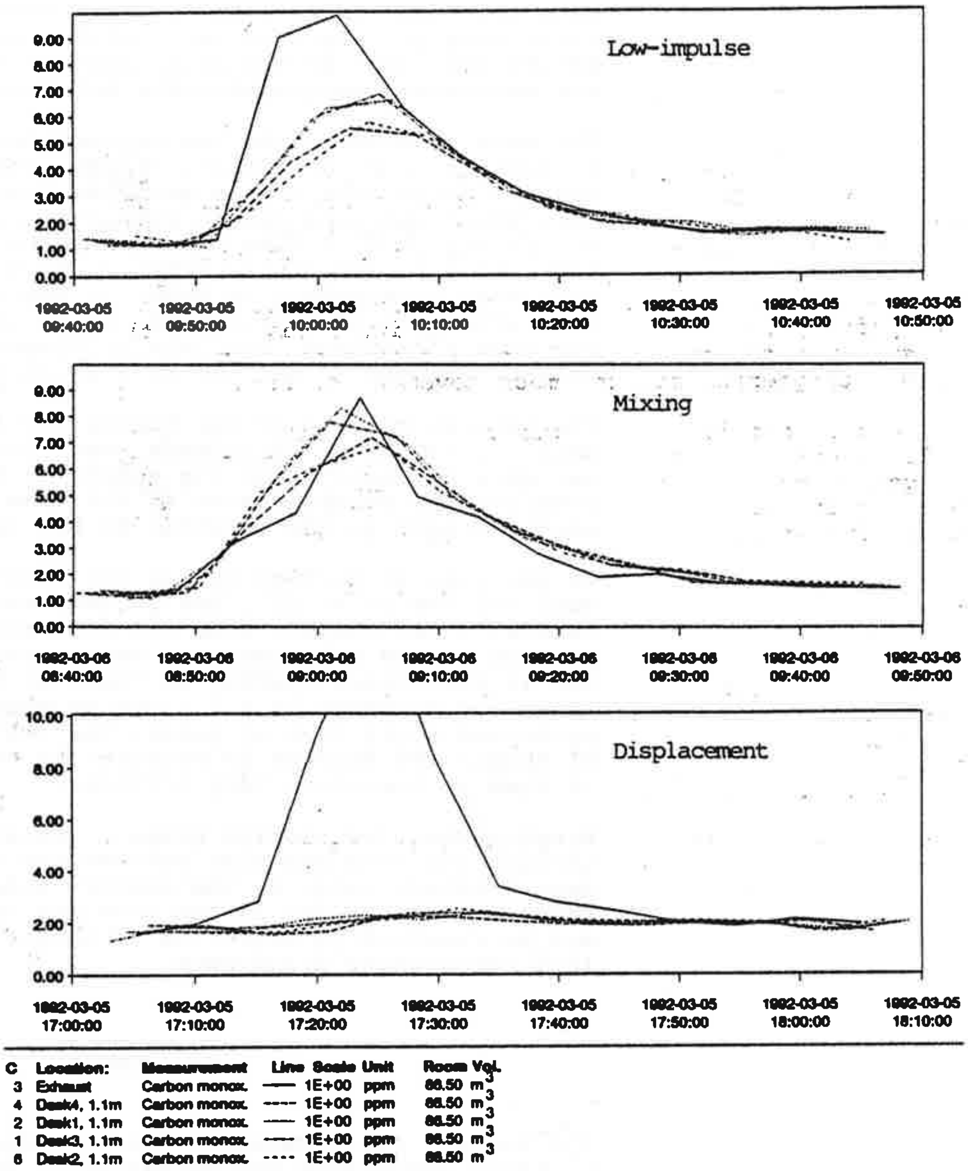



Fig. 6 Dispersal of pollutants from a source at desk 3 to the four workplaces in the room. The curve is from measurements on low-impulse ceiling diffuser, mixing ventilation, and displacement ventilation. The source of pollution is 10 cigarettes that burned for approx. 20 minutes.

## CONCLUSION

The measurements we have performed do not directly indicate whether the use of low-impulse ceiling diffusers is a good idea or not. There are a number of problems about this principle of ventilation, but also some advantages; just as the principles of ventilation used in the comparison have advantages and disadvantages.

The main problem of the low-impulse ceiling supply is that it accelerate a too big air volume. The result being that the air velocities in the occupied zone are too high and that the displacing effect does not occur. Injection with two diffusors will give better results than injection with one diffusor, and it is probably the air supply diffusors that need development in order to improve results with this principle of ventilation. It is imperative that the air supply diffusors are able to disperse the supply air without triggering off too much movement of air.

The largest problem of the mixing ventilation is a very small air-exchange efficiency. More than 20% of the supply air goes dicrectly from the supply to the extract without entering the occupied zone at all. The reason for this short-circuit is the location of the exhaust

In the case of perfect mixing the location of the extract does not matter at all, but perfect mixing does not exist in real life. Judging from the air velocities and air flow pattern in the occupied zone we can estimate that the room air is circulated approx. 20 times an hour. Since the fresh-air exchange is 6.7 times an hour, 30% of the air is exchanged every time it passes the ceiling. The location of supply and extract in relation to the general direction of flow is therefore very critical.

Displacement ventilation gives a satisfactory air flow through the room and also removes the cigarette smoke from desk 3 effectively. On the comfort side the large temperature gradient in the room may cause problems. This may be remedied by injection of larger amounts of air with less temperature difference.

## REFERENCES

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