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Paper 21

DISPLACEMENT VENTILATION FOR OFFICE BUILDINGS

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DISPLACEMENT VENTILATION FOR OFFICE BUILDINGS

Synopsis

A test room with a Displacement Ventilation System has been built. Air velocity and temperature profiles were measured at different places in the room under summer and winter conditions.

Additional numerical simulations for the same conditions as in the experiment were performed. The measured and calculated values showed good correspondence.

An office room is normally not occupied permanently, therefore its transient behaviour was also investigated.

1. INTRODUCTION

The idea of using the Displacement Ventilation System for the air conditioning of office buildings is becoming more and more popular nowadays. Nevertheless, many building owners and designers have reservations in applying it.

On the other hand, numerous results from R&D projects and field measurements relating to displacement systems are already available. Performance has been good, and according to the application the system presents advantages compared to Mixing Ventilation-Systems.

The demand for better and more efficient systems is growing with our increasing comfort requirements in buildings.

It is not only the behaviour of the room with a displacement system that is not yet exactly known. Human perception and its effect on the momentary requirement for comfort also are not sufficiently understood.

Thus today's investigations on displacement ventilation have to deal with the air flow patterns and temperature distributions in the room, as well as with the sensation of comfort of human beings, a rather complex situation, as the comfort problem does not have a simple solution.

To find some practical solutions, we tested two typical cases:

a) a winter condition, with and without additional heating

b) a summer condition with two different local distributions of the solar heat load.

For both, the measurements and their impact on comfort were discussed.

In addition, both cases were calculated with the AIRCOND numerical simulation program. Simulation was performed before the experiments.

These experiments describe the situation for steady state conditions. As the time constant of an office room is of the same order of magnitude as the daily working hours, the transient behaviour of the room was also investigated.

2. TEST ROOM

An office for two persons (15 m^2/person) was built as a test room in our laboratory. Floor plan and measuring points are shown in Fig. 2.1.

The room represents a typical office having one outside wall with windows.

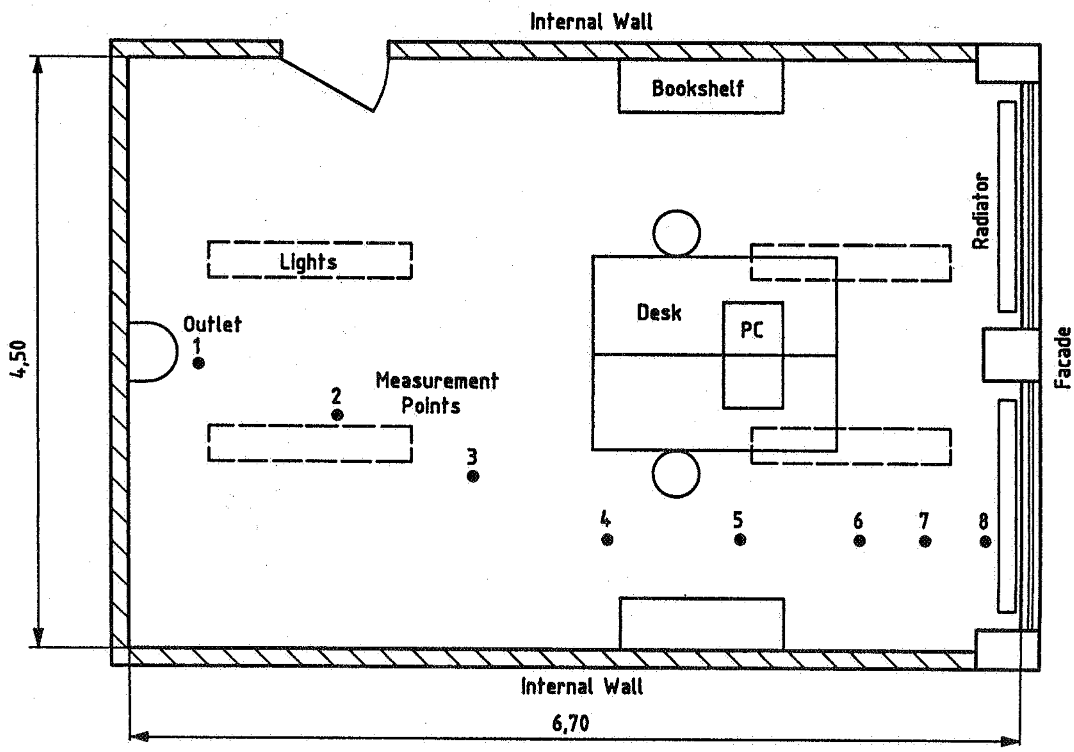

Fig. 2.1 Floor plan of the test room with furniture and location of the internal loads. In addition the measurement points for the temperatures and air velocities are indicated.

Dimensions	:	6.70 x 4.50 x 2.65 m
Room volume	:	80.0 m^3
Floor heating	:	20..33°C
Radiators	:	2 x 0..600 W Below the window
Ventilation system	:	Displacement outlet REPUS RAC 25-10 Surface area 0.95 m^2 Air volume 0..820 m^3/h Temp. 12..20°C

Internal load	:	2 persons 2 x 80 W 2 PCs 2 x 120 W Lights 464 W Extract light fittings
Windows	:	2 x 3.1 m^2 Temp. 8..20°C
Walls	:	U value 0.25 W/m^2K M* (spec. mass) 50 kg/m^2
Temperature measurement	:	Fe/CuNi elements Time const. 1 sec Range -200..900°C
Air velocity measurement	:	Sulzer Low-Velocity Hot-Wire Anemometer Time const. 0.1 sec Range 0.04..0.50 m/s

3. EXPERIMENTAL INVESTIGATIONS

Related to displacement systems, mostly the maximum internal heat load is mentioned. For all-air systems, it will be around 30 W/m^2, for certain situations even as high as 40 W/m^2.

Since in practice lower heat loads often occur, the measurements were taken for different conditions. For the maximum internal load during summer condition, the temperatures and air velocities were measured at different locations in the room. The same measurements were taken for winter conditions, where the internal load compensates for the transmission heat loss of walls and windows.

The aims in both cases were to:

1. investigate the stability of the air flow in the room and

2. measure and assess the temperatures and air velocities with regard to comfort criteria.

3.1 Winter Conditions

For comfort reasons, the cold air downdraft from windows is often compensated with radiators below the window.

With new windows having a U value between 1.3 and 2.1 W/m^{2}K and mixing ventilation, radiators do not necessarily have to be underneath the window. Whether this would apply also for rooms with a displacement system was tested in two similar cases: with and without radiator. Details for both cases are listed in Table 3.1.

All the measurements were made at steady state conditions with a constant air inlet temperature. No control for the room temperature was used.

		Winter without heating	Winter with heating
Persons	[W]	2 x 80	2 x 80
PCs	[W]	2 x 120	2 x 120
Lights	[W]	-	-
Radiator	[W]	-	270
Window	[W]	-250	-280
Tot.int. spec. load	[W/m^2]	13	22
Air change rate	[1/h]	4	4
Air inlet temp.	[°C]	19,3	19,5

Table 3.1 Internal load, transmission losses and key data of the ventilation system for winter conditions.

Air velocity and temperature profiles for both winter cases are shown in Fig. 3.2. The most impressive result is the small temperature gradient within the occupied zone. This was found to be true even when the radiator was used, thus the assumption was disproved that the air rising from the radiator would induce so much room air that stable air stratification is disturbed.

Both winter cases have similar air velocity and temperature profiles in the occupied areas. Most critical for the comfort are the first few centimetres above the floor (supply air layer). There the velocities are below 12 cm/s and the temperature is 20,5 °C, leading to a FANGER PPD rate of less than 10 %.

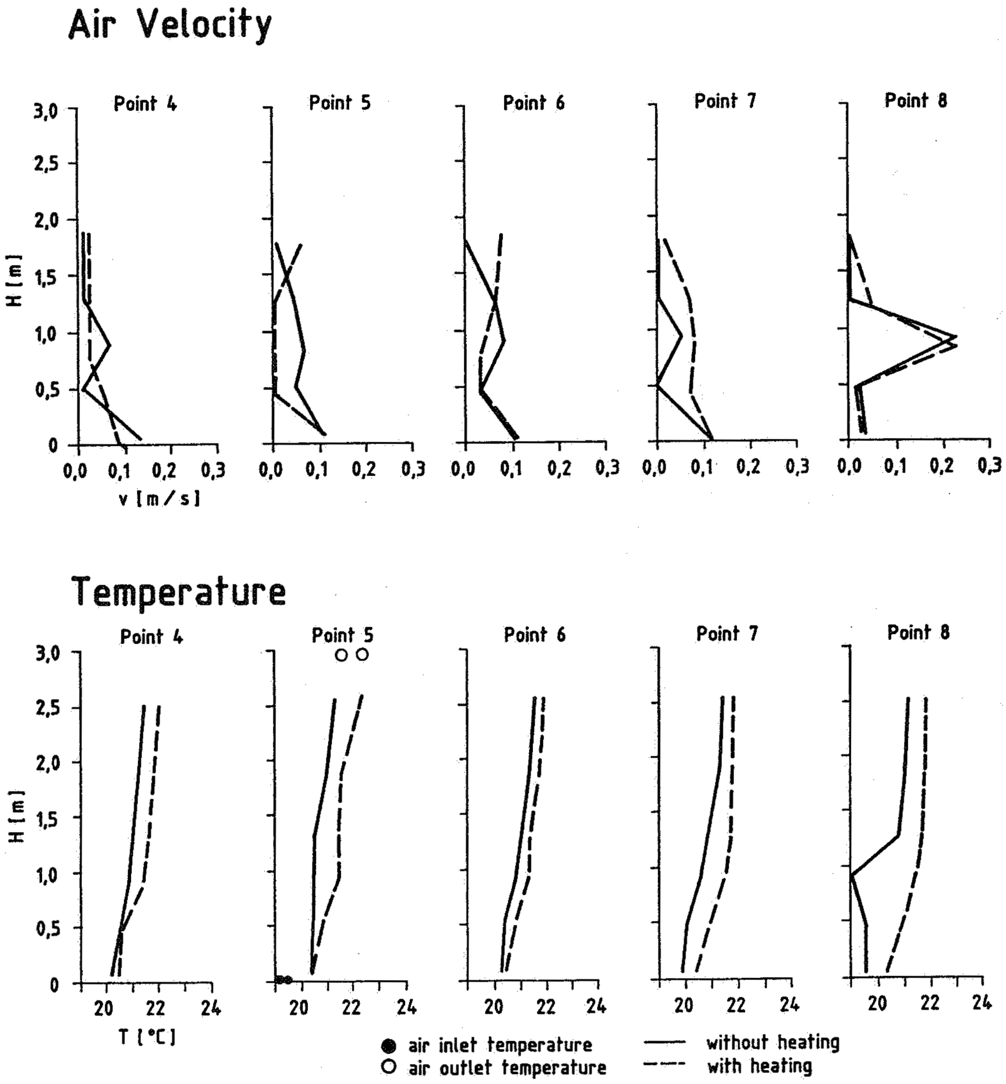

Fig. 3.2 Air velocity and temperature profiles for the winter case with and without radiator heating.

The two experiments were made with low values of internal loads (13 W/m^2 and 22 W/m^2).
Additional experiments with lighting showed that the characteristics of the air velocity are not influenced. The room temperature increases by 1.0 K below the ceiling and by 0.2 K at foot level, corresponding to 25 % of the installed electrical power.

The above results apply only for walls and fenestrations with low U values. The U values we simulated were:

Wall : 0.3 W/m^2K

Fenestration : 1.4 W/m^2K

For offices with more than one exterior wall, further investigations are necessary.

As it is not possible to provide space heating with a displacement system, an additional heating system would always be necessary providing heat during nights and weekends. If the internal heat load compensates for the transmission losses, it is possible to shut off the heating without any loss of comfort.

For buildings with less insulated windows, the radiator heat load may be reduced in accordance with the internal load during occupation. In this case the window sill construction has to be optimized to obtain the best possible configuration of the downward and upward air flows along the window.

3.2 Summer Conditions

During summer, the transmission heat for well insulated facades is of minor importance. However the heat gained by solar radiation through the windows may represent a substantial addition to the internal load of the room.

The temperature gradient in the room is affected by the capability of the walls to absorb the solar radiation. Surfaces having a slightly higher temperature than the room air emit their energy mainly through radiation. In cases where the temperature is increased, the convection heat exchange becomes more intense. And with more convection, the temperature gradient in the room also becomes bigger.

The designer has some influence on the effect of the heat gains from solar radiation in the space by selecting proper materials and colours. Having for example a light coloured floor, the reflectivity is increased, thus a uniform distribution of the heat within the space and a small temperature gradient may be achieved. On the contrary, internal heat gains from people, PCs etc. are independent of the colour of the sufaces, as the absorbtion coefficient for long wave radiation is constant.

In the summer case 1, solar radiation of 1010 W ($34\ W/m^2$) was distributed over the entire floor.

In the summer case 2, 530 W ($18\ W/m^2$ for the entire floor area) was distributed over one quarter of the floor area near the window; a somewhat more realistic case, as during summer the solar radiation does not reach the far end of the room. A comparison of both cases demonstrates the important influence of the heat distribution on the temperature and velocity profiles within the room.

Details of both cases are listed in Table 3.3.

		Summer 1	Summer 2
Persons	[W]	2 x 80	2 x 80
PCs	[W]	2 x 120	2 x 120
Lights	[W]	-	-
Solar radiation	[W]	1010	530
Tot. spec. load	[W/m^2]	47	31
Air change rate	[1/h]	6	6
Air inlet temp.	[°C]	16,9	19,3

Table 3.3 Internal load, solar radiation heat load and key data of the ventilation system for summer conditions.

With regard to the comfort requirement the situation with the heat load over the entire floor (summer case 1) was found to be better than the case where the heat is only emitted in the window area.

The characteristic values at the desk area are:

	Summer 1	Summer 2
Temp. gradient :	2.0 K/0.1-1.3 m	2.9 K/0.1-1.3 m
Velocity at 0.1 m:	0.15 m/s	0.20 m/s

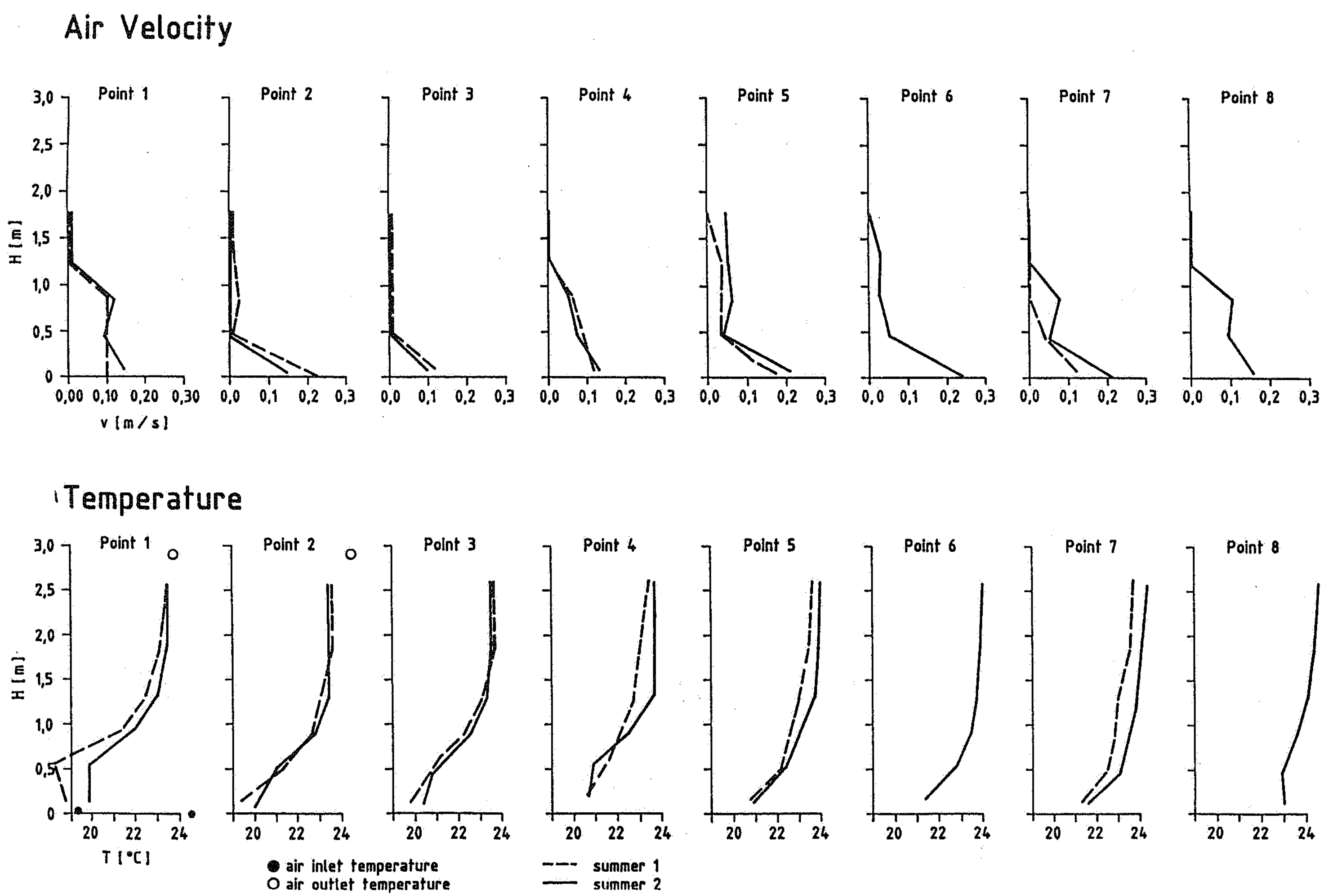

Fig. 3.4 Air velocity and temperature profiles for summer cases 1 and 2

Figure 3.4 shows how the air temperature rises over the heated floor area in case 2. The heated air causes high air velocities in the window area. On the other hand, the air velocity near the outlet is higher in case 1. This is due to the increased temperature difference between the supply and the room air.

For the influence of the outlet construction on the air velocity distribution, see H.M. MATHISEN 1988 and P.V. NIELSEN et.al. 1988.

The major differences between the two summer cases were in the energy density and the area of the heated floor.

With 70 W/m^2 in the window area of case 2, the floor temperature was higher and therefore the convective heat exchange more intensive than for case 1. This convective heat flow caused the high temperature gradient in case 2, although the solar heat gain of case 1 was twice that of case 2.

As a design guideline it can be said that surfaces impinged by solar radiation should be of light colour and of a material with a high energy absorbtion capacity, so that the surface temperature can be kept as low as possible.

In addition to the above-mentioned recommendations, solar protection devices should be installed on all sun-orientated windows, as the unprotected solar radiation often exeeds the allowed internal load.

4. NUMERICAL SIMULATION OF TEMPERATURES AND AIR VELOCITIES

The experiments as described above were simulated with the numerical program AIRCOND.

The characteristics of AIRCOND are as follows:

- finite volume method
- 3-dimensional
- nonsteady flow
- incompressible flow
- laminar / turbulent flow
- logarithmic wall function
- Newtonian fluids
- cartesian coordinates, orthogonal grid
- boundary conditions on walls fixed for either temperature or heat flux
- turbulence : $k-\varepsilon$ model

The results of the simulation and the experiment for summer case 2 are compared in Fig. 4.1. This example is also representative for the other cases, as the results are similar.

It is interesting to observe the similar shape of the computed and measured velocity and temperature distribution shown in Fig. 4.1.

The velocity profiles coincide extremely well. Most of the differences of 1 to 3 cm/s are caused by having only 6 measurement points in the height of the rooms, whereas with the simulation 18 points were calculated.

For the measuring points 5 to 8 at floor level, the calculated velocities are up to 4 cm/s below the measured ones. The reasons for this are not yet completely understood.

The deviations of the temperatures exceed those of the velocities. All the calculated values are systematically about 1 K lower than the measured ones. Nevertheless the shapes of the curves correspond to each other.
The reasons for these differences are as follows:

1. The air inlet temperature is 0.3 K lower for the simulation than for the experiment.

2. The measured temperatures are global, not air temperatures. For our room configuration the global temperatures are 0.2 to 0.3 K higher than the air temperatures.

3. The simulation program does not consider the radiation within the room.
   The radiant heat transfer between internal loads and walls was estimated. These values were then used as boundary conditions for the simulation.
   If the radiant heat exchange is estimated too high, then the calculated air temperature is lower than the measured values.

Generally it can be said that the results for the air velocities are reasonable. The absolute temperatures have some deviations, but the shape of the temperature distribution (relative temperature) is correct.

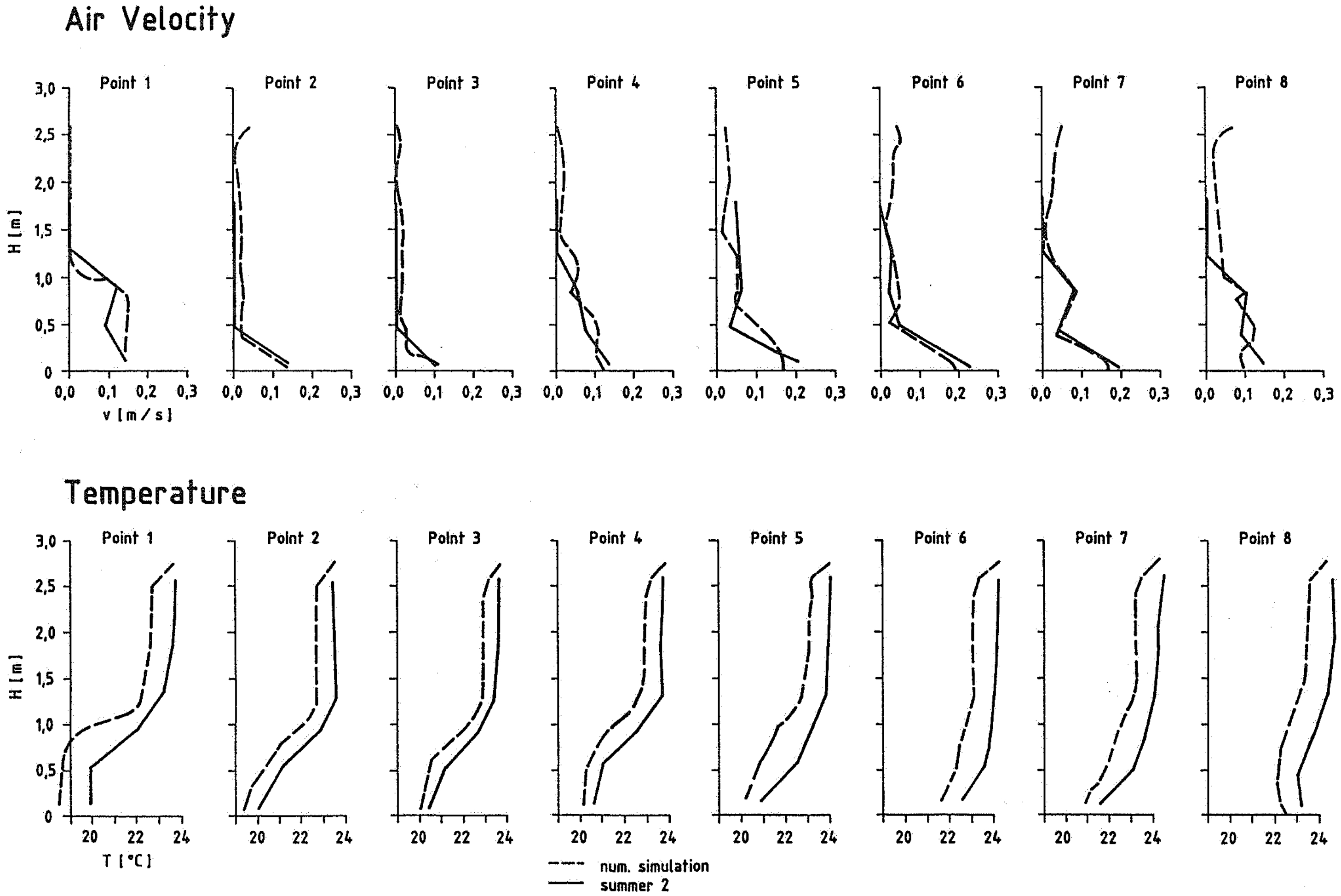

Fig. 4.1 Air velocity and temperature profiles for summer case 2. Results from the numerical simulation and the experiment.

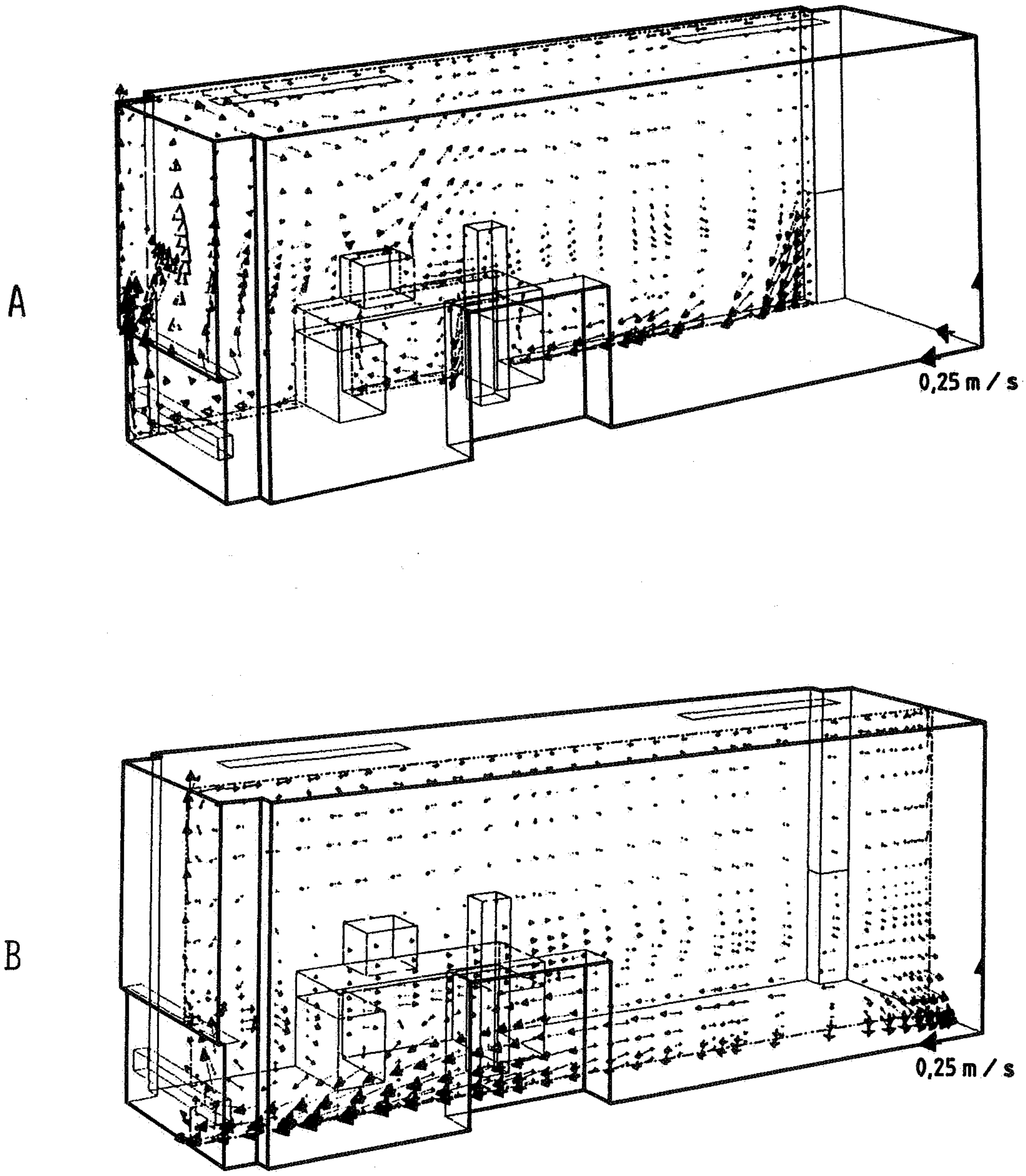

Fig. 4.2 Calculated air velocities for the summer case. Fig. A shows the velocities in the center of the room; Fig. B those in the middle of the free section between the desk and the bookshelf.

In addition to the experimental results, the simulation shows some interesting results:

1. A reduction of the free floor area causes a substantial increase of the air velocity above the floor. In our test room the free floor area was reduced by 66 % due to two desks, bookshelfs and cylinders (simulating persons). Fig. 4.2 B shows the increase of the thickness and velocity of the supply air layer.

   This effect can be reduced by increasing the cross section area, e.g. moving the bookshelf away from the narrow zone of the desks.

2. Rooms with displacement ventilation normally have a very little horizontal temperature gradient (such as the rear side of the room in Fig. 4.3).

   The high and local internal heat load of summer case 2 caused a temperature difference of 2 K between the window area and the back of the room. The two desks and the high load of 70 W/m^2 in the window area prevented a uniform temperature distribution in the occupied zone.

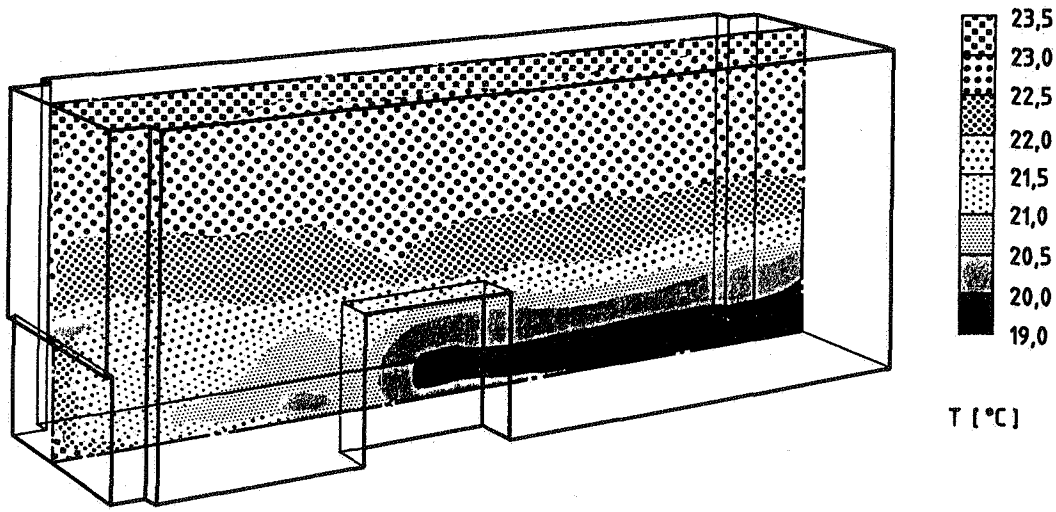

Fig. 4.3 Calculated air temperatures for summer case 2. The temperatures apply for a cross section through the center of the simulated person. Note how the lower part of the room is divided into two sections by the "wall" of desks, bookshelves and persons.

It would have taken a lot of time to measure the same number of points that were numerically calculated. Having the temperatures and velocities for many points all over the room allows much better interpretation than with the few values of the measurements. This is another important advantage of the numerical simulation.

5. TRANSIENT BEHAVIOUR OF THE TEST ROOM

In a room with a mixing ventilation system, the kinetic energy of the supply air is always higher than the kinetic energy of the buoyancy airflow from internal loads. This means the temperature gradient is small and internal surface temperatures are equalized with such a system.

In a room with a displacement ventilation system, the buoyancy airflow is the only motor of the air movements. For this reason the air temperature is not uniform. As a consequence, the influence of the building structure on the transient behaviour of the room is increased.
The utilization of a room featuring a displacement ventilation system causes its temperature to rise. In the upper part of the room (1,0 to 1,5 m under the ceiling) the temperature rise is up to 3 K, over the floor it is around 1 K. (Experimental values for internal loads of 20 to 30 W/m^2 and an air change rate of 4 to 6 per hour).

In such a room (with an air temperature gradient), the upper parts of the surfaces (ceiling, wall) are cooler than the air, and the lower parts (mainly the floor and the first metre of the wall) are warmer than the air. The air temperature difference between floor and ceiling is more than twice the difference between the corresponding surface temperatures. This has to be taken into account using the comfort equation.

As the surface temperatures of the room are not equal,there is an intensive radiation heat exchange between the surfaces. For an internal load of 400 W, the radiation heat exchange from the ceiling to the floor is 64 W in our test room. This energy heats up the supply air and improves the comfort condition at floor level.

In rooms with cooling panels on the ceiling, this radiation is missing at floor level, and the heating effect of the supply air is reduced. In addition, the cooled ceiling keeps the surface temperatures constant, so that the storage effect of the walls is not used in such room.

For comfort reasons, it is also important to know that the air velocities do not change during the transient time.

In our test room, it took between 20 and 35 hours until we reached the steady state condition. During the first 10 to 12 hours, a constant energy flux of 0,5 to 1 W/m^2 was stored in the room structure, thus reducing the load of the ventilation system by 15 to 30 %.

The temperature gradient in the room depends on the internal load and the air change rate:

The higher the air change rate, the lower the temperature gradient becomes, but as soon as a temperature gradient has been established it cannot be reduced by means of an increasing air change rate. This means the entire room is cooled at a constant gradient if the air volume is increased.

Further experiments on the storage effect and the temperature control in the room are in progress.

As a result, it can be said, that for displacement systems the transient behaviour represents an additional important parameter. Though it complicates the system, a proper application can reduce the energy consumption and improve comfort conditions at the same time.

6. SUMMARY

The experiments in the room with a displacement ventilation system showed that for winter and summer conditions, comfortable conditions can be obtained.

In a well insulated building, heating can be shut off during the time of occupation. For summer conditions and intensive solar radiation through the windows, Venetian blinds are necessary.

The result from the numerical simulation of the test cases showed a good correspondance with the measurements. The values for the air velocity coincide better than those for the temperature.

It is a feature of displacement systems that the room temperatures vary within a few degrees during occupation. The transient behaviour of the building structure contributes therefore considerably to the resulting indoor climate.

7. ACKNOWLEDGEMENTS

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Discussion
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E. Olsson (Chalmers University, Sweden)

1. Have you tried to change the level of the front by balancing heating and ventilation flow?
2. What kind of turbulence and radiation models were used?

Beat Kegel (Sulzer Bros, Switzerland)

1. No, the aim of the experiments was to measure a characteristic office room not an optimisation of the front.
2. Turbulence: k-e
radiation: rough estimation of the radiative and convective heat flows used as boundary conditions.

Marco Masoero (Politecnico di Torino, Italy)

If the major problem in summer operation is the heating of the floor surface due to incident solar radiation, would it make sense to use cool water pipes buried in the floor slabs as the cooling system?

Beat Kegel, (Sulzer Bros, Switzerland)

Maybe, but the time constant of such a system is too high so it would be very difficult to control such a configuration.

Charles Filleux, (Basler & Hofmann, Switzerland)

a) Do the air change figures you give include recirculation air? They seem very high.
b) Did you try to run lower air change rates and simultaneously lower the inlet temperature?

Beat Kegel (Sulzer Bros, Switzerland)

a) The experiments did not deal with the way the air comes from; quantity and temperature were the important parameters.
b) Yes, but we did not meet the comfort criteria anymore.

B. Fleury (ENTPE/LASH, France)

Can we get the turbulence intensity from the numerical results?

Beat Kegel (Sulzer Bros, Switzerland)

Yes, you can get the 50 and 84% time value of the velocities.