CH-81-17 No. 2

AIR FLOW EXPERIMENTS IN FULL SCALE TEST ROOMS

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ABSTRACT

Airflow inside air-conditioned rooms is influenced by many different forces, producing a complexity which still prevents even a rough calculation of the flow pattern or the air velocities within the occupied areas. Therefore, experiments in test rooms are necessary to approve comfort conditions, especially concerning draft or gas concentrations.

The test room dimensions vary because a test room must represent a section which is characteristic of the original room dimensions, in so far as the air outlets and the airflow are concerned. The flow pattern is made visible; the velocities and, in some cases, the gas concentration are measured. The experiments are done under thermal steady-state conditions, and therefore tests are very reliable.

Some general results are:

Comfort conditions can easily be realized up to thermal internal loads of 40 W/m^2; for loads up to 100 W/m^2 special air outlets producing e.g. horizontally spreading flow patterns are necessary.

For optimized flow conditions there likely is a dependency of the maximum local velocity in the occupied zone and the cooling energy of one induction or one air outlet. Moreover, the local velocity is a function of the internal load per floor area.

Gas concentration measurements show that linear ceiling diffusors produce a nearly homogenous concentration over the height of the room. The concentration decreases with the distance from the source, the exponent of decreasing depends on the type of outlet.

Inhomogenous gas distributions are obtained by air outlets in the floor. The investigated outlet enables a reduction of air exchange of about 20% compared with standard-type ceiling diffusors as far as the concentration is concerned.

INTRODUCTION

Although much is known about airflow in air-conditioned rooms, the flow pattern and the air velocities can only be predicted in very simple cases without experiments.

Under the following circumstances test room experiments should be made:

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1. High space cooling load, say $q > 50\ W/m^2$ (q cooling load divided by the floor area);

2. Complicated room geometry, e.g. obstructed ceilings within jet outlet region;

3. High exchange rates of the air, e.g. exchanges of 20 to 100 times the room volume per hour;

4. Generally, room tests should be done if the number of similar arrangements of air outlets is very large. In this case it is easier and cheaper to find out and prevent mistakes during tests in test rooms.

If possible, the scale of the test room should be 1 : 1; obviously this, of course, cannot always be achieved. But even for bigger room experiments in full scale 1 : 1, it may be possible to choose a smaller section of the large room, which is still representative for the flow in the entire room or the critical portion of it.

The main aim of the experiments is to be sure that the air velocity in the occupied zone is low enough to prevent draft. To approve this, the velocities are measured and the airflow pattern is made visible by smoke or metaldehyde particles. All investigations should be performed with air, and the temperatures and the room walls should be the same as in reality. Thus, besides the measurements we can obtain a subjective impression of the conditions in the room.

In some special cases, one can also be interested in the gas concentration in rooms, e.g. to compare different types of air outlets or to control the effectiveness of special return air devices.

TEST ROOM

Fig. 1 shows schematically a typical installation of a test room; inside a bigger room in which the external temperature can be controlled, the test room itself is installed. Two walls of the room are usually fixed. One of these walls can be cooled or heated to simulate the influence of unisothermal windows. The other fixed wall is made of glass to enable observations of the airflow.

The ceiling of the room usually contains the original luminaires and air terminal devices. The height of the ceiling can easily be changed. The two other walls are movable, one of them is made of perspex.

The floor has controlled electric heating. The main part of the heating load of the room is simulated by this heating. If the location of internal heat sources, e.g. occupants or machines, is fixed and known, these influences are simulated by heated devices which have a surface temperature similar to the real sources.

If the flow in small rooms with a floor area less than 5 m x 11 m is to be investigated, the whole room is built inside. In the case of larger rooms, a typical section of it is established.

Fig. 2 shows a view of an installed test room. A section of an office with induction units in the perimeter area and linear ceiling outlets in the interior area is installed in the test room.

Fig. 3 shows a plan of a large office. The room has ceiling induction units with linear diffusors which produce a radial flow pattern by special diverging vanes inside the diffusor. This example shows that the test room dimensions are not fixed, they are influenced by the main dimensions of the original room and the positions of the outlets.

If the original room can be divided into similar sections concerning the airflow, then 6 to 9 of these sections should be built up in the test room. If the ceiling module is 1.8 m as it is in the shown example, the width of the test room should be 3 times 1.8 m = 5.4 m. If the interior area of the building can be divided into similar districts, the test room should have a length and width of 3 of those.

If there are induction units in the perimeter area and ceiling inlets in the interior area of the building, the test room should have the length of both areas, because interactions of both zones may occur. Even if three times three typical room sections are established, the influence of the test room walls must not be neglected, especially if the specific space load increases.

There is less influence of the test room walls if the air inlets are near the floor. One example are the air inlets in chairs of theatres or congress buildings. It is usually sufficient to install three rows of chairs and three chairs in one row. However, in this case it is important to have the correct temperature differential between the discharged air and the air in the room in a height of about 1.2 m. This temperature difference usually changes between 2 and 4 K.

When building a test room the question arises which details of the original room are to be established exactly. Not every detail of the room geometry or of the furniture inside the room must be copied. The air outlets themselves should be the original outlets. Also all elements should be included which are near the outlets in the direction of air jets, e.g. luminaires at the ceiling, if there are ceiling inlets. In the case of induction units below the window, the details of the windows or venetian blinds should be similar to the original. In any case details must be exact in all regions where free jets or wall jets occur, and where these jets may be influenced by declinings, separations, or reattachments.

The influence of furniture usually may be neglected, if not more than 25% of the flow cross-section is obstructed by them and if no new jets are produced by them.

Returning to the example of Fig. 3, the hatched section on Fig. 3 has been built up in the test room. In this arrangement all important interactions between the flow from the diffusors and between the diffusors and the walls can be studied.

TEST PROCEDURE

At the beginning of a test, the flow pattern is made visible by smoke or metaldehyde particles. Fig. 4 shows a luminaire, which enables the visibility of a small vertical plane of the flow inside the room. It is very important to have thermally steady-state conditions during the test. We developed some special heating and cooling devices by which the temperature of the supply air can be kept constant within .1 K. The room air is also kept constant within about .2 K.

To approve the steady-state conditions the temperature is measured by thermocouples at about 12 different positions and the results are plotted during the test. Generally, measurements are taken of the room temperature at 3 to 6 positions in the room, of the temperature of supply and return air, and of the temperatures of the walls and the outer room. The examinations are to be done with the supposed critical thermal loads and air volumes, which are usually the maximum loads and volumes; but in some instances also smaller volumes or smaller loads may be critical.

Velocity Measurement

The velocities are measured by thermal anemometers, e.g.TSI probes or Lambrecht-NTC-type probes with a time constant less than 1 sec. As the local velocity fluctuates, it is measured during 3 min. The signal of each of up to 10 (usually 3) probes is measured 5 times per sec. A multiplexer connects the probe with the digital voltmeter. A calculator gets the values and linearizes the signals and calculates the average velocity and the standard deviation of the velocity. Fig. 5 shows a diagram of the measuring device. The results are plotted as soon as one measurement of 3 min has finished.

Both types of anometers used do not have omni-directional sensors. The sensor of the Lambrecht anemometer has nearly a cosine characteristic in both directions. The TSI sensor has a cosine sensitivity in one direction and a constant signal to velocity ratio in the other direction. Measured with the Lambrecht-anemometer, the velocity should not be higher than 16 to 18 cm per sec; measured with the TSI it should not be higher than 19 to 21 cm per sec in the occupied zone.

Some General Results

The airflow in rooms is mainly influenced by:

1. the form and the place of the air outlet,
2. the air exchange,
3. the cooling load,
4. the direction of the flow in respect to the direction of gravity.

The influence of air return outlets usually may be neglected.

Introducing heated air from ceiling outlets may be difficult in some special cases. Complications arise with heated jets, if, e.g. ceiling outlets are installed in rooms with badly insulated floors.

Outlets of cold air in the floor or at any place inside the occupied zone may cause local discomfort. In this case only the local flow is to be investigated and measured.

If the jet region of outlets are outside the occupied zone, there are no draft complaints if the flow is isothermal or the space load is smaller than 40 W/m^2. If the air exchange is bigger than 20 times the room volume, there will also be difficulties with standard-type outlets. These difficulties can be solved by laminar flow outlets which usually must cover all the ceiling or one wall of the room. Of course, any unisothermal jet is mainly influenced by its momentum and gravity forces. Concerning ceiling outlets or wall outlets there is a dependency between the maximum local air velocity and the cooling load in the room.

Fig. 6 shows the time-averaged maximum local velocity as a function of the cooling energy of an induction unit installed below the window or at the ceiling. In the case of the window version, the upper band is for isothermal windows, and the lower hatched band is for all measurements with window temperatures 20 K higher than the space air temperature.

Inspite of different building modules and different lengths of the units, the hatched bandwidth covers all results of more than a hundred measurements. The difference between isothermal and warm windows can be explained by the heat transfer from the windows to the window parallel jet. The flow velocity in the room is mainly influenced by the cooling energy, which enters the room at the ceiling. If the window is warm, the amount of the cooling energy, which enters the room at the ceiling, is diminished by the heat exchange from the window to the jet.

If one wants to be sure without investigations in a test room that there will be no draft in a room with induction units, the internal space load of the area, which is served by one unit, must not be higher than 400 W. In the case of induction units at the ceiling, the load per unit may be doubled as compared with the window unit. The flow of the ceiling induction unit is directed to both sides of the linear diffusor axis. This may be a rough explanation for the higher possible cooling energy of the ceiling diffusor. On the other hand, one ceiling induction unit may condition an area of about 10 m^2, which means a tolerable cooling load of 80 W/m^2 without draft.

Generalizing the results of tests with diffusors at the ceiling or at the walls of a room, one finds that it is nearly impossible to get draft-free rooms with specific cooling loads higher than 80 to 100 W/m^2.

Gas Concentration Measurements

Gas concentration measurements have been made in our laboratory to examine whether the gas concentration in the occupied zone is influenced by the location of air outlets. We especially compared the flow produced by two types of ceiling diffusors with air outlets in the floor. As a tracer gas Nitrous oxide (N_2O) was discharged into the test room with a floor area of 40 m^2, the gas was discharged either at 4 places, where occupants usually would be situated or with one source only, if the dependency of the gas concentration with the distance from the source should be measured. Fig. 9 shows a view of the test room.

The density of Nitrous oxide (N_2O) is similar to Carbon dioxide (CO_2). The gas outlet was combined with a heating source of about 80 W, to discharge the gas similarly into the room as the Carbon dioxide is discharged by occupants.

The gas concentration is measured in a steady-state manner, meaning that a constant rate of test gas is discharged into the room. Two methods of exhausting the samples from the test room were used. To get the average concentration as a function of the height above the floor, the air samples were simultaneously taken at forty places equally distributed in a horizontal plane in an area of a quarter of the room (10 m^2). To measure the concentration vs distance from the source, only one source and only one gas sampling probe was used, and the distance of the probe from the source was changed during the investigation. The main results are shown in the following figures.

Fig. 7 shows the average concentrations vs the height of the room. Two different types of linear diffusors were used, one discharging the air horizontally as a nearly plane spreading wall jet; the other one discharging a lot of small free air jets under an angle of about ± 45 deg to the vertical line to both sides of the diffusor.

Inspite of these different performances we obtained nearly the same homogenous distribution of concentration vs the height and no measurable difference between room air and return air concentration. The floor outlets produce free upwards jets into the occupied zone. Further details are given in Ref 5.

Related to the concentration of return air, the concentration is about 70% at the floor and 80% in a height of 1.3 m. That means the air is cleaner in the occupied zone, if the same rate of air is discharged by these floor outlets; or if you allow the same concentration in the occupied zone you may reduce the air rate by 20% compared with the flow from the ceiling outlets.

The gas concentration vs the distance from the source is shown in Fig. 8. There are differences for the different types of outlets in the slope of the concentration. The linear diffusor DSV, which discharges the air horizontally shows a quicker decay of concentration than the other linear diffusor. On the other hand the local concentration near the source is higher with the DSV outlet. A still bigger decay of concentration with the distance is realized by the floor outlets which is shown in Fig. 8 for a height of 1.2 and 1.8 m.

BIBLIOGRAPHY

1. Laux, H., "Experimentelle Untersuchungen der Luftführung in Räumen mit Hochdruckinduktionsanlagen", VDI-Berichte No. 139, 1969, Seite 43 - 50.
2. Finkelstein, W.; Moog, W.; Fitzner, K., "Measurement of Room Velocities within Air-Conditioned Buildings", Heating and Ventilating Engineer, May/June 1975.
3. Fitzner, K.; Laux, H., "Induktionsgeräte für Deckeneinbau", Heizung, Lüftung, Haustechnik, Düsseldorf, HLH 27 (1976) Nr. 10, Seite 366/372.
4. Fitzner, K., "Luftströmungen in Räumen mittlerer Höhe bei verschiedenen Arten von Luftauslässen", Gesundheits-Ingenieur (1976) Heft 12, Seite 293 - 300.
5. Fitzner, K., "Klimadrantsystem", DKV-Jahrestagung 1978. Deutscher Kelte - technischer Verein.

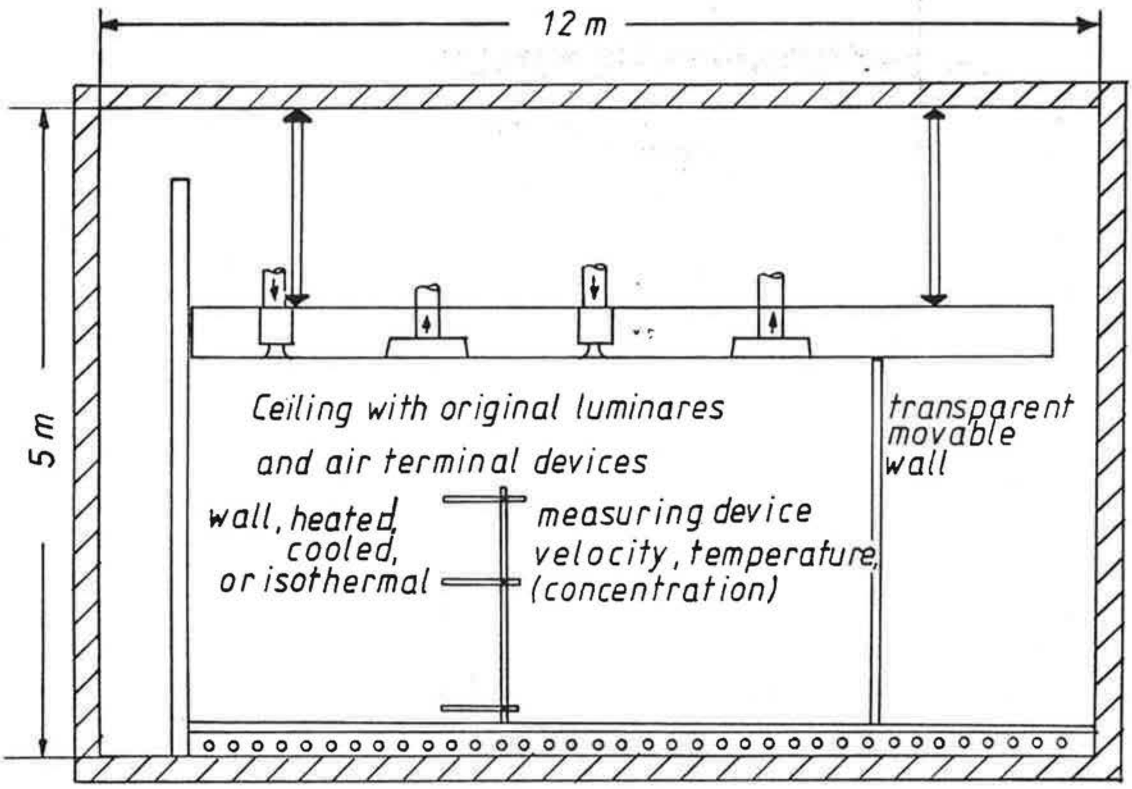

Fig. 1 Sketch of the test room: The test room is inside another temperature controlled room. Two walls of the test room and the ceiling can easily be moved. The floor is heated electrically; one wall may be cooled or heated.

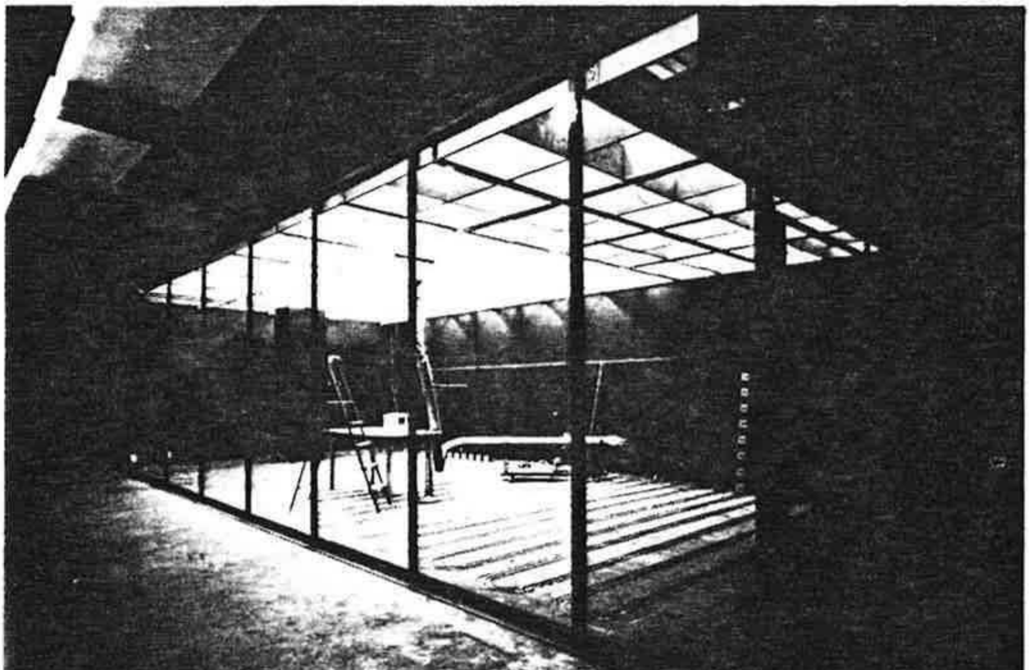

Fig. 2 View of a test room: Induction units in the perimeter area, slit diffusors in the internal area, return air through the lamps. Internal load is established by electric heating of the floor.

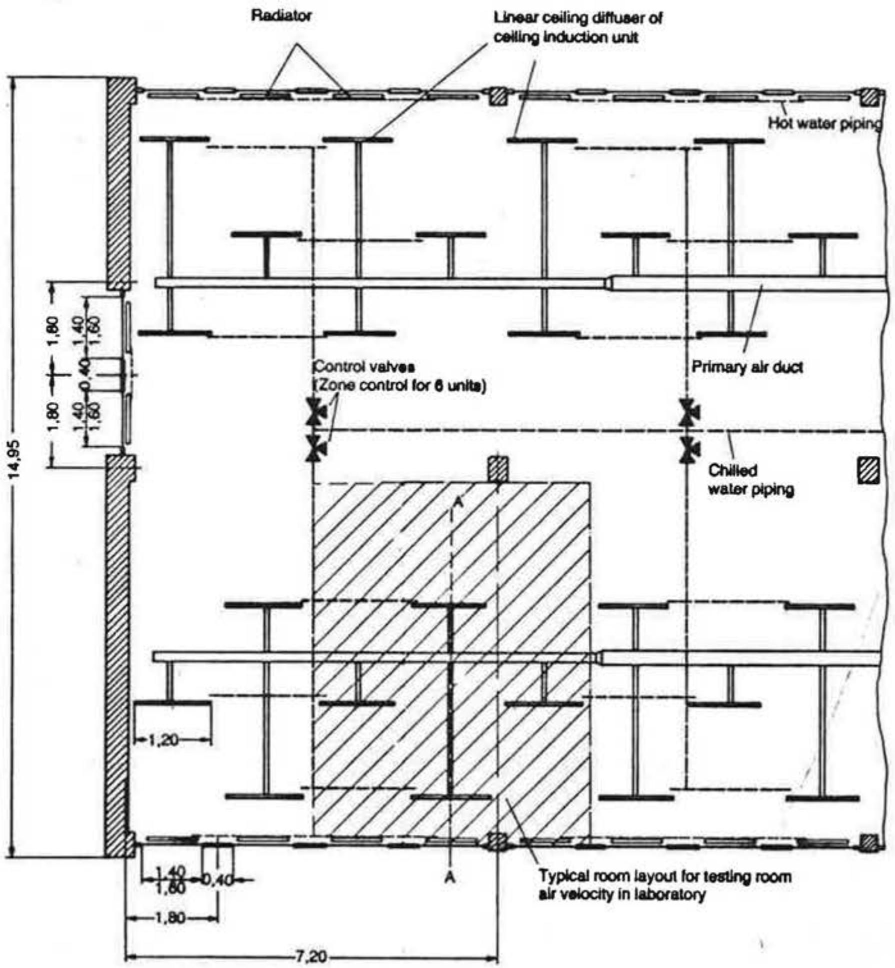

Fig. 3 Drawing of a part of an office building -- the hatched section is to be built up in the test room

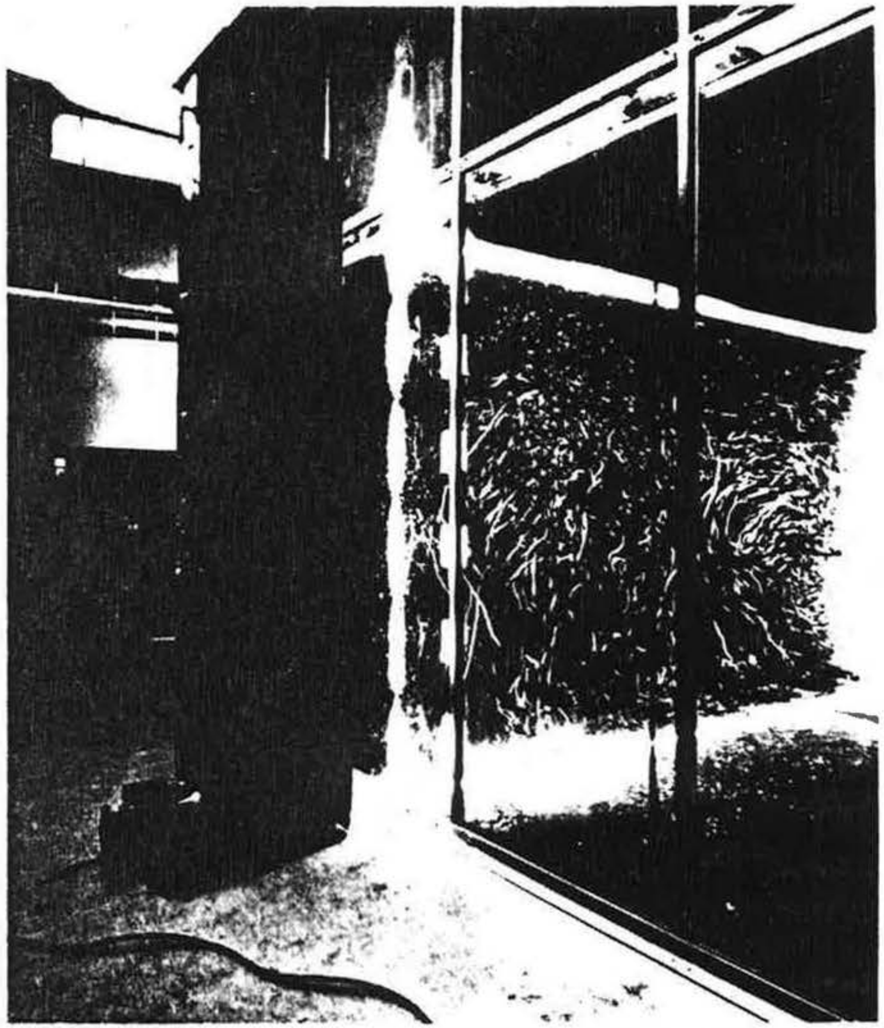

Fig. 4 Special lamp to visualize the airflow in the test room in a small vertical plane by the metaldehyde particles

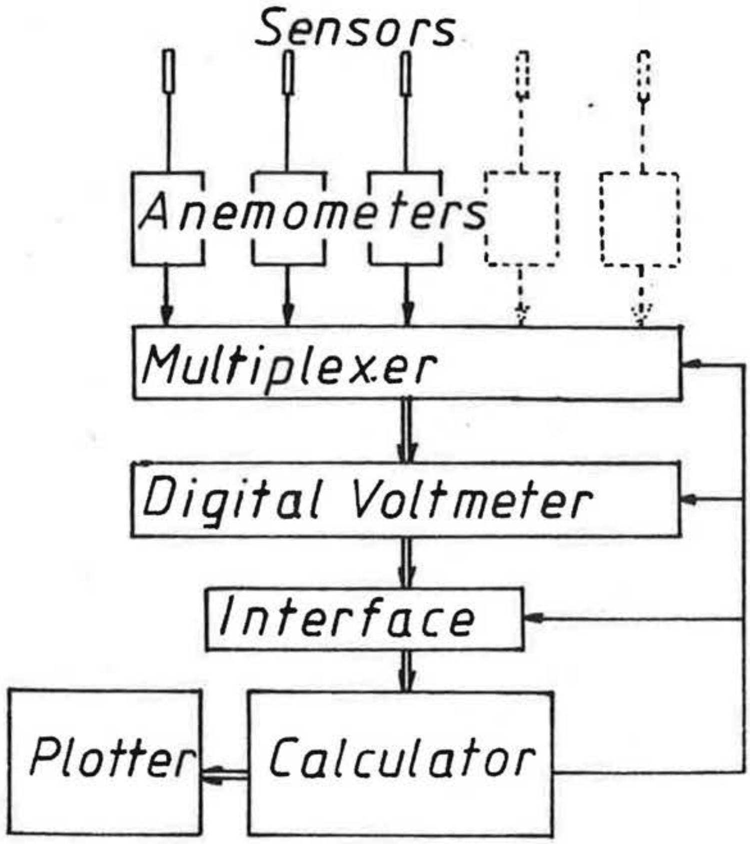

Fig. 5 Velocity and temperature on-line-measuring device

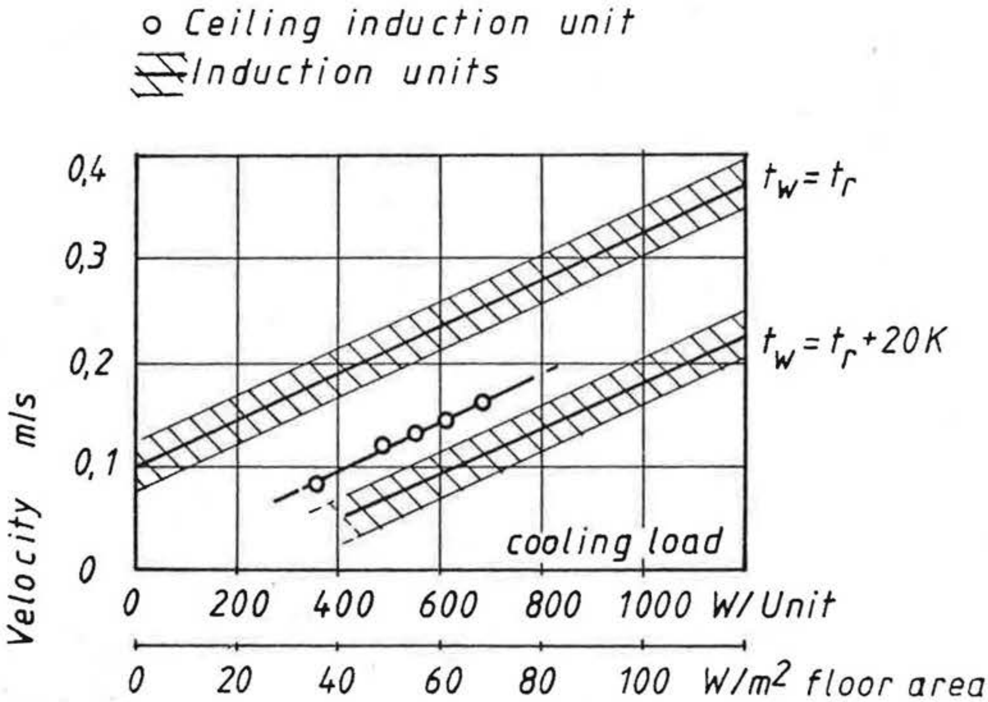

Fig. 6 Maximum (time-averaged) local velocity in a room vs. cooling energy per induction unit at the window (surface of the window has room air temperature or room air temperature plus 20 K) and for an induction unit in the ceiling. The velocity is also related to the specific space load (cooling load divided by floor area).

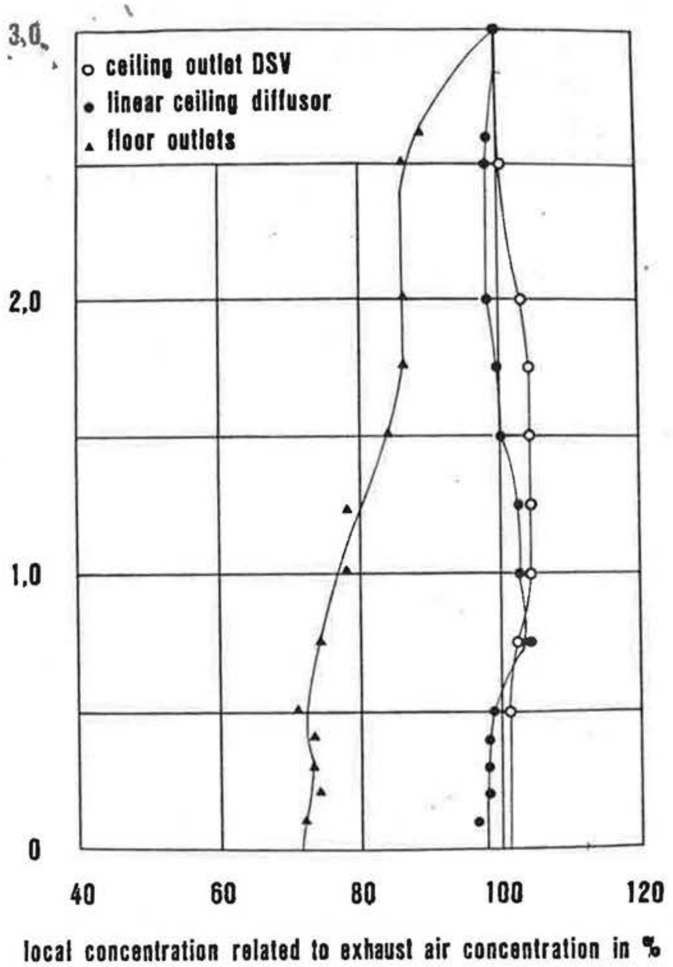

Fig. 7 Concentration averaged in a horizontal plane of the room in different heights for floor outlets and two different types of ceiling diffusors. The concentration is related to the exhaust air concentration.

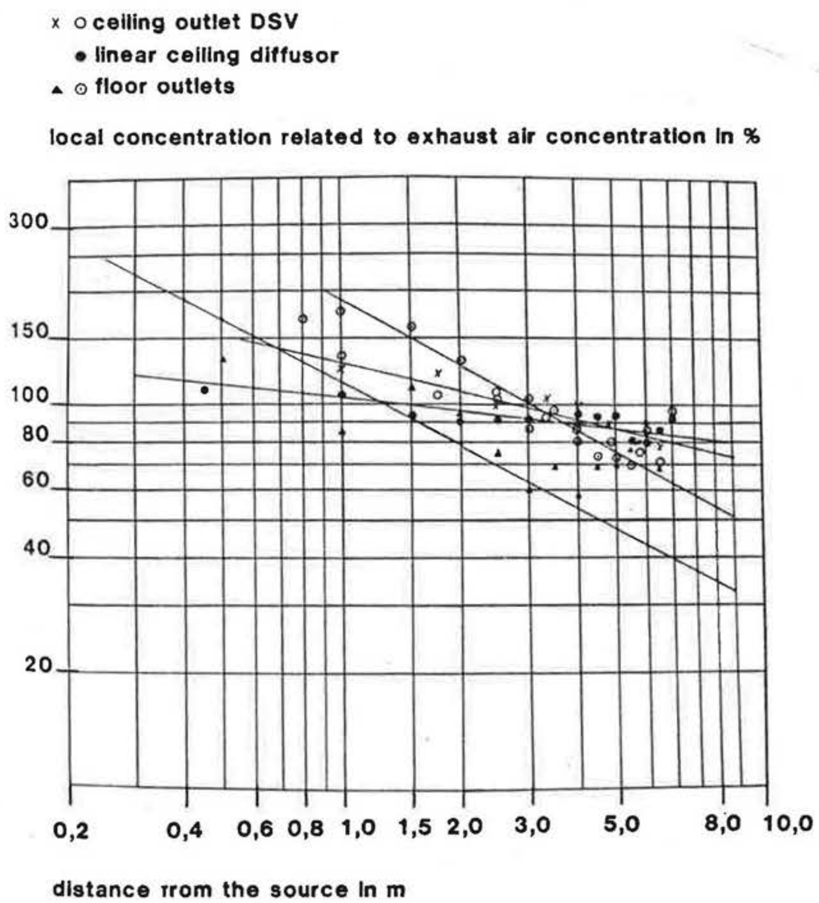

Fig. 8 Local concentration related to return air concentration vs the distance from the source. The concentration is independent of the height for the ceiling outlet. For the floor outlets the concentration is measured 1.2 m and 1.8 m above the floor.

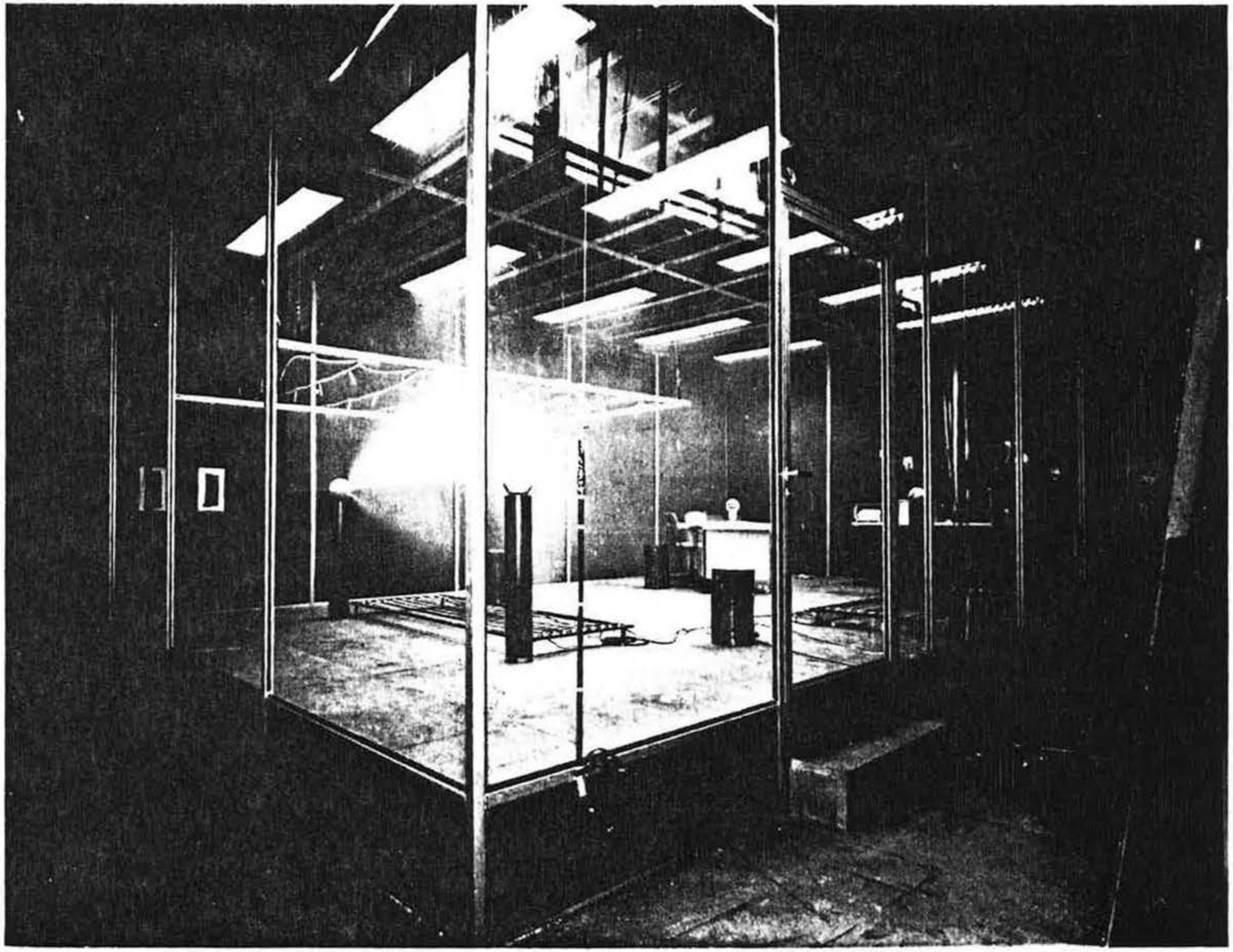

Fig. 9 Test room for the concentration measurements: The air is discharged either by floor outlets and column outlets or by two different types of linear ceiling diffusors. The tracer gas N_2O is discharged at the upper side of the 4 small heated (80 W) cylinders. The gas samples for measuring the concentration vs. height are taken by 40 equally distributed probes inside the frame which covers one quarter of the room.

DISCUSSION

H. BANKS EDWARDS, Owner, H. Banks Edwards Co., Houston, TX: This system is similar to air floor-under floor air distribution.

DR. K. FITZNER: There are two possibilities of air distribution. One may use the space under the floor as a plenum. This is preferred for the interior zone. In the perimeter area one should connect the outlets by flexible pipes to the air supply channels. We have developed a special system of quick connecting devices to enable a fast exchange of the placement of floor outlets.

DINKAR B. PATEL, Staff Engr., Abbott Labs, North Chicago, IL: When local outlets are used, what kind of humidity limitation of the surrounding area was considered? Was there a condensation problem at the local cooled air outlet?

DR. K. FITZNER: We did not investigate the influence of humidity, because the humidity does not influence the concentration of other gases. We could have used vapor as a tracer gas, but it is easier to do the investigations, e.g. with N_2O, because the usual air does not contain N_2O. In the customary way in which the floor outlets are installed, there are no condensation problems because the temperature of the supplied air is, of course, not below the dew point of the air in the space.

OLE FANGER, Prof. Technical Univ. of Denmark, Lyngby, Denmark: This morning we have discussed new standards on required ventilation in different countries, always assuming a fairly uniform air distribution and constant concentration of contaminants throughout a space. What really matters is the air quality in the breathing zone and Dr. Fitzner has shown that the air distribution system may have a significant influence on the required ventilation rate. Dr. Fitzner should be complimented for an excellent paper and I would like to encourage more studies in the future to investigate the efficiency of different air distribution systems. There is a potential for significant energy savings.

DR. K. FITZNER: I thank Professor Fanger for this encouragement.