J. Hyg., Camb. (1973), **71**, 633
Printed in Great Britain

Particle concentrations in patient rooms with various types of ventilation

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(*Received* 22 *January* 1973)

SUMMARY

Particle concentration in patient rooms at various ventilation rates and with differing methods of air supply has been investigated experimentally in a specially built test room. The size of the test room corresponded to an ordinary bedroom for two patients. Air was supplied isothermally to this test room, either through induction units or through a perforated ceiling, and the number of air changes per hour varied from 1 to 16. When the air was supplied by means of induction units, tests with different airflow patterns in the room were also carried out. The principle of the measurements was to estimate the decrease in particle concentration at certain points when the initial concentration was uniform all over the room and no generation took place during the measuring period. Talc powder was used as test dust, and the particle concentration was measured at up to six points in the room with a particle counter.

The measurements show that air-supply method and airflow pattern affect the particle concentration, but that the differences in concentration are small compared with those obtained when the ventilation rate is varied. However, the results should not be directly applied to systems with particle generation.

INTRODUCTION

The design of ventilation systems in hospitals has been treated by several authors from the point of view of limiting the bacterial air contamination (Charnley & Eftekhar, 1969; Galson & Goddard, 1968; Goddard, 1966; Lidwell, Richards & Polakoff, 1967). In this connexion the influence of the ventilation rate and of the types of air diffusers selected, and their location, has been discussed. It has also been shown that bacteria in the air are to a great extent carried by particles (Goddard, 1966; Noble, Lidwell & Kingston, 1963), and therefore the risk of infection can be minimized by limiting the concentration of airborne particles.

The present experimental investigation is a continuation of a previous paper (Allander & Faxvall, 1971), in which results from measurements of the particle concentration in patient rooms were presented, together with a theoretical analysis of how the particle concentration varies with the ventilation rate and the particle size. It was found in this previous investigation that, especially for particles $\gtrsim 5 \mu m.$, the particle concentration may increase considerably if the air supply system gives rise to an airflow pattern with vortices. As particles of this size can be expected to carry bacteria, it was regarded as necessary to continue with further experimental investigations.

The investigation presented below is a first step in an attempt to obtain an answer to the question of whether gravity and particle diffusion affect the transport of airborne particles in ventilated rooms, or whether these factors are negligible. The experiments were carried out at the laboratories of AB Svenska Fläktfabriken in Jönköping, whereas the previous experiments were carried out in patient rooms at two hospitals in the Stockholm area – one with modern ventilation and the other without mechanical ventilation. As the measurements were made in a laboratory, it was possible to control the generation of particles and to vary the ventilation rate within wide limits. Moreover, such differing methods of air supply as through induction units and through perforated ceilings could be tested in one and the same room.

As the tests were carried out in a system without particle generation, the results cannot be directly applied to systems where particles are continuously generated without further investigation.

TEST ROOM AND MEASURING EQUIPMENT

The experiments were carried out in a test room 6 m. long, 3·6 m. wide and 2·7 m. high. A room of this size corresponds to an ordinary patient room for two patients. The walls of the room were made of double plates of Masonite with an insulating layer of Rockwool 50 mm. thick. To keep the wall temperature constant, air at a controlled temperature was circulated around the test room.

When the air was supplied with induction units three SANIVENT units, type RBAA-09 (AB Svenska Fläktfabriken), were used. This induction unit is intended for local heating of pretreated air, and it has rotatable grilles through which the primary airflow can be directed. The unit has no inlet for secondary airflow, as it is mainly intended for use in hospitals, where secondary air through induction units should be avoided for hygienic reasons.

When supplying the air through perforated ceilings it is very difficult to keep the airflow equally distributed over the whole ceiling. A ceiling was therefore built with several layers, i.e. the airflow had to pass an absolute filter, a perforated steel plate with 3 mm. holes 5 mm. apart, a grille with a thickness of 20 mm. and square holes 20×20 mm., and finally a perforated steel plate with 3 mm. holes 25 mm. apart.

During the test with the induction units the exhaust air was vented through three KGE registers (AB Svenska Fläktfabriken), which during the first part of the investigation were mounted in the ceiling near the inner wall and later in the inner wall near the ceiling. During the experiments with the perforated ceiling the room air was exhausted through slots near the floor in each of the intermediate walls. In both cases the temperature and the humidity of the supply air were controlled. To keep down the particle concentration in the room the supply air was cleaned by means of an absolute filter.

The particle concentration was measured by means of a ROYCO 220 particle counter, with additional equipment for automatic data logging (Department of Heat Technology, Royal Institute of Technology). With this instrument the number of particles per 2·8 l. (0·1 ft.^{3}) is measured within six size ranges, $>0{\cdot}3$, $>0{\cdot}5$, >1, >2, >5 and $>10\,\mu$m. The number of particles in each range is printed out about 50 times/hr. (The time between the measuring series is 78 sec.) For further computer analyses the measured values can be transferred to a tape punch.

An artificial test dust with known size distribution was regarded as most suitable for the experiments. In view of the results from the previous investigation for particles $>5\,\mu$m. and $>10\,\mu$m., the test dust should contain a considerable fraction of particles in the range, say, 5–20 μm. It was found that talc powder, Microdol-1 (A/S Norwegian Talc), has about the desired size distribution. This test dust was supplied to the room by means of compressed air. It should be observed that the talc particles are far from spherical and that the particle diameters measured with the ROYCO counter may differ from the aerodynamic diameters of the particles.

EXPERIMENTAL PROCEDURE

When it is important to keep down the particle concentration in a room, a ventilation system with air supply through a perforated ceiling and air exhaust near the floor should be almost the ideal solution. But a perforated ceiling is difficult to keep clean and this solution is therefore not very useful in practice. A certain measure of the ability of a ventilation system to carry away particles from a room can, however, be obtained by making a comparison with a system with a perforated ceiling. The first part of the present investigation is devoted to a comparison of the particle concentration in the test room when it is ventilated in a conventional way by means of induction units, with the concentration when the air is supplied through a perforated ceiling. During the second part of the investigation the airflow pattern in the room was varied when supplying the air with induction units. Different airflow patterns were produced by placing a screen in the ceiling, or by supplying the air with a relatively low discharge velocity.

All experiments started with the supply of the test dust (the talc powder) to the room air. The dust was distributed uniformly over the whole volume of the test room by means of a fan placed in the room. The time required for adding and distributing the test dust was 5 min. (During this time the ventilation system was in operation.) The decay of the particle concentration was then measured for the particle sizes $>0{\cdot}3$, $>0{\cdot}5$, >1, >2, >5 and $>10\,\mu$m. As the measured values for the range $>0{\cdot}3\,\mu$m. are uncertain, those values were cancelled.

For the various particle sizes the concentration values measured were plotted in a semilogarithmic diagram. If complete mixing of the dust occurs in the test room, straight lines are obtained in these diagrams, as the decay then follows an exponential function. Accordingly the particle concentration C_t at the time t can be written

$$C_t = C_0 \exp\left\{-\frac{q}{V}t\right\},$$

where q is the ventilation airflow and V the volume of the room. The decay constant for the particle concentration decrease is then

$$k = q/V = n,$$

where n is the number of air changes per time unit.

By expressing the results in terms of the decay constant instead of the absolute value of the particle concentration after a certain time, the results are independent of the original particle concentration. This is important as there are experimental difficulties in keeping the original concentration constant. It is true that a specific quantity of dust was added at each experiment (0·3 or 0·5 g.), but part of the test dust is lost by sedimentation during the mixing period. As it is difficult to keep the mixing and distributing conditions constant, improved accuracy is obtained by measuring the decay constants.

All the tests were carried out under the following conditions: supply air temperature, 20° C., wall temperature, 20° C., room temperature, 20° C., relative humidity, 40–50 %.

During the first part of the investigation, i.e. that dealing with the direct comparison between the induction units and the perforated ceiling, the particle concentration was measured at six points in the room (in a plane through the centre of the room, parallel with the intermediate walls). The positions of the measuring points are shown in Fig. 1 (airflow pattern I), where the notation for these points is also given. The tests were carried out at 1, 2, 4, 8 and 16 air changes/hr. One series of measurements was carried out with the ventilation system shut off ($n = 0$).

During the second part of the investigation the particle concentration was measured for two other airflow patterns in the room when $n = 2$, 4 and 8 air changes/hr.

In these cases measurements were only made at points C1 and C2, or C1, C2 and I2. The three airflow patterns (Fig. 1) can be described as follows:

(I) Airflow pattern in which the supply air flows upwards along the window wall, follows the ceiling to the inner wall, and then flows down the inner wall to the floor, where it turns back into the room. This corresponds to a 'normal' airflow pattern in the room.

(II) Airflow pattern in which the supply air flows upwards along the window wall, follows the ceiling for about 3 m. and then flows downwards into the room. Near the floor, part of the air flows towards the window wall and part of it towards the inner wall. To effect this airflow pattern a screen was put up in the ceiling, 3 m. from the inner wall.

(III) Airflow pattern in which the supply air flows upwards along the window wall, turns at the ceiling and flows downwards. Near the floor, part of the air flows towards the inner wall and part of it is ejected upwards by the supply air.

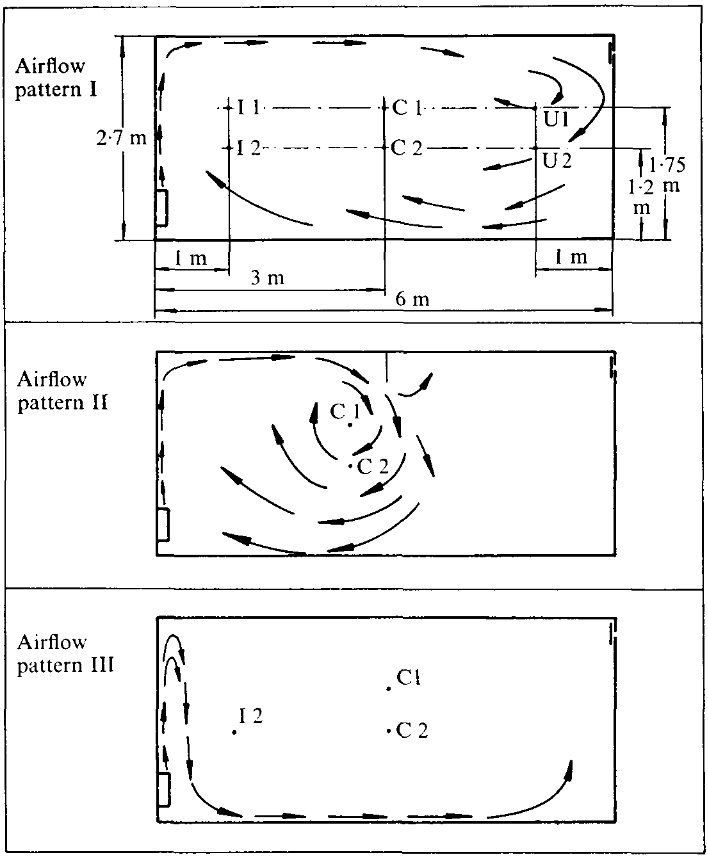

Fig. 1. Three airflow patterns investigated, with air supply through induction units. Also shown are the positions and notations of the measuring points.

To effect the low discharge velocity required for this flow pattern, the rotatable grilles of the induction units were replaced by perforated plates with suitable perforation.

RESULTS

The decay constants for the comparative investigation of induction units and perforated ceiling and for the investigation of different airflow patterns were obtained by fitting straight lines to the measured particle concentrations in semi-logarithmic diagrams. The decay follows an exponential function quite well for the various measuring points and ventilation rates.

In Table 1 the decay constant measurements are summarized. It is clear that the particle concentration decays with almost the same rate when the air is supplied with induction units and perforated ceiling. On the average, only a slightly faster decay is obtained for the perforated ceiling, due to increased sedimentation.

A comparison of the measured values for the normal airflow pattern and the case when the supply air is forced downwards in the middle of the room shows, as could be expected, that the particle concentration decays more slowly in the latter case

Table 1. *Comparison of the decay constant mean values when the air is supplied through induction units* (k_i) *and a perforated ceiling* (k_p)

(The airflow patterns I, II and III are shown in Fig. 1.)

Ratio of decay constants	Particle size (μm.)	k_i/k_p				
		n = 1 hr.$^{-1}$	n = 2 hr.$^{-1}$	n = 4 hr.$^{-1}$	n = 8 hr.$^{-1}$	n = 16 hr.$^{-1}$
Induction I/perf. ceiling	>0·5	0·98	0·96	0·89	0·94	0·88
	>1	1·00	1·00	0·94	0·98	0·89
	>2	0·84	0·83	0·91	0·93	0·88
	>5	0·92	0·96	0·97	0·99	0·93
	>10	0·92	0·98	1·04	1·11	1·05
Induction II/perf. ceiling	>0·5	—	0·80	0·65	0·81	—
	>1	—	0·83	0·71	0·84	—
	>2	—	0·84	0·78	0·86	—
	>5	—	0·96	0·82	0·88	—
	>10	—	0·82	0·80	0·86	—
Induction III/perf. ceiling	>0·5	—	0·91	0·70	0·77	—
	>1	—	0·96	0·70	0·80	—
	>2	—	1·04	0·86	0·82	—
	>5	—	1·09	0·87	0·82	—
	>10	—	0·97	0·87	0·77	—

(at points C1 and C2). The difference is most evident for small particles. It should be observed that the measuring points C1 and C2 were moved about 0·5 m. to the left when the airflow pattern II was investigated. The point C1 was then very close to the vortex centre.

For airflow pattern III the particle concentration (at points C1, C2 and I2) decays more slowly than for a normal flow pattern in the room. Here also the difference is most evident for small particles.

When the air is supplied through induction units (airflow pattern I) the particle concentration decreases with almost the same rate for all the measuring points. The coefficient of variation is less than 0·05 in this case. When the air is supplied through a perforated ceiling the measured decay constants have a considerable spread particularly when the ventilation rate is low, i.e. the coefficient of variation is about 0·20. The reason for this is presumably the reduction in turbulence which becomes insufficient to maintain mixing within the room, and the average velocity at which the air is supplied through the ceiling, no more than 0·001 m./sec. at n = 1 hr.$^{-1}$, is too low to produce so-called piston ventilation. A temperature difference between walls and air of only 0·01° C. will generate a convectional velocity near to the wall of as much as 0·013 m./sec.*

The mean values of the measured decay constants for the case n = 0 and for airflow pattern I are plotted in Fig. 2. The results show that the rate of clearance falls off for both large and small particle sizes, especially the latter, when the

* The maximum velocity produced near a vertical wall $v_{max.} = c\sqrt{(H\Delta\theta)}$, where c is a constant, typically about 0·08, H is the height of the wall and $\Delta\theta$ the temperature difference (Eckert & Drake, 1959). For H = 2·7 m. and $\Delta\theta$ = 0·01° C., $v_{max.}$ = 0·013.

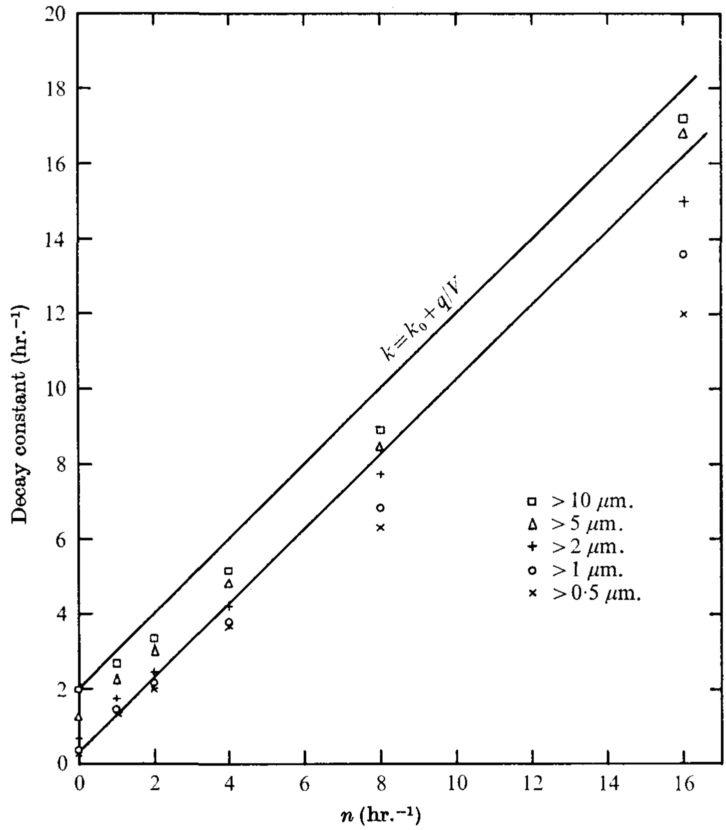

Fig. 2. Decay constants for various particle sizes and ventilation rates when the air is supplied through induction units (airflow pattern I). The parallel lines for the particle sizes > 0·5 and > 10 μm. are derived from the settling rates, $n = 0$, and the ventilation supply rates.

ventilation supply is increased. The effect at small particle sizes is probably due to incomplete mixing in the room, i.e. the effective ventilation flow is less than the real flow.

DISCUSSION

The experiments in the laboratory test room concerning the decay of the concentration of an artificial test dust lead to certain rules for the design of ventilation systems for patient rooms from the point of view of bacterial contamination.

According to the test results the decay constant for the particle concentration is directly proportional to the ventilation rate for the particle sizes of interest. Thus the ventilation rate should be chosen as high as possible with respect to draught problems in the room.

The comparison between induction units and perforated ceilings shows that somewhat lower particle concentrations should be obtained if the air is supplied by means of a perforated ceiling instead of an induction unit, owing to increased sedimentation. But the improvement is small, and it is difficult to find any practical method of supplying the air which gives substantially lower particle concentrations than those obtained by means of induction units, provided that these units are carefully adjusted and do not give rise to vortices.

As was found in the previous investigation (Allander & Faxvall, 1971), the comparison between the three airflow patterns shows that the particle concentration increases if the airflow pattern contains vortices or areas with stagnant air. The difference, however, is not as evident as might have been expected from the previous investigation.

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