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DOWNWARD PARALLEL FLOW SYSTEM FOR OPERATING ROOMS WITH MODERATE AIR VOLUME FLOWS

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SUMMARY

In view of the questions that have been raised during the past few years about the capability of ventilation systems to supply a suitable indoor climate and remove dispersed contaminants, the authors participated in tests with a system using vertical parallel air flow with the air flows at 2000 m^3/h and 4000 m^3/h respectively. When this system has some five times higher air flow it is known as an "ultraclean air system" and is used during orthopaedic surgery. The results from these tests have been compared with the results from a conventional mixing system when air is supplied (1900 m^3/h) in the operating room through an inclined screen.

Tracer gas tests were employed to measure interaction between air movements and the dispersion of airborne contaminants. The operating room lights and other heat producing devices were also in operation during these tests. In order to establish the sensitivity of the system to disturbances, tests were also performed with two persons replacing two of the heaters. During the course of the measurements the people moved their hands and arms above the operating table, in the operating region. The recorded tracer gas quantities are shown in dimensionless concentrations - local ventilation index.

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INTRODUCTION

There are two main ways of supplying air to an operating room. One is "total mixing ventilation", which is based on the concept of mixing incoming air relatively quickly with air already present in the room, whereby complete mixing is considered to be achieved. This principle, which is most commonly used in Sweden, makes use of symmetrically positioned supply-air devices in the ceiling. Air can be alternatively introduced through an inclined screen. The air volume flow for total mixing ventilation is the conventional flow rate 2000 m^3/h.

In the second principle, the air is introduced in a parallel manner through the room. The air can be conveyed from ceiling to floor, or between two opposite walls, to create unidirectional flow. These systems - also called "ultraclean air systems" - are used to control bacteria during very demanding operations, notably during orthopaedic surgery, and especially during hip-replacement operations.

This principle, introduced by Charnley [1,2] is frequently termed Laminar Air Flow (LAF) ventilation, or unidirectional air flow. Both systems aim to achieve an air velocity of about 0.4 - 0.5 m/s in a parallel flow. An air flow of approximately 10,000 - 16,000 m^3/h is thereby achieved, which is 5 to 8 times higher than air flows in conventional, total mixing systems.

Whyte et al [3], Lindberg [4] and Lidwell et al [5] report that horizontal air distribution contains higher concentrations of microorganisms than vertical flows. A possible, and likely, explanation is that operating room personnel block the main flow air, causing wake vortices behind the body, resulting in the accumulation of contaminants. Vortices, and their ability to accumulate contaminants, have been described by Ljungqvist [6]. The study in this paper is limited to investigating only the unidirectional air system with vertical air distribution at moderate air volume flows at the conventional flow, 2000 m^3/h (550 l/s), and twice this flow, 4000 m^3/h, (1100 l/s).

DESCRIPTION OF TESTS

In Sweden, Andersson et al [7] reported that when room air is well mixed, the dispersion patterns for bacteria-carrying particles and gases will both be satisfactory when a conventional air flow is supplied. As a consequence, tracer gas and visualization methods with smoke (particles) can be used, in most cases, to determine the ventilation standard of an operating room qualitatively, with regard to particles that may be interesting from a bacterological point of view.

Based on the above background, the tests described below were conducted with tracer gas (nitrous oxide) and with smoke for visualization, in order to establish an overall picture of the situation.

The temperatures and air velocities around the operating table were established before the smoke and tracer gas tests were conducted. The temperatures and velocities were recorded by collecting digital data from 36 probes positioned in a grid pattern in the room.

Four heat sources (devices), each producing 75 W for a total of 300 W, were used during the tests and placed by the operating table in a standardized arrangement to simulate heat produced by an operating team (see Fig. 1). Heat was also radiated from general lighting fixtures (160 W) and an aerodynamic design of operating lamp (310 W). The operating lamp (diameter 85 cm) was positioned 100 cm over the operating table (190 cm above the floor) during all tests. The smoke and tracer gas tests were conducted with four heat-producing devices but without human acitivity or presence, and with two devices and two persons, who remained completely still, moving mainly their arms and hands above the operating table, according to a standardized plan of movements. The smoke tests were documented by photographs and video.

During the tests tracer gas, the source for dispersing the gas was placed by the operating table, where the surgeon would stand, and the concentrations were recorded at two places by the operating table, and in the exhaust air duct. Fig. 1 shows the positions of the tracer gas source and the probes by the operating table.

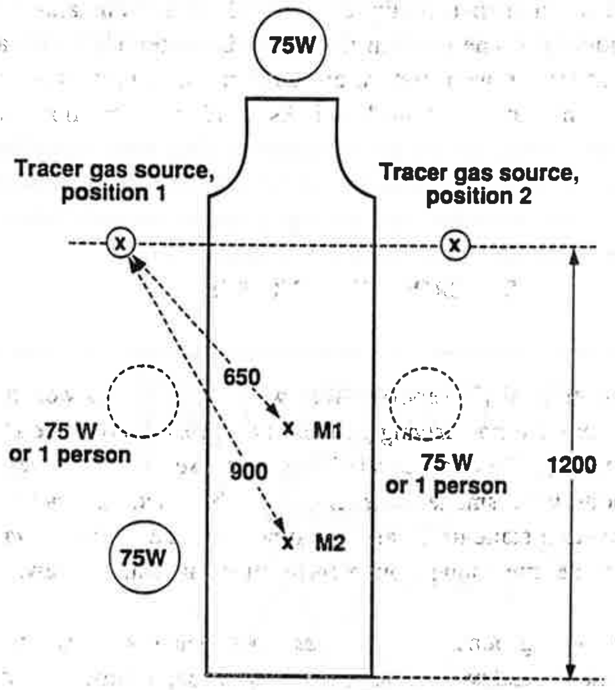

Fig. 1. Placement of the heat-producing devices, persons, sources for distributing tracer gas and probes around the operating table.

The precise positions of the devices to disperse tracer gas, and those of the probes, were 10 cm above the operating table, 100 cm above the floor. The tracer gas flow was standardized at 130 l/h.

TEMPERATURE, VELOCITIES AND AIR MOVEMENTS

The temperature and flow patterns in the empty room (without activity from people and heat radiation) were symmetrical in the region around the operating table for the two test cases. When heat devices were used, different temperature and flow patterns were obtained. The position of the heat devices around the operating table played a decisive role in this respect. The supply air temperature was about one degree below room temperature in all test cases. In summary the temperature and velocity levels for the two flow cases were different in the important area around the operating table.

With air flows through the ceiling of 2000 m^3/h (550 l/s) and 4000 m^3/h (1100 l/s), the air velocity of the unidirectional vertical flow was approximately 0.1 m/s and 0.2 m/s respectively.

To establish an overall picture of the air movements, they were visualized with smoke. The tests were conducted with and without people performing activities. The air flow patterns were again recorded both photographically and with video. Figure 2 shows the principle of the flow pattern for the ceiling system.

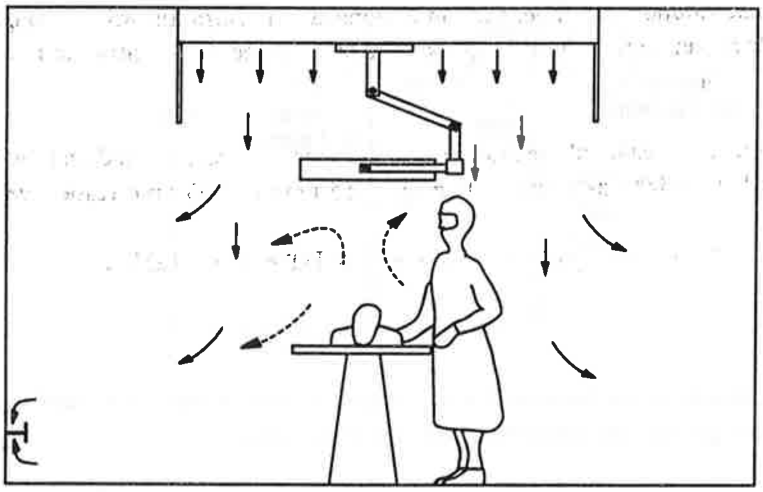

Fig. 2. Observed main flow.

The smoke tests showed that the region between the ceiling and the operating lamp had a well organized unidirectional flow. In the region between the operating lamp and the operating table the air movements were more irregular and sensitive to disturbances by hand and arm movements. Not surprisingly, when the air flow was 4000 m^3/h the conditions were more stable than at 2000 m^3/h.

TRACER GAS TESTS

Tracer gas tests were performed in accordance with the arrangement shown in Figure 1, in which the gas dispersing source was placed in both position 1 and position 2. The distance between the source and probes was 65 and 90 cm respectively.

The recorded tracer gas quantities are shown as dimensionless concentrations for comparison purposes. These are defined as the quotient between the theoretically calculated concentration value given by the dilution principle and measured mean value.

When the mean concentration value of the exhaust air is the same as the value given by the dilution principle, the dimensionless concentration will be congruent with the local ventilation index. This index relates the local concentration to that in the exhaust air.

The concentration value of the dilution principle for both cases, based on previously stated air flows, 2000 m^3/h and 4000 m^3/h, is 65 ppm and 33 ppm respectively.

The results of the tracer gas tests are shown in Table 1 and Table 2.

Table 1. Dimensionless concentration (local ventilation index) for ceiling system with 2000 m^3/h. The distance between the gas distribution source and probe is 90 cm and 65 cm respectively in accordance with the arrangement shown in Figure 1.

	DIMENSIONLESS CONCENTRATION (local ventilation index)			
	Position 1		Position 2	
	Dist 90 cm	Dist 65 cm	Dist 90 cm	Dist 65 cm
Without people +4x75 W	0.5	0.3	0.4	0.3
2 people still +2x75 W	0.5	0.3	0.3	0.2
2 people moving +2x75 W	0.3	<0.1	0.4	0.2

Table 2. Dimensionless concentration (local ventilation index) for ceiling system with 4000 m³/h. The distance between the gas distrubution source and probe is 90 cm and 65 cm respectively in accordance with the arrangement shown in Figure 1.

	DIMENSIONLESS CONCENTRATION (local ventilation index)			
	Position 1		Position 2	
	Dist 90 cm	Dist 65 cm	Dist 90 cm	Dist 65 cm
Without people +4x75 W	0.4	0.3	0.3	0.2
2 people still +2x75 W	0.6	0.3	0.4	0.3
2 people moving +2x75 W	0.3	0.2	0.4	0.2

It can be seen from Table 1 and Table 2 that there are no major differences in terms of dimensionless concentration between the lower and the higher air flow configurations. This can be explained by the simularity of the way that the air movements affect the dispersion process in the two air flow cases. In conclusion, when the air flow has the higher value (4000 m³/h) the absolute concentration values are about half the values found at the lower air flow (2000 m³/h), and are in accordance with the dilution principle.

By using the same test method Hillerbrant and Ljungqvist [8] have measured a total mixing system with inclined screen, with an air flow of 1900 m³/h and a ceiling system with unidirectional air flow, with a total air flow of 9000 m³/h. These results can be used for comparison purposes and the following dimensionless mean value concentrations calculated from values based on tracer gas position 1 and posistion 2 are presented. Table 3 shows, with conventional flows (about 2000 m³/h), a comparison between the ceiling system and the system with inclined screen.

Table 3. Comparison between ceiling system (2000 m³/h) and system with inclined screen (1900 m³/h) in the form of dimensionless mean value concentrations at position 1 and position 2, in accordance with the arrangement in Figure 1.

	DIMENSIONLESS CONCENTRATION (local ventilation index)			
	Ceiling system (2000 m³/h)		Inclined system (1900 m³/h)	
	Dist 90 cm	Dist 65 cm	Dist 90 cm	Dist 65 cm
Without people +4x75 W	0.5	0.3	0.4	0.3
2 people still +2x75 W	0.4	0.2	0.3	<0.1
2 people moving +2x75 W	0.4	<0.1	0.3	<0.1

The values from Table 3 show that the differences between the two systems are small but the ceiling system provides the best results. This might be explained by the fact that entrainment of ambient air is greater for the system with the inclined screen than for the ceiling system. For both systems, in the region above the operation table, the air moves in a turbulent way and the movements by people seem to play an important role of the dispersion process.

For the ceiling system, described by Hillerbrant and Ljungqvist [8] (a HEPA-filter system) with a total air flow of 9000 m³/h in which 7000 m³/h was recirculated, the air velocity of the unidirectional vertical flow was approximately 0.4 m/s. The theoretical concentration calculated on the dilution principle on the basis of an outdoor air flow of 2000 m³/h, gives a level of 65 ppm. The calculation of the dimensionless concentration took into account the fact that air containing with tracer gas has been recirculated. In accordance with the calculations in Table 3, the dimensionless mean value concentrations based on results from tracer gas position 1 and 2 (see figure 1) are described below. The obtained figures in this case are approximative, although the order of size for the obtained values can be considered correct. The results of the tracer gas tests from the air flows of 2000 m³/h, 4000 m³/h and 9000 m³/h with two people present at the operation table are shown in Table 4.

Table 4. Ceiling system with different air flows with two people present at the operation table. Dimensionless mean value concentrations of position 1 and position 2 in accordance with the arrangement in Figure 1.

	DIMENSIONLESS MEAN CONCENTRATION (local ventilation index)			
	2 people still +2x75 W		2 people moving +2x75 W	
	Dist 90 cm	Dist 65 cm	Dist 90 cm	Dist 65 cm
air flow 2000 m³/h velocity 0.1 m/s	0.4	0.2	0.4	≈0.1
air flow 4000 m³/h velocity 0.2 m/s	0.5	0.3	0.4	0.2
air flow 9000 m³/h velocity 0.4 m/s	8	6.7	6.7	4.4

In accordance with the results in Table 1 and 2, it can also be seen from Table 4 that there is no major difference in dimensionless mean value concentrations between the two moderate air flows of 2000 m³/h and 4000 m³/h. The dimensionless mean value concentrations with the air flow of 9000 m³/h, are in the range 16-44 times higher than these of moderate air flows. The better values for the air flow of 9000 m³/h are, of course, due to its higher air velocity (0.4 m/s) and subsequent, stable air distribution.

DISCUSSION

A comparison between the air distribution system with inclined screen - the total mixing system - and the ceiling system with an air flow of 2000 m³/h showed no major difference from a contamination standpoint, but the ceiling system provides somewhat better results. When the ceiling system has the air flow 4000 m³/h, the dimensionless concentrations are in the same range, but the absolute concentration values are about half the values than that of 2000 m³/h, in accordance with the dilution principle. The three air distribution cases are sensitive to disturbances. Personnel, movements, the convection of heat and "bluff" objects have a decisive impact on the flow pattern and the transport of contaminants.

The ceiling system with an air flow of 9000 m³/h shows the best results due to the higher air velocity (0.4 m/s) of the vertical flow which results in more stable conditions.

Lidwell et al [5,9] have determined the average value for the number of bacteria carrying particles per cubic meter of air (CFU/m³) during operation, for both the total mixing system and unidirectional air flow system with air velocities about 0.35-0.45 m/s. The relation between the average value of the total mixing systems and the vertical, unidirectional flow systems is 17 and 82 with these results, depending on whether or not the unidirectional flow system is equipped with vertical side walls. The earlier discussed relations based on tracer gas measurements lies in the range of 16 to 44 agree with the microbiological relations given by Lidwell [5,9].

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