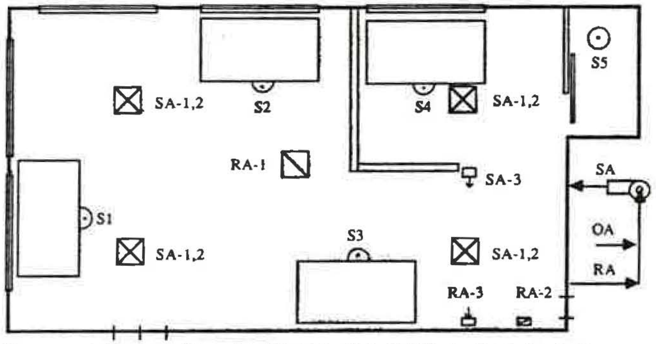
Figure Captions

Figure 1. Floor plan of office space depicting locations of measurement locations and supply and return air ducts.



Measurement locations: SA outlet, RA inlet, S1-5 at 109 cm above the floor.

HVAC Configuration:	1	2	3
Supply air:	4 ceiling diffusers	4 ceiling openings	1 high wall jet
Return air:	1 ceiling panel	1 low wall point	1 high wall point

VENTILATION EFFICIENCY IN CLEAN ROOMS

Bertil Larsson and Kenneth Neikter
Fläkt Svenska AB, Stockholm, Sweden

Ove Strindehag
Fläkt AB, Jönköping, Sweden

Abstract

An experimental study of the ventilation efficiency has been carried out in a clean room with vertical airflow. Special interest has been devoted to the ventilation efficiency in the working zone when the heat load, the vertical air velocity and the arrangement of the workplace were varied. The results show that high values of the ventilation efficiency can be achieved, provided that due attention is paid to the air movements in the working zone.

Introduction

In many industries, the demands on the air quality are so stringent today that the production has to be carried out in special clean rooms. This is true, for instance, in the electronic industry. To achieve satisfactory cleanliness of the air in a clean room, the supply air to the room has to be cleaned by means of a filter with very high particle-collection efficiency. To maintain a high air quality in the clean room, also during various working operations, it is important to ensure that operators, machines and equipment that emit particles are appropriately located in relation to the airflow.

A study of the air distribution and the particle content in a clean room with vertical airflow is presented in this paper. The particle content of the air at various points in the room, and the mean value of the particle content in the working zone, are given in relation to the particle content in the exhaust air from the room. This provides a measure of the efficiency of the ventilation system.

Ventilation efficiency

The ventilation system must remove very effectively the contaminants generated during working operations in a clean room. This can be achieved by supplying air to the room through high-efficiency filters covering most of the ceiling area. The airflow in the room will then be very uniform, known as unidirectional flow, which is the ideal flow pattern in a clean room.

The ability of a ventilation system to remove contaminants from a room is usually specified in the form of various efficiency numbers (2,3). The contents of contaminants at a certain point in the room is often specified by a local ventilation index according to:

$$\varepsilon_p = \frac{C_e(\infty)}{C_p(\infty)} \qquad (1)$$

where $C_e(\infty)$ denotes the equilibrium concentration in the exhaust air and $C_p(\infty)$ the equilibrium concentration at point p.

A very frequent requirement is that only a defined part of a clean room must be kept extremely clean. For this zone, in this paper referred to as the working zone, a ventilation efficiency $\langle\varepsilon_w\rangle$ can be defined according to:

$$\langle\varepsilon_w\rangle = \frac{C_e(\infty)}{\langle C_w(\infty)\rangle} \qquad (2)$$

where $\langle C_w(\infty)\rangle$ denotes the average concentration in the working zone under equilibrium conditions.

Test room arrangement

The air distribution and the ventilation efficiency were studied in a clean room with a floor area of 3.6 . 3.7 = 13.3 m^2 and a ceiling height of 2.4 m. Two service rooms are located adjacent to the clean room, see Fig. 1. The clean room and the service rooms all have a double floor, the upper of these floors consisting of perforated plates.

HEPA filters cover the whole ceiling in the clean room. The air is supplied through these filters and is exhausted through the double floor to the service rooms. About 90 % of the exhaust air from the service rooms is mixed with about 10 % outside air and recirculated through the filter ceiling of the clean room. The total supply air flow is normally 5.8 m^3/s, which gives an average vertical air velocity of 0.45 m/s.

The HEPA filters have a particle-collection efficiency of 99.97 % for DOP particles with a diameter of 0.3 µm. Liquid sealing is employed between the filters and the supporting framework, so that the filters can easily be dismounted and replaced without jeopardizing the tightness.

During some of the tests, the clean room was arranged as a work-place for one operator. An example of such an arrangement is shown in Fig. 2.

Measurements in a room without heat sources

Particle measurements and investigations of the airflow pattern by means of smoke were carried out in the test room described, to determine the efficiency of the ventilation system in removing particulate contaminants. During the first series of measurements, there were no heat sources in the room (except for the fluorescent tubes).

Contaminant sources in the form of line sources and point sources were used during the particle measurements and the airflow tests with smoke. The particle measurements were carried out with DOP particles from an aerosol generator with stable output, TSI, Model 3076, (1). Smoke was generated by means of a Rosco Model 8211 fog and smoke machine. The outlet velocities from the line source and the point source were very low, and the contaminants were supplied isothermally to the room.

A laser based particle counter (Met One, Model 205) was used for measurements of the particle concentration in the clean room. A sampling system is employed with this counter, which allows for sequential measurements at up to 15 measuring points. The particle sizes measured are 0.16, 0.30, 0.50, 1.5 and 10 µm.

The background of particles in the clean room is normally very low. The concentration of particles larger than 0,3 µm, for instance, is 1-2 particles/cubic foot, when no activities are pursued in the room. If the DOP generator is used as a contaminant source, the average particle concentration in the room upstream of the source is about 30 particles/cf for particles > 0.3 µm. At the same time, the concentration in the exhaust air is about 9.10^5 particles/cf. Values of ε_p or $\langle\varepsilon_w\rangle$ of up to 3.10^4 can thus be obtained, depending on the location of the contaminant source.

A series of measurements were carried out in the clean room to determine the ventilation efficiency in the working zone for various locations of the contaminant source. A work table with a length of 1.4 m, a width of 0.8 m and a height of 0.75 m was located in the clean room during these measurements. The zone between the table-top and a plan 100 mm above it was in case regarded as the working zone. Moreover, the mean value of the particle concentration at four (or eight) points along the 1.4 m centre line of the table was assumed to represent the average particle concentration in the working zone.

The ventilation efficiency was measured at normal vertical air velocity (v_o = 0.45 m/s) and at half the normal velocity. An example of the results obtained during such a test at normal air velocity and with a line source is shown in Fig. 3. The concentration of particles > 0.3 µm was measured at four points in the working zone and in the exhaust air. The line source was located 1.7 m above the floor and at various distances from one of the walls of the clean room. As can be seen from Fig. 3, the ventilation efficiency in the working zone decreases below the average value only when the source is located very close to the table, i.e. when the vertical line from the source is about 50 mm from the edge of the table. The tests using smoke also demonstrated that the spreading of contaminants in the horizontal direction is very small.

Measurements in a room with heat sources

Even fairly small heat loads may have a detrimental effect on the airflow pattern in a clean room. A series of measurements with various heat sources in the test room was therefore taken, including particle measurements and airflow tests using smoke.

During one of these tests, the room was furnished as a workplace for one operator, see Fig. 2. A work table and a dummy of a machine with a height of 1.8 m, a width of 1 m and a depth of 0.6 m were then arranged in the test room. The operator was simulated by a dummy with a heat emission of 75 W. At the middle of the table-top (length = 1 m and width = 0.55 m) a local extraction was arranged through a 0.25 m^2 perforated plate. The velocity of the exhaust air was adjusted to correspond to the vertical air velocity in the room during the various measurements. Tests were carried out with and without this local extraction in operation. Since the machine dummy disturbs the airflow in the working zone, tests were also carried out with the work table located at a certain distance from the machine dummy. The air could then flow through the slot formed in this way.

The ventilation efficiency is obviously seriously affected if a heat source is located directly in the working zone. The results of such a test are shown in Fig. 4. The heat source (an electrical light bulb) was then located mid-way between the centre of the table and the table edge nearest to the machine dummy. DOP particles were supplied at the face level of the operator. The values shown in Fig. 4 refer to measurements without local extraction through the perforated plate, and without air slot between the work table and the machine dummy. Fig. 4 shows that a considerably higher ventilation efficiency is obtained at normal air velocity ($v = v_o$) than at half the normal air velocity.

Conclusions

The tests show that high values of the ventilation efficiency can be achieved in the working zone of a clean room. However, this is conditional on the contaminant sources, heat sources and any equipment that may disturb the airflow being located in an appropriate way. When planning a workplace in a clean room, it is therefore highly desirable to investigate the airflow pattern experimentally.

References

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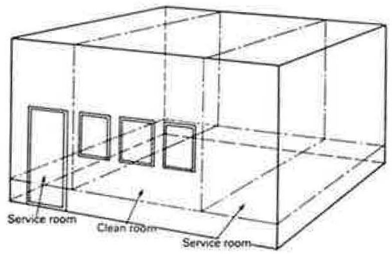

Fig. 1. Schematic layout of the clean room and the service rooms.

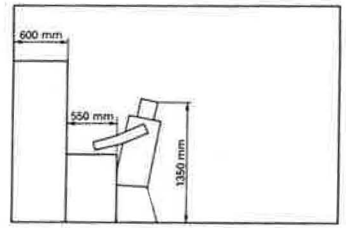

Fig. 2. Cross-section of the clean room with one workplace.

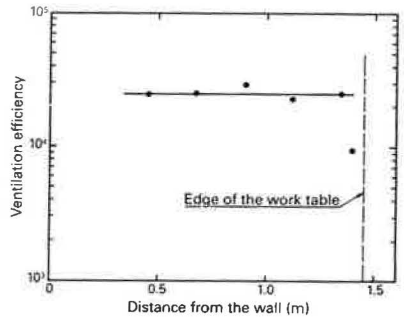

Fig. 3. Measured ventilation efficiency in the working zone when a line source was located 1.7 m above the floor and at various distances from one of the walls of the clean room. (Particle size >0.3 μm.)

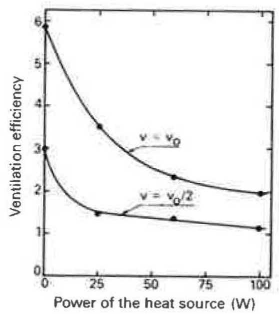

Fig. 4. Measured ventilation efficiency in the working zone with a heat source at the work table and the operator dummy at the workplace. (v_o = 0.45 m/s, particle size >0.3 μm.)