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APPLICATION OF THE "AGE OF AIR" CONCEPT IN EVALUATING THE VENTILATION CHARACTERISTICS OF A CLEANROOM

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ABSTRACT

This study has the objective of applying the "age of air" concept and tracer gas techniques in the evaluation of ventilation characteristics of workplaces equipped with a general ventilation system. A Class 10K cleanroom was selected for this study and CO₂ was used as a tracer gas. After the tracer gas was released in the form of a pulse into the cleanroom, its concentration was measured as a function of time at various locations by non-dispersive infrared photometers. The average age of air at each location was then calculated from the CO₂ concentration data. The results show that the average age of air varied markedly from location to location, indicating that the air in the cleanroom was not well mixed. An examination of the flow pattern in the cleanroom reveals that the design of the air inlets and outlets was inappropriate. The study has demonstrated that the use of the "age of air" concept can provide a clear picture of the airflow pattern.

INTRODUCTION

Although a general ventilation system is useful for providing clean air to a closed indoor environment, the efficiency of air exchange may vary markedly from point to point in the room if the system is not designed properly. The local air exchange efficiency depends on the airflow pattern. The factors which influence the airflow pattern include the size, location and type of the air inlets and outlets, air velocity at the inlets, temperature difference between the inlets and the interior, location of heat sources, the size and shape of the room, and the arrangement of furniture or equipment in the room. A poorly designed system is likely to result in an inappropriate airflow pattern, which in turn leads to poor ventilation performance and low energy efficiency. A complete picture of the flow field in a room would be useful for evaluating the local ventilation effectiveness. However, mapping of the three-dimensional flow field in an entire room is time-consuming and impractical. Instead of measuring the flow field directly, it is possible to gain a good understanding of the airflow pattern in a room by employing computational fluid dynamics. However, numerical simulations also have limitations, especially for spaces with a complicated layout. Another approach is to determine the age distribution of air at various locations in a room. The age of an air element is the time elapsed since its entry into the room. Since air elements arriving at a certain location in the room may have taken different routes from the inlet, their ages will differ from each other. The theory of age distribution was first developed by Danckwerts(1) to describe the behavior of non-ideal flow in a vessel. Subsequently, Sandberg and

Sjoberg(2) applied the theory for assessing air quality in ventilated rooms. More recently, Breum(3) used it in diagnosis of ventilation by tracer gas techniques. Measurements of the age distribution of air at certain locations in a room can provide a clear picture of the airflow pattern. In this study, the "age of air" concept and tracer gas techniques were applied in diagnosing the effectiveness of the general ventilation system of a cleanroom.

METHODS

The field measurements were taken in a Class 10K cleanroom of a semiconductor plant. The dimensions of the room were 9.1x11.2x2.5 m (lengthxwidthxheight). To identify the various locations of measurement, the floor was divided into 100 rectangles, each designated by an alphabet and a numeral such as A10 (see Figure 1). The room had one air inlet (1.41x0.35 m in an oblique section) located at H9 and 2.72 m above the floor. There were four air outlets (widthxheight = 0.49x0.285 m) locating at A10, B1, J10 and H1 respectively. The bottom of each air outlet was 0.2 m above the floor. The design value of air changes per hour was 33.3 hr⁻¹.

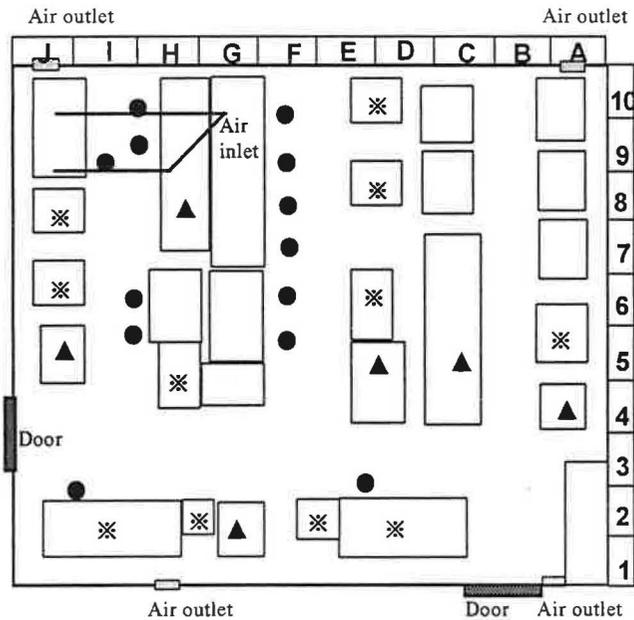


Figure 1 Layout of the cleanroom

- ▲ : Heat sources (furnaces) * : Xylene sources
- : Position of workers □ : Air outlets
- ▭ : Work bench

CO₂ was selected as the tracer gas in this study. SF₆ was not selected because it might decompose in the furnaces in the cleanroom. At the beginning of each run, the tracer gas was

introduced at the air inlet at 100 L/min for 10 s. The CO₂ concentration at 1.4 m (breathing zone) above the floor was then measured and recorded as a function of time at four different locations simultaneously by four portable non-dispersive infrared photometers (MIRAN, 1 BX/1 B2, The Foxboro Co., East Bridgewater, MA, USA). To minimize the interference from the CO₂ exhaled by workers, field measurements were taken during the night shift with fewer than 10 people working in the room.

If the measured CO₂ concentration at an arbitrary point P is represented by C_P(t), the age distribution of air at the point is then given by:

$$A_P(t) = \frac{C_P(t)}{\int_0^{\infty} C_P(t) dt} \quad (1)$$

By definition, the average age of air at P is given by:

$$\tau_P = \int_0^{\infty} t A_P(t) dt \quad (2)$$

Numerical integration of the CO₂ concentration-time curve was carried out by discretizing the time.

RESULTS AND DISCUSSION

Figure 2 shows the spatial distribution of the average age of air calculated from the CO₂ concentration data obtained at 1.4 m above the floor in the cleanroom studied. The distribution shows that the average ages of air in the upper right corner of the room were generally smaller than those in the other areas. The average ages of air near the two air outlets (A10 and B1) were 50 and 114 s respectively, considerably smaller than those in the central and left parts of the cleanroom. This implies that the air might be short-circuiting. A substantial part of air appeared to flow from the inlet H9 directly toward the outlet A10.

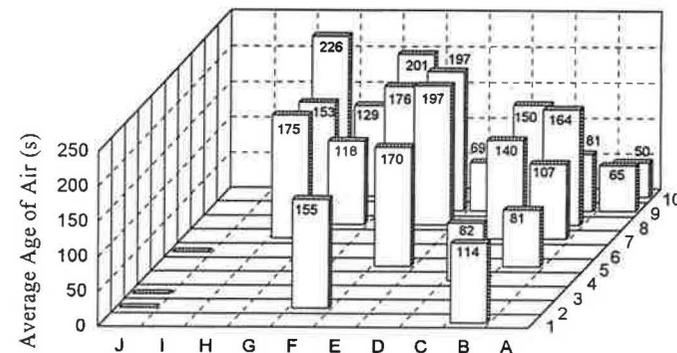


Figure 2 The spatial distribution of the average age of air in the cleanroom.

To examine the airflow pattern from the inlet H9 to the outlet A10, the average age of air was also determined at 1.4 and 1.9 m above the floor for the locations D9 and B10 (designated as D9_L, D9_H, B10_L, and B10_H respectively). The results shown in Table 1 indicate that a substantial part of air flowed from the inlet H9 to D9_H ($\tau_p = 31$ s), B10_H (45 s), and then to the outlet A10 (50 s) in order. Table 1 also shows that the average ages of air at D9_L (62 s) and B10_L (144 s) were 2-3 times the values at D9_H and B10_H respectively, indicating that there were no strong currents from the air inlet to the locations D9_L and B10_L. This suggests that while air movement from B10_H, D9_H to A10 was strong, airflow was weak at B10_L and D9_L. The flow pattern in other areas of the cleanroom can be examined in the same way.

Table 1 The average age of air at five locations between H9 and A10.

Location	Average Age of Air (sec)	
	Mean	Standard deviation
D9 _H	31	5.1
B10 _H	45	2.8
D9 _L	62	5.0
B10 _L	144	3.3
A10	50	4.8

* The mean was based on three measurements.

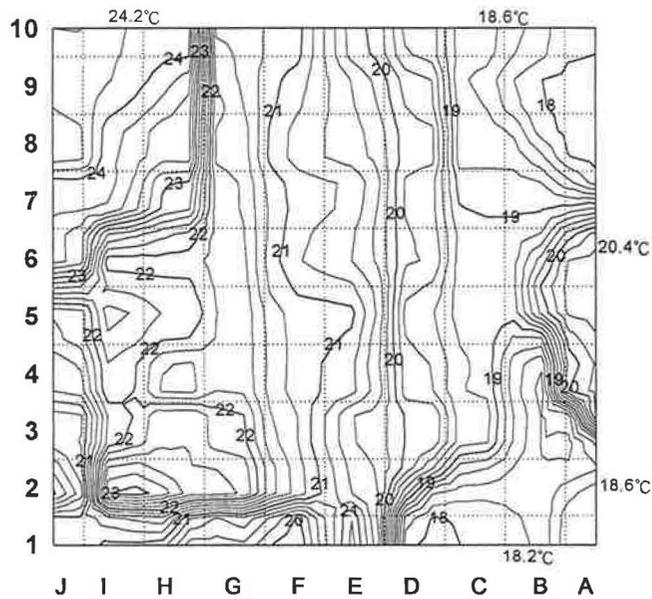


Figure 3 The two-dimensional temperature distribution at 1.4 m above the floor in the cleanroom.

For comparison, air temperature was measured (by Meter testo 452, Testo GmbH&Co., Lenzkirch, Germany) at 1.4 m above the floor at each of the 100 rectangles of the cleanroom. The temperature distribution shown in Figure 3 indicate that the minimum temperature (17.9°C) appeared at A9 while the maximum temperature (24.5°C) appeared at J8. In general, the temperature decreased gradually from the left side to the right side of the room even though the heat sources (furnaces) were evenly distributed. This indicates that the air currents in the left side were not as effective as those in the right side in removing the heat. The temperature distribution was therefore consistent with the airflow pattern.

Because the only air inlet and the four air outlets were not properly placed in the cleanroom, the high air changes per hour did not give a good ventilation performance in the left side of the room.

CONCLUSIONS

The study has demonstrated that the use of the "age of air" concept together with tracer gas techniques provides a simple practical method for examining the airflow pattern in a closed indoor environment. In addition, the results of this study has shown that the location and type of the air inlets and outlets have a major influence on the airflow pattern, which in turn plays an important role in local ventilation performance at various locations in a ventilated room.

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