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CLEAN SPACE TECHNOLOGY FOR 0.1 μm CLASS 10 LEVEL

Koji Miyasaka
Takeo Takahashi

1 INTRODUCTION

During the recent years, advancement and popularization of very fine treatment technology is remarkable in the semiconductor industries, and the clean room (hereinafter abbreviated toas CR) which supports the very fine treatment technology has required a higher cleanliness than before.

The CR requires not only cleanliness but also temperature/humidity control and prevention of vibration.

Installing a CR for simulation, Fuji Electric is conducting a fundamental study to cope with the social needs. This paper describes air flow contol, fine grain control and systemization for composing CRs of super high cleanliness (equivalent to 0.1 μm class 10).

2 CR FOR SIMULATION

The overall configuration of the CR for simulation is shown in *Fig. 1*. This CR consists of a turbulent air flow type clean zone, laminar air flow type clean zone and local clean zone. With this CR, experiments can be conducted for air flow control, relationship between air flow and cleanliness and relationship between air flow and temperature/humidity.

Fig. 2 shows the inside of the laminar air flow type clean zone, and *Table 1* shows dimensions, cleanliness and temperature/humidity characteritics of each clean zone. For this table, dust and heat generated by machines and workers are presumed.

3 AIR FLOW CONTROL

For CR of a super high cleanliness, the cleanliness of the HEPA filter flow out surface must also be maintained in the work range. In case of a laminar air flow ventilation, grain moving route can be presumed and the air flow can be

Fig. 1 Diagram of test room

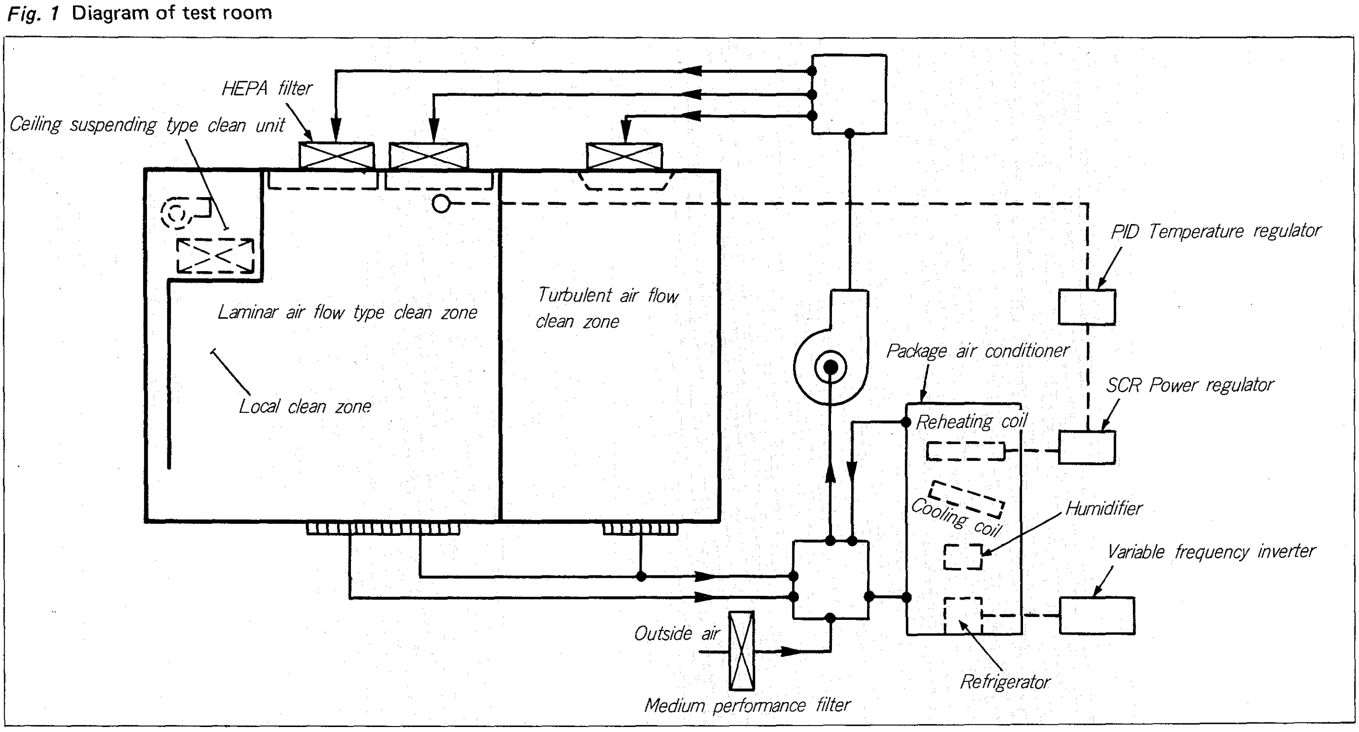


Fig. 2 Laminar air flow type clean zone

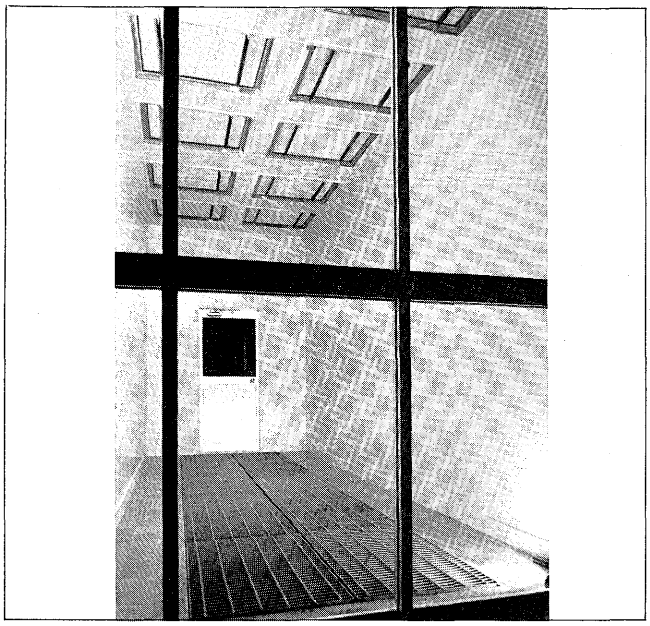


Table 1 Specifications of test room

Item	Laminar air flow zone	Local clean zone	Turbulent air flow zone
Floor area	10m²	2m²	14m²
Ceiling height	2.8m	2m	2.8m
Air blow	200m³/min or less	60m³/min or less	60m³/min or less
Cleanliness	Class 100 or less	0.1μm class 10 or less	Class 1,000 to 100,000
Temperature	20～25±0.2°C	Same as left	Same as left
Humidity	30～60±3 RH%	Same as left	30～60±10RH%

controlled comparatively easily. And, for CR of a super high cleanliness also, this is considered to be a fundamental and elemental technology.

3.1 Laminar air flow ventilation and room cleanliness

The laminar air flow applied to CR does not mean a fluid dynamic laminar but linear streamline with a minor turbulence. The concept of air flow within a laminar air flow room is shown in *Fig. 3*. In the 'linear streamline, movement of contamination grain toward the air flow tangent can be minimized. A worker is covered by the linear streamline air flow, and the work table placed toward the horizontal direction can be handled separately from the worker.

When the worker walks, a turbulence occurs in the linear streamline air flow. The time required in recovering the turbulence to the original linear streamline air flow was measured. *Fig. 4* shows the results. Velocity of the air within this laminar air flow zone flucutates, and the turbulence of air flow due to movement of the worker is affected by the fluctuation. When mean wind velocity is reduced, the air flow disturbed in the low wind velocity space does not recover to the original laminar air flow easily.

Fig. 3 Schematic drawing for air flow of laminar clean room

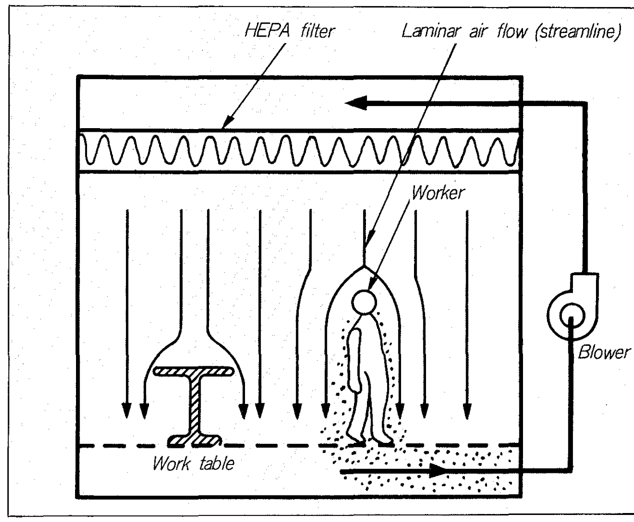
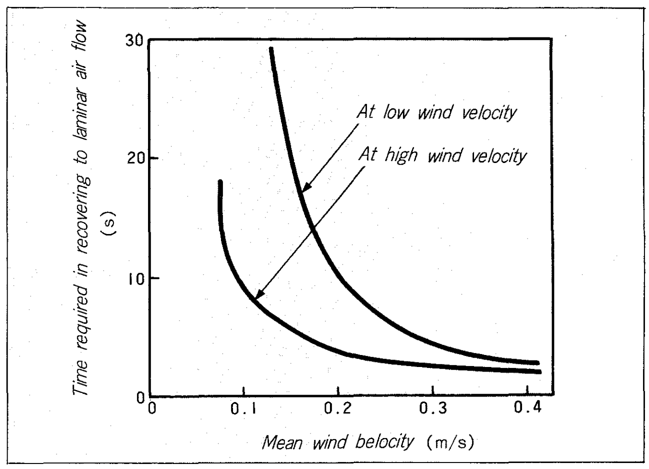


Fig. 4 Recovery time of laminar air flow room (When a worker walks)



When the mean wind velocity is 0.3m/s or higher, air flow energy in the low wind velocity space is high and recovery to the original laminar air flow can be made within several seconds.

Characteristics of recovery from contamination to clean room were also examined. *Fig. 5* shows the results. When mean wind velocity is 0.3m/s, recovery to 100 grains per cu. ft requires about 30 seconds, while, in case of 0.2m/s, 4 minutes or longer time is required.

Based on these results, the practical larmina air flow velocity for CR is considered to be 0.3m/s or higher.

3.2 Induction of outside air

Secondary air flow is induced around the laminar air flow formed in a CR, and this causes the inside room cleanliness to drop in many cases. As shown in *Fig. 6*, the manner of the induction differs depending on the existence of secondary air flow force or not. One of the reasons why the HEPA filter installation rate must be examined in a total laminar air flow type CR is to prevent this induction. On the other hand, the clean unit with an air curtain described in 3.3 below is an example which actively uses the

Fig. 5 Recovery characteristics of laminar air flow room

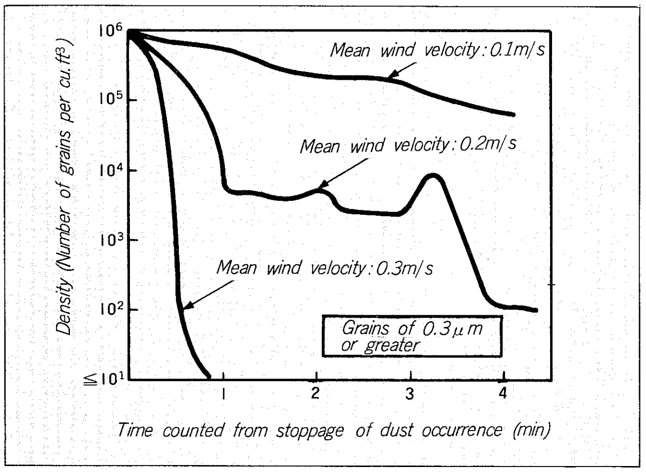


Fig. 6 Secondary air flow induced by laminar air flow

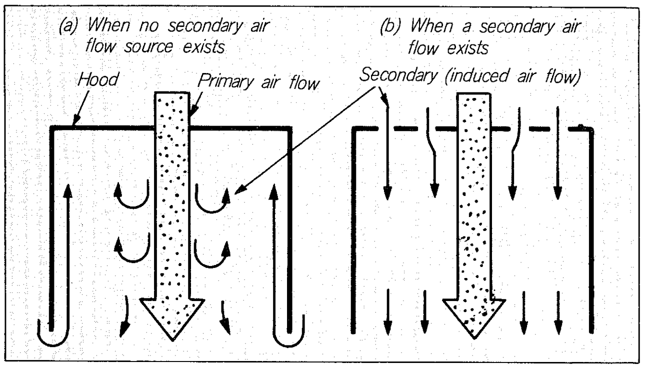


Fig. 7 Air flow of clean bench

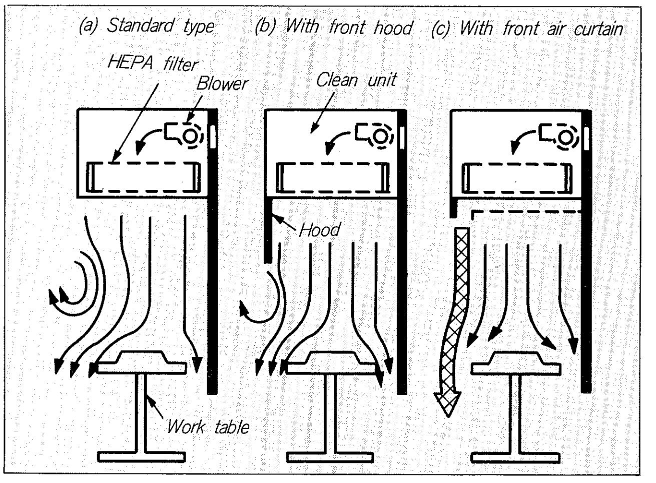
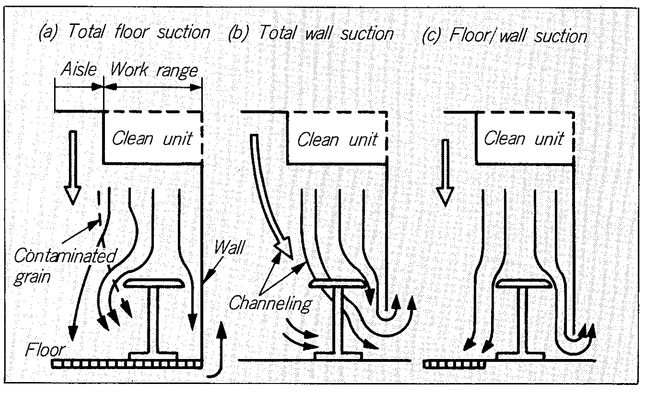


Fig. 8 Air flow of clean tunnel



induction having a secondary air flow source.

3.3 Local laminar air flow cleaning system

As a clean air supplier using local laminar air flow, Fuji Electric has placed the clean bench and clean booth in the markets. Recently, proceeding the step, Fuji Electric has responded to the various requirements of CRs with a combined system which uses the ceiling suspending type clean unit as the fundamental module.

(1) Ceiling suspending type clean unit

This is a clean air supplier which self-contains a HEPA filter and blower. *Fig. 7* shows the fundamental method of use of Fuji Electric's ceiling suspending type clean unit. In the front opening of the standard model, internal contamination is likely to occur due to an induction. To suppress the induction to the minimum, it can be realized by providing the front fact with a hood and curtain air flow. With the air curtain system, it is also possible to suppress the internal air flow to the level lower than before, however, on the other hand, turbulence of air flow occurs easily due to the high speed air curtain air flow and workers.

(2) Clean tunnel

A clean unit can be made to a clean tunnel by systemizing it. *Fig. 8* shows an example of classification with the intake method. In the total floor suction method, laminar air flow can be formed easily, but contaminated grains intrude into the work range from the aisle. In the total wall suction method, it is advantageous as long as the building vibration prevention, however, reduction of cleanliness is likely to occur due to the channeling from the aisle. Based on these facts, the floor/wall suction method is considered to be one of the ideal methods. In any cases, correspondence with the shape of a production machine placed in the clean tunnel is more important, and a pertinent method must be selected in response to the local situation.

4 FINE GRAIN CONTROL

4.1 Outside air dust distribution and 0.1 μm class 10

Fig. 9 shows particle size distribution of the outside dusts measured around the simulation CR. In this figure, the maximum and minimum values of the measured data are indicated. Number of 0.1 μm or greater particles is 1×10^8 per cu.ft. at the maximum.

In the space of 0.1 μ m class 10, number of particles is 10 per cu.ft., and in comparison with the outside air dust distribution, the cleanliness is $1/10^7$ times as higher.

4.2 Particle collecting rate of HEPA filter

Fig. 10 shows particle collecting rates of various HEPA filters presently used by Fuji Electric. In this figure, results

Fig. 9 Particle size distribution of outside air

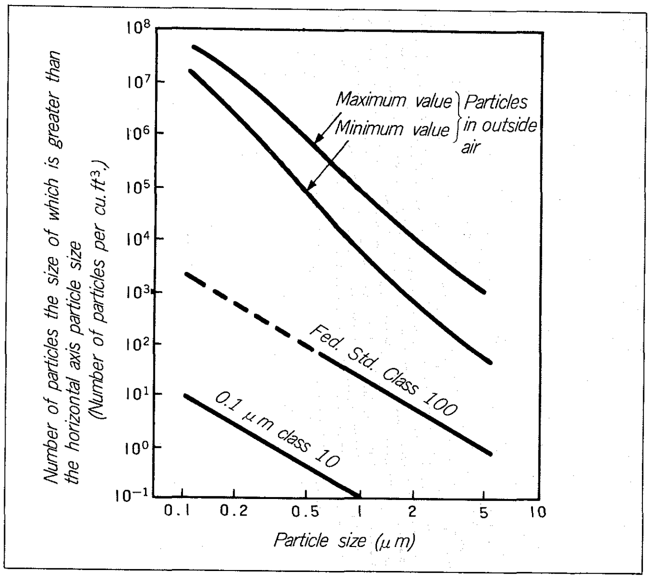
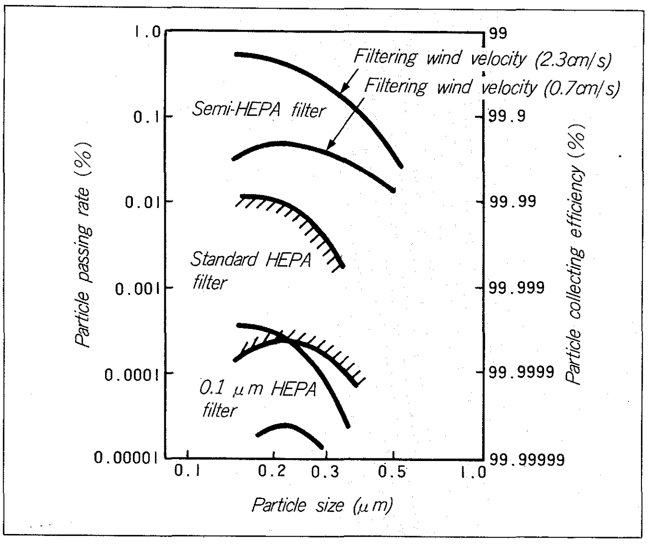


Fig. 10 Particle collecting efficiencies of various HEPA filters



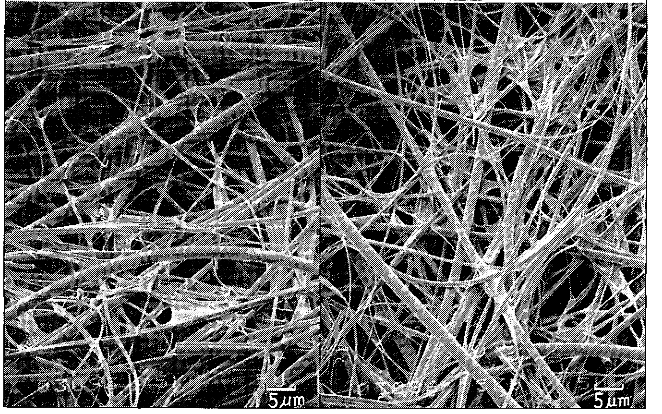
of the experiments conducted on the conventionally used standard type HEPA filter, semi-HEPA filter and 0.1 μ m HEPA filter are shown.

In the case of 2.3cm/s which is similar to the rated filtering wind velocity, for all filter materials, smaller the particle size may be, the particle collecting rate reduces. On the other hand, in case of 0.7cm/s which is a low wind velocity filtering, the particle collecting efficiency improves about one digit, and it indicates the minimum particle collecting efficiency at particle size of about 0.2 μ m. The result has indicated that the particle collecting efficiency in the case of rated filtering with a 0.1 μ m HEPA filter does not make any difference with that in the case of low wind velocity filtering with a standard HEPA filter.

Fig. 11 shows conditions on the surfaces of materials used in the standard HEPA filter and 0.1 μ m HEPA filter. Number of less than 1 μ m fine fibers which affects particle collecting characteristics is slightly more on the 0.1 μm HEPA filter.

Fig. 11 S.E.M. photograph of HEPA filter

(a) Standard HEPA filter (b) 0.1 μ m HEPA filter



4.3 Cleanliness of flow out surface of HEPA filter

(1) Internal dust occurrence and filtering velocity

Cleanliness of flow out surface of the HEPA filter of a clean booth installed in a CR the recirculation rate of which is high is approximately decided by the valur of internal dust occurrence. Using the internal dust occurrence value as a parameter, blow out air velocity of the local clean zone HEPA filter in the CR for experiment was changed and particle distribution in the clean zone was measured. Further, based on the measurement results, number of particles which reached the work area per unit area and unit time was calculated. The results are shown in *Table 2*.

As previously described, slower the blow out wind velocity, particle collecting effeciency of the HEPA filter increases, causing particle distribution to reduce. Further, when number of particles which reach the work area is examined, it further reduces under a low blow out wind velocity because volume of air which carries particles reduces. When HEPA filter blow out wind velocity is set to 0.5m/s, HEPA filter having six types of filter element, surface wind velocity can be selected. With this fact, it can be understood that even if a standard HEPA filter is selected, a high cleanliness can be sufficiently obtained as long as the filter is used under a low wind velocity.

(2) Cleanliness on HEPA filter flow out surface

To maintain a high cleanliness on a HEPA filter flow out surface, it is essential to suppress particle density to the minimum at the up stream of the filter.

Beside, it has been reported that the cleanliness on the HEPA filter flow out surface reduces when air blow begins or temperature and humidity change. With the temperature maintained constantly, relative humidity was changed and timely correspondence of particle density on the HEPA filter flow out surface was measured. *Fig. 12* shows the results. When relative himidity is constant, particle density rise is not recognized on the flow out surface. Regardless of type of filter, particle density on the HEPA filter flow out surface increases only when relative humidity changes.

Table 2 Particle density in the clean booth air
(Relationship between internally generated dust and HEPA filter blow out wind velocity)

Total number of particles generated in clean booth (Number of particles per min.)	Particle density within clean booth (Number of particles per cu.ft)			Number of particles reaching unit area (Number of particles/min · sqm)		
	0.3m/s	0.6m/s	1.1m/s	0.3m/s	0.6m/s	1.1m/s
2.3×10^8	–	10	30	–	1.3×10^4	7.1×10^4
3.5×10^{10}	380	1,600	4,500	2.5×10^5	2.1×10^6	1.1×10^7
1.1×10^{11}	1,490	6,500	23,000	9.6×10^5	8.3×10^6	5.4×10^7

(Note) Particles of 0.12 μm or greater were measured.

Table 3 Type of HEPA filter

HEPA filter blow out wind velocity (m/s)	Wind velocity at the surface of HEPA filter element (m/s)					
	Standard filter element			Filter element for large wind volume		
	Depth 75 mm	Depth 150 mm	Depth 290 mm	Depth 75 mm	Depth 150 mm	Depth 290 mm
0.5	2.5	1.4	0.8	1.5	0.85	0.5

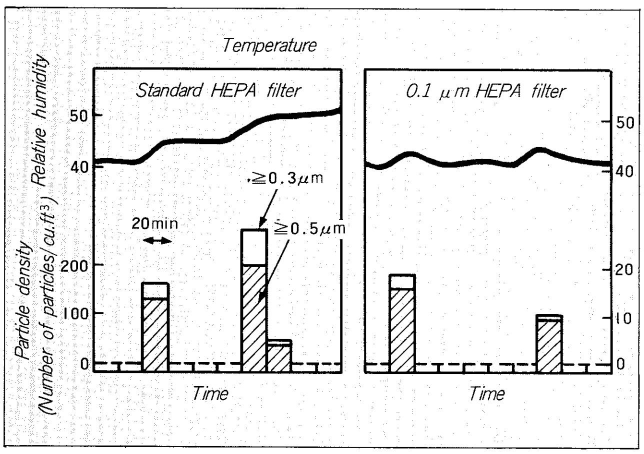


Fig. 12 Experimental results showing the effect of humidity change speed on particle density of HEPA filter down stream

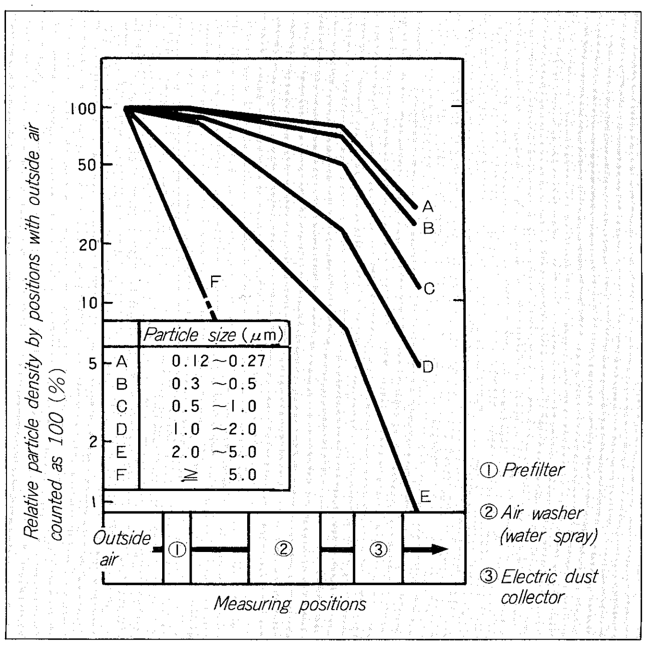


Fig. 13 Particle density decay along prefiltering of outside air

5 SYSTEM EXAMINATION

5.1 Outside air processing harmonizer

Attenuation ratio of particle density in the outside air processing harmozing system employed in an actually operated CR was measured. *Fig. 13* shows the results. Particle density is attenuated whenever air passes through the prefilter (roll mat type), air washer (water spray) and electric dust collector. For submicron particles, dust eliminating effect of the outside air processing harmonizer is small.

When the object of a CR is 0.1 μm, it is desirable to install a higher efficiency dust collector within the outside air processing system.

5.2 Selection of HEPA filter

A clean space equivalent to 0.1 μm class 10 was made with a 0.5 μ m class 100 CR and local larmina clean zone simulated to a clean tunnel, and using this clean space, particle density was measured. *Table 4* shows the results.

For the particle density evaluation, even very fine particles were measured by using a conventional light dispersing type particle counter, laser light source and condensed nuclear particle size enlarger.

In a conventional class 100 CR, smaller the measured particle size may be, number of particles per cu.ft. increases. On the other hand, in a 0.1 μ m class 10 clean zone, even if all particles of 0.005 μ m or greater were counted, it was about 10 particles per cu.ft.

From these facts, it can be understood that the 0.1 class 10 can be sufficiently accomplished by using not only 0.1 μm HEPA filter but also by using a standard HEPA filter under a low wind velocity.

Next, for a case in which a 0.1 μm class 10 is composed with a clean tunnel type CR, example of calculation of particle collecting efficiency required by the HEPA filter is shown in *Table 5*. Further, for your reference, total laminar air flow type CR is also indicated. In this, the following conditions are set based on the experimental results. (1) HEPA filter blow out wind velocity is 0.3 ms;

Table 4 Measuring results of 0.1 μm class 10 clean space

Type		0.5 μm class 100 CR (laminar air flow type)	0.1 μm class 10 CR (Clean tunnel type)	
Used HEPA filter		Standard HEPA fitler	0.1 μm HEPA filter	Standard HEPA filter with low wind velocity filtering
HEPA filter blow out wind velocity		0.5m/s	0.5m/s	0.3m/s
	0.3 μm or greater (light dispersing method)	1~50 Number of paritcles/cu.ft	≦0 Number of paritcles/cu.ft	≦0 Number of paritcles/cu.ft
	0.12 μm or greater (laser dispersing method)	50~500 Number of paritcles/cu.ft	≦10 Number of paritcles/cu.ft	≦10 Number of paritcles/cu.ft
	0.005 μm or greater (condensed nucleou)	500~50,000 Number of paritcles/cu.ft	≦10 Number of paritcles/cu.ft	≦10 Number of paritcles/cu.ft

Table 5 HEPA filter selection for 0.1 μm class 10 clean space

Required condition	Total laminar air flow type CR	Clean tunnel type CR	
		Passage class 1,000	Passage class 10,000
Outside air particle density	1 x 10^8 Particles per cu.ft.	Same as left	Same as left
Cleanliness on HEPA filter flow out surface	5 Particles per cu.ft.	Same as left	Same as left
HEPA filter up stream particle density	0.3m/s	Same as left	Same as left
HEPA filter up stream particle density	5 x 10^6 Particles per cu.ft.	5 x 10^4	5 x 10^5
HEPA filter particle collecting rate	99.9999%	99.99	99.999
Selection of HEPA filter	0.1 μm HEPA filter + Low wind velocity filtering	Standard HEPA filter + Low wind velocity filtering	0.1 μm HEPA filter or standard HEPA filter low wind velocity filtering
Outside air processing	With an intermediate filter employed, Recirculation rate: 90%	Outside air is processed with passage HEPA filter	Same as left

(2) Induced outside air dust density is reduced to a half by the use of an outside air processing harmonizer; and (3) for the clean tunnel type CR, it is assumed that the HEPA filter up stream particle density is decided by volume of dust generated inside the CR, and number of 0.1 μm particles of class 1,000 and class 10,000 was calculated regardless of *Fig. 9*. Further, the HEPA filter up stream paritcle density of total laminar air flow type CR was calculated to be 5 x 10^6 particles per cu.ft with the recirculation rate assumed to be 90%.

For the total laminar air type CR, a 0.1 μm HEPA filter must be used, and in addition, a low wind velocity filtering is required. For the clean tunnel type CR, however, cleanliness of 0.1 μm class 10 can be obtained by using the standard HEPA filter under a low wind velocity, and reduction of equipment cost can be expected.

6 POST SCRIPT

Air flow control and very fine particle control technologies-Fundamental technologies for composing super high clean space were discussed. The results are outlined as follows.

(1) The lower limit lamina air flow ventilation air velocity required in maintaining a cleanliness is about 0.3 ms.
(2) A countermeasure is required for local laminar air flo flow ventilation because outside air inducing phenomenon is involved.
(3) Particle collecting efficiency of HEPA filter;
  (a) Reduces in the rated filtering air velocity range when particle size reduces.
  (b) Indicates the minimum value at particle size around 0.2 μm at a low filtering air velocity range.
(4) When the standard HEPA filter is used under a low filtering air velocity, particle collecting efficiency equivalent to that of a 0.1 μm HEPA filter can be obtained.
(5) Even if no dust exists in the up stream of HEPA filter, dust density increase at the down stream of HEPA filter when humidity of the air passing through the HEPA filter changes rapidly.
(6) With a clean tunnel type used, clean space equivalent to 0.1 μm class 10cm be obtained easily by using the standard HEPA filter at a low filtering air velocity.