SIEMENS

Cerberus®
Fire protection concept for the semiconductor industry

Protecting fabrication plants and associated areas

Application guide

Fire & Security Products

Siemens Building Technologies Group

1 Fire protection concept

1.1 Our aim

The early detection of incipient fire in clean rooms and in the related utility installations for the safety of personnel and to limit damage.
A clean room is an area in a company where strict air cleanliness standards are maintained. A fire in such an area can cause major economic damage.
This protection concept will give you a basic knowledge of the special air handling aspects of clean rooms and, using examples, present possible solutions for early fire detection.

The fire protection concept presented here applies purely to areas where the clean room is protected from contamination in the surrounding area by overpressure (see also chapter 2).

1.2 Facts

The semiconductor industry is one of the most modern in the world. Chips with the finest microstructures are produced in clean rooms by means of complex processes and installations. The processes involve considerable risk. Semiconductor production is comparable with a chemicals plant with many hazardous materials and sources of danger. 350 chemicals in 75 different processes are typical. The following dangerous chemicals and gases *) are commonly used:

– acids (HF, H_2SO_4, H_3PO_4, HCL etc.)
– solvents (Isopropanol, N-Bromo-Acetamide, Xylene etc.)
– metals (As, Sb)
– gases (SiH_4, PH_3, AsH_3, HCl, Cl_2, H_2, O_2).

SiH_4, silane, for example, can combust spontaneously at concentrations of 1.37% – 96% at room temperature and can also react explosively with other materials. Radiotherapy equipment, high voltage installations and the like are additional sources of danger.
The processes must be carried out in an exceptionally clean environment. For this reason the quality requirements for the air in the clean room are extremely high.
Fires in clean rooms can have catastrophic consequences. Even the slightest contamination through fire aerosols and corrosive gases can endanger production and if the fire develops to any size it can shut down production for weeks.
According to Factory Mutual, the average amount of damage caused per incident in the semiconductor industry in 1995 exceeded $8 million. In addition to this, incidents involving damage were recorded for every tenth insured building. By comparison with this, one incident involving an average amount of less than $250,000 was recorded for every 100 insured industrial buildings. As this example shows, the level of damage expected in clean rooms greatly exceeds the usual limits. It represents a new risk dimension.

*) For further information about dangerous chemicals and gases refer to chapter 7

1.3 Why these high costs?

- Even the slightest contamination can endanger processes and destroy an entire production lot.
- Clean room systems must be continuously in operation. That means overpressure or underpressure must be maintained at all times and this includes air recirculation and air filtering. A breakdown can have catastrophic consequences for production.
- Even small fires can cause smoke and corrosion damage.
- Following contamination, the clean room must be painstakingly cleaned.
- Installations and equipment must be repaired, often even replaced.
- The entire filter installations must be cleaned, possibly replaced and requalified.
- The production downtime causes high costs and delivery bottlenecks can occur.
- Highly qualified personnel are temporarily unproductive.
- Customers buy from the competition.
- etc.

1.4 What are the likely causes of fire?

Factory Mutual lists the following causes:

– Many fires were of electrical origin, typically involving process liquid heating equipment
– Over two thirds occurred while the area was unoccupied.

1.5 The Cerberus fire protection concept

We recommend an air sampling smoke detection system with high sensitivity smoke detectors for the monitoring of clean room areas in classes 10 – 1000. Areas of > class 1000, should supplement these measures with point-type smoke and flame detectors at suitable locations.
We recommend individual solutions with suitable fire detectors and extinguishing systems for the monitoring of process flow operations.
Prompt alerting of the works fire brigade and the relevant specialists is assured with an automatic fire detection system.
To limit damage we also recommend the selective use of extinguishing systems.

The enclosed planning guidelines were produced on the basis of experience with actual installations. We now use the company’s own product „Titanus” for high-sensitivity air sampling smoke detection systems. Corporate headquarters provides support in the planning of new systems.

2 An introduction to clean room technology

Clean room technology protects products, processes and the workforce from the harmful influence of contamination in a clean workplace. It is a key feature of modern production processes in:

- The semiconductor and microelectronics industry
- Microcircuitry and precision mechanics
- The pharmaceutical industry
- Biotechnology
- The health care and surgical products industry
- Food processing
- Satellite and space technology
- Research and development
- Operating theatres
- etc.

Clean room technology is designed to provide:

- Clean air at the workplace by eliminating extraneous particles
- Clean product and work surfaces as well as packing materials through the use of high-purity process media (gases, liquids, chemicals).

The cleanliness of the air at the workplace is assured in the following ways:

- Air filtering and air flow control
- Room equipment and structure optimally adapted to the movement of material and personnel
- Under and overpressure gradation between rooms and types of rooms
- Organization of operational sequences
- etc.

Clean rooms with overpressure or underpressure are based on two fundamentally different clean room concepts.

Clean rooms with overpressure	In order to prevent the transport of air contamination from one room to another (so-called cross-contamination), pressure differences are maintained between adjacent workrooms. If the room has to be protected from processes in the surrounding area an **overpressure system** is set up in that room. Clean rooms with overpressure are found especially in high-tech industries such as the semiconductor and microelectronics industry, microcircuitry and precision mechanics, satellite and space technology etc.
Clean rooms with underpressure	If, on the other hand, the surrounding area has to be protected from extraneous particles released into the air in the workroom (micro-organisms), then an **underpressure system** must be set up in that room. Clean rooms with underpressure are frequently found in the pharmaceutical and medical industry and similar fields of activity.

However, the monitoring of clean rooms with a fire detection system is very difficult due to the extremely powerful air handling systems. A basic knowledge of air filtering and flow control as well as the pressure gradation in clean rooms is absolutely essential.

The examples and recommendations given, apply to clean rooms with overpressure as are found in the semiconductor and microelectronics industries.

Other criteria apply to clean rooms with underpressure for the planning of air sampling smoke detection systems.

You will find more detailed information on clean room technology in section 6.

3 Detailed planning of fire detection systems

3.1 Aim

The early detection of incipient fire in clean rooms and in the related utility installations to limit damage.
The prevention of false alarms through the use of suitable and tested fire detectors.

3.2 Critical aspects of planning to be taken into account

The purpose of clean room technology is to maintain a predetermined level of air cleanliness. This is achieved by an appropriate choice of air handling concepts. The air handling systems provide the room with clean air by means of airflow of varying strength. Here are the most important points in brief:

Unidirectional airflow	Here air speeds of 0.3 – 0.5 m/s are reached at approx. 600 room air changes/h
Non-unidirectional airflow	With this type of air handling approx. 10 – 50 room air changes/h are reached
Continuous operation of the air handling system in the clean room	Clean room systems are usually in continuous operation, even if work is not in progress. The air control principle must always be maintained. Often the air handling is switched to 50% capacity outside working hours, e.g. with the unidirectional airflow at approx. 0.2m/s.
Circulated air	The clean room is continually supplied with outside air conditioned by the air handling equipment. Roughly ¾ of this is returned to the air handling equipment as circulated air. The remaining quarter is carried off via the workplaces and processing equipment as processed used air. The monitoring of this processed used air is only possible with specially treated heat detectors due to the high contamination from aggressive and corrosive vapours.

Note: These high rates of change of air are necessary so that the foreign particles in the room are either swept away by the flow of air or diluted to a tolerable level.

Fire aerosols versus airflow	Fire aerosols which arise in a clean room are comparable with airborne foreign particles. Depending on the size and type of fire, they are diluted by the powerful air flow and immediately swept away
Detectors on the ceiling	Conventional fire detection systems with detectors on the ceiling are only suitable for the early detection of incipient fires in clean rooms in areas of non-unidirectional airflow with 10 – 50 changes of air/h. (service areas) When using point-type smoke detectors, they must be installed according to the EDP system monitoring concept with 25m^2 per detector and a distance of 5m between detectors. The area of a perforated ceiling around the detector must be sealed according to CRP e432. In areas with unidirectional airflow (laminar flow) ceiling-mounted detectors provide redundant protection against a catastrophe.
Air handling equipment	The treated outside air and circulated air must always be monitored after the air handling equipment by air sampling smoke detector units type DBZ1197/DO1153. This enables fires in the air handling equipment as well as smoke drawn in with the outside air to be detected at an early stage.
Pressure differences between adjacent workrooms	Another tricky point is the pressure differences between adjacent workrooms. With the air sampling smoke detection system, where the air is extracted via a tube system, after the active detector the air extracted must be taken back to the area with the same air pressure.

For the planning of a fire detection system in a clean room, it is essential that the air handling system concept is known. The planning engineer must be familiar with the various air handling concepts and design the fire detection system accordingly.

3.3 Typical fire hazards

- the ignition of process gases and solvents in heating equipment
- short circuit/overloading in equipment and installations
- danger through fires from outside
- arson/tampering

3.4 Concept for fire detection

Basic concept for	
• Clean room monitoring	
– High sensitivity air sampling smoke detection system with HSD detectors	For early fire detection through the monitoring of extract air from the clean room.
– and additional MB2 detector boxes with DO1153	The MB2s automatically alert the fire department in the second alarm stage
– DO... point-type smoke detectors with the most sensitive parameter set	To monitor the ceiling voids and air return areas particularly found in large installations.
• Service areas	
– Point type smoke detectors type DO11..	To provide redundancy for the HSD detectors, point-type smoke detectors are mounted on the ceiling of the room in the service areas as for the monitoring concept for EDP systems (25m^2 per smoke detector)
– Manual call points	To manually alert intervention forces
Additional possibilities	
– D2410 maximum temperature heat detector with teflon-coated capillary tube	To monitor process extract air
– DF11.. infrared flame detector	In areas where dangerous solvents are used and flaming fires are expected.
– DF11.. infrared flame detector	Ceiling voids, in which filter fan units are installed, must be monitored against flaming fires with infrared flame detectors (see also Fig. 17). Smoke from an overloaded but still functioning filter fan unit is difficult to detect because the smoke is immediately blown into the filter section and deposited there. Only if the filter section is burnt through can smoke penetrate to the clean room and be detected. If in a fire the filter fan unit malfunctions, the smoke is blown in the reverse direction back into the ceiling void (due to the overpressure in the clean room) where it is extracted by other filter fan units and deposited in the filters.
– Air sampling smoke detection unit DBZ1197/DO1153	The treated outside air and circulated air must always be monitored after the air handling equipment by air sampling smoke detector units type DBZ1197/DO1153. This enables fires in the air handling equipment as well as smoke drawn in with the outside air to be detected at an early stage. The air handling control must be layed sown with the customer or the engineering company.

Detector siting

– High sensitivity air sampling smoke detection system with HSD detectors and additional MB2 detector boxes MB2 with DO1153

Plan and site the tube system taking into account the air handling system. See the following planning examples, section 4
For maintenance reasons the HSD detectors must be sited in the service area of the clean room.

Air recycling is important, i.e. the air sampled via a tube system must be taken back to the area with the same air pressure.

– Manual call points

– at fire points
– where personnel circulate
– at entrances and exits as well as airlocks
– in areas with dangerous gases and chemicals
– at workplaces with a serious fire hazard
– in explosion-hazard areas

– Siting parallel display for the HSD

– The parallel display for the HSD can be sited up to 1000m from the HSD detectors
– A suitable location is e.g. the entrance to the clean room

Supporting measures

– The specific use of extinguishing systems
– Gas detection system specifically adapted to the processes and the gases used
– Access control system for clean room area

Aspects that require special attention

– Conditions impede Installation and maintenance work in the clean room
– Test gas not to be used for detector testing
– Material for the air sampling tubes in air sampling smoke detection systems only to be selected in agreement with the customer (e.g. ABS, stainless steel tubes and the like).

Test fires

During the construction phase of a clean room there is often a possibility of checking the performance of the fire detection system practically using test fires. Suitable test fires are:

– For HSD detectors

– Test fire with 2 – 5 metal film resistors 10W 0.6 Watt connected in parallel at 9V max. 5A.

– For MB2 performance check

– Test fire with smoke sticks (document HSD2400 e993).
– Smoke generators

– **In clean rooms ready for operation**

– **Do not use smoke generators and test fires such as TF2, TF4, TF6 etc.**

3.5 Stages in the planning of a fire detection system

Production processes in the semiconductor industry are highly specialized and adjusted to current products. Each factory looks different and has a different environment.
Our recommendations are therefore of a general nature. However, with the detailed information on clean room technology, the planning engineer should be able to work out his own concepts and solutions.
We recommend proceeding as follows:

Step	Assignment
1	Discuss the fire protection and intervention aims (e.g. extinguishing) with the customer.
2	Obtain important clean room data on: – the air handling concept and the – operating modes of the air handling equipment – air flow control in the clean room – pressure differences in the area monitored; overpressure, underpressure areas. Which areas have overpressure/underpressure? – areas with different air cleanliness classes – etc. *Detailed information on clean room technology can be found in section 6!* **Here it is very important that early contact is made with the consulting engineers who designed the clean room and the air handling systems.**
3	Check out the possible positions of air sampling tubes and point-type detectors.
4	Check out where critical processes which pose a fire hazard are taking place and also those installations which have to be monitored or protected.
5	Check out where there are explosion-hazard areas.
6	Check out requirements to be met for installation and the material for clean rooms.
7	Define monitoring concept.
8	Specify fire control installations with the consulting engineer/operator.
9	Define system design.

⚠ In comparison with a standard fire detection system e.g. a hospital or the like, the realization of a clean room project always involves more work. This must be taken into account when calculating the quotation.

Where do the additional costs arise?

- Checking out the entire air flow control and air handling systems is time-consuming
- The same applies to the working out of a monitoring concept for wet benches and other process-controlled manufacturing devices.
  Note: Wet benches, work stations and process-controlled manufacturing devices and equipment always require individual fire protection solutions, therefore this topic is not dealt with in this paper.
  The manufacturing processes have inherent high risks due to the extensive use of toxic, highly corrosive and flammable gases and liquids. Standard fire detection and fire extinguishing equipment does not always meet the necessary material specifications.
- Whoever has to work in clean rooms must comply with various requirements, e.g. in respect of clean room clothing, compliance with specific operational regulations etc.
- Access to clean rooms is often difficult. Authorization must be obtained for access.

- Working conditions are rendered much more difficult. The stages of work must be planned and prepared down to the last detail with the customer’s personnel.
- It may be necessary to use special wiring and installation material
- Time-consuming arrangements have to be made if the customer requests acceptance test fires.
- etc.

It is therefore very important to check out such details with the customer and the engineering companies involved in the planning in advance so that such aspects can be suitably taken into account for the fire detection system project.

The planning engineer who has to approach the customer or the engineering company with such matters must be highly qualified.

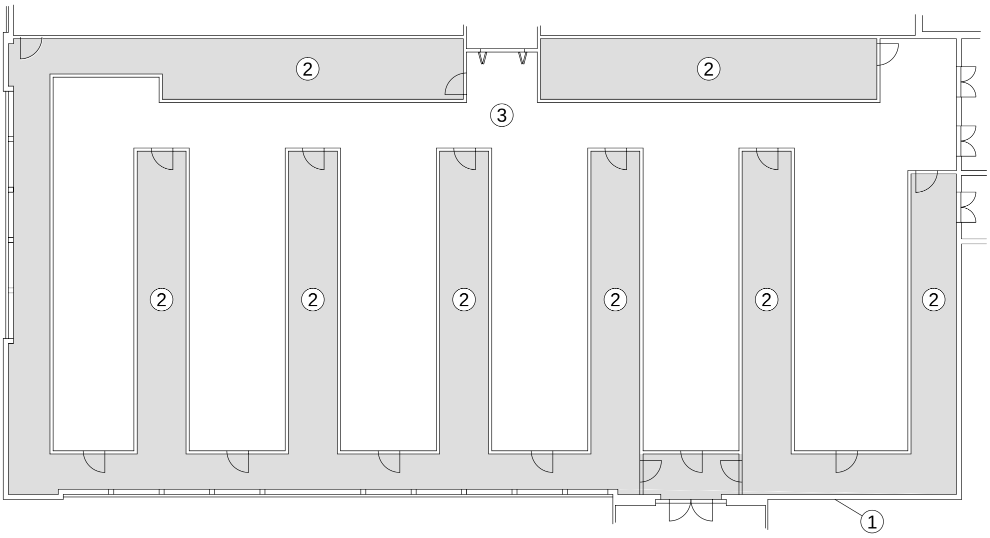
4 Planning examples

The first planning example shows a factory for watch microelectronics. Here so-called „linear protection" is used for the clean room protection concept . We talk of linear protection if a clean room conditions have to be provided for a row of adjacent workplaces. A common application of this principle is the „clean tunnel" which is often found in the microelectronics field (see also 4.1.2).
The second example shows a spacious microchip factory. In this case so-called „surface protection" is used for the protection concept. Surface protection is used for extensive clean rooms. Basically speaking, with surface protection concepts the building is one gigantic air re-circulating machine in which the clean room (that is the area which is immediately useful for production) often only makes up 10% of the total room volume.

4.1 Factory for watch microelectronics

4.1.1 Room-in-room construction

This example deals with a room-in-room construction. The clean room and the service areas are on the same floor.
The initial pressure stage prevents contaminated outside air from infiltrating the building where the service area (technical zone) encloses the clean room. This area has air cleanliness class 100,000. The second pressure stage which is between the service area and the actual clean room has air cleanliness class 1000.



Legend:
1 Building shell
2 Service area, technical zone air cleanliness class 100,000 * (sometimes also known as „grey zone")
3 Clean room area air cleanliness class 1000 *
* according to U.S. Federal Standard 209D

Fig. 1 Room-in-room construction

4.1.2 Air handling principle at the workplace

Here the clean room is divided into various air cleanliness zones according to the processing and circulation zones. For certain workplaces, air cleanliness class 1000 is inadequate. Frequently the so-called tunnel principle is used for the organization of adjacent workplaces with air cleanliness classes 1 or 10. In such a case, partitions are installed between the critical work areas and the surrounding areas. In clean room technology this technique is referred to as linear protection. In the example shown, the air from the clean room escapes via vents at floor level in the service area or the technical zone where the air is extracted at the ceiling.

Legend:
1 Outside air intake
2 Outside air purification
3 Mixing chamber
4 Air circulating equipment
5 Pressure box
6 Workroom according to tunnel principle, air cleanliness class 10 and better
7 Service area, technical zone or incl. corridor
8 Entire area of workroom ventilated by displacement flow
9 Extract air duct
10 Extract air fan
11 Extract air purification
12 Extract air vent

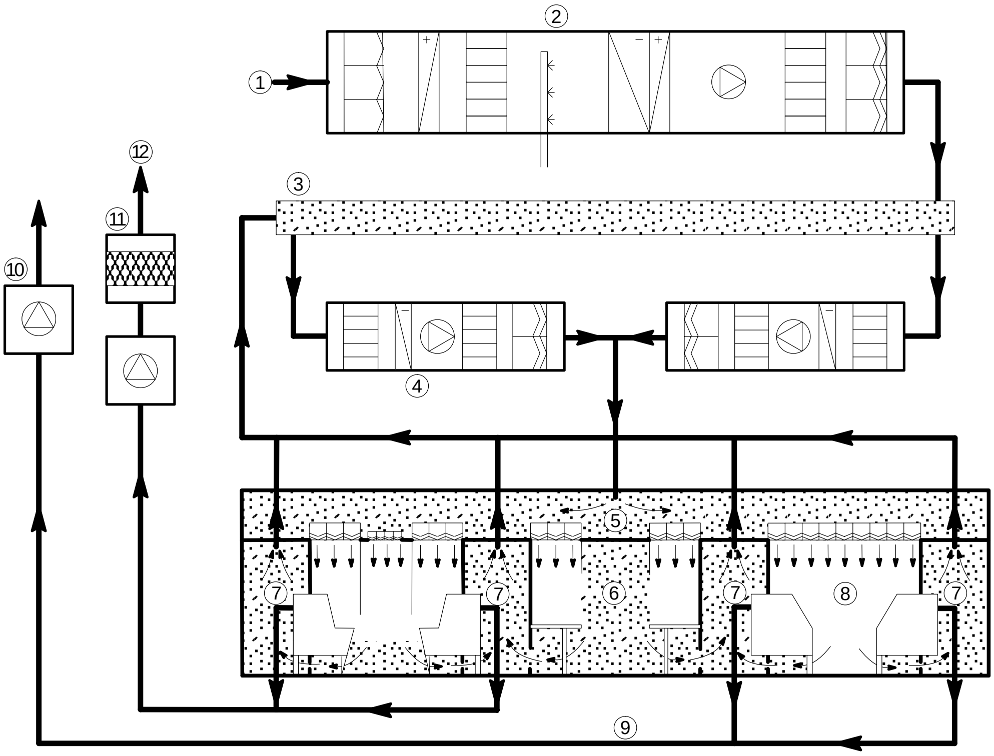


Fig. 2 Workplace air handling from the microelectronics area

4.1.3 Fire detection system

In this situation we use an air sampling smoke detection system with HSD detectors and additional MB2 detector boxes with DO1153 for early fire detection.
Point-type smoke detectors cannot be used in the clean room for early fire detection because any fire aerosols are immediately blown away by the powerful air flow. On the other hand, the service area is equipped with point-type smoke detectors according to the monitoring concept for EDP systems.

4.1.4 Air sampling smoke detection system concept

In this situation the best location for an air sampling smoke detection system is the service area through which the air from the clean room blows before it is taken back to the air purification system.
The ideal location for the detection of fire aerosols from the clean room would be the extract air vents at floor level where the air from the clean room flows into the service area. Unfortunately this zone is unsuitable for the installation of air sampling tubes due to the technical equipment and installations.
We have therefore decided to monitor the air flow for fire aerosols only at the ceiling in the service area. For this purpose a U-shaped tube system is mounted near the ceiling at a height of 2m.
Each U is connected to an MB2 detector box. The air from three detector boxes is transported to an HSD detector.

4.1.5 Concept for point-type smoke detectors

In the service sector, in addition to the air sampling smoke detection system, DO1151 smoke detectors with a monitoring area of 25m^2 per detector and with a maximum distance between detectors of 5m are mounted on the perforated ceiling.

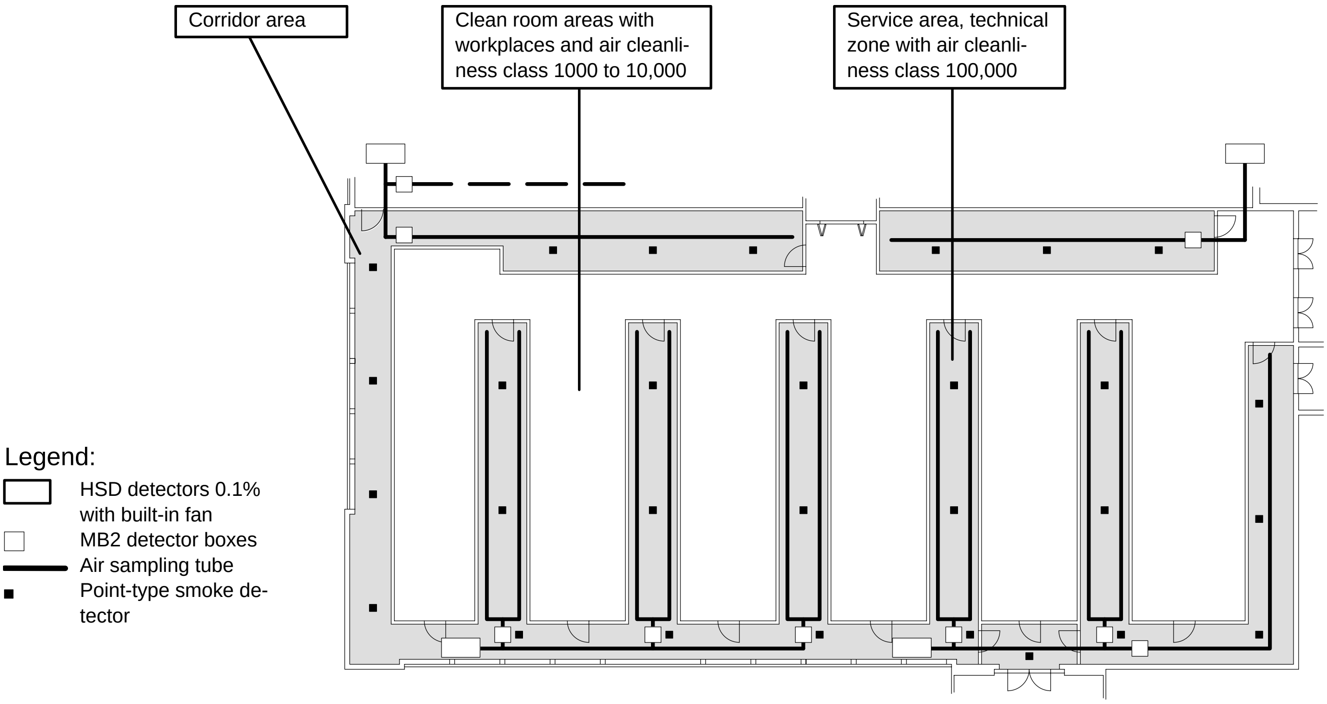


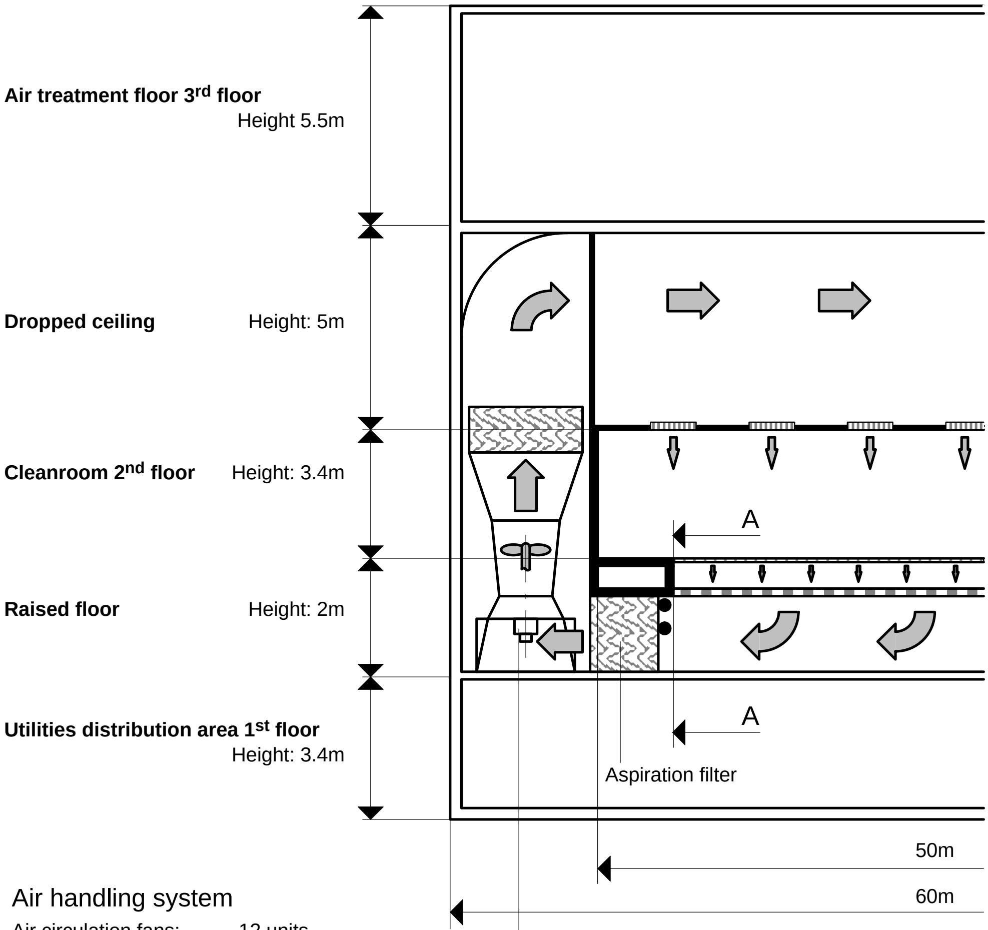
Fig. 3 All service areas or technical zones are fully monitored

4.2 Factory for the production of microchips

The following examples taken from practical situations were realized with the MP2424 air sampling chamber. In the meantime, this product has been replaced by the AD1 and AD2 active detectors. For this reason we are showing the system configurations with AD2 devices.

4.2.1 Clean room type A, 1st example

A cleanroom with axial air circulation fans installed sideways connecting the supply-air plenum (dropped ceiling) at the top and the return-air plenum (raised floor) at the bottom.



Air handling system

Air circulation fans:	12 units
Output per unit:	92,000m³/h
Total output:	1,104,000m³/h
Siting:	6 air circulation fans on each side of the 50m wide room

Fig. 4 Cross-section through the clean room type A

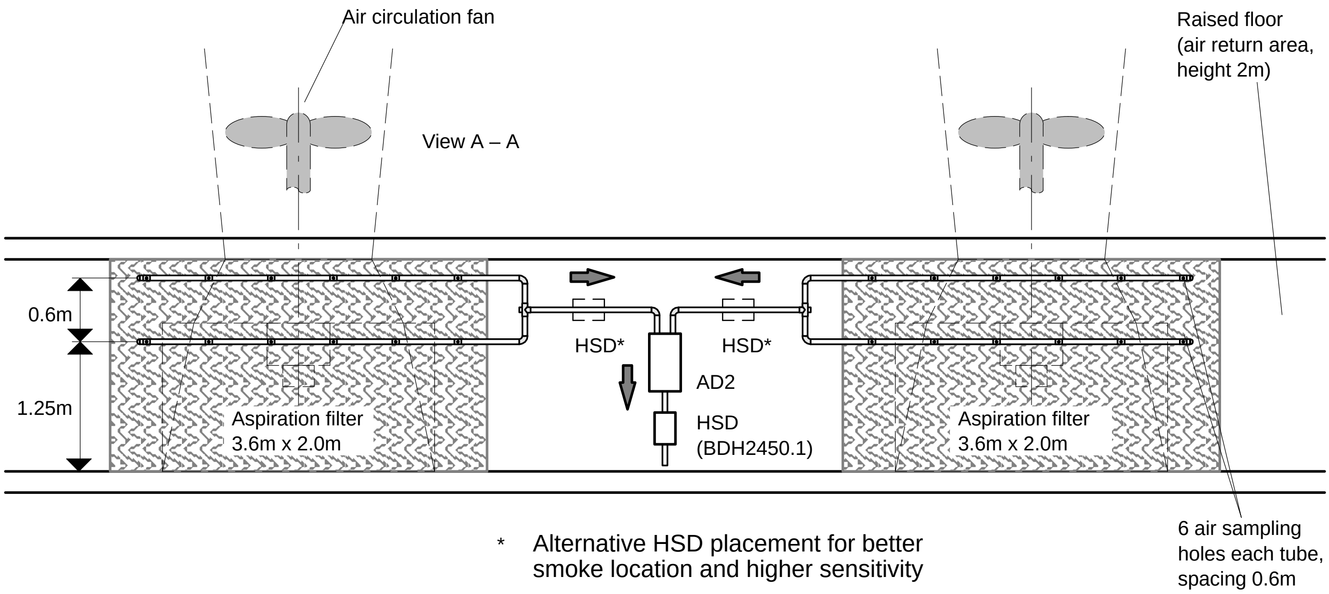


Fig. 5 High sensitivity air sampling smoke detection system in raised floor type A

Details on the planning of the fire detection systems

Clean room on 2nd floor

Length	55m
Width	50m
Area	2750m^2
Height	3.4m

High sensitivity air sampling smoke detection system with HSD detectors in a 2m high raised floor:
- 6 or 12 BDH 2450.1 detection devices with interface card BDC2400 (pre-alarm 15%, Alarm 30%)
- 6 AD2 active detectors

Air sampling tubes:
- 2 air sampling tubes mounted parallel in 2 metre high raised floor; first tube 1.25m above the floor, second tube 1.85m above the floor, both in front of the aspiration filters of the air circulation fans.

Air sampling holes:
- Holes every 60cm (see planning guidelines)

Response sensitivity:
- The system reacts to a test fire with 5 metal film resistors 10Ω 0.6W connected in parallel at 9V max. 5A.

Utilities distribution area, 1st floor

Length	55m
Width	60m
Area	3300m^2
Height	3.4m

Ventilation: minimal (< 0.1 m/s)
Point-type smoke detectors:
- Type DO1151 with APS007S parameter set (1 detector every 25m^2)
- Type DO1101 Ex for various explosion-hazard areas

Suitable test fire:
- SG3000 smoke generator

Air treatment floor, 3rd floor

Length	55m
Width	60m
Area	3300m^2
Height	3.4m

Size: 55m x 60m = 3300m^2
Ventilation:
- Depending on location between <0.1m/s and < 0.5m/s

Point-type smoke detectors:
- Type DO1151 with APS007S parameter set (1 detector every 50m^2)

Suitable test fire:
- SG3000 smoke generator

4.2.2 Clean room type B, 2nd example

A cleanroom with filter fan units installed in the dropped ceiling connecting the supply-air plenum (dropped ceiling) at the top and the return-air plenum (raised floor) at the bottom.

Air handling system

Air circulation fans:	1300 units
Output per unit:	800m^3/h
Total output:	1,040,000m^3/h
Siting:	in the dropped ceiling

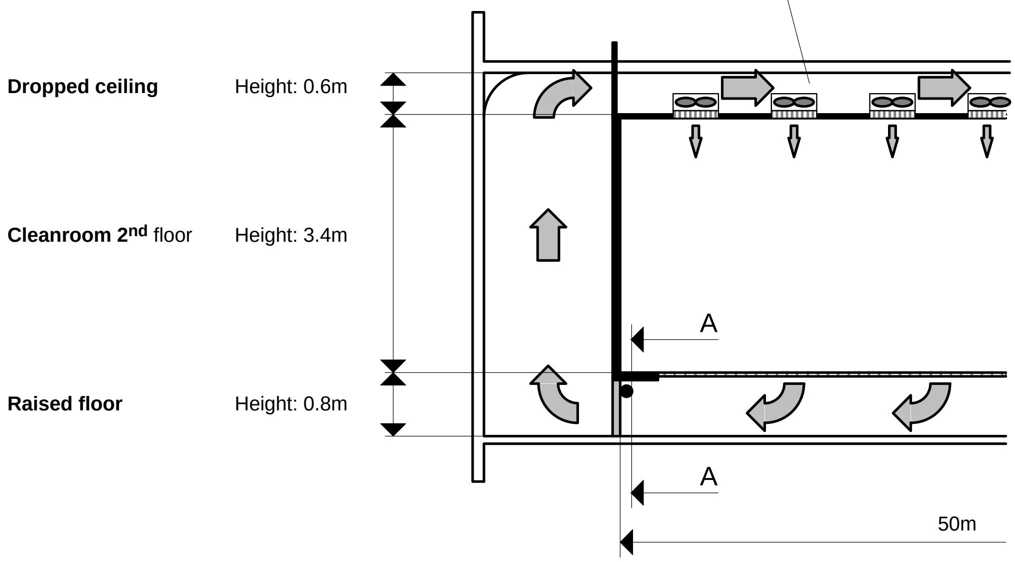


Fig. 6 Cross-section through the clean room type B

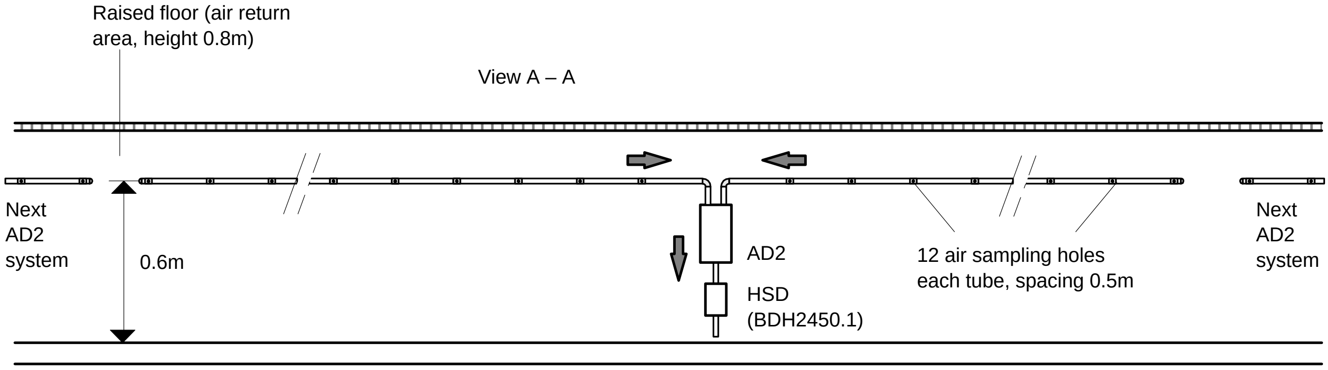


Fig. 7 High sensitivity air sampling smoke detection system in raised floor

Details on the planning of the fire detection systems

Clean room, 2nd floor

Length	55m
Width	50m
Area	2750m^2
Height	3.4m

High sensitivity air sampling smoke detection system with HSD detectors in an 0.8m high raised floor.

- 10 BDH2450.1 detection devices with interface card BDC 2400 (pre-alarm 15%, alarm 30%)
- 10 AD2 active detectors

Air sampling tube:

- 1 air sampling tube installed in the 0.8m high raised floor, 0.6m above the floor

Air sampling holes:

- One hole every 50cm (see planning guidelines)

Response sensitivity:

- The system reacts to a test fire with 5 metal film resistors 10Ω 0.6W connected in parallel at 9V max. 5A.

Dropped ceiling

Length	55m
Width	50m
Area	2750m^2
Height	0.6m

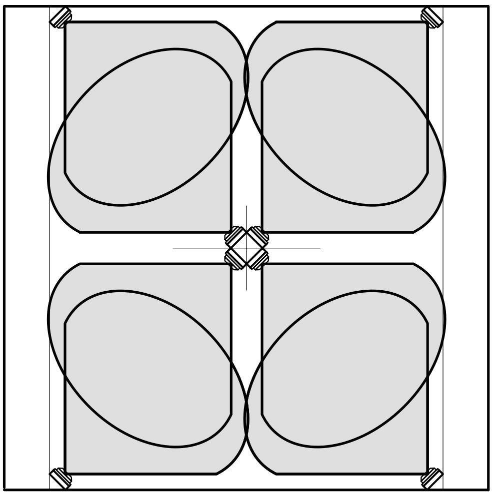


Fig. 8 Eight infrared flame detectors above the filter fan units

4.2.3 Clean room type B, 3rd example

A cleanroom with air circulation fans installed in the dropped ceiling connecting the supply-air plenum (dropped ceiling) at the top and the return-air plenum (raised floor) at the bottom.

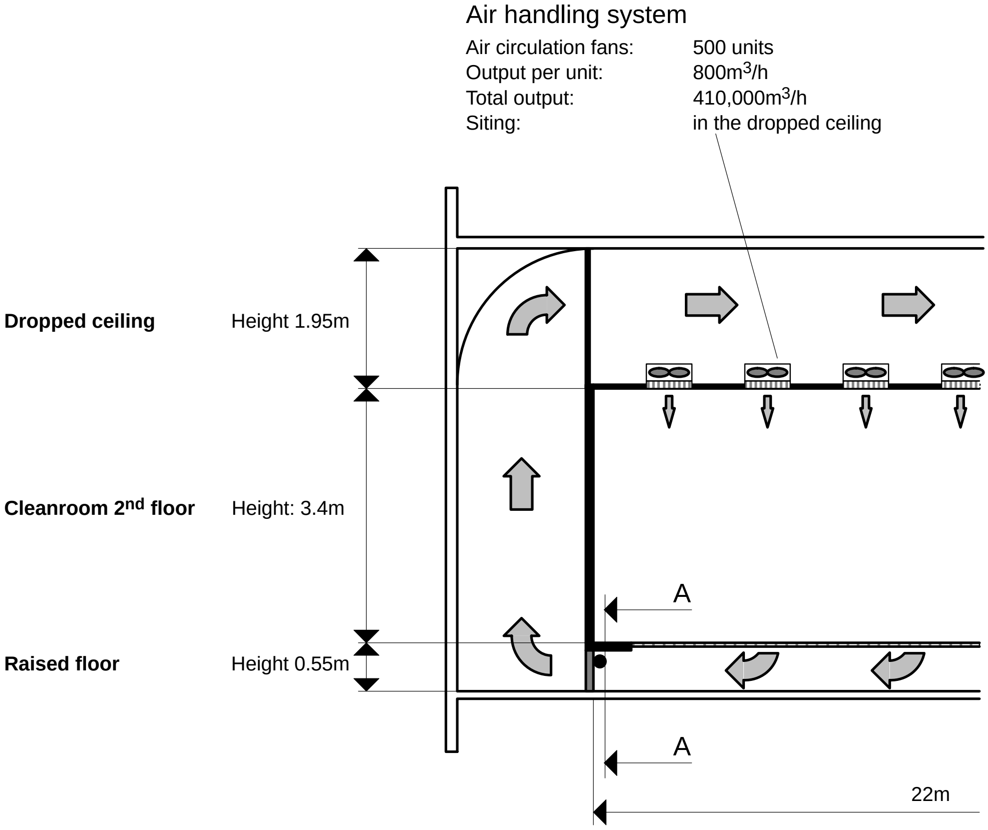


Fig. 9 Cross-section through the clean room type B

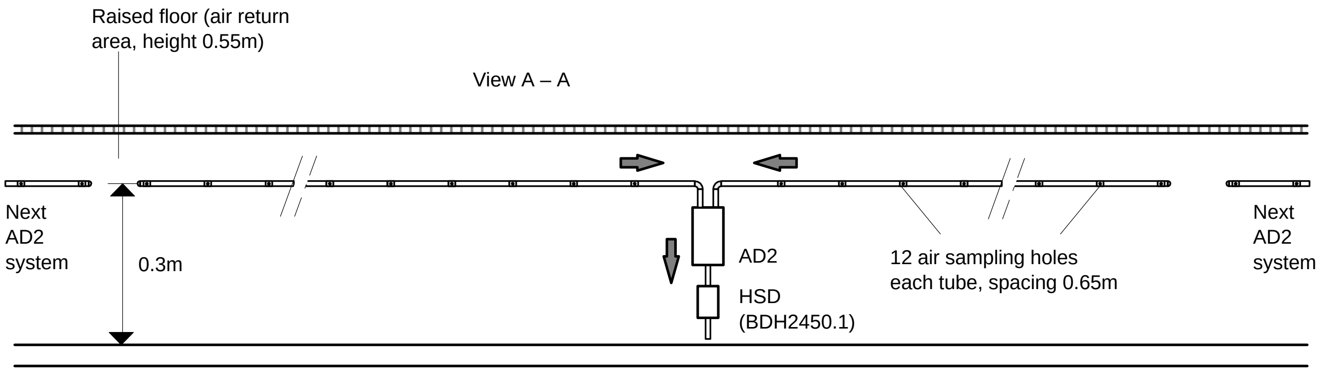


Fig. 10 High sensitivity air sampling smoke detection system in raised floor

Details on the planning of the fire detection systems

Clean room, 2nd floor

Length	86m
Width	22m
Area	1892m^2
Height	3.4m

High sensitivity air sampling smoke detection system with HSD detectors in an 0.55m high raised floor.

– 14 BDH2450.1 detection devices with interface card BDC 2400 (pre-alarm 15%, alarm 30%)
– 14 AD2 active detectors

Air sampling tube:

– Air sampling tube mounted at 30cm above the floor in the 0.55m high raised floor.

Air sampling holes:

– A hole every 65cm (see planning guidelines)

Response sensitivity:

– The system reacts to the test fire with 5 metal film resistors 10Ω 0.6W connected in parallel at 9V max. 5A.

4.2.4 Clean room type B, 4th example

A cleanroom with filter fan units installed in the dropped ceiling connecting the supply-air plenum (dropped ceiling) at the top and the return-air sideways.

Air handling system

Air circulation fans:	320 units
Output per unit:	920m³/h
Total output:	294,400m³/h
Siting:	in the dropped ceiling

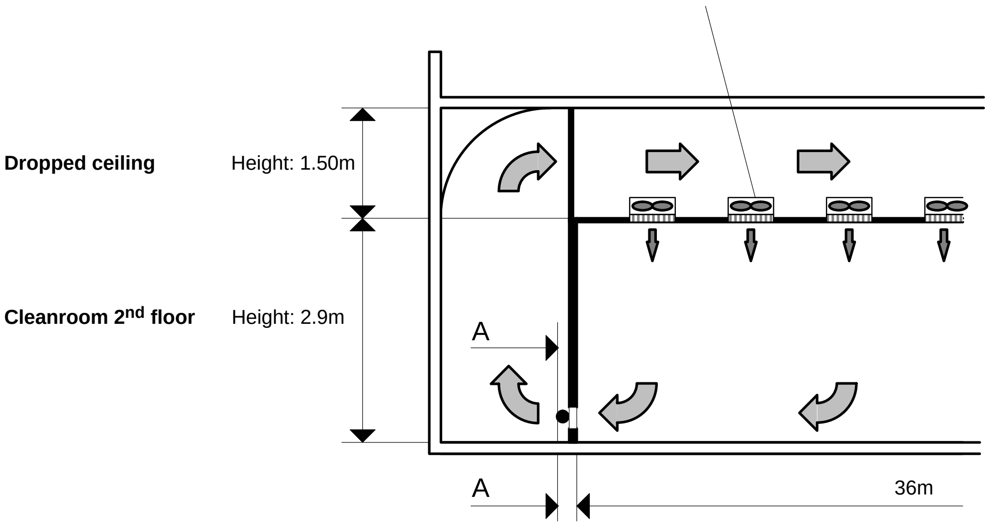


Fig. 11 Cross-section through the clean room type B

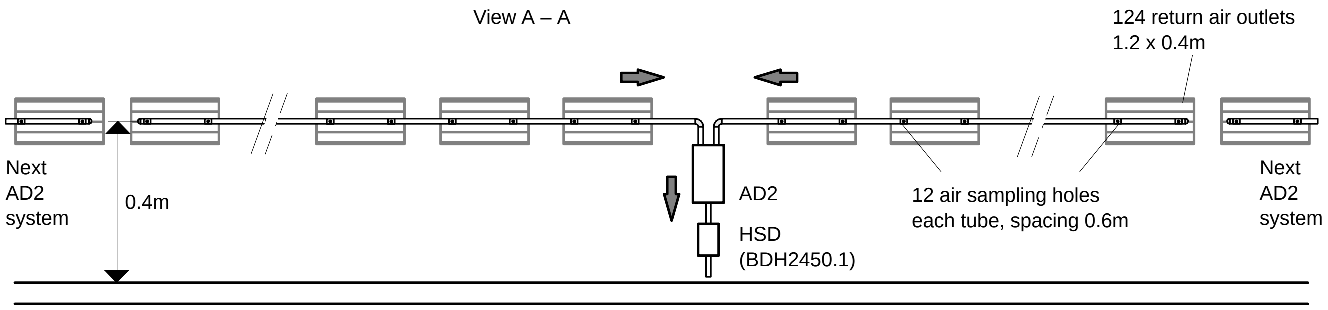


Fig. 12 High sensitivity air sampling smoke detection system at return air outlets

Details on the planning of the fire detection systems

Clean room, 2nd floor

Length	62m
Width	36m
Area	2232m^2
Height	2.9m

High sensitivity air sampling smoke detection system with HSD detectors at the return air outlets slightly above floor level:

- 10 BDH2450.1 detection devices with interface card BDC2400 (pre-alarm 15%, alarm 30%)
- 10 AD2 active detectors

Air sampling tube:

- Max 12 return air outlets (see planning guidelines)

Air sampling holes:

- 2 air sampling holes per return air outlet

Response sensitivity:

- The system reacts to the test fire with 5 metal film resistors 10Ω 0.6W connected in parallel at 9V max. 5A.

5 Information on microchip production

5.1 Introduction into the semiconductor industry

The semiconductor industry has its roots in the 1947 discovery of the transistor. Integrating electronics into every aspect of life has provided the impetus for the development of cheaper and yet more powerful devices. Progress has continued at an accelerated pace from discrete transistors, operational amplifiers through to the modern microprocessor. In 1995 total sales of semiconductors reached US$140 billion. The trend towards a greater use of semiconductors in replacing discrete components will increase the percentage of semiconductor usage. One prediction puts sales for the year 2030 at $12,000 billion.
Huge worldwide demand for microprocessors and microcontrollers has meant the major manufacturers have had to make large investments in purpose-built semiconductor manufacturing plants. They are found all over the developed world and while the detailed design of the building housing the manufacturing plant may vary, the concept is the same. Strictly speaking the manufacturing plant is concerned with the production of semiconductor wafers. These wafers , literally thin slices of semiconductor material such as silicon, are the basis of integrated production. After processing, the individual units are „packaged". Packaging in this case refers to the final assembly of protective encapsulation and external conductors or pins.

5.1.1 Manufacturing process

Specialist machinery is used in the manufacture of semiconductors. In addition a carefully controlled environment must be created. The area where semiconductor wafers are manufactured and processed is known as a „clean room". Clean rooms are categorised by the ratio of one particle of a defined size to a volume of air. Contamination is a major source of product failure in this industry. Dust particles are regarded as wholly unacceptable and operatives are required to wear complete protective coveralls when working in the clean room.
The technology that produces high filtration levels for clean rooms is also found in other industries, particularly pharmaceuticals. High Efficiency Particulate Air-filters (HEPA) and Ultra Low Penetration Air filters (ULPA) are used to help achieve the required air cleanliness. Typically air movement is high and travels vertically, from ceiling to floor.
Within this environment the process itself takes place. Simplistically, the process is analogous to photographic development. It can take between ten and thirty steps to complete the process depending upon the complexity of the devices being manufactured.
There can be as many as four hundred separate steps for a 16MB DRAM (dynamic RAM) in the manufacture of integrated circuits. Starting point is the creation of high purity single crystal silicon ingots. These are sliced into wafers of varying diameters. Improving technology has meant the diameter of wafers has increased over the past few years. The greater the diameter , the larger the number of finished products obtainable from each wafer. Recently, 20cm to 30cm wafers have become commonplace.
The major steps in the process are outlined below:

Polishing
High levels of cleanliness are essential for the success of the manufacturing process. Disc-shaped wafers are polished before moving on to the next stage.

Thin film deposition
It is essential to coat the wafer with layers of material that create the structure necessary for the operation of the millions of transistors within the integrated circuit. This is achieved by thermal deposition of high purity oxygen into the silicon. A uniform layer of silicon dioxide is thus created.

Masking
Different parts of the wafer are processed at different times. Areas of the wafer are masked using either a photoresistive or light-sensitive film. This creates a surface similar to photographic paper. Masks are then precisely applied and aligned to allow the layout of the integrated circuits to be located on the wafer. Using a photo-lithographic process, an intense light beam exposes the sensitive areas of the mask.

Etching
Unwanted photo-resist material is removed using various chemicals. The remaining pattern is baked and finally etched using gas plasma to ensure the required circuit layout remains. At this stage the image transfer from the mask to the wafer is thoroughly checked.

Doping or ion implantation
Providing the semiconductor with the electrical characteristics required is achieved by implanting either phosphorous(N-type) or boron(P-type) atoms into the silicon material.
The processes indicated above are repeated many times until the required number of devices have been formed on each wafer.

Dielectric deposition and metalization process
After the individual devices have been formed it is necessary to create the interconnections between devices. These interconnections are formed by sandwiching insulating material (dielectric) between metallic layers, masking and etching.

Passivation
A final insulating layer (passivation) is formed to protect the finished wafer from contamination. Openings will be let into this layer to permit the attachment of wire links during final assembly. Electrical tests are conducted at this stage.
Individual chips are cut from the finished wafer using a diamond saw. External links, smaller in diameter than the human hair, are made before encapsulation in the appropriate package. Final testing now takes place before supply to customers

6 Detailed information on clean room technology

6.1 Flow control in the clean room

The sources of particulate air contamination in workrooms are

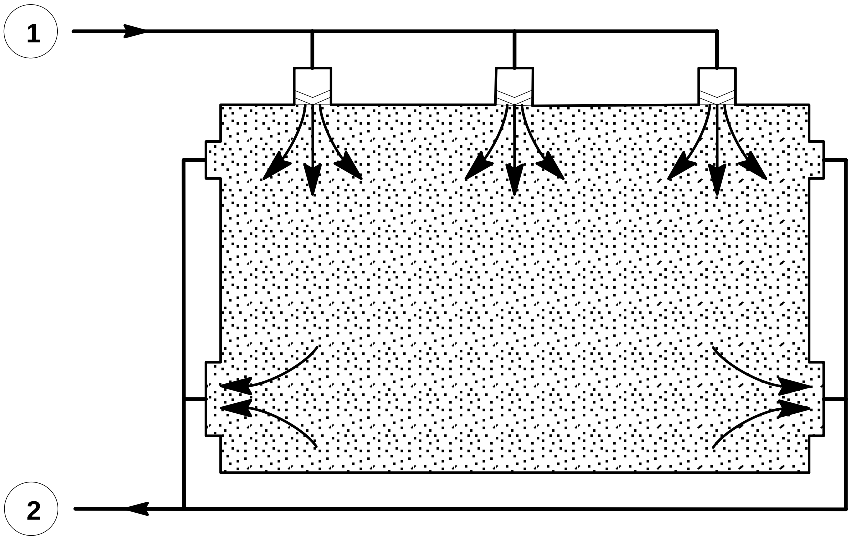
- the outside air
- the air handling systems and
- the release of particles in the workrooms themselves (e.g. through work processes, personnel, expendable material, cleaning agents, maintenance work etc.)

Certainly filtering the air for floating particles creates an air supply of outstanding quality, however, nothing can be done against the release of minute objects and microorganisms in the workrooms.

Therefore, airflow techniques are implemented to counter the air contamination released in the rooms themselves.

6.1.1 Non-unidirectional airflow

If the level of air cleanliness demanded is not too high, then it is sufficient to dilute the contamination released in the air in the room with an adequate fresh air supply (first air) filtered for floating particles. This is achieved by means of the principle of non-directional airflow.



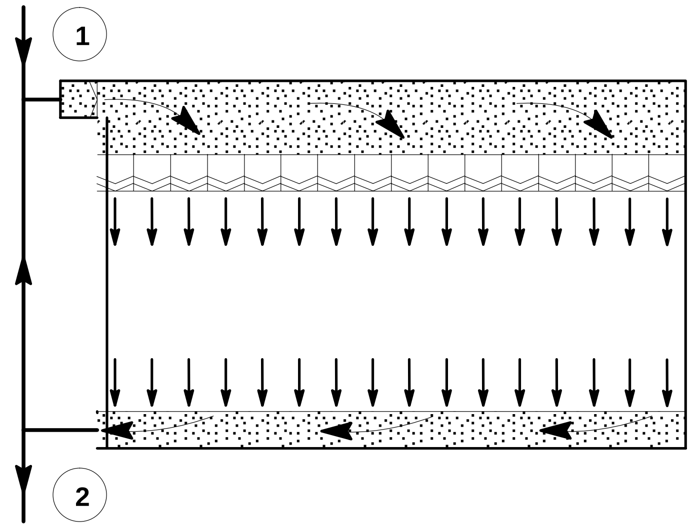
Legend:
1 Pre-treated outside air
2 Extract air

Fig. 13 Section through clean room with non-unidirectional airflow

With suitable floating particle filters and comparatively moderate air supply (10 – 50 air changes/hour) the requirements for air cleanliness classes 10,000 and 100,000 (ISO 7 and ISO 8), and if particular care is taken even class 1000 (ISO 6) can be met (See section 6.6 for a definition of air cleanliness classes).

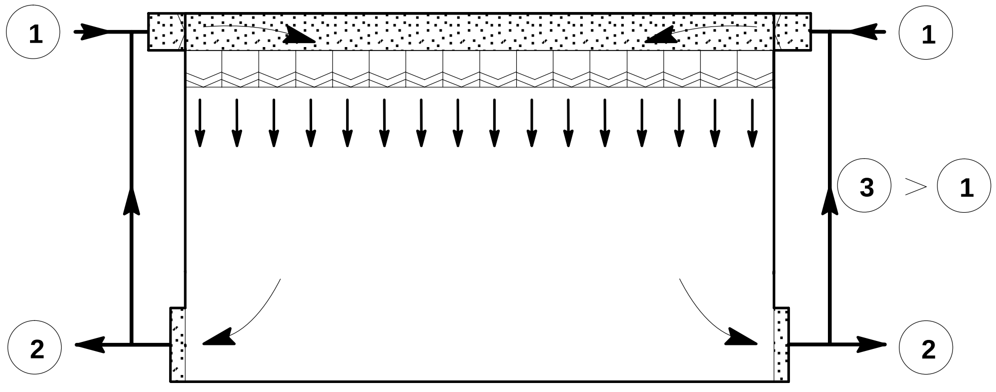
6.1.2 Unidirectional airflow

If the demand is for higher and the highest level of air cleanliness, we apply the principle of unidirectional airflow, as it is called. In everyday language it is also known as laminar flow although it is not quite physically correct. With this method, the contaminated air released in the room is carried away by the shortest route and so rendered harmless.



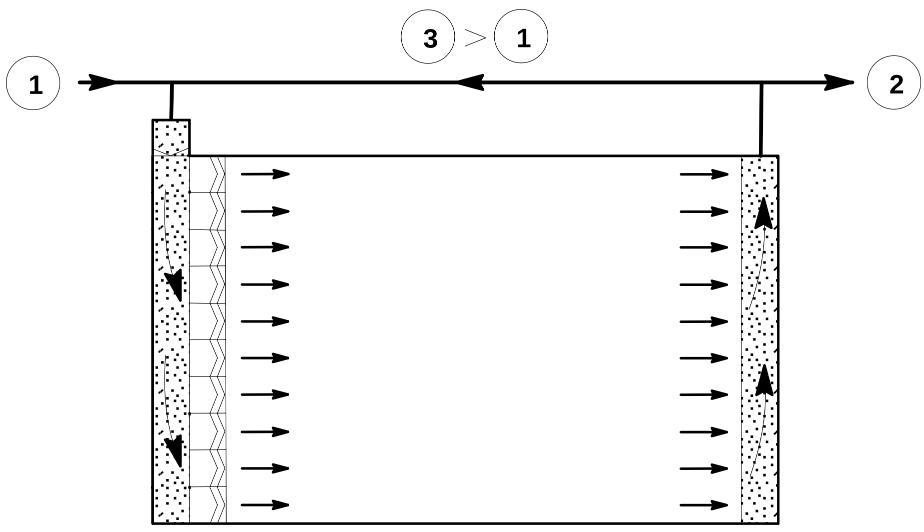
Legend:
1 Pre-treated outside air
2 Extract air

Fig. 14 Section through clean room with vertical flow, extracted via floor void



Legend:
1 Pre-treated outside air
2 Extract air
3 Circulated air

Fig. 15 Section through clean room with vertical fresh air supply and lateral air extraction



Legend:
1 Pre-treated outside air
2 Extract air
3 Circulated air

Fig. 16 Section through clean room with horizontal flow

Fig. 14 and Fig. 15 show clean room variations with unidirectional airflow directed vertically downwards and Fig. 16 with unidirectional airflow directed horizontally (laminar flow). Another variant with so-called filter-fan units is gaining increasing importance. With this system, the filters can be exchanged more easily and safely. The overpressure in the clean room ensures that falling dust particles cannot reach the clean room. The concept with filter fan units offers better and greater flexibility.

Legend:

Fan

Filter

1 Pre-treated outside air
2 Extract air
3 Circulated air

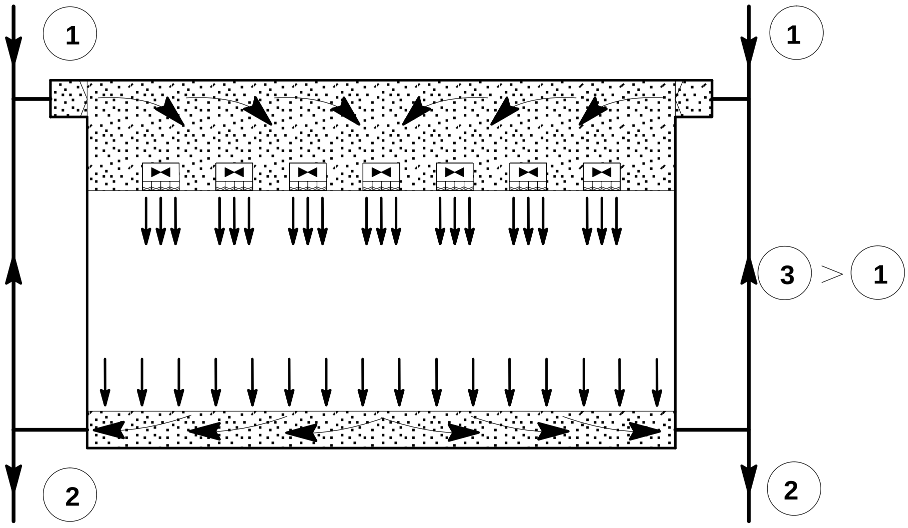


Fig. 17 Section through clean room with vertical flow and filter fan units

Normally, according to the principle of unidirectional airflow, air speeds of 0.3 to 0.5 m/s are required to ensure stable flow control. For that reason there are considerable quantities of air to be re-circulated here (approx. 600 air changes/hour).

6.2 Air change

Air cleanliness class	Number of air changes per hour (approx.)
10,000	15 – 30
1,000	20 – 60
100	70 – 300
10 and 1	600 – 700

To achieve the required air cleanliness class for new products, e.g. 16 Mbit DRAM, process-controlled equipment is placed in so-called „mini-environments". Only in these mini-environments is the highest air cleanliness class maintained, e.g. class 1 means that in a cube of air with sides 30 cm long, only one 0.5μm^3 particle is accepted. Due to this feature, in areas around the mini-environments a lower class can be tolerated without prejudice to the process.

6.3 Air speed

In order to guarantee the necessary stability, as a rule, unidirectional airflow in clean rooms requires air velocities of between 0.3 and 0.5m/s.

6.4 Pressure differences, overpressure, underpressure

6.4.1 Overpressure

In order to prevent the transport of contaminated air from one room to the neighbouring rooms (so-called cross-contamination) pressure differences are maintained between neighbouring workrooms. If the room has to be protected from the processes in its surroundings, then overpressure must be maintained in that room.

6.4.2 Underpressure

If, conversely, the surroundings have to protected against the contaminated air released in the workroom, then underpressure must be maintained in the room against the surroundings. The pressure difference between neighbouring rooms of differing air cleanliness is at least approx. 5 Pa (pascal); in the pharmaceutical industry, however, the authorities demand values of 10 – 15 Pa.
Note: 1 pascal is the pressure exerted vertically and uniformly on an area of 1m^2 by 1 newton. 1 newton is a unit of force that imparts an acceleration of 1 metre per second to a mass of 1 kilogram.

6.4.3 Room-in-room construction

Overpressure can help to prevent the infiltration of air contamination from outside into a building to be protected. At higher wind speeds and with the accompanying wind pressure on the building shell, such infiltration cannot be avoided. It is impossible to make fassades entirely air-tight.
That is the reason why room-in-room construction is preferred for clean room working areas, as a result of which infiltration can be intercepted in the corridors surrounding the clean room areas.

6.5 Operating mode of air handling systems

6.5.1 Continuous operation

Normally, clean room systems are continuously in operation, even outside working hours. The flow control principle must be guaranteed at all times. However, it is often switched to half power, e.g. with unidirectional airflow, at approx. 0.2m/s.

6.6 Air cleanliness classes

There are various national standards and guidelines with corresponding air cleanliness classes for the assessment of the cleanliness of room air. The air cleanliness classes are determined by measuring the particle concentration per volume unit for specific sizes of particle. At present the ISO (International Organization for Standardisation) is working on a harmonized standard which will supersede the following national standards:

U.S. Federal Standard 209
Internationally, this is the standard most complied with on this subject. Up to version 209D the standard was based on British units of mass, i.e. particle concentrations were given in the number of particles per cubic foot (ft^3). The currently valid version 209E contains two reference volumes, namely the cubic foot as before and the cubic metre in accordance with the metric SI unit.

NFX44-101 (France)
Definition, classification of air cleanliness and other gases in relation to their dust content, 1981

BS 5295 Part 1: 1989 (Great Britain)
The cleanliness of the air in closed rooms. An introduction to and terminology for clean rooms and clean room installations.

JIS B 9920 (Japan)
Measuring techniques for airborne particles in clean rooms and assessment criteria for air cleanliness in clean rooms, 1989

JIS B 9922 (Japan)
Clean workplaces, 1992

ISO/DIS 14644-1 Draft International Standard

This standard will supersede the various national standards. The work is at an advanced stage worldwide and and is about to be approved by the International and European standards committees ISO and CEN.

Air cleanliness class	Particle size in µm Maximum concentration value per m³ air					
N	≥ 0.1 µm	≥ 0.2 µm	≥ 0.3 µm	≥ 0.5 µm	≥ 1µm	≥ 5 µm
ISO 1	10	2				
ISO 2	100	24	10	4		
ISO 3	1,000	237	102	35	8	
ISO 4	10,000	2,370	1,020	352	83	
ISO 5	100,000	23,700	10,200	3,520	832	29
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293
ISO 7				352,000	82,200	2,930
ISO 8					832,000	29,300
ISO 9						293,000

VDI 2083 Guidelines sheet 1 (1995)

In these guidelines, dated April 1995, the air cleanliness classes 1 to 6 are practically identical to the corresponding air cleanliness classes of the U.S. Federal Standard 209D (Classes 1 to 100,000).

Limit concentration of particles per cubic meter (m^3) for air cleanliness classes

Air cleanliness classes	Particle sizes in µm						
n	≥ 0.1	≥ 0.2	≥ 0.3	≥ 0.5	≥ 1.0** 10^n	≥ 5.0	≥ 10.0
0	150	33	14	–	10^0		
1 (1)*	1500 (35)*	330 (8)*	140 (3)*	45 (1)*	10^1		
2 (10)*	15,000 (350)*	3,300 (75)*	1,400 (30)*	450 (10)*	10^2		
3 (100)*		33,000 (750)*	14,000 (300)*	4,500 (100)*	10^3		
4 (1000)*				45,000 (1000)*	10^4	300 (7)*	
5 (10,000)*				450,000 (10,000)*	10^5	3,000 (70)*	
6 (100,000)*				4,500,000 (100,000)*	10^6	30,000 (700)*	
7 ***					10^7	300,000	70,000

* Cleanliness classes and particle concentrations per cubic foot (ft^3) according to US Federal Standard 209D (for comparison)
** Reference particle size for the definition of classes (not to be measured!)
*** This class was primarily introduced in view of the assessment of clean rooms in rest condition.

7 Dangerous chemicals and gases

7.1 Dangerous gases

Gas	Formula	Comments / Hazards
Ammonia	NH_3	– flammable – toxic – corrosive
Arsenic Pentafluoride	AsF_5	– toxic – corrosive – oxidizing gas
Arsine	AsH_3	– extremely flammable – very toxic
Boron Trichloride	BCl_3	– very toxic – corrosive
Boron Trifluoride	BF_3	– very toxic – corrosive
Carbon Monoxide	CO	– extremely flammable – toxic
Carbon Tetrachloride	CCl_4	– low to moderate toxicity
Chlorine	Cl_2	– toxic – corrosive – strong oxidizing gas
Chlorine Trifluoride	CLF_3	– toxic – corrosive
Diborane	B_2H_6	– very toxic – extremely flammable – ignites spontaneously in moist air
Dichlorosilane	SiH_2Cl_2	– extremely flammable – corrosive
Dimethylzinc	$(CH_3)_2Zn$	– spontaneously flammable in air – reacts violently with water – corrosive
Disilane	Si_2H_6	– spontaneously flammable in air
Germanium hydride	GeH_4	– flammable – toxic
Hydrogen	H_2	– extremely flammable
Hydrogen Chloride	HCl	– toxic – corrosive
Hydrogen Selenide	H_2Se	– toxic – flammable
Hydrogen Sulfide	H_2S	– toxic – highly flammable
Nitrogen Trifluoride	NF_3	– toxic
Phosgene	$COCl_2$	– very toxic – corrosive
Phosphine	PH_3	– extremely flammable – very toxic

Gas	Formula	Comments / Hazards
Phosphorous Pentafluoride	PF_5	– toxic – corrosive – oxidizing gas
Silane	SiH_4	– very toxic – spontaneously flammable in air
Tetrachlorosilane	$SiCL_4$	– corrosive – react violently if mixed with water
Silicon Tetrafluoride	SiF_4	– toxic – corrosive
Tungsten Hexafluoride	WF_6	– toxic – corrosive

7.2 Inert gases

Gas	Formula	Comments / Hazards
Argon	Ar	– inerte (nonflammable)
Carbon Dioxide	CO_2	– inerte (nonflammable)
Nitrogen	N_2	– inert
Sulphur Hexafluoride	SF_6	– inert (nonflammable)
Xenon	Xe	– inert (nonflammable)

7.3 Other gases

Gas	Formula	Comments / Hazards
Nitrous Oxide	N_2O	– oxidizing gas
Oxygen	O_2	– powerfull oxidizing gas

7.4 Dangerous acids

Acids	Formula	Comments / Hazards
Sulphuric Acid	H_2SO_4	– highly corrosive – noncombustible, but contact with metals may produce highly flammable hydrogen gas
Hydrofluoric Acid	HF	– extremely corrosive – noncombustible, but contact with metals may produce highly flammable hydrogen gas
Ammonium Hydroxide	NH_4OH	– highly corrosive – the vapor is slightly flammable and ignites only with difficulties
Hydrogen Chloride	HCl	– highly corrosive – noncombustible, but contact with metals may produce highly flammable hydrogen gas
Hydrogen Peroxide	H_2O_2	– noncombustible, but contact with certain metals and many organic compounds can lead to fires and explosions
Phosphiric Acid	H_3PO_4	– corrosive – noncombustible, but contact with common metals may produce highly flammable hydrogen gas

7.5 Solvents

Solvents	Comments / Hazards
Isopropanol (IPA)	– flammable
Xylenes	– flammable

7.6 Other material

Material	Comments / Hazards
N-Bromoacetamide (NBA)	– white powder (probably combustible)

8 Terms, Definitions

Airborne contamination
Contamination of the air due to particles.

Airlock
Room with mutually bolted doors between two or more rooms of different cleanliness classes or different pressure levels. It may be designed for the movement of personnel or material.

Changing rooms
Rooms to change clothes before entering or leaving clean rooms and/or aseptic areas.

Clean room
A clean room in a manufacturing plant is an area which makes particularly strict demands on the cleanliness of the room air, the workplace, the process media as well as the personnel.

Clean workplace
A controlled area with a cleanliness level corresponding to a defined air cleanliness class. The personnel can stay either within the clean workplace (cleanroom) or outside (e.g. clean work bench or clean cubicle)
Different types of clean work places can be distinguished by size and structural demarcation, e.g.:

- clean room (personnel work in the room);
- clean cubicle (personnel only open the all-enclosed cubicle if required);
- clean room tent (clean area enclosed by foil);
- clean work bench (personnel take action but are situated outside);
- isolator (action only by means of gloves or half-suits).

Cleanliness
Air cleanliness at the work place is particulate cleanliness i.e. the absence of airborne contamination (particles) which appear as dust, mist, or micro-organisms. This cleanliness is defined by the particulate concentration per volume unit.

First air
Air entering the clean area through high-performance air filters or downstream distribution equipment.

Isolator
Pharmaceutical minienvironments are called isolators, and they permit, for the aseptic manufacture of medical products to obtain sterility assurance levels

Leak
A point in a filter element at which the local efficiency of the filter is lower than a given limit value.

Minienvironment
A compact localised enclosure with the purpose of isolating the process from its environment and from people.

Non-unidirectional airflow
An air handling method where first air entering the room mixes with the more contaminated indoor air by means of induc tion. This type of air handling results in a dilution of the particulate concentration (dilution air handling).

Particle size
The apparent maximum linear dimension of a particle.

Particle/particulate contamination
Minute objects of solid or liquid composition with defined physical limits.
Fibers are particles with a length/diameter ratio greater than 5.

Particulate concentration
Number of particles per volume of air (particles/m3) determined by the respective measuring technique.

SMIF-box
Standard Mechanical Inter-Face for the transport of wafers from one work station to another, thus avoiding the exposure of the wafers to room atmosphere.

9 Bibliography

- The Fundamentals of Clean room Design. Dr. Hans Schicht AG, CH-Zumikon 1998
- Reinraumtechnik VDI 2083 Blatt 1 und 2
- Clean room technology VDI 2083 Part 1 and 2
- Loss prevention data sheet on semiconductor fabrication facilities. Factory Mutual Engineering Corp. January 1997

Keyword index

Siemens Building Technologies AG
Alte Landstrasse 411
CH-8708 Männedorf
Phone +41 1 – 922 61 11
Fax +41 1 – 922 64 50
www.cerberus.ch