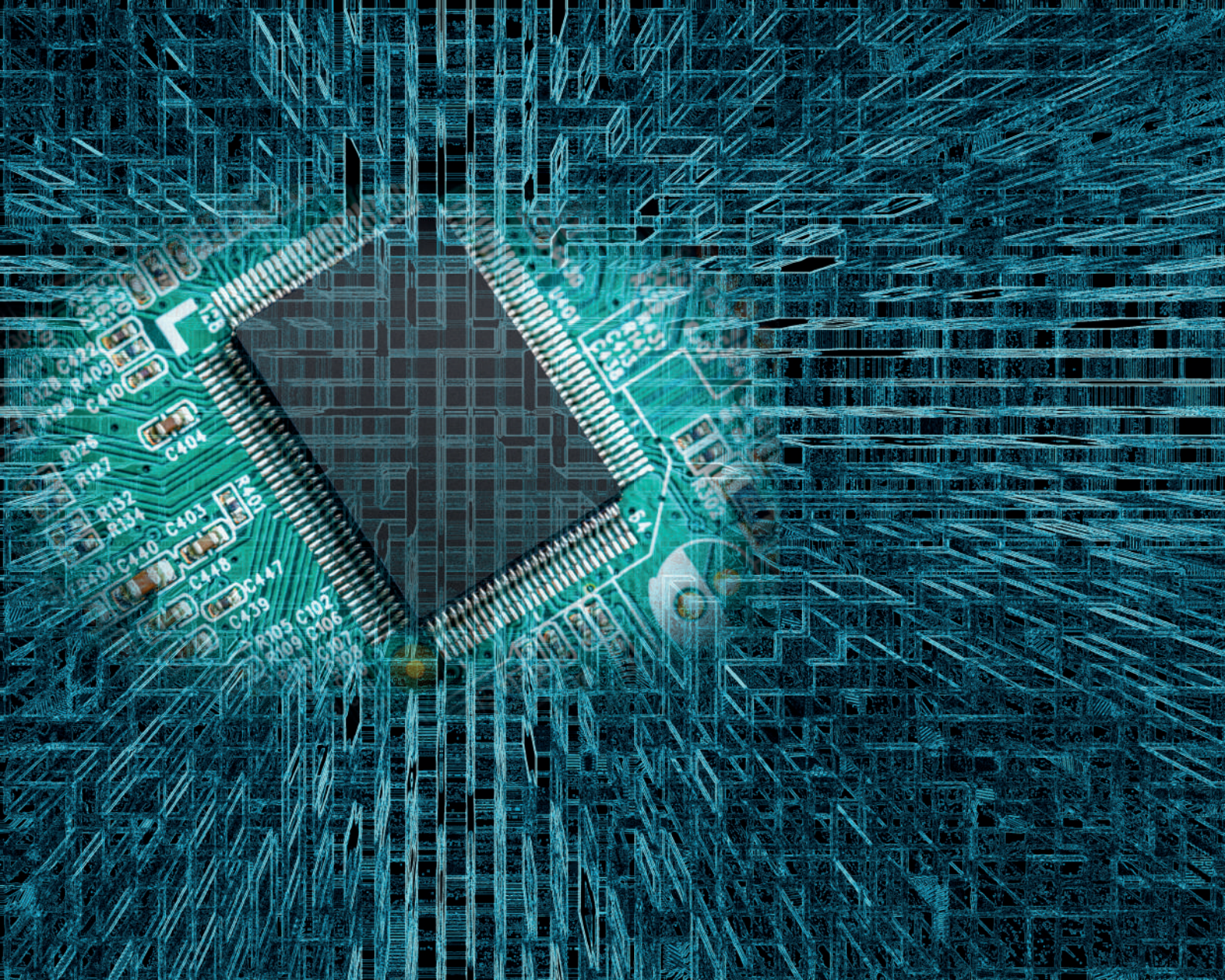


# TROX<sup>®</sup> TECHNIK

The art of handling air

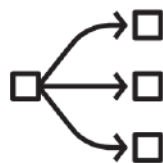
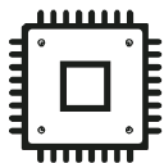


## **HVAC Systems for Microelectronics Industry**



## The Microelectronics Industry & HVAC Importance

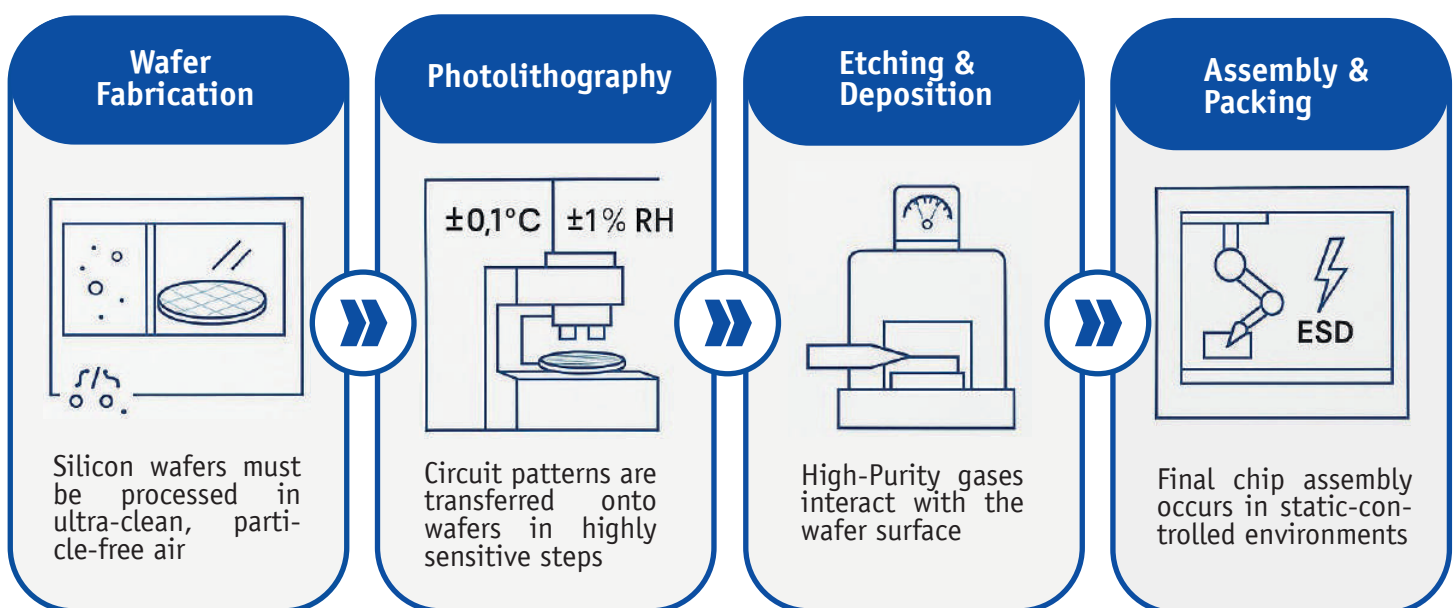
The microelectronics industry is fundamental to modern technology, producing semiconductors, integrated circuits (ICs), and microchips used in devices from consumer electronics to aerospace systems. These components are manufactured in highly controlled environments known as semiconductor fabrication facilities (fabs), where even minor environmental deviations can cause defects.



# Semiconductor Manufacturing Processes & Environmental Sensitivity

Each step of **semiconductor fabrication** demands precisely controlled **HVAC conditions** to ensure process stability and product integrity:

- 1. Wafer Fabrication:** Silicon wafers must be processed in ultra-clean, particle-free air to avoid contamination that could lead to circuit failures.
- 2. Photolithography:** Circuit patterns are transferred onto wafers in highly sensitive steps that require tight control of temperature ( $\pm 0.1^\circ\text{C}$ ) and relative humidity ( $\pm 1\% \text{RH}$ ) to prevent alignment errors and pattern distortion. These processes are carried out inside specialized equipment but depend on precise room conditions.
- 3. Etching & Deposition:** In this phase, high-purity gases interact with the wafer surface to build microscopic structures. Any temperature or airflow instability can alter chemical reactions and compromise yield.
- 4. Assembly & Packaging:** Final chip assembly occurs in static-controlled environments, where HVAC systems prevent electrostatic discharge (ESD) and maintain cleanliness.



**Environmental Control Across All Steps:** Particle count, temperature, and relative humidity must be consistently regulated in every phase. These parameters are critical to avoiding defects, ensuring chemical stability, and maintaining the cleanroom classification necessary for reliable semiconductor

# Why is Precision HVAC Critical in Semiconductor Manufacturing?

Semiconductor fabs require ISO Class 1–5 cleanroom conditions to achieve defect-free production. Any deviation in particulate levels, airborne molecular contamination, temperature, or humidity can compromise yield, causing significant financial losses.





ISO CLASS	Maximum Particles/m <sup>3</sup>						Particles/ft <sup>3</sup>	FS 209E Equivalent	Microelectronics Industry Application
	≥0.1µm	≥0.2µm	≥0.3µm	≥0.5µm	≥1µm	≥5µm	≥0.5µm		
ISO 1	10	-	-	-	-	-	-	-	EUV Lithography, advanced wafer fabrication
ISO 2	100	24	10	-	-	-	-	-	High-end semiconductor processing
ISO 3	1	237	102	35	-	-	1	Class 1	Etching, deposition, thin-film processes
ISO 4	10	2,37	1,02	352	83	-	10	Class 10	Assembly, testing, clean packaging
ISO 5	100	23,7	10,2	3,52	832	29	100	Class 100	Final assembly, quality control environments

## Cleanroom Challenges and HVAC Solutions for Semiconductor Manufacturing

### Challenge 1: Particulate Contamination

Even sub-micron particles can interfere with semiconductor processing. ISO Class 1 cleanrooms allow only 10 particles of 0.1 µm per cubic meter, compared to 35 million particles per cubic meter in typical office air.

The HVAC solution is:

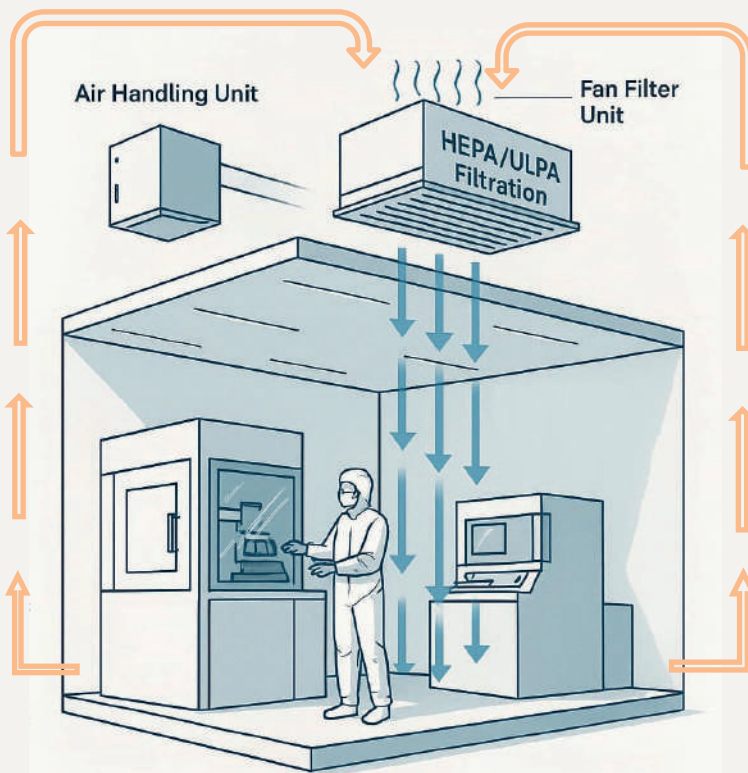
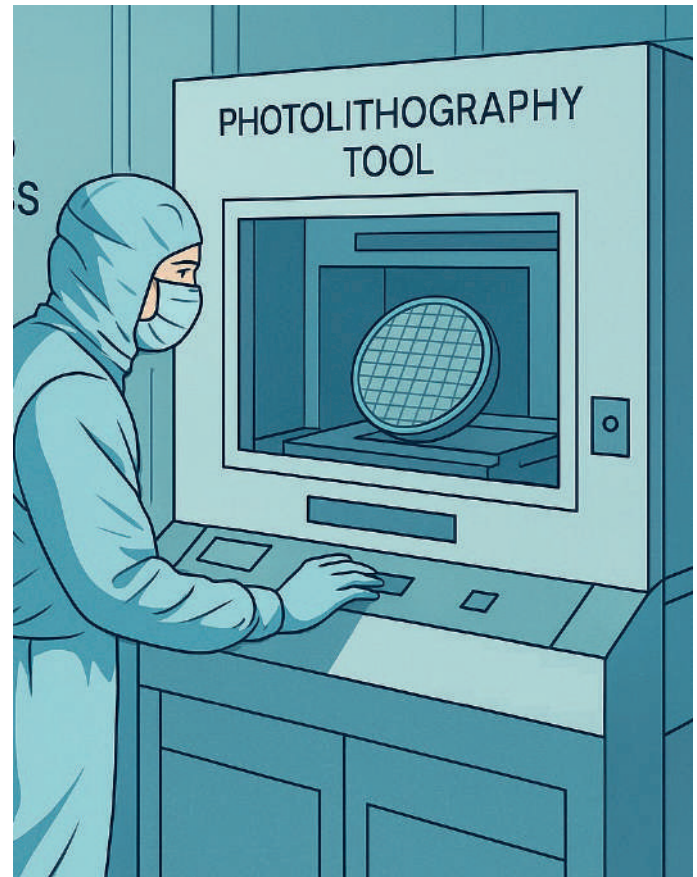
-  High-efficiency HEPA/ULPA filtration integrated into AHUs and Fan Filter Units (FFUs) to remove airborne particles and maintain ISO Class 1–5 conditions.
-  Laminar (unidirectional) airflow systems to deliver ultra-clean air vertically across critical zones, minimizing turbulence and particle deposition.
-  High air change rates using centralized AHUs and localized FFUs for continuous particle dilution and removal.
-  Low-outgassing construction materials in filters, ducts, and internal components to avoid introducing new contaminants.

## Challenge 2: Airborne Molecular Contamination (AMC)

Semiconductor processes involve high-purity gases that react with airborne contaminants such as HF (hydrofluoric acid), NH<sub>3</sub> (ammonia), VOCs (volatile organic compounds), and dopant gases. These reactions can lead to defects and reduced wafer yield.

The HVAC solution is:

- ✘ AMC control through gas-phase filtration media integrated into the AHU to capture molecular-level contaminants.
- ✘ Airflow zoning and differential pressure control, managed by the AHU and BMS, to prevent cross-contamination between zones.
- ✘ Continuous monitoring and replacement strategies to maintain effective AMC filtration performance over time.



## Challenge 3: Environmental Precision (Temperature & Humidity)

Small temperature or humidity fluctuations can cause lithographic pattern distortions, condensation, and oxidation, resulting in critical defects. Semiconductor fabs require:

- ✘  $\pm 0.1^\circ\text{C}$  precision for photolithography tools
- ✘ Sub-1% RH control for wafer drying and deposition processes

The HVAC solution is:

- ✘ Enclosed precision air handling units in ISO rooms with active temperature and humidity control.
- ✘ Desiccant dehumidification systems to maintain ultra-low humidity environments.
- ✘ Integrated climate control systems, often built directly into lithography tools, for ultra-precise local control.



#### Challenge 4: Equipment Heat Load

Semiconductor fabs generate extreme heat loads from process equipment (e.g., etching tools, lithography machines). Unmanaged heat buildup can disrupt cleanroom conditions and impact wafer processing.

The HVAC solution is:

- ✘ Chilled water and refrigerant-based cooling systems for direct process tool cooling.
- ✘ Dedicated exhaust systems to remove heat and chemical byproducts without affecting cleanroom air balance.
- ✘ Integration with facility cooling infrastructure to ensure stable thermal load management across all zones.

#### Challenge 5: Energy Efficiency & Sustainability

Semiconductor fabs are among the most energy-intensive industrial facilities, with HVAC systems consuming over 50% of total fab energy. Energy inefficiency can lead to high operational costs and environmental concerns.

The HVAC solution is:

- ✘ Variable air volume (VAV) systems to modulate airflow based on real-time demand.
- ✘ Energy recovery systems that capture and reuse heat from exhaust streams.
- ✘ Smart HVAC integration with the Building Management System (BMS) for real-time optimization of airflow, temperature, and energy consumption.
- ✘ Optimized filter design to get lower pressure drops.

# Standards & Regulations for Cleanroom HVAC in Microelectronics

Why is Compliance with Standards Essential in Semiconductor Cleanrooms?

In the U.S., semiconductor manufacturing must comply with stringent cleanroom HVAC standards to ensure contamination control, process stability, and energy efficiency. These standards define airborne particulate limits, AMC (Airborne Molecular Contamination) thresholds, airflow design, and HVAC system efficiency to maintain high-yield production environments.

Failure to meet these standards can result in increased defect rates, equipment failures, and regulatory penalties, making compliance a critical priority for semiconductor fabs.

The primary U.S. regulations governing cleanroom HVAC in microelectronics include:



- ✕ ISO 14644 – Cleanroom air cleanliness classification. ISO 14644 is the globally recognized cleanroom classification system, widely adopted in the U.S. semiconductor industry. It establishes maximum allowable particle concentrations based on the cleanroom class designation.
- ✕ SEMI Standards (F21, E44, E52) – Microelectronics-specific contamination control. The Semiconductor Equipment and Materials International (SEMI) Standards provide industry-specific cleanroom and HVAC guidelines tailored for wafer fabrication, lithography, etching, and deposition processes.
  - SEMI F21: Airborne Molecular Contamination (AMC) control limits for semiconductor manufacturing environments.
  - SEMI E44: Airflow uniformity requirements for cleanroom ventilation systems to prevent contamination
  - SEMI E52: Filtration performance standards for removing particulates and molecular contaminants in semiconductor HVAC systems.
- ✕ ASHRAE 90.1, 62.1 & 170 – Energy efficiency and ventilation requirements
  - ASHRAE 90.1 – Energy Efficiency: HVAC systems must meet minimum efficiency requirements to reduce power consumption without sacrificing performance.
  - ASHRAE 62.1 – Ventilation & Air Quality: Defines minimum outdoor air ventilation rates for clean environments.
  - ASHRAE 170 – Cleanroom Ventilation: Specifies airflow rates, air changes per hour (ACH), and pressure differentials for controlled environments.

**X** IEST RP (Recommended Practices) – Filtration, airflow, and cleanroom operation.

Key IEST Recommended Practices for HVAC in Semiconductor Fabs

- IEST-RP-CC001.6 – HEPA/ULPA filter efficiency standards.
- IEST-RP-CC002.5 – Testing and certification protocols for HEPA/ULPA filters.
- IEST-RP-CC006.3 – Airflow uniformity testing in cleanrooms to prevent contamination risks

## TROX: The Leader in HVAC Solutions

TROX specializes in high-performance HVAC components that can be applied for semiconductor manufacturing, ensuring compliance with ISO, SEMI, and ASHRAE standards while delivering energy-efficient, precision-controlled cleanroom environments.

TROX regulatory compliance for the Microelectronics Industry:

Regulation/Standard	Requirement	TROX Solution
ISO 14644	Cleanroom classifications & particle control	HEPA/ULPA filtration, FFUs, AMC filtration
SEMI F21	Airborne Molecular Contamination (AMC) limits	Gas-phase filtration in AHUs FFUs
SEMI E44	Airflow uniformity & laminar flow requirements	Precision airflow diffusers
SEMI E52	Minimum filtration efficiency for semiconductor fabs	High-performance HEPA/ULPA filters
ASHRAE 90.1	Energy-efficient HVAC design	Energy recovery AHUs, smart VAV systems
ASHRAE 62.1	Ventilation & air quality	Demand-controlled airflow, optimized air changes per hour (ACH)
IEST-RP-CC001.6	HEPA/ULPA filter performance & maintenance	TROX-certified HEPA/ULPA filters
IEST-RP-CC006.3	Airflow uniformity testing	Optimized diffuser placement








Air supply, filtration (pre-/mid-level), heating/cooling, and distribution to cleanroom system






## TROX X-CUBE Air Handling Units (AHUs)

TROX X-CUBE Air Handling Units (AHUs) provide the primary source of conditioned, ultra-clean air for semiconductor ISO cleanrooms. These high-efficiency AHUs integrate HEPA/ULPA filtration, temperature and humidity control, and airborne molecular contamination (AMC) mitigation into a single system.

Applications in Semiconductor Manufacturing:

-  ISO Class 1–5 cleanrooms – Provides primary air supply with precise environmental control.
-  Lithography & wafer patterning – Maintains stable temperature and humidity for the ISO rooms to prevent process variations.
-  Deposition & etching – Prevents contamination from unwanted chemical interactions.

Industry Compliance:

-  ISO 14644 – Ensures air cleanliness and pressure control standards are met.
-  SEMI F21 – Adheres to airborne molecular contamination limits.
-  ASHRAE 90.1 – Meets energy efficiency requirements for cleanroom HVAC systems.

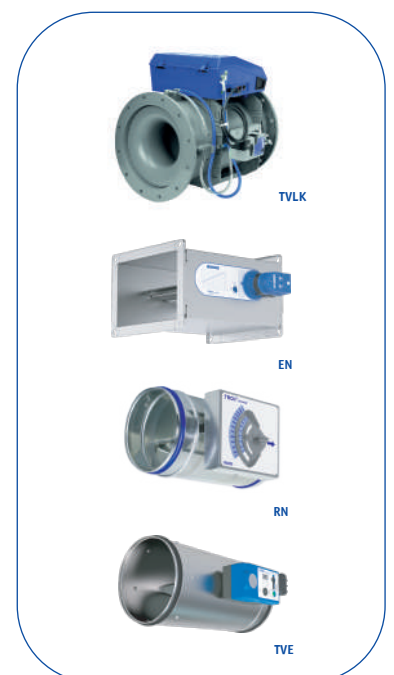
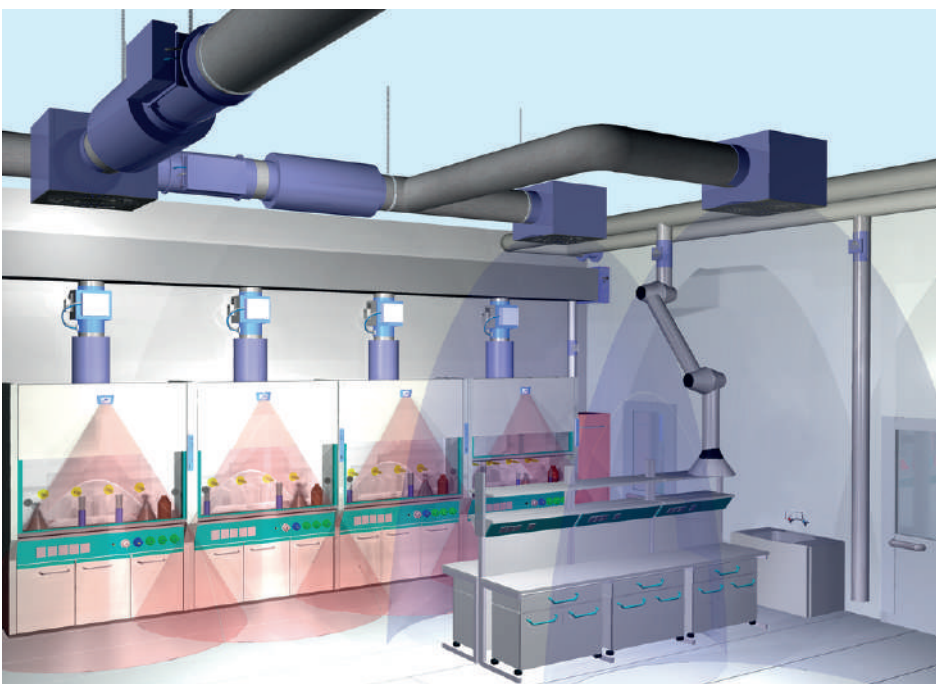
# TROX Variable Air Volume (VAV) Control Systems and LABCONTROL

TROX's Variable Air Volume (VAV) control systems are designed to optimize airflow rates in HVAC systems by dynamically adjusting the volume of air delivered or extracted in real time, ensuring precise control over temperature, humidity, and air quality while maximizing energy efficiency. Complementing this, the LABCONTROL system provides a modular air management solution specifically developed for cleanrooms and laboratories, offering enhanced volume flow balancing and accurate control of fume cupboard airflow—boosting both safety and environmental stability in critical applications. Applications in Semiconductor Manufacturing:

- ✘ Cleanroom Environments: VAV systems maintain the required airflow rates to uphold ISO Class 1–5 cleanroom standards, crucial for minimizing particulate contamination during semiconductor fabrication.
- ✘ Process-Specific Zones: Adjustable airflow ensures optimal conditions for various processes, such as maintaining higher airflow rates in areas with elevated particulate generation and lower rates in less critical zones.

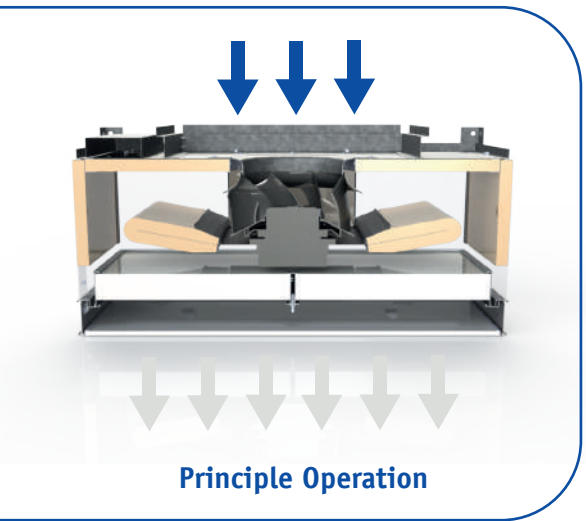
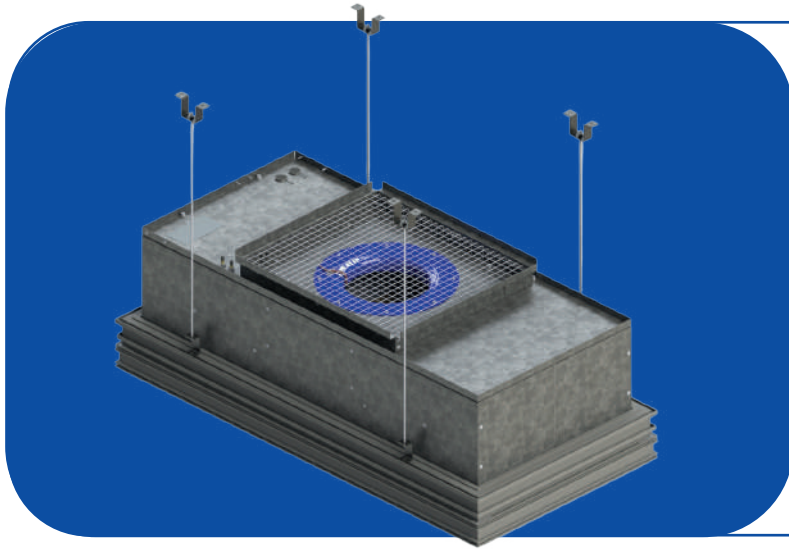
Industry Compliance:

- ✘ ISO 14644: Ensures adherence to cleanroom particulate cleanliness classifications.
- ✘ SEMI Standards (F21, E44, E52): Aligns with semiconductor industry-specific guidelines for contamination control and airflow uniformity.
- ✘ ASHRAE 90.1: Meets energy efficiency requirements for HVAC systems in commercial buildings.

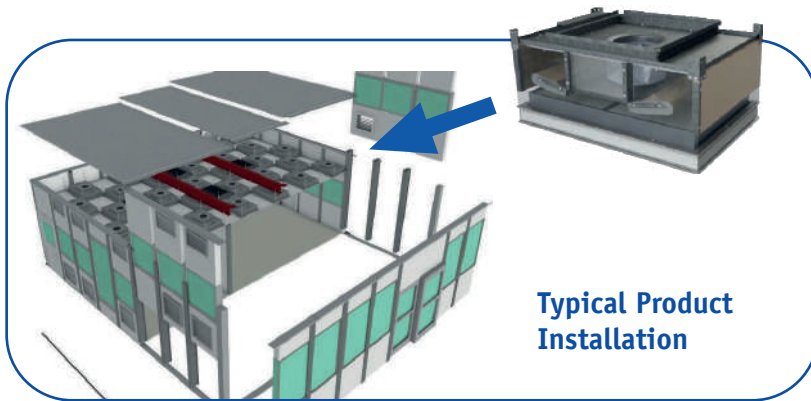


Function: Regulate airflow volume (variable or constant) to match room demands and maintain ISO classification

# TROX Fan Filter Units (FFUs) – FFT-TC Model



Principle Operation



Typical Product Installation

The TROX FFT-TC Fan Filter Unit (FFU) is designed to deliver ultra-clean, laminar airflow directly over critical areas in semiconductor cleanrooms and other controlled environments. These units integrate high-efficiency filtration, low-noise airflow, and scalable modularity to maintain particle-free conditions and meet ISO 5 – ISO 9 air cleanliness classifications.

## Applications in Semiconductor Manufacturing

TROX FFT-TC FFUs ensure clean, uniform airflow and contamination control in critical semiconductor fabrication processes, including:

- ✘ Photolithography & Wafer Exposure – Protects delicate circuit patterns from airborne contamination.
- ✘ Etching & Deposition Areas – Maintains stable laminar airflow, preventing particle deposition.
- ✘ Cleanroom Ceiling Integration – Provides point-of-use ultra-clean air, ensuring airborne particulate control in localized areas.

## Industry Compliance & Certifications

TROX FFT-TC FFUs adhere to strict international cleanroom and air handling standards, including:

- ✘ ISO 14644 – Defines cleanroom particle control and airflow consistency.
- ✘ SEMI E44 – Ensures airflow uniformity for semiconductor cleanroom processes.
- ✘ IEST-RP-CC001.6 – Establishes performance standards for HEPA/ULPA filtration.
- ✘ 21 CFR Part 11 (Optional HMI Integration) – For audit trail compliance in pharmaceutical applications.

# TROX High-Efficiency Filtration (HEPA/ULPA & PTFE Filters)

TROX filtration solutions provide high-performance protection against both particulate matter and airborne molecular contaminants (AMC), ensuring cleanroom compliance for semiconductor manufacturing. HEPA (99.97% at  $0.3\mu\text{m}$ ) and ULPA (99.9995% at  $0.1\mu\text{m}$ ) filters, integrated into FFUs and AHUs, deliver ISO Class 1–5 air quality with low airflow resistance and long service life, meeting IEST and ISO 14644 standards. For AMC control, PTFE filters offer chemical resistance, while gas-phase filtration using activated carbon and impregnated alumina media effectively removes HF,  $\text{NH}_3$ , VOCs, and dopant gases at the source.



Applications in Semiconductor Manufacturing:

- ✕ ISO Class 1–3 zones – Used in lithography, etching, deposition to ensure extreme cleanliness.
- ✕ Wet processing areas – Filters out chemical vapors and particulates.
- ✕ Photolithography tools – Prevents molecular contamination from distorting UV exposure patterns.

Industry Compliance:

- ✕ ISO 14644 – Particulate contamination limits.
- ✕ SEMI F21 – AMC control for semiconductor fabs.
- ✕ IEST-RP-CC001.6 – Filtration efficiency certification.



Function: Final HEPA/ULPA filtration at point of air entry into cleanroom space, ensuring ISO-classified air quality



Function: Monitor room pressure, flow, and provide automated control of VAV/CAV systems

## TROX Smart HVAC Control & Building Management System (BMS) Integration

TROX's Smart BMS-integrated HVAC controls enhance cleanroom performance in semiconductor fabs by continuously monitoring key air quality parameters such as particles, AMC, temperature, and humidity. These systems enable automated airflow adjustments through smart VAV technology, adapting to real-time process demands. The integrated platform also supports maintenance planning and energy optimization, reducing power consumption while ensuring compliance with strict cleanroom standards.

Applications in Semiconductor Manufacturing:

- ✘ ISO Class 1–5 cleanrooms – Ensures constant environmental monitoring.
- ✘ Energy-intensive fabs – Optimizes HVAC operation to reduce costs.
- ✘ Contamination-sensitive zones – Automates adjustments based on particle and AMC levels.

Industry Compliance:

- ✘ ASHRAE 90.1 – Energy-efficient HVAC standards
- ✘ ISO 14644-2 – Continuous cleanroom monitoring requirements
- ✘ IEST-RP-CC006.3 – Airflow performance validation



## Why Choose TROX?

TROX stands out as the industry leader in cleanroom HVAC solutions for semiconductor fabs due to its innovative engineering, energy-efficient designs, and compliance with the highest industry standards.

### 1. Unmatched Cleanroom Air Quality & Contamination Control

- ✘ ISO 14644-1 compliance with integrated HEPA/ULPA filtration, FFUs, and AMC gas-phase removal.
- ✘ Particulate-free & low-outgassing materials for critical semiconductor processes.
- ✘ Smart airflow zoning & pressure control to prevent cross-contamination.

### 2. Precision for Temperature & Humidity Control

- ✘ Temperature and humidity control for ISO rooms.
- ✘ Desiccant dehumidification for ultra-dry processing environments.
- ✘ BMS integration for automated temperature/humidity monitoring & adjustments.

### 3. Energy-Efficient & Sustainable HVAC Systems

- ✘ ASHRAE 90.1 compliance with energy recovery, VAV control, and demand-based airflow adjustment.
- ✘ Lower operational costs with optimized fan efficiency and reduced HVAC power consumption.
- ✘ Heat recovery & smart exhaust management for minimized energy waste.

### 4. Advanced Smart Monitoring & BMS Integration

- ✘ Real-time data tracking of air quality, pressure, and molecular contamination.
- ✘ Predictive maintenance & AI-driven filter replacement alerts reduce downtime.
- ✘ Remote HVAC control & automation for optimal efficiency.

### 5. Compliance with the Most Stringent Semiconductor Industry Standards

- ✘ ISO 14644-1 & 14644-2 – Cleanroom classification & continuous monitoring.
- ✘ SEMI F21, E44, E52 – AMC control, airflow uniformity, and filtration performance.
- ✘ ASHRAE 90.1 & IEST RP – Energy efficiency, HEPA/ULPA testing, and airflow validation.

## Providing support with TROX AHU configurations and selections

The wide range of custom and semi-custom AHU options and configurations can seem overwhelming. TROX has a dedicated team of consultants and engineers to support the design process and guide clients through the portfolio.

Based on project requirements, they select and layout feasible options, define components, and assess the air treatment process. TROX partners with well-known suppliers to ensure high-quality components in every product.

The Eurovent certification for TROX AHUs goes beyond casing standards; it verifies that the selection tools are continuously validated for accuracy, ensuring that units built using these tools perform as specified. Contact our team, and they will be on board to tackle your most challenging AHU and air treatment requests.

## EASY Product Finder

Fast, reliable and innovative. TROX's Easy Product Finder software has become a vital tool in the construction services engineering industry. The user concept is intuitive and friendly. Users have the ability to freely design and configure individual workspaces.



## TROX X-BIM CAD BROWSER

The TROX X-BIM CAD Configurator is a tool developed by TROX to simplify project design. It provides a fast and secure way to obtain data records for TROX components, making them easy to integrate into your BIM project applications. The configurator interfaces with the Easy Product Finder (EPF) software. Download it from the TROX website to enhance your project efficiency.



## Walkair

We are proud to partner with Walkair US LLC, whose team brings vast expertise in designing and supporting clean rooms and laboratories. With years of experience solving complex challenges, Walkair enhances our ability to deliver top-tier solutions.

TROX's global team works closely with designers and engineers, helping them select the optimal components from our extensive portfolio.

Thanks to our worldwide manufacturing presence and sales offices on every continent, we guarantee product availability wherever your project may be. From air handling units (AHUs) to air diffusers, we offer a single-source solution that ensures high-end HVAC systems function flawlessly—without the risk of redesigns due to component shortages across borders.

**TROX<sup>®</sup> TECHNIK**  
The art of handling air

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