VisionAir Clean for Cleanroom Air Change Rate Optimization

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ABSTRACT

A challenging decision in the cleanroom design process is how to determine the required supply air volume to achieve the target cleanliness classification in a given application. Historically, these decisions are made based on experience and following practices or guidelines that have evolved from multiple sources which we can today say have been conservative at best.

Following these practices may supply enough clean air to meet the classification requirements, however at the expense of overdesigning the system with higher capital costs and by default higher operating costs than necessary. AAF Flanders has developed a scientific approach to this problem for predicting the contamination in a cleanroom based on sources of particle generation, air filter efficiency and air change rates.

VisionAir Clean is a web based application that allows the user to see factors that impact indoor air quality and energy consumption related to the air filtration system. Starting from the PM 2.5 levels in the outdoor environment, this program displays the particle count in a room as a function of the air change rate and compares it to the selected cleanliness standard requirements. VisionAir Clean also accounts for particle generation within the clean space, such as people in various garment types and process related contamination, and shows the changes in contamination as inputs are modified. In summary, VisionAir Clean is an easy to use air filtration, air change rate and contamination simulation software that was developed to allow the user, for the first time, to optimize system economy and system integrity always with sustainability in mind throughout the design and selection journey.

KEYWORDS: Air Filtration, Cleanroom Air, HEPA Filter, Life Cycle Cost, Optimization

BACKGROUND on Outside Air Contamination

First step is to quantify the outdoor air quality with information readily available from local government agencies such as the EPA or measured with sensors on site.

Table 1 – Average particulate matter concentration in different regions

Region	Residential	Country	Heavy Industrial	Urban - Highly Polluted
Annual Average PM10 (μg/m³)	20 - 25	10 - 20	25 - 50	> 50
Annual Average PM2.5 (μg/m³)	10 - 15	5 - 10	15 - 40	> 30

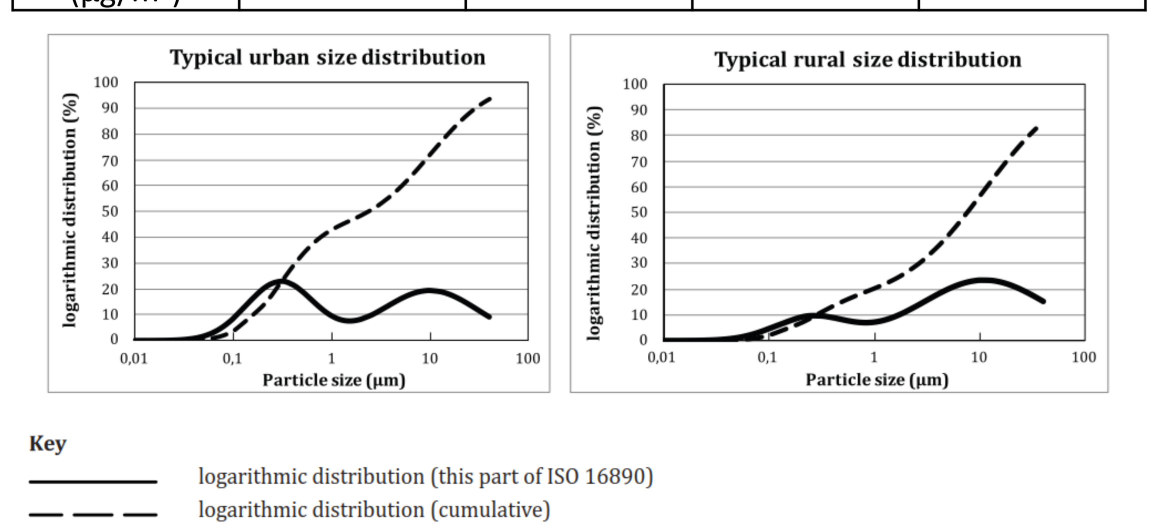
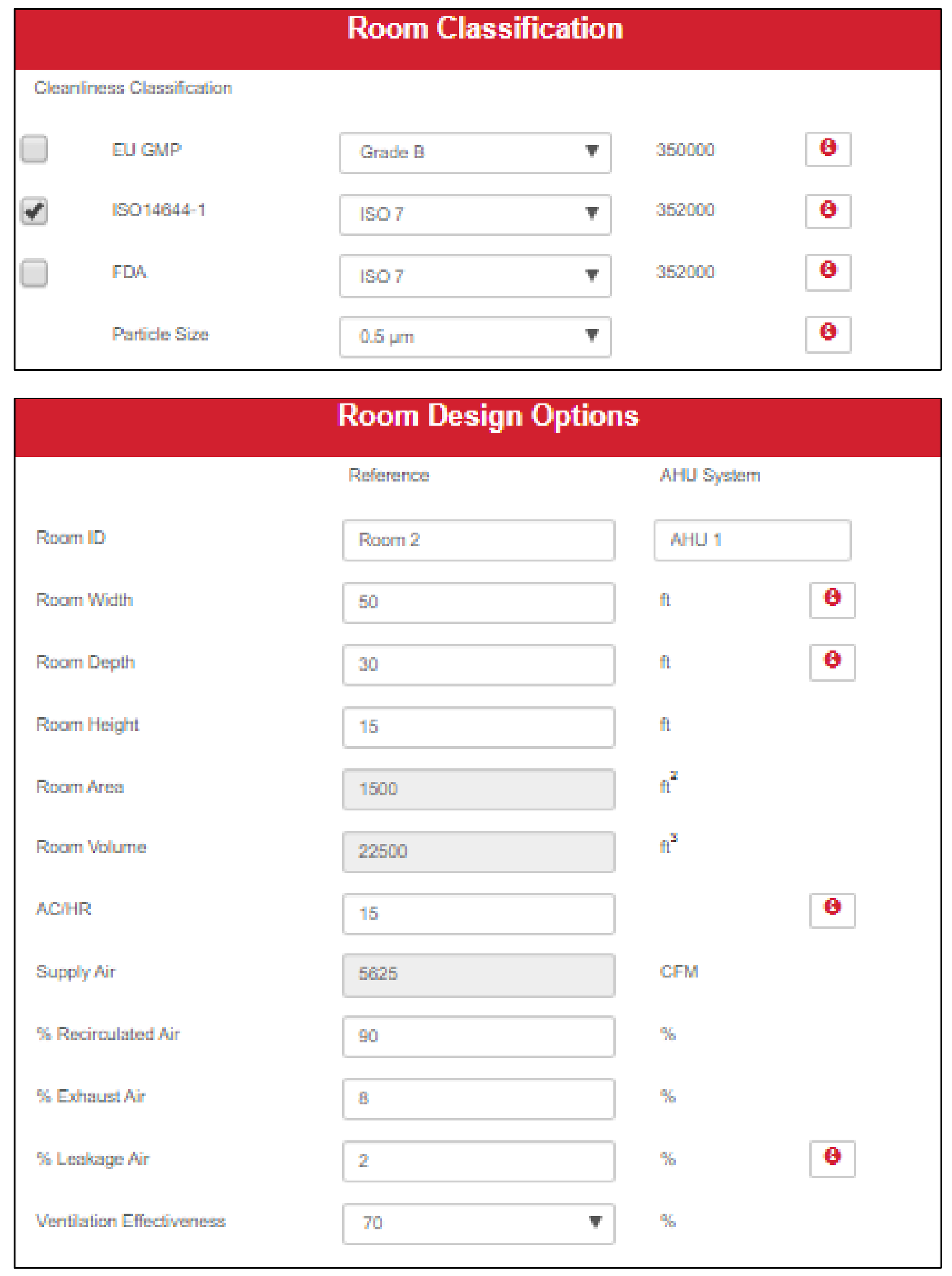


Figure 1. Typical particle size distribution from ISO 16890-1 air filtration test standard

BACKGROUND on Contamination Inside Room and Air Change Rate

Particle generation within the room also needs to be quantified. One of the largest sources of particulate is from people working inside the rooms, dependent on the types of garments they are wearing and the level of activity as illustrated in Table 2.

The primary way to remove contamination from the room is to displace it with clean air. This is quantified by a number of air changes per hour (AC/HR), defined as the number of times the room's volume worth of air is supplied into the room in one hour. Figure 2 shows the flow of the air into and out of the cleanroom and the contamination sources (people) in the room. Each filter stage in the diagram can be selected to add, remove or change the efficiency rating to observe the effect on the contamination level within the room.



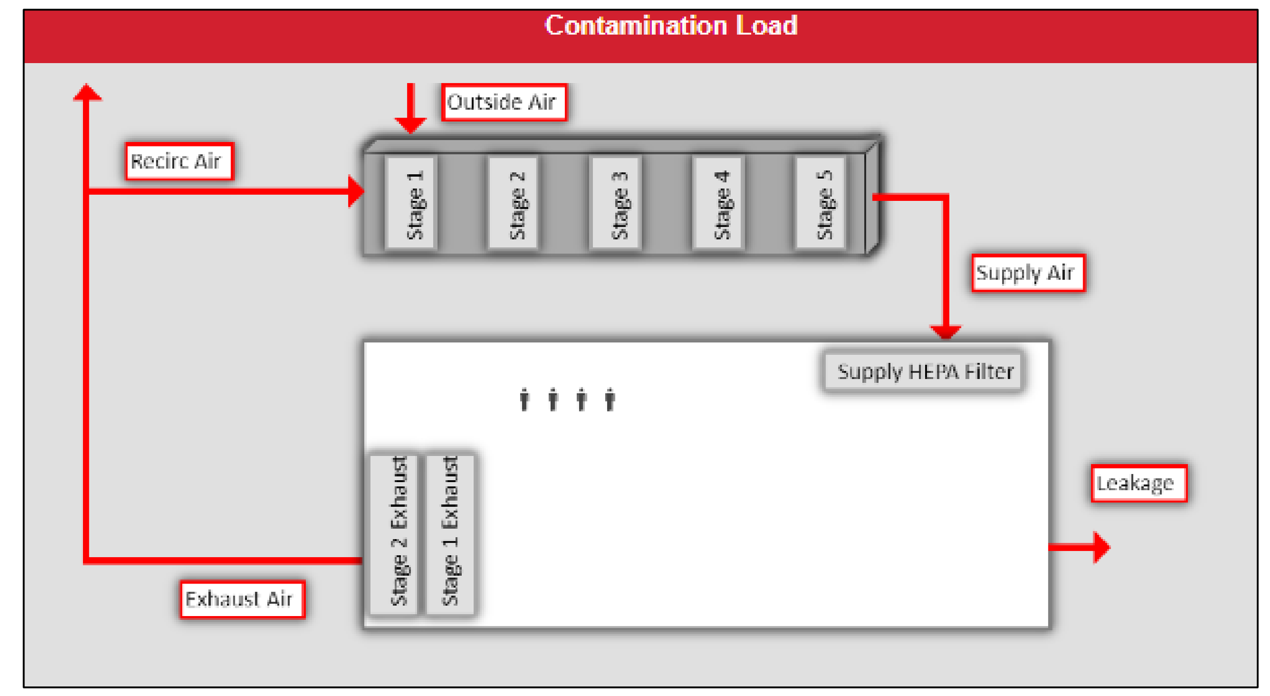


Table 2 – Particle dispersion form people in cleanrooms with different clothing types

Type of Garments	Description	Average Particle Dispersion, counts/s per person		
		≥ 0.5 μm	≥ 5.0 μm	MCP
Normal Clothes	Two piece scrubs, mob caps, shoes, controlled laundry cycle, change to fresh set daily	35,500	5,500	40
Typical Coveralls	One piece smock, over-boots, hood, gloves, mask, glasses, decontamination cycle, change to fresh set daily	17,000	600	3
High Quality Cleanroom Garments	One piece coverall, over-boots, hood, gloves, mask, goggles, sterilized by irradiation, change to fresh set with each entry	1,000	100	0.5

Figure 2. User inputs on VisionAir Clean interface.

RESULTS AND DISCUSSION – Cleanroom Contamination

The flow of clean air into the room is quantified as a volumetric rate, if the room volume is also known, then the amount of contamination in the room can be estimated by using the equation below:

$$C = \frac{D}{VE * Q_s}$$

- **C** is the amount of contamination in the room (counts/m³)
- **D** is the dispersion of contamination from sources (counts/s)
- **VE** is the ventilation effectiveness
  - Related to the mixing of the air within the room
- **Q_s** is supply rate of air into the room (m³/s)

In the figure below, the graph displays how the contamination level in the room is decreased with an increase of air change rate in the room.

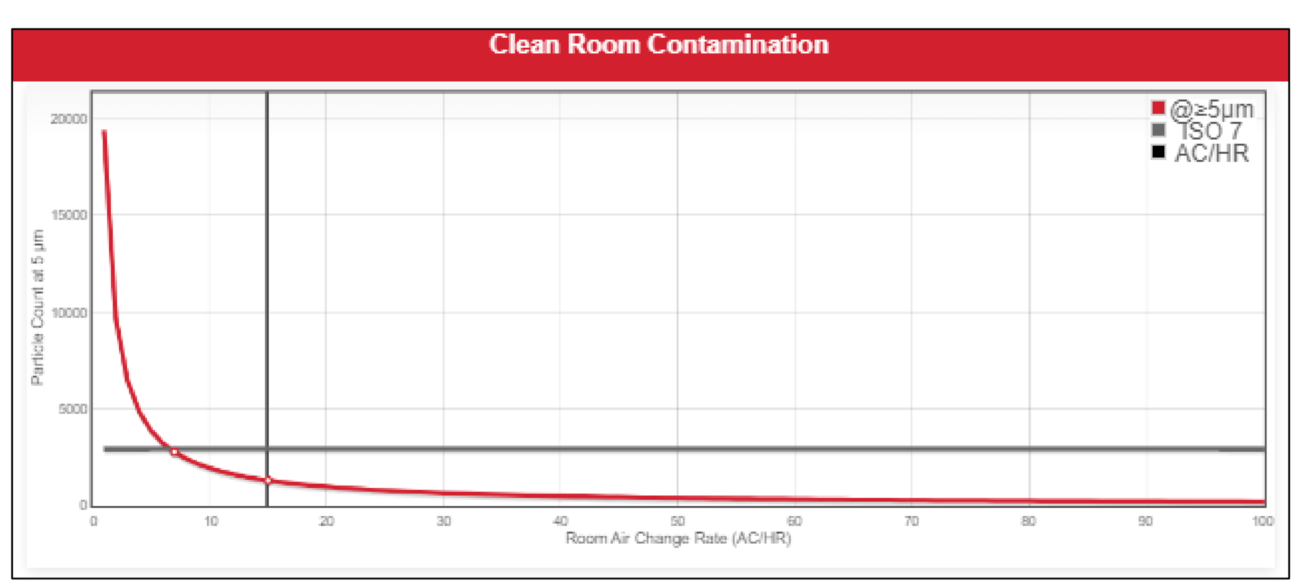


Figure 3. Cleanroom contamination level

RESULTS AND DISCUSSION – Recovery TIme

Another important factor for cleanroom classification calculations is the recovery time, i.e. the time it takes from a room in operation to return to an at rest state when all contamination generating activity is ceased. The equation to calculate this recovery time is below:

$$C = C_0 e^{-Nt}$$

- **C** is the room contamination after time **t**
- **t** is the elapsed time in hours
- **C_0** is the initial room contamination concentration (t=0)
- **N** is the room supply air change rate (AC/HR)

In the figure below, the graph displays how long it takes for the room to recover.

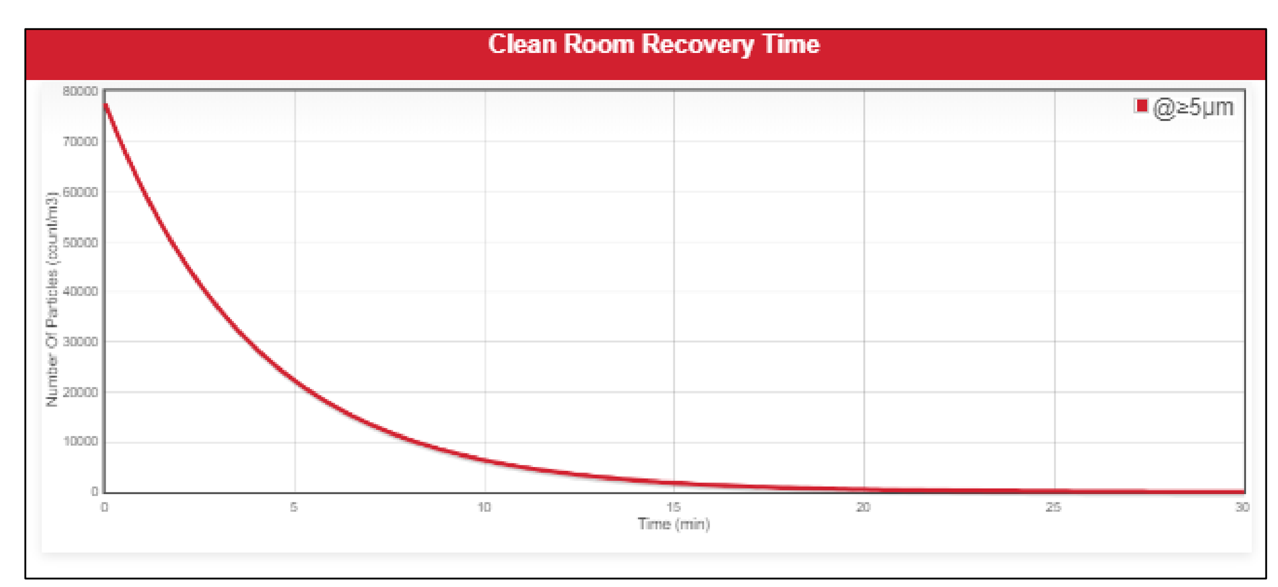


Figure 4. Cleanroom recovery time

RESULTS AND DISCUSSION – Energy Impact on Filter Selection

Energy consumption of the air filter system can be calculated from the average pressure drop over the filter's lifecycle and the total system air flow. Using the equation below, it can then be determined that filters with a lower pressure drop and higher capacity for dust loading can improve the total cost of ownership of the filters.

$$E = \frac{Q * \Delta P_{avg} * t}{Fan\ Efficiency * 1000}$$

- **E** is the filter energy consumption (kWh)
- **Q** is the total system air flow (m³/h)
- **ΔP_{avg}** is the filter's average pressure drop (Pa)
- **Fan Efficiency** is the fractional fan efficiency

In the figure below, the graph displays how the filter's total cost of ownership can be quantified.

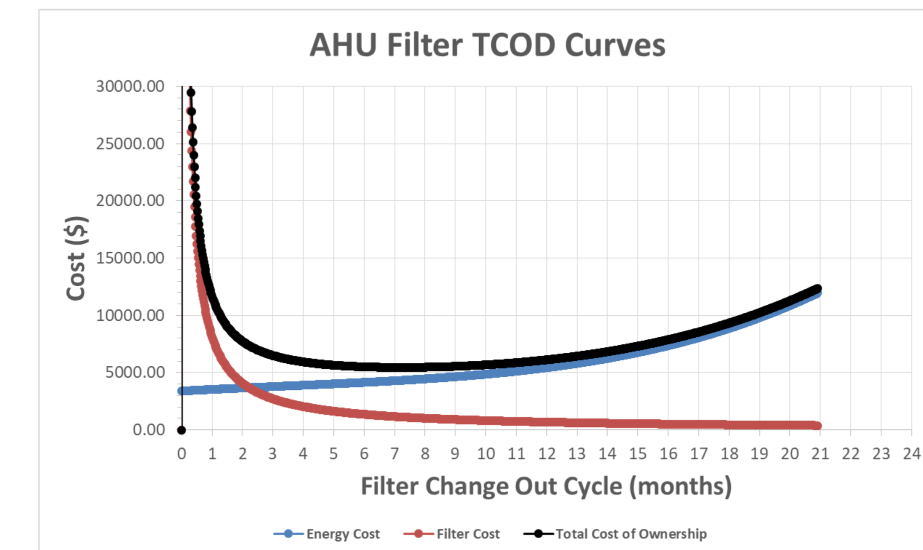


Figure 5. Total cost of ownership curves

This energy cost analysis can also be applied to the resistance from filters and housings that supply air into a cleanroom.

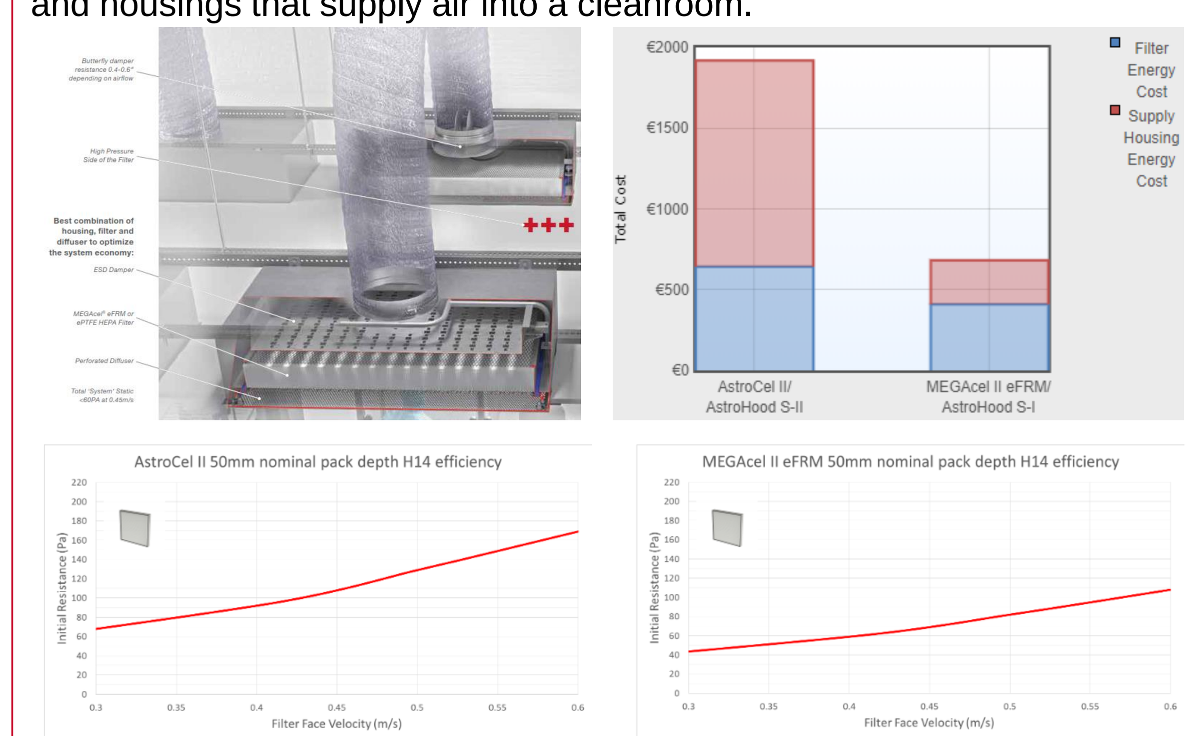


Figure 6. Energy cost evaluation of cleanroom air supply components

CONCLUSION

Combining information on HVAC filters, HEPA supply filters and cleanroom classifications, we are able to provide a full filtration system solution with VisionAir Clean. The goal of this program is to help end users and specifiers better understand how air filtration decisions (filter selection, change-out cycle, air flow rate, etc…) can have an impact on total cost of ownership while at the same time make science based decisions on optimizing air change rates.

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