AAF | Flanders

Bringing clean air to life.

Ensure Optimal System Integrity and Economy

System Integrity and System Economy

Is it the filter integrity that's important or is it the system integrity?

What % of leaks are in the filter media? Is it the frame of the filter? The seal? Which seal? The housing to filter seal? The housing to grid/ceiling seal? The media to the frame? The gasket seal? The gel seal? Is the room positive or negative? Is the leak nothing to do with the filter but is from entrainment of particles from a different source? Is the leak from an adjacent housing or filter? Is it from a nearby door? Is it through the light fixture? The list goes on, we are sure many certifiers reading this will add some additional 'traveling leak' stories.

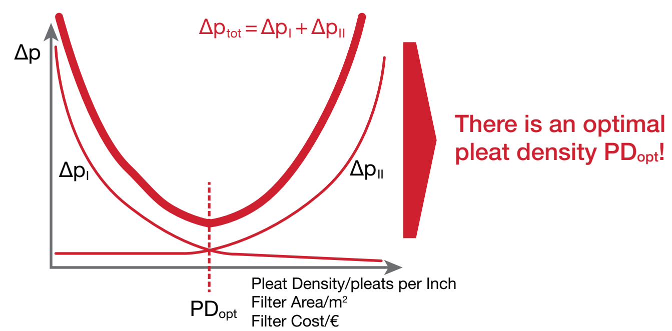
The point being, the filter is only as good as the housing or frame it is mounted in and by default, the frame or housing is only as good as the ceiling or unit they are mounted in, so yes. It's the SYSTEM integrity that's important.

Filter + Housing + Seal = SYSTEM INTEGRITY.

We'll come back to what to look for when we discuss system integrity later. Let's first review what we mean by system economy. What does the perfect filter look like? It has 100% efficiency, zero resistance and lasts forever! We in the filter industry are fixated on reducing the resistance in the finished filter by normally optimizing the configuration or construction of the finished product. This is not a negative but there are limitations today in the type of media commercially available (there are some new developments we'll touch on later with membrane technology) and how much **effective** filter media can be configured in a way that makes technical and commercial sense. We highlighted the word effective for a reason. More media does not always mean less resistance, slower media velocity and higher efficiency. It is the optimum use of media in a given boundary (pack depth, density, outer frame and so on) that ensures best performance.

Depending on the filter type and design (both 'good and bad' design) the construction (how the manufacturer pleats a pack, shapes a pocket, what frame design/type is used and so on), resistance or pressure drop can exceed in some cases 60-70% of the initial pressure drop of the filter. In other words the flat sheet media before it is converted into a pack, or pocket, is only 30% of the initial pressure drop and the construction pressure drop is 70%. That said, generally speaking it's about a 50/50 split so there is equal opportunity to optimize design through filter design (configuration) and media selection/specification.

Pressure Drop as Function of Pleat Density



English Units

		Media Pressure Drop at Media Face Velocity (IWG)	Filter Pressure Drop (IWG)	Structure Dp (IWG)	Structure Contribution to Dp (%)	Media Contribution to Dp (%)
Product Type	AstroCel I (HCX)	1.01	1.45	0.44	30	70
	AstroCel II (2 inch)	0.45	0.53	0.08	15	85
	AstroCel III	0.47	0.85	0.38	45	55
	MEGAcel I	0.56	0.7	0.14	20	80
	MEGAcel II (2 inch)	0.23	0.27	0.04	15	85
	MEGAcCel III	0.23	0.76	0.53	70	30

SI Units

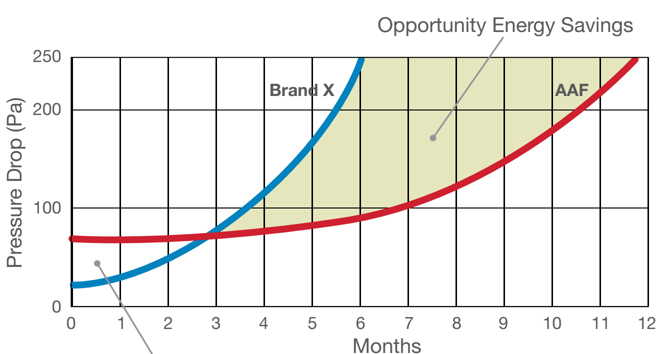
		Media Pressure Drop at Media Face Velocity (Pa)	Filter Pressure Drop (Pa)	Structure Dp (Pa)	Structure Contribution to Dp (%)	Media Contribution to Dp (%)
Product Type	AstroCel I (HCX)	251	361	109	30	70
	AstroCel II (2 inch)	112	132	20	15	85
	AstroCel III	117	212	95	45	55
	MEGAcel I	139	174	35	20	80
	MEGAcel II (2 inch)	57	67	10	15	85
	MEGAcel III	57	189	132	70	30

The filter industry has seen no real change or paradigm shift in how filters are constructed in the last 50+ years. The design is essentially the same. From filter manufacturers globally, it is either a Box, V-bank, Pockets or Minipleats. The majority of manufacturers try to improve filter performance over the other by squeezing another 10-20PA from the media suppliers and/or re-shaping a frame or pleat density to get another 20PA from the filter design. Where is the limit? Have we already reached the limit on current design? Is there a revolutionary new media that has 100% efficiency and zero resistance? Never say never but not yet.

We are not minimizing the quest for lower resistance. Pressure drop = money. For every PA we save equates to approximately $1 in energy saving ($100 for every 0.4" of static) which is worth pursuing especially when there are multiple stages and large volumes of high efficiency filters in advanced facilities.

% Reduction in Resistance is Proportional to % Reduction in Energy

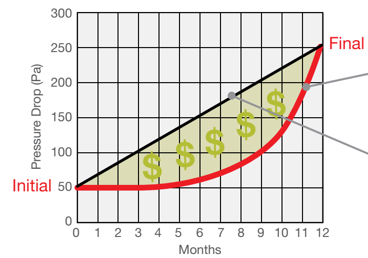
While on this topic it's important to remember that the configuration of the filter has a significant influence on how the filter loads over time. Some filters that start off with a low initial resistance might not maintain this advantage due to inferior construction of the filter and will see an accelerated loading curve and ultimately a much higher total cost of ownership (TCO) over the filters working life. Equally important when benchmarking pressure development over the filters life we ensure we are comparing apples to apples with efficiency.



Although Brand X had a lower initial resistance the AAF 'equivalent' filter demonstrated a longer life and lower energy cost due to the superior configuration of the media and frame even at the same efficiency

How is average pressure drop calculated?

There is the simple straight line average calculation which means Δ Initial + Δ Final / 2 = Average. This is not how a well-constructed filter loads. The loading has a parabolic trajectory (as shown in the next column) which means the true average is much lower than the simple straight line calculation and more reflective of real life. These calculations are important when it comes to calculating energy through TCOD (Total Cost of Ownership Diagnostics) simulation software in order to optimize design and the economy of an installation.



A well-constructed filter will have a parabolic loading curve (shown in red) where the actual true average pressure drop is approximately 25% lower than the straight line calculation (shown in black).

This 25% reduction in average resistance results in approximately the same reduction in energy consumption.

HEPA filter construction pressure drop has less influence from the pleating or configuration and more from the media selection itself. For cleanroom ceiling applications the options are limited from a construction or pleat pack type standpoint.

The 'mini-pleat' design is utilized by most of the major manufacturers. There are different separator types. Hot melt separators are probably the most common globally, string, ribbon, aluminum, embossed are others. Glass fiber is by far the most common media in use today and has been around for 75+ years, well established and reliable although the media itself is susceptible to damage due to the nature of the wet laid glass construction. A pin hole can cause failure, as well as damage from transport is common in the form of media shear, which is when the pack splits vertically across the pleats.

- The media that has grabbed the most attention over the last decade or so has been the membrane technology **PolyTetraFluoroEthylene (PTFE)**

PTFE has some really interesting characteristics especially with durability, almost impossible to damage and has a very low resistance due to its unique structure. The resistance of glass media is 30-50% higher than PTFE for the same pack depth and construction type. This can have significant benefits in energy consumption for major cleanroom operators especially in the microelectronics world where the media has been widely deployed in the form of FFU's (Fan Filter Units).

Very Fragile During:

- Filter Installation
- Filter Validation
- Cleaning of Ceiling
- Cleanroom Modifications
- Working Activities in the Cleanroom

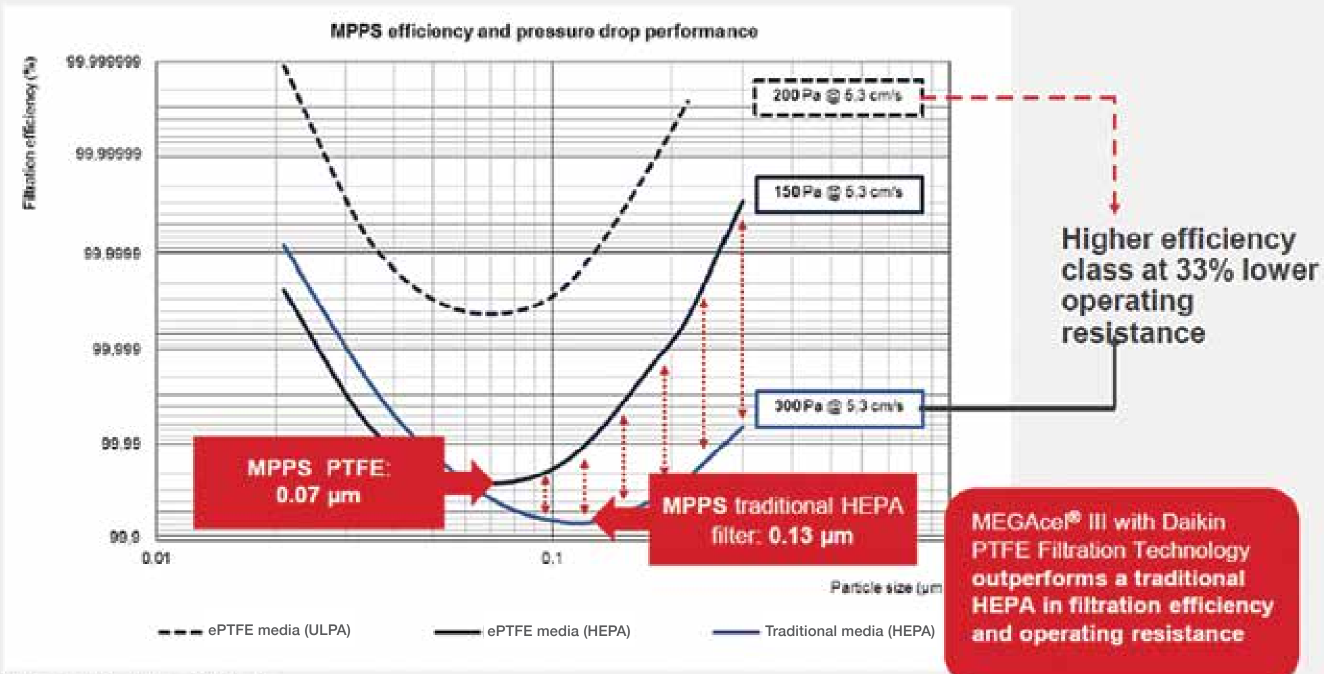
Risks of Filter Damage, Resulting In:

- Cleanroom Downtime
- Unscheduled Replacements
- Costly Recovery Actions
- Cross Contamination
- Uncontrolled Release of Harmful Substances

System Integrity and System Economy

MEGAcel® ePTFE Membrane Media

High Filtration Efficiency Combined with Low Operating Resistance:



- *MPPS = Most Penetrating Particle Size*
- *Comparative MPPS graphs are based on efficiency tests with flat media sheets @ airflow of 5.3 cm/s*

So, the media pressure drop is important, construction pressure drop has less influence on the combined factors of configuration and media in a HEPA filter. It has an approximate 30/70 split (the opposite is true with PTFE due to the low PD) in favor of the media. Adoption of the membrane technology will continue to accelerate as availability and cost has comes closer to glass. The well-known durability benefits of PTFE and/or FRM (PAO testable media) along with the reduced energy costs will ensure more wide spread adoption in the future.

Many engineers focus on specifying the lowest pressure drop HEPA or ULPA filter in order to minimize energy consumption and the total static in the system. Most engineers will calculate with the tried and tested ‘double the initial’ pressure drop as a rule of thumb for the dirty condition. In reality, assuming good pre-filtration and ‘normal’ cleanroom operating conditions these filters rarely meet the projected ‘double the initial’ as the change out point.

In Microelectronic applications the vast majority of the air is recirculated. Installations with 20+ years of service will see only a nominal increase in pressure drop. It is not unusual to see a 20% to 50% increase over this 20 year period in this environment. Life Science applications can be more challenging and varied from a load standpoint depending on the product being produced (tablets, powders, liquids) and environment (cleaning, decontamination, test aerosols etc) but again these filters are rarely changed because they have reached their final resistance, it’s mainly because of an internal protocol or SOP.

The ‘dirty’ additional static is in fact often absorbed by miscalculated, forgotten or simply unknown resistance within the housing itself.

Where does this static come from?

The common denominator is the damper.

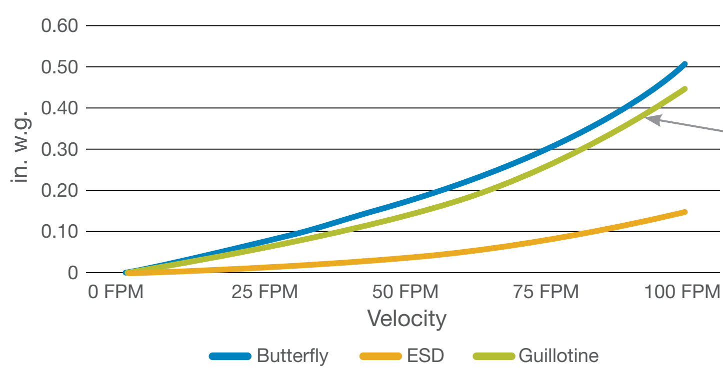
Supply housings in Life Science applications in particular are commonly installed with a balancing or sometimes full volume control damper in the form of a Guillotine or Butterfly design. There are dampers known as ESD or ATEC's style designs now utilized that have significantly lower pressure drops (normally 50% less) than the aforementioned dampers. FFU's by the way have low static through the housing itself (excluding coils or additional features for specialized applications). Typical static is about 25PA..

You can see in the table and graph the actual inlet velocity necessary through the collar to deliver the desired CFM and the resulting resistance generated through the common dampers utilized today.

	Filter Velocity (FPM)		Inlet Velocities (FPM)			
System Desired CFM	2x2	2x4	8"	10"	12"	14"
0	0	0	0	0	0	0
100	43	18	300	205	159	57
200	87	37	520	330	274	151
300	130	55	800	520	380	246
400	174	73	1100	700	500	360
500	217	92	1300	850	610	420
600	261	110	1600	1025	745	530
700	304	128	1900	1200	850	645
800	348	147	2100	1400	950	710
900	391	165	2400	1550	1100	800
1000	435	183	2700	1725	1200	875
1100	478	202	2900	1800	1300	975
1200	522	220	3200	2100	1400	1150

Nominal air volume or inlet velocity on a '4x2' housing. Measurements are when the dampers are 100%

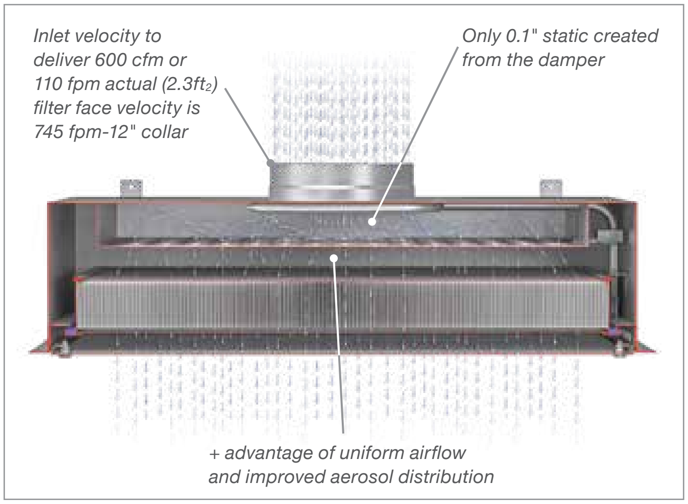
Filter face velocity is often more than expected due to the reduced filter size of the nominal '4x2' housing

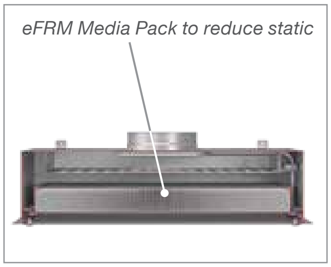


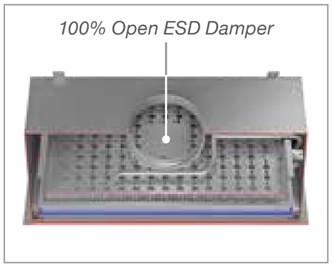
Actual resistance on a guillotine or split butterfly damper is above the typical HEPA filter pressure drop efficiency required (H14) in these applications

System Integrity and System Economy

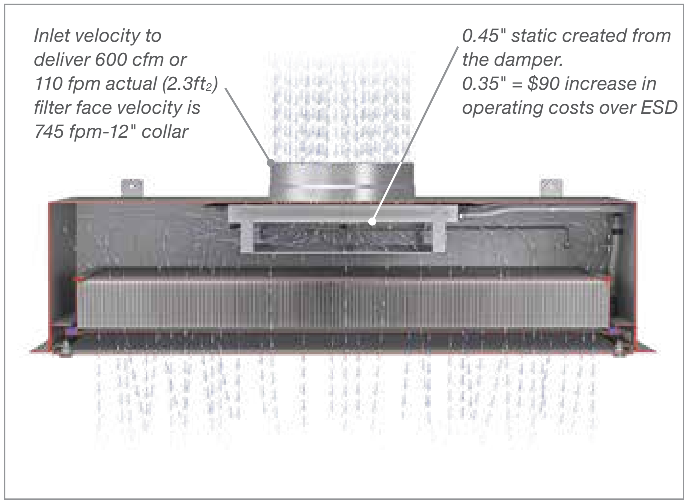
AstroHood® ESD Damper Static:

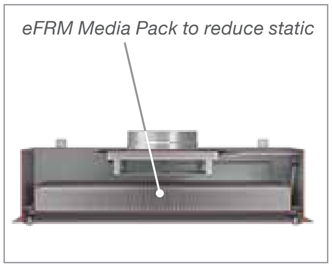


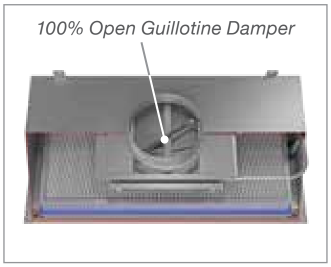




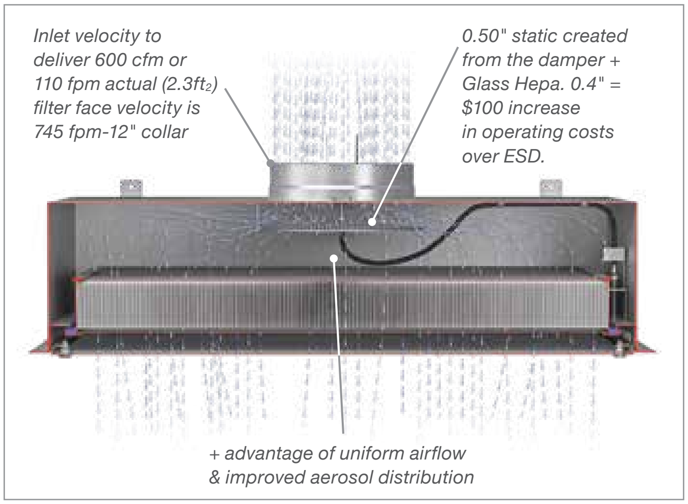
AstroHood® II Guillotine Damper Static:

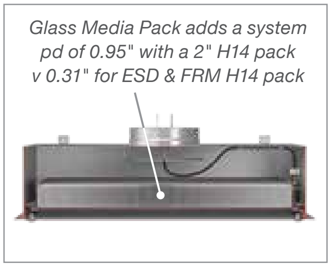


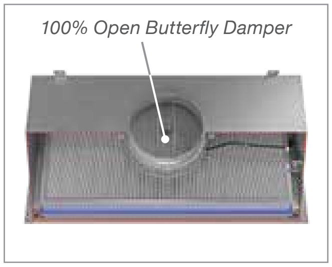




AstroHood® Butterfly Damper Static:







BIBO or safe change housings are the biggest culprits with some linear style bubble tight dampers exceeding 250PA in static in the fully open position. These dampers are sometimes specified on the inlet of a supply housing used to minimize migration of decontamination agents or contamination back into the HVAC system and when specified for their original design are necessary. There have been misapplication of these dampers and unnecessary static of 0.5"+ (125PA) is absorbed for what could be an avoided operating expense.

In addition to the housing or damper resistance there is an additional resistance again often not taken into account from the supply diffuser. In the US a Perforated diffuser with a nominal pressure drop is the most common solution. In Europe and Asia however a Swirl or 4-Way diffuser is the diffuser of choice. Static pressure of 50PA+ is common especially at the elevated velocities of 1m/s+ (200FPM) in these regions.

System Economy Calculations

Imperial

System Airflow	Filter Face Velocity		Collar Inlet Velocity			Damper PD			Damper PD			Diffuser PD			Filter PD (H14)					
	2x2	4x2	10"	12"	14"	2x2 ESD	2x2 Gu*	2x2 Bu**	2x4 ESD	2x4 Gu*	2x4 Bu**	Perf	Swirl	4-Way	2x2 Glass	2x2 PTFE	2x2 FRM	2x4 Glass	2x4 PTFE	2x4 FRM
cfm	fpm	fpm	fpm	fpm	fpm	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.	"w.g.
100	43	18	205	159	57	0.01	0.02	0.04	0.01	0.02	0.03	0.002	0.02	0.003	0.13	0.07	0.09	0.06	0.03	0.05
200	87	37	330	274	151	0.03	0.05	0.17	0.01	0.05	0.08	0.004	0.05	0.005	0.28	0.14	0.17	0.13	0.07	0.09
300	130	55	520	380	246	0.08	0.25	0.29	0.02	0.09	0.13	0.005	0.08	0.01	0.45	0.19	0.21	0.20	0.11	0.13
400	174	73	700	500	360	0.14	0.45	0.50	0.03	0.13	0.17	0.01	0.18	0.02	0.52	0.25	0.29	0.28	0.14	0.17
500	217	92	850	610	420	0.18	0.57	0.63	0.06	0.17	0.22	0.02	0.27	0.03	0.68	0.31	0.35	0.35	0.17	0.19
600	261	110	1025	745	530	0.22	0.71	0.78	0.08	0.25	0.29	0.03	0.36	0.05	0.81	0.37	0.41	0.45	0.19	0.21
700	304	128	1200	850	645	-	-	-	0.11	0.35	0.33	0.05	0.45	0.09	-	-	-	0.49	0.23	0.25
800	348	147	1400	950	710	-	-	-	0.14	0.45	0.50	0.07	0.55	0.14	-	-	-	0.52	0.25	0.29
900	391	165	1550	1100	800	-	-	-	0.15	0.46	0.49	0.10	0.60	0.19	-	-	-	0.62	0.29	0.32
1000	435	183	1725	1200	875	-	-	-	0.17	0.52	0.55	0.13	0.67	0.26	-	-	-	0.69	0.32	0.35
1100	478	202	1800	1300	975	-	-	-	0.19	0.58	0.61	0.16	0.75	0.35	-	-	-	0.76	0.35	0.38
1200	522	220	2100	1400	1150	-	-	-	0.21	0.64	0.67	0.20	0.83	0.44	-	-	-	0.83	0.38	0.42

* Gu = Guillotine
** Bu = Butterfly

Typical Design Airflow (US) *ESD Damper PD* *Diffuser PD* *FRM PD*

Housing (Damper) + Diffuser + Filter (FRM/PTFE) = REAL System Static

Metric

System Airflow	Filter Face Velocity		Collar Inlet Velocity			Damper PD (610x610)			Damper PD (1220x610)			Diffuser PD			Filter PD (H14) (610x610)			Filter PD (H14) (1220x610)		
	610x 610	1220x 610	250mm	300mm	350mm	ESD	Gu*	Bu**	ESD	Gu*	But**	Perf	Swirl	4-Way	Glass	PTFE	FRM	Glass	PTFE	FRM
m³/hr	m/s	m/s	m/s	m/s	m/s	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa
169	0.1	0.1	1.0	0.8	0.3	3	5	10	1	5	8	0.5	5	0.8	33	18	23	15	8	13
340	0.3	0.1	1.7	1.4	0.8	8	13	43	3	13	20	1.0	13	1.3	70	35	43	33	18	23
510	0.4	0.2	2.7	1.9	1.3	20	63	73	4	23	33	1.3	21	2.5	113	48	53	50	28	33
680	0.6	0.3	3.6	2.6	1.8	35	113	125	8	33	43	2.5	44	5.0	130	63	73	70	35	43
850	0.7	0.4	4.3	3.1	2.1	44	141	156	15	43	55	5.0	68	7.5	170	78	88	88	43	48
1020	0.9	0.4	5.2	3.8	2.7	55	179	194	20	63	73	7.5	90	12.5	204	92	104	113	48	53
1189	1.0	0.5	6.1	4.3	3.3	-	-	-	28	88	82	12.5	113	22.5	-	-	-	123	58	63
1359	1.2	0.6	7.1	4.8	3.6	-	-	-	35	113	125	17.5	138	35.0	-	-	-	130	63	73
1529	1.3	0.6	7.9	5.6	4.1	-	-	-	36	115	123	25.0	150	47.5	-	-	-	156	72	80
1700	1.5	0.7	8.8	6.1	4.5	-	-	-	41	130	138	32.5	168	65.0	-	-	-	173	80	88
1869	1.6	0.8	9.2	6.6	5.0	-	-	-	46	144	153	40.0	189	87.5	-	-	-	190	88	96
2039	1.7	0.8	10.7	7.1	5.9	-	-	-	51	159	168	50.0	208	110.0	-	-	-	208	96	104

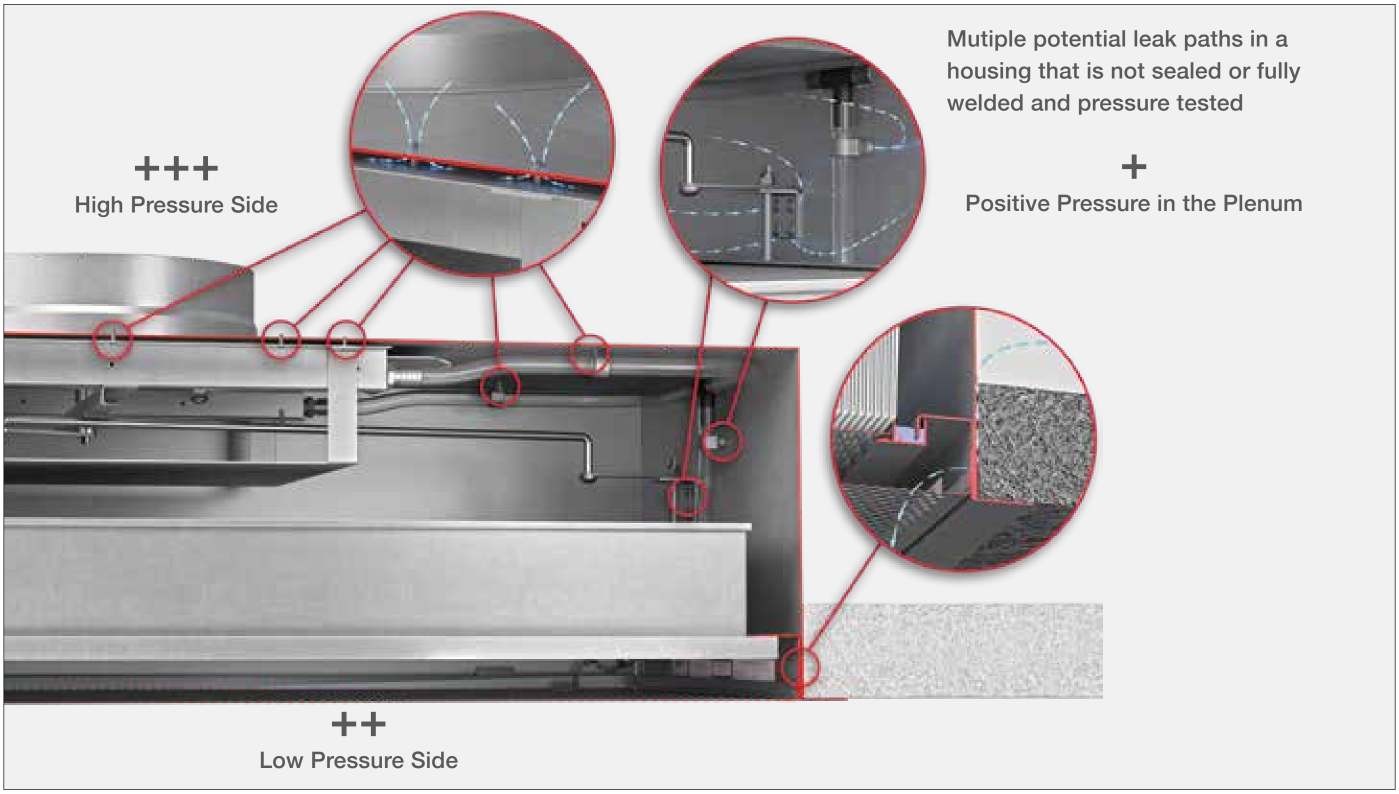
* Gu = Guillotine
** Bu = Butterfly

In summary, yes, we should focus on optimizing initial pressure drop of the HEPA filter ideally by utilizing membrane technology which is 30-50% less than traditional glass fiber media. Take care with the additional static from the housing (damper) and diffuser (Swirl) when calculating the necessary system static.

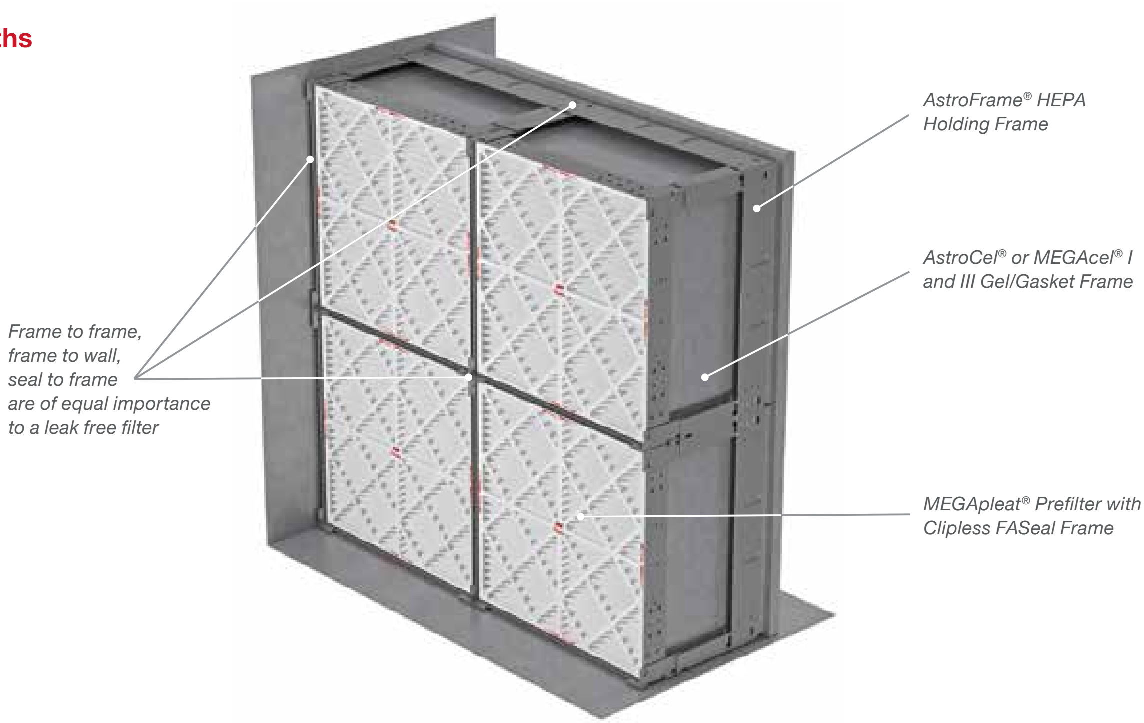
System Integrity and System Economy

It is clear there are opportunities to first understand and then optimize the system static by utilizing energy efficient dampers (ESD) and HEPA filters (PTFE or FRM) but the system economy will always come second to the system integrity. We mentioned at the beginning of this section that the filter is only as good as the housing or frame it is housed and installed in.

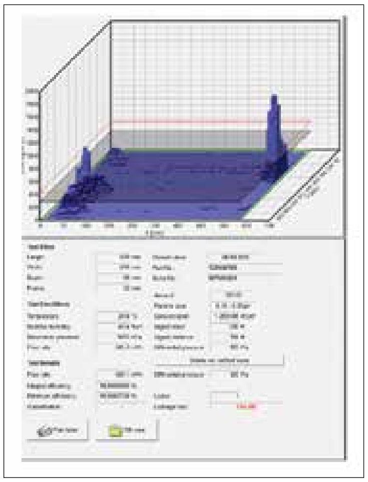
Supply Housing Leak Paths



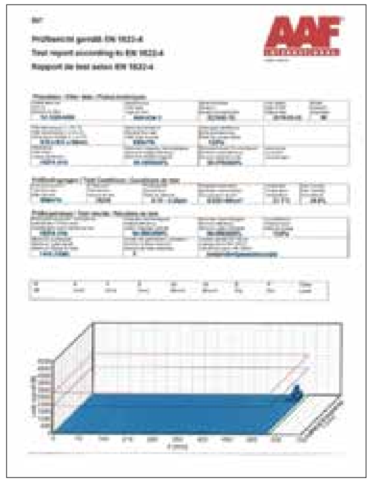
AHU Leak Paths



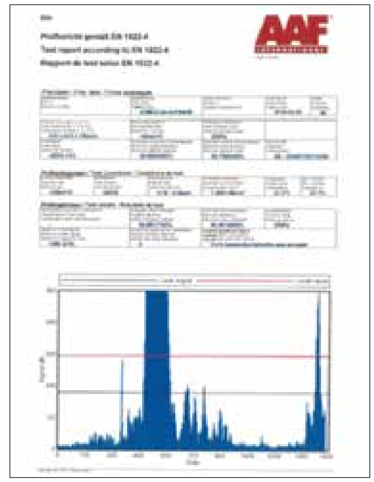
As a user or specifier of filters and housings it is common knowledge to expect a test certificate for the HEPA filter as shown below.



Typical Scan Test Protocol



PASS

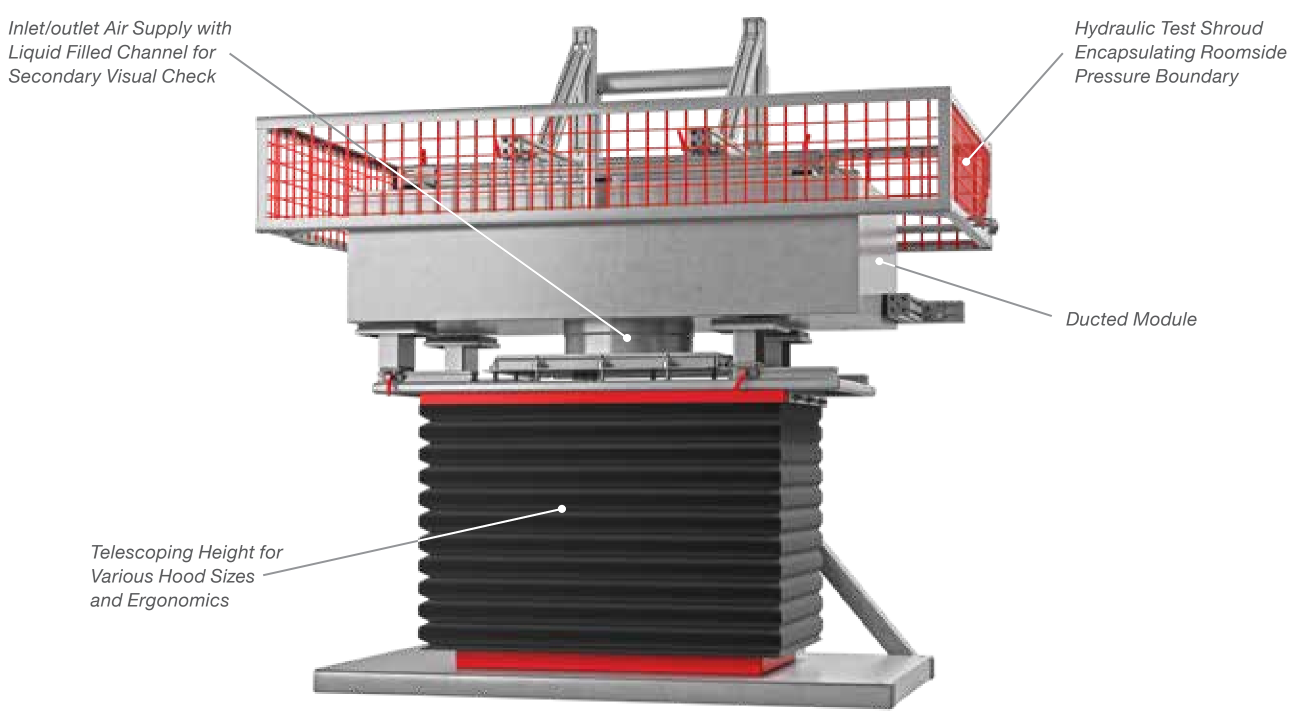


FAIL

We should treat the housing as we should treat the filter by performing a leak test (essentially a pressure decay test) to ensure there are no leaks in the body of the housing and all penetrations through the pressure boundary. Some manufacturers use caulk which will increase the risk of failure over time if applied in the critical leak paths identified in the schematic on the previous page.

Even though all these penetrations are on the dirty side or above the filter, these penetrations if not properly sealed are all potential leak paths into the plenum and then through the housing to trim penetration of trim to ceiling penetration.

Pressure Decay Housing Test Rig



Room and Air Pressure Guidelines

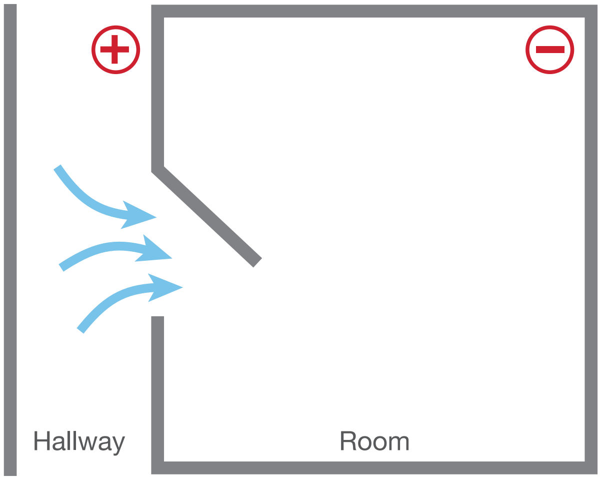
Air always moves from areas of high pressure to areas of low pressure. Pressure Differential (Gauge) can be positive, negative or neutral.

Air filter requirements for negative pressure rooms:

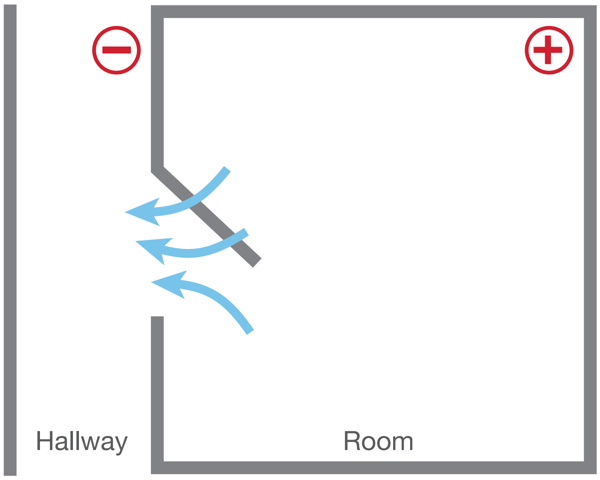
The most common types of negative pressure cleanrooms or zones are isolation rooms in healthcare facilities along with BSL 3-4 facilities used for research of infectious diseases and or hazardous compounds in life science facilities.

For negative pressure rooms, air should be exhausted to the outside through HEPA filters and not be recirculated except to the same area, and provided that an additional HEPA filter stage is in place in the return air. Some facilities prefer where possible a single-pass air-handling systems with no recirculation should be provided. The exhausted air or return air should be filtered through a safe-change or bag-in-bag-out filter housing. The filter housing should contain prefilters and HEPA filters, both of which should be removable within a reliable bagging system.

We have seen both recirculated and once through air for the exact same hazardous compound facilities in different parts of the world for the same manufacturer. Local regulations and the sites EHS teams often drive the decision for the M&E teams.



Negative room pressures are present when air flows from the hallway to the room.



Positive room pressures are present when air flows from the room to the hallway.

Room Pressurization Levels:

Some examples of room differential pressures outlined below

Airborne Infection Isolation Rooms:

- -0.01” w.c. minimum differential
- Permanent monitoring device required

Protective Environment Rooms:

- +0.01” w.c. minimum differential
- Permanent monitoring device required

USP 797 Compliant Pharmacy:

- 0.02” - 0.05” w.c. range
- Permanent monitoring device required

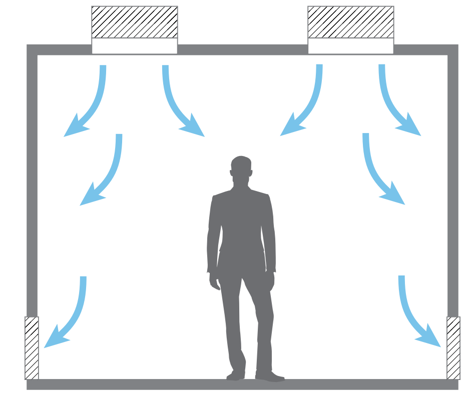
Operating Rooms:

- +0.01” w.c. minimum differential
- Monitoring devices not required

Positive pressure is a pressure within a system that is greater than the environment that surrounds that system. Consequently, if there is any leak from the positively pressured system it will egress into the surrounding environment.

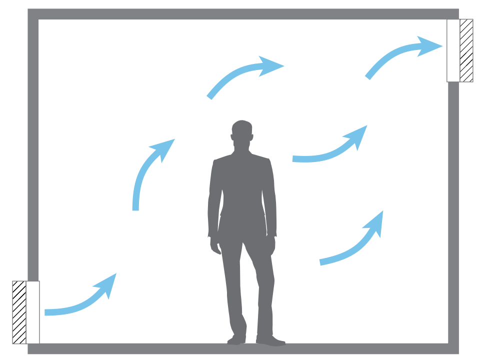
Positive pressure cleanrooms are used primarily for industries where the cleanroom functions to keep the product clean and safe from particulates and in some applications AMC (Airborne Molecular Contamination) and MCP's (Microbial Carrying Particles) seen in the Life Science and Microelectronic industry.

Cleanrooms are designed to maintain positive pressure, preventing "unclean" (contaminated) air from flowing inside and less-clean air from flowing into clean areas. A differential air pressure of 0.03 (7PA) to 0.05 (12PA) inches water gauge is typically recommended between spaces.



Positive Pressure

Negative pressure is generated and maintained by a ventilation system that removes more exhaust air from the room than air is allowed into the room. Air is allowed into the room through a gap under the door (typically about one half-inch high). Except for this gap, the room should be as airtight as possible, allowing no air in through cracks and gaps, such as those around windows, light fixtures and electrical outlets. Leakage from these sources can compromise or eliminate room negative pressure. Negative air pressure cleanrooms are used in industries that manufacture pharmaceutical products (potent compounds), Bio Safety Level (BSL) 3 & 4 Rooms, and also in hospitals to quarantine seriously contagious patients. Any air that flows out of the room has to first flow through a HEPA filter, ensuring that no contaminants can escape.



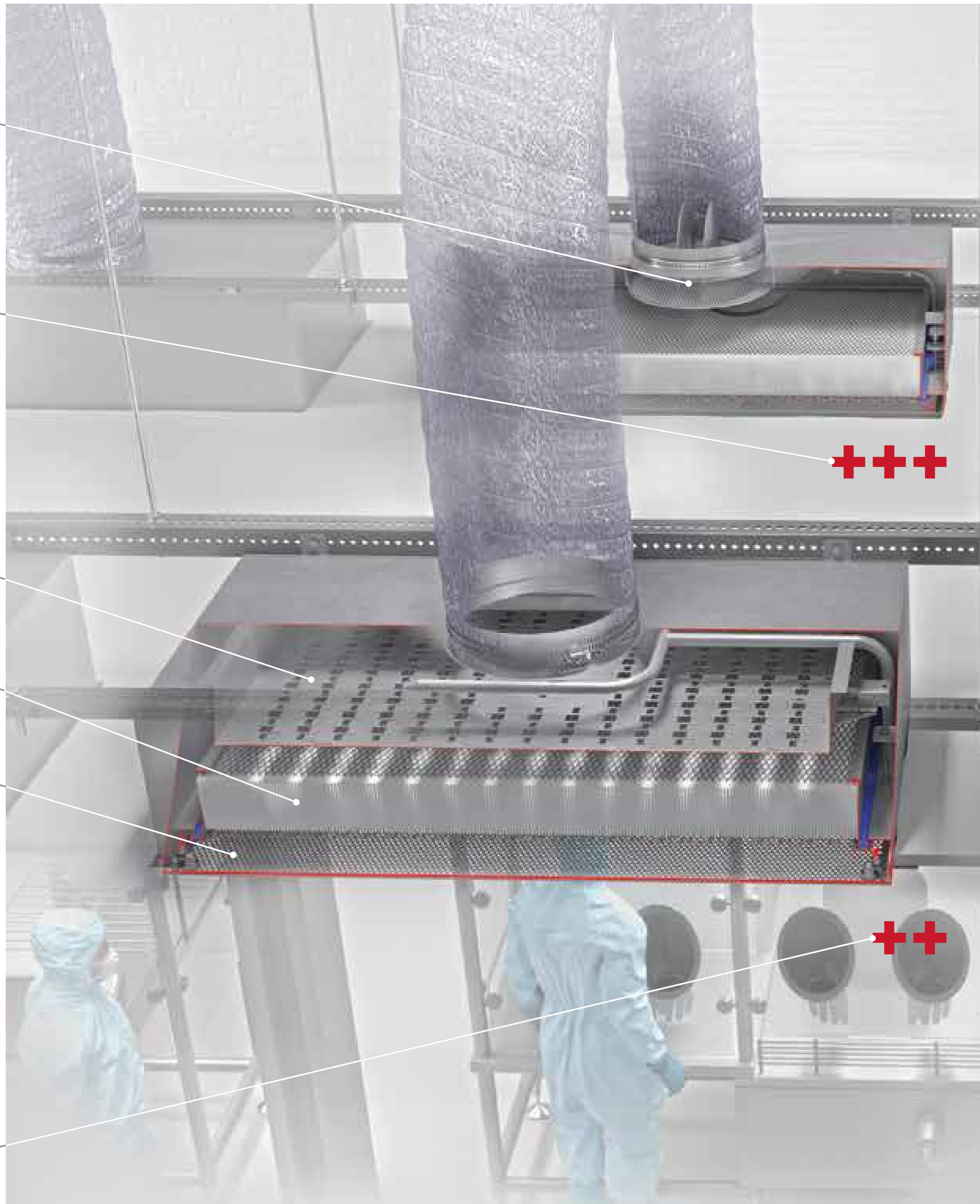
Positive Pressure

Space Function	Pressure Relationship to Adjacent Space	Recirculated Air
Operating Room	Positive	Yes
Infectious Isolation Room	Negative	Yes
BSL 1	Positive	Yes
BSL 2	Negative*	Yes
BSL 3	Negative	Yes
BSL 4	Negative	Yes
Grade A	Positive	Yes
Grade B	Positive	Yes
Grade C	Positive	Yes
Grade D	Positive	Yes
ISO 1-9	Positive**	Yes

** Not specified but recommended*
*** Plenum is negative when FFU's are installed*

Terminal Device Installations

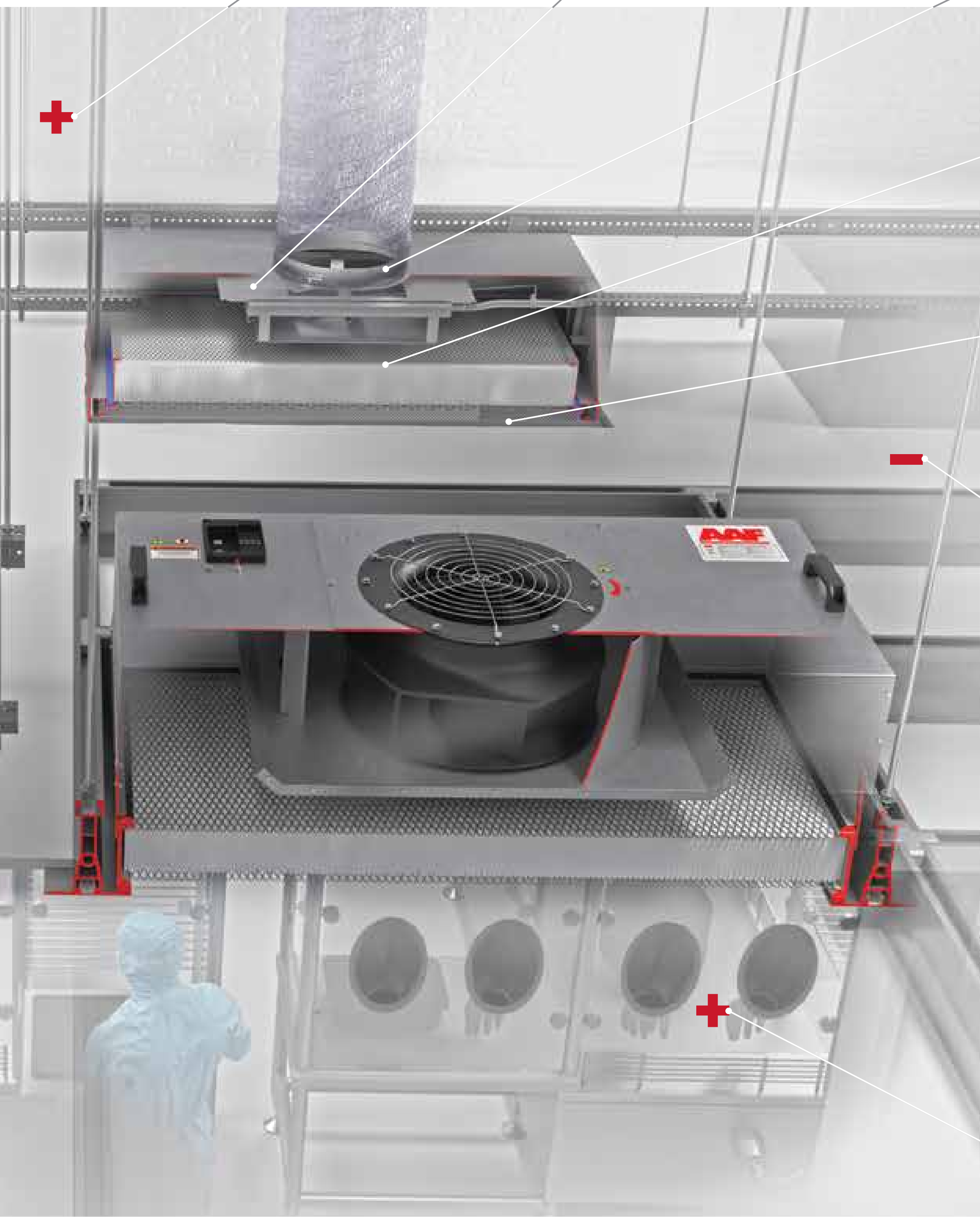
We will see a Housing (50-100PA) + Filter (100PA) + Diffuser (30-70PA) which could equate to an average CLEAN static pressure drop above 250PA, more than double the filter static we focus on during design discussions.



Typically positive in the plenum for direct ducted HEPA housings

Guillotine damper resistance 0.4-0.6″ depending on airflow

High inlet collar velocity 800-1200 FPM depending on airflow and collar size



HEPA filter initial resistance can vary from 0.15″ to 0.5″ depending on pack depth and media type (Glass or PTFE/ FRM) and efficiency selected.

Diffuser pressure drop can vary from 5PA-75PA depending of type selected (Perf, 4-Way, Swirl)

Negative Pressure Plenum

Using FFU's in an open negative pressure plenum design helps prevent leakage or by-pass of contaminants into the room.

Another advantage to the FFU design is the reduction in size of the AHU's as the FFU's handle more of the recirculated air requirements that can save space and cost.

Positive Pressure Room

AAF International Plant Locations

AAF, the world's largest manufacturer of air filtration solutions, operates production, warehousing and distribution facilities in 22 countries across four continents. With its global headquarters in Louisville, Kentucky, AAF is committed to protecting people, processes and systems through the development and manufacturing of the highest quality air filters, filtration equipment, and associated housing and hardware available today.

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