FILTER ENGINEERING
Standards, Regulations, Recommendations

VENTILATION FILTERS

Standards

Year	Reference	Type of test	Classification
1968	ASHRAE	ARRESTANCE / EFFICIENCY	
1980	EUROVENT 4/5	ARRESTANCE / EFFICIENCY	EU1 to EU4 - EU5 to EU9
1982	AFNOR NFX 44.012	ARRESTANCE / EFFICIENCY	
1993	CENE N7 79	ARRESTANCE / EFFICIENCY	G1 to G4 - F5 to F9

EN 779 Classification

EN7 79 standard		Average arrestance Am (%)	Average efficiency Em (%)	EUROVENT4 /5 equivalent
Filter group	Filter class	Filter class limits		Filter class
Coarse (G)*	G1	Am < 65	-	EU 1
	G2	65 ≤ Am < 80	-	EU 2
	G3	80 ≤ Am < 90	-	EU 3
	G4	90 ≤ Am	-	EU 4
Fine (F) **	F5	-	40 ≤ Em < 60	EU 5
	F6	-	60 ≤ Em < 80	EU 6
	F7	-	80 ≤ Em < 90	EU 7
	F8	-	90 ≤ Em < 95	EU 8
	F9	-	95 ≤ Em	EU 9

Initial efficiency (Ea) : * Ea < 20% ; ** Ea ≥ 20%
Final pressure drop: * 250 Pa ; ** 450 Pa

Fed Std 209D - ISO 14644-1 guide

209D	ISO 14644-1 (@0.5µm,unmanned)
1	ISO 3
10	ISO 4
100	ISO 5
1 000	ISO 6
10 000	ISO 7
100 000	ISO 8

VERY HIGH EFFICIENCY FILTERS

Standards

Year	Reference	Type of test		Classification
1956	MIL STD 282	DOP	0.3 µm	-
1972	AFNOR NFX 44.011	Uranine	0.15 µm	-
1976	EUROVENT 4/4	NaCl	0.65 µm	EU10 to EU14
1995	CENE N1822	MPPS	0.1 to 0.2 µm	HEPA: H10 to H14 ULPA: U15 to U17

EN 1822 Classification

		MPPS integral values			MPPS local values		
Filter group	Filter class	Minimum efficiency (%)	Maximum penetration (%)	Minimum D.C.	Minimum efficiency (%)	Maximum penetration (%)	Minimum D.C.
HEPA (H)	H10	85	15	6.7	-	-	-
	H11	95	5	20	-	-	-
	H12	99.5	0.5	200	-	-	-
	H13	99.95	0.05	2.000	99.75	0.25	400
	H14	99.995	0.005	20,000	99.975	0.025	4.000
ULPA (U)	U15	99.9995	0.0005	200,000	99.9975	0.0025	40,000
	U16	99.99995	0.00005	2.000,000	99.99975	0.00025	400,000
	U17	99.999995	0.000005	20,000,000	99.9999	0.0001	1.000,000

HEPA : High Efficiency Particulate Air (filter)
ULPA : Ultra Low Penetration Air (filter)
D.C. : Decontamination Coefficient

Classification as per Eurovent 4/4 recommendation, NaCl method

EUROVENT4 /4	Inicial efficiency Ei (%)	Penetration Pi (%)
Filter class	Limits of filter classes	
EU 10	95 ≤ Ei < 99.9	5 ≤ Pi < 0.1
EU 11	99.9 ≤ Ei < 99.97	0.1 ≤ Pi < 0.03
EU 12	99.97 ≤ Ei < 99.99	0.03 ≤ Pi < 0.01
EU 13	99.99 ≤ Ei < 99.999	0.01 ≤ Pi < 0.001
EU 14	99.999 ≤ Ei	0.001 ≤ Pi

CLEAN ROOMS

Classification of different air qualities required for manufacture of sterile products

	Maximum number of particles per m³ of a size greater than or equal to				Max. nbr: of µorganisms per m³ (active)
	0.5 µm	5 µm	0.5 µm	5 µm	
	inactive (b)		active		
A	3.500	0	3.500	0	< 1
B	3.500	0	350,000	2.000	10
C	350,000	2.000	3.500,000	20,000	100
D	3.500,000	20,000	not defined (c)	not defined (c)	200

Rules and Guidance for Pharmaceutical Manufacturers and Distributors (2002)
(b) Corresponds approximately to the US Federal Standard 209 E and ISO as follows: classes A and B to class 100. M3 .5. ISO 5; class C to class 10,000. M5 .5. ISO 7; class D to class 100.000. M6 .5 ISO 8.

Comparison of international classification standards

Nbr of part ≤ 0.5 µm/ m³ (approx.)	US Fed. Std 209 E 1992		ENI SO 14644-1 1996	France AFNOR NF X 44.101 1981	European Union Pharma industry Guide GMP 1989	Nbr of part ≤ 0.1 µm/ m³ (approx.)
-	-	-	ISO 1	-	-	10
1	-	-	-	-	-	35
4	-	-	ISO 2	-	-	100
10	M1	-	-	-	-	350
35	M1 .5	1	ISO 3	-	-	1.000
100	M2	-	-	-	-	3 500
353	M2 .5	10	ISO 4	-	-	10,000
1.000	M3	-	-	-	-	35.000
3.530	M3 .5	100	ISO 5	4.000	A and B	100,000
10,000	M4	-	-	-	-	350,000
35.300	M4 .5	1.000	ISO 6	-	-	1.000,000
100,000	M5	-	-	-	-	-
353.000	M5 .5	10,000	ISO 7	400,000	C	-
1.000,000	M6	-	-	-	-	-
3.530,000	M6 .5	100,000	ISO 8	4.000,000	D	-
10,000,000	M7	-	-	-	-	-
35.000,000	-	-	ISO 9	-	-	-

Permissible particle levels in different classes of clean rooms and clean zones

ISO classification CD1 4644-1 (1996)	Maximum permissible concentrations (partículas/m³ of air) of particles of a size greater than or equal to the size shown below					
	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1 µm	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	83.200	2.930
ISO 8	-	-	-	3.520,000	832.000	29,300
ISO 9	-	-	-	35.200,000	8.320,000	293.000

$C = 10^{N}(0.1/D)^{2.08}$ part / m³

US Fed Std 209 E (1992)

Class Name		Class Limits									
		0.1 µm		0.2 µm		0.3 µm		0.5 µm		5 µm	
		Volume Units		Volume Units		Volume Units		Volume Units		Volume Units	
S1	English	m³	ft³	m³	ft³	m³	ft³	m³	ft³	m³	ft³
M1	-	350	9.91	75.7	2.14	30.9	0.875	10.0	0.283	-	-
M1 .5	1	1.240	35.0	265	7.50	106	3.00	35.3	1.00	-	-
M2	-	3.500	99.1	757	21.4	309	8.75	100	2.83	-	-
M2 .5	10	12,400	350	2.650	75.0	1.060	30.0	353	10.0	-	-
M3	-	35,000	991	7.570	214	3.090	87.5	1.000	28.3	-	-
M3 .5	100	-	-	26,500	750	10,600	300	3.530	100	-	-
M4	-	-	-	75,700	2.140	30,900	875	10,000	283	-	-
M4 .5	1000	-	-	-	-	-	-	35,300	1.000	247	7.00
M5	-	-	-	-	-	-	-	100,000	2.830	618	17.5
M5 .5	10,000	-	-	-	-	-	-	353,000	10,000	2.470	70.0
M6	-	-	-	-	-	-	-	1.000,000	28,300	6.180	175
M6 .5	100,000	-	-	-	-	-	-	3.530,000	100,000	24,700	700
M7	-	-	-	-	-	-	-	10,000,000	283,000	61,800	1.750

$\text{particles} / m^3 = 10^{M}(0.5/d)^{2.2}$
$\text{particles} / ft^3 = N_c(0.5/d)^{2.2}$

AIR-CONDITIONING / COMFORT

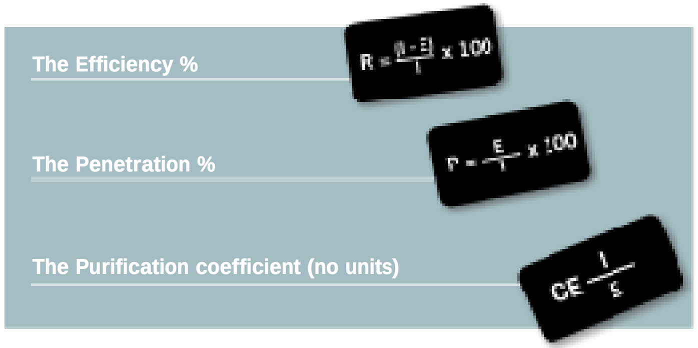
Air quality of premises with non specific pollution

	Regulatory aspect	Recommendations
	Labour code / Circular of application of decrees 84/1093-1094 dated 7/12/1984	UNICLIMA Air-conditioning & Health guide (1993)
Fresh air	Labour code Art. R235.2.6 Minimum arrestance efficiency 90% (G4 according to EN7 79)	Air-conditioning system inlet: 85% opacimetric (F7 according toE N 779) Air-conditioning system outlet: 90% opacimetric (F8 according toE N 779)
Recycled air	Labour code Art. R232.5.4 Minimum opacimetric efficiency 50% (F5 according to EN7 79)	85% opacimetric (F7 according to EN7 79)

FILTER ENGINEERING - Calculations

EFFICIENCY OF THE FILTERS

An air filter's efficiency is expressed in 3 forms:



Clearly the purification coefficient is the most representative expression for high level of filtration. E.g.:
Efficiency 99.995 % : CE of 20,000
Efficiency 99.9998% : CE of 500 000
The second filter is 25 times more efficient than the first.

Nota : **I** = particle concentration upstream **E** = particle concentration downstream

Conversion table (%)

Efficiency	Penetration	Purification Coefficient	Efficiency	Penetration	Purification Coefficient
95	5	20	99.99	0.01	10,000
99	1	100	99.995	0.005	20,000
99.5	0.5	200	99.999	0.001	100,000
99.9	0.1	1.000	99.9995	0.0005	200,000
99.95	0.05	2.000	99.9999	0.0001	1.000,000
99.97	0.03	3 333	99.99995	0.00005	2.000,000
99.98	0.02	5 000	99.99999	0.00001	10,000,000

COMPARATIVE EFFICIENCIES

		on 1 µm			on 0.5 µm		
		E	P	PC	E	P	PC
90%	ARRESTANCE	10%	90%	1.1	5%	95%	1.05
50%	EFFICIENCY	30%	70%	1.4	10%	90%	1.1
65%	EFFICIENCY	45%	55%	1.8	25%	75%	1.3
85%	EFFICIENCY	85%	15%	6.6	70%	30%	3.3
95%	EFFICIENCY	95%	5%	20	90%	10%	10
95%	0.3 µm	≥ 99%	< 1%	≥ 100	98%	2%	50

E = Efficiency P = Penetration PC = Purification Coefficient

OPERATING LIFE

An air filter's operating life is not directly proportional to its useful filtering surface. It is much better to opt for a model comprising 50% addtional surface. This increases its operating life by 100%, not 50%.

Actual case study

Filter model	Effective filtering surface	Initial pressure drop at 3 600m³/ h	Operating life*
Hi-Flo 3P8 5	6.5 m²	120 Pa	3.500 hours
Hi-Flo 3M8 5	9.4 m²	100 Pa	6.500 hours
Gain	3 m²	50 Pa	3.000 hours
Conclusion	**+ 46% in surface** (x 1.5)**	- 17% in energy	**+ 86% in operating life** (x 1.9)**

* Determined usingt he Camfil Farr calculation charts in the Hi-Flo brochure, for an average town environment
** factor of increase

ENERGY COSTS

Energy consumed by an air filter due to its pressure drop:

$$E = \frac{q \times \Delta p \times h}{\eta \times 1000} = \text{kWh / year}$$

q = flow rate (m^3/s)
Δp = pressure drop (Pa)
h = operating period (hours) / year
η = fan efficiency (generally 0.6 to 0.7)

ACRONYMS AND ABREVIATIONS

AFNOR	French standardization body
ASHRAE	American Society of Heating, Refrigeratinga nd Air-conditioningE ngineers (USA)
ASPEC	Association for prevention and study of contamination (France)
BSI	British Standards Institute
CEN	European standardization body
CETIAT	Technical centre for air handing and thermal industries (France)
CNC	Condensation Nucleus Counter
VOC	Volatile Organic Compounds
CSTB	Scientific and technical centre for construction (France)
DEHS	Di-Etil-Hexil-Sebaçate (= DES = DOS)
DIN	Deutsches Institut für Normung
DOP	Di-Octil-Phtalate
EUROVENT	European Committee of Manufacturers of Air Handing Equipment
Arrest	Arrestance efficiency
HEPA	High Efficiency Particulate Air (filter)
ISO	International Standards Organization
MPPS	Most Penetrating Particle Size
Opa	Opacimetric efficiency
ULPA	Ultra Low Penetration Air (filter)
UNICLIMA	Association for refrigeration equipment and air handing equipment (France)
VTT	Technical research centre (Finland)
Δp	Pressure drop

CONVERSIONS

Speed

1 m/s = 3.6 km/h	1 km/h = 0.278 m/s	1 ft/mm = 0.00508m/s	1 m/s = 196.85 ft/mm

Length

1 mile = 1.609 km	1 km = 0.621 mile	1 yd = 0.914 m	1 m = 1.09 yd
1 ft = 0.305 m	1 m = 3.28 ft	1 in = 25.4 mm	1 mm = 0.039 in
1 mm = 1.000 µm	1 µm = 0.001 mm	1 µm = 1.000 nm	1 nm = 0.001 µm
1 µm = 10,000 Å	1 Å = 0.0001 µm		

Surface

1 ft^2 = 0.0929 m^2	1 m^2 = 10.8 ft^2	1 in^2 = 6.45 cm^2	1 cm^2 = 0.155 in^2

Volume

1 ft^3 = 0.0283 m^3	1 m^3 = 35.3 ft^3	1 ft^3 = 28.3 litres	

Flow rate

1 cfm = 0.472.10^{-3} m^3/s		1 m^3/s = 3 600 m^3/h	1 m^3/h = 0.278.10^{-3} m^3/s
1 cfm = 1.699 m^3/h		1 m^3 = 2 120 cfm	

Weight

1 lb = 0.454 kg	1 kg = 2.20 lb	1 oz = 28.3 g	1 g = 0.0352 oz

Force

1 kgf = 9.80665 N	1 N = 0.102 kgf	1 lbf = 4.45 N	1 N = 0.225 lbf

Pressure

1 mmCE = 9.81 Pa	1 Pa = 0.102 mmCE	1 kPa = pz	1 kPa = 10.2 g/cm^2
1 kg/cm^2 = 0.980665 bar	1 bar = 1.02 kg/cm^2	1 kg/m^2 = 98.0665 kPa	1 kPa = 0.00987 atm
1 psi = 6.89 kPa	1 bar = 101325 Pa	1 atm = 101.325 kPa	1 mb = 100 Pa
1 mmCE = 1kg/m^2	1 kPa = 0.145 psi	1 Pa = 1 N/m^2	1 in w.g. = 254 Pa

Energy

1 kgm = 9.80665 J	1 J = 0.102 kgm	1 cal = 4.184 J	1 J = 0.239 cal
1 kWh = 3.6 MJ	1 MJ = 0.278 kWh	1 Btu = 1.055 kJ	1 J = 0.945.10-3 Btu

Power

1 CV = 0.736	1 kW = 1.36 CV	1 kcal/h = 1.16 W	1 W = 0.860 kcal/h
1 Btu/h = 0.292 W	1 W = 3.42 Btu/h		

Temperature: conversion formulae

0 °C = 32 °F	0 °F = -17.8 °C
°F = (9/5) x °C + 32	°C = (5/9) x °F-1 7.8

Temperature: conversion table

°F	°C	°F	°C	°F	°C	°F	°C
0.	- 17.8	30	-1.1	50	10.0	80	26.7
10	- 12.2	32	0	60	15.6	90	32.2
20.	- 6.7	40	4.4	70	21.1	100	37.8

Energy

1 kcal/kg = 4.19.103 J/kg	1 J/kg = 0.239.10-3 kcal/kg

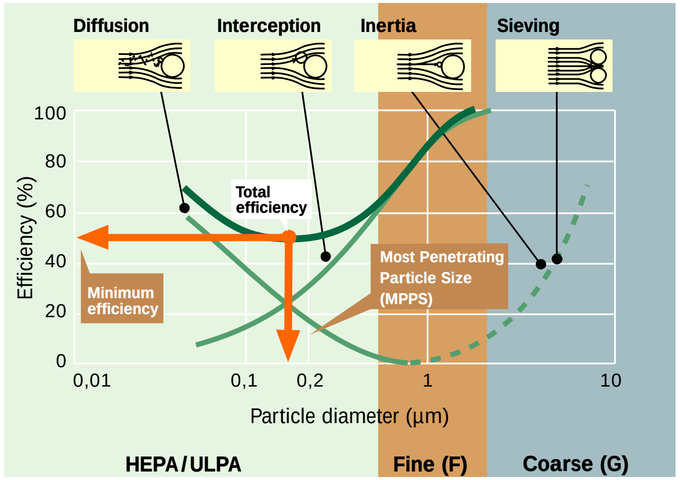
Heat transmission

1 kcal/h.m^2.°C = 1.16 W/(m^2 °C)	1 W/(m^2 °C) = 0.86 kcal/h.m^2 °C
1 Btu/(h.ft^2 °F) = 5.64 W/(m^2 °C)	1 W/(m^2 °C) = 0.177 Btu/(h.ft^2 °F)

FILTER ENGINEERING - Theory

MPPS

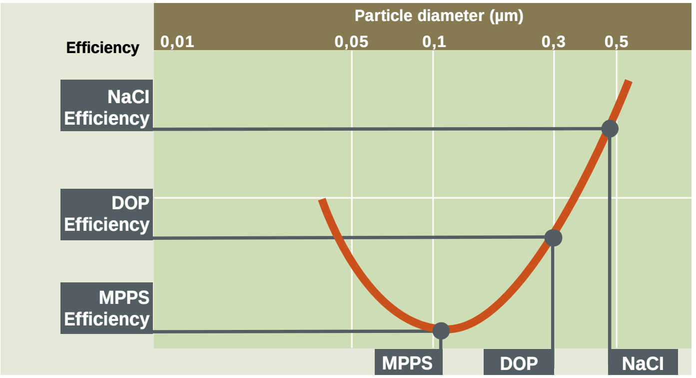
Minimum efficiency of air filters



The overall efficiency of an air filter is the result of a combination of 4 basic filtration mechanisms (sieving, inertia, interception and diffusion), so that the efficiency curve of an air filter adopts a characteristic V shape showing a minimum level of efficiency. This minimum efficiency corresponds to a particle size called MPPS (Most Penetrating Particle Size). In other words, the MPPS is the particle size that is the most difficult to stop. The MPPS is situated between 0.1 et 0.2 µm depending on the filter type, and the speed of air flow through the filtering media

EFFICIENCY TESTS (Not all the tests are equivalent)

MPPS (Most Penetrating Particle Size)



The NaCl test (EUROVENT 4/4) is less demanding then the DOP test, which in turn is less demanding than the MPPS test.

WHITBY DIAGRAM

Distribution of particles in atmospheric air

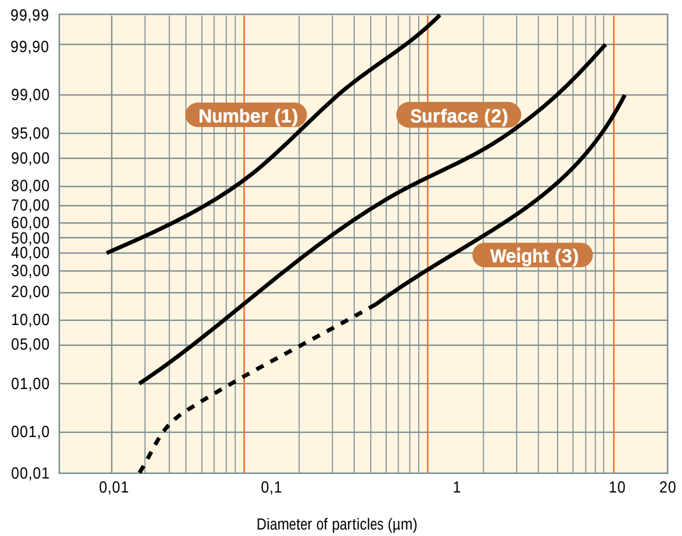


Diagram of Whitby: This diagram shows that more than 99.90% of airborne particles are less than or equal to 1µm in size.

Therefore, the essential part of air filtration's activity takes place in the invisible domain (human ocular partition power: 30 µm).

DIAGRAM OF PARTICLE SIZES