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The Cobeal Difference

Cleanroom Applications

Cleanrooms are high technology solutions with high or very high demands on the air cleanliness level. Not only particulate matter but also airborne molecular contaminants (AMC) are addressed in more and more applications. Therefore it is important to estimate the level of air cleanliness in cases of new production of, or reconstruction of a cleanroom.

“Cobeal has developed fast and efficient methods to describe the relationship between the cleanliness and the most important variables in a general model of a system.”

-Bo Hollsten, Chief Engineer

The air cleanliness level in a clean room is dependent on the quality of the supply air, contamination sources and the design of the ventilation system. Due to this it is difficult to estimate the final cleanliness class, but Cobeal does it by using mathematical algorithms and/or experimental mock up studies. The most cost effective and fastest approach is to use computer aided analysis. The fluid dynamic calculations (CFD) are used to determine airflow patterns, and can be used to analyze the contamination spread, this is time consuming but each project is case specific and on occasions the additional time invested upfront results in time and cost savings over the long run.

“Cobeal has developed fast and efficient methods to describe the relationship between the cleanliness and the most important variables in a general model of a system.” These methods help Cobeal constructors and engineers to compare different solutions and evaluate the impact on the clean room class depending on what components and room design is used. It is relatively easy to estimate the result of outdoor environments, room activity, different particle sizes and contamination sources with specific software applications, but deciphering this information requires the analysis of AC specialists, which Cobeal has in-house.

The heart of the cleanroom consists of the filters which can be selected in different qualities in different locations in the cleanroom. This report describes the theory and the basic data for calculation of particle concentration and can be used for estimating the cleanliness class for a certain cleanroom design. It also addresses the factors that influence cleanroom design and construction costs.

The Cobeal Method

Cobeal utilizes various analysis tools for air filtration performance, life cycle cost and other calculations. This enables us to create a customized cleanroom application. The application allows Cobeal engineers to calculate the Life Cycle Cost and cleanliness class for different cleanroom designs. Different cleanroom configurations can be analyzed ranging from ventilating to unidirectional (Laminar flow) installations. Expected operational time of filters, energy consumption and the total operating cost for the filter installation is calculated. Wide ranges of reports are available, including Cleanroom classifications as well as specifications for selected Cobeal products. Additional information such as CO_2, emissions and efficiency of the filter system is also available.

Making exact calculations of cleanroom cleanliness levels for real situations is as much an art as it is a science since some variables are difficult to measure and quantify. Internal particle generation is one such factor that can be difficult to verify. The accuracy modeling of air filter performance in cleanrooms depends on the complexity of the system design and the operation. However, the diversity of projects Cobeal has performed has enabled us to focus on air filter performance across a wide range of applications. This data has enabled us to estimate a higher degree of accuracy that can only be obtained by comparing very specific calculations, as well as the use of old practices in comparison to newly adopted ones. Using this information together with the knowledge of important parameters leads us to useful end results for our clients.

Cobeal’s process simplifies design, product selection and enables us to make recommendations related to the energy use related to the air supply in the final design. By making a first analysis on a general cleanroom model, the selection of appropriate clean air components is simplified and accurate and based upon modern design and concepts. In addition to the room classification calculations Cobeal performs, we have developed a filtration system component pressure drop calculator to optimize the energy consumption once the desired cleanliness level is achieved.

The cleanliness level in a cleanroom is dependent on the design of the ventilation system, and the sources of contaminants. It is possible to express the relationship with mathematical formulas but they become highly complex for larger systems. In these cases Cobeal utilizes proprietary software applications to make design evaluations for a cleanroom. Even without accurate data on contamination sources, the air filter performance and system functionality can be evaluated and the most important design parameters can be identified. Cobeal utilizes the right analysis tools to simplify and optimize air filter selection from given data.

The Theory

Mass Flow balance

A cleanroom is dependent on having a balanced airflow in order to stop contamination from entering the room as well as having an effective removal of any contamination generated inside the room (processes, accidents, human activity etc.). The mass flux law governs the airflow balance: $\mathbf{m_{in} = m_{out}}$

Particulate Balance

The level of particle air contaminants in a room is determined by particles entering and exiting the room. However, sources inside the room especially from people and the type of garments they are wearing plays an equally if not more important role. Any particles from the process, people or other activities are contributing to the concentration inside a room. Air filters can, if correctly used, very efficiently increase the cleanliness level. Additional measures to improve the clean room class could be to use recirculation devices (air cleaners) or use a higher ratio of recirculation through filters for the complete room, install exhaust outlets close to known sources and improve the clothing on the people working in the area.

It is possible to make a mathematical model for the connection between the ventilation system design, particle sources and filter solutions and obtain results on the level of particle concentration, C(t).

Figure 1 shows the mass and particulate balance in a room with the volume "V" m^3. The supply air is denoted "Q" m^3/s and the re-circulated air "XQ" m^3/s, where "X" is the part of the supply air that is "recycled" (X is between 0 to 1). The exhaust airflow (air exiting the system) is (1-X)Q m^3/s. This system model has a supply air filter (Filter "s") with the particle efficiency "η_s" and a recirculating air filter (Filter "re") with the efficiency of "η_{re}". The supply air (outdoor) particle concentration "C_s" [particles/m^3] is the challenge aerosol concentration for filter "s". An additional leakage into the room is denoted "q" m^3/s, having the concentration "C_{leak}" particles/m^3.

Ventilation efficiency (contamination removal efficiency factor)

Ventilation efficiency (ε), or ventilation efficiency factor is the factor that describes how effective the ventilation system is in removing contaminants. This factor is also referred to as "Contamination removal efficiency factor", and can be described as:

Figure 1

$$\varepsilon = \frac{C_{exit} - C_s}{C(t) - C_s}$$

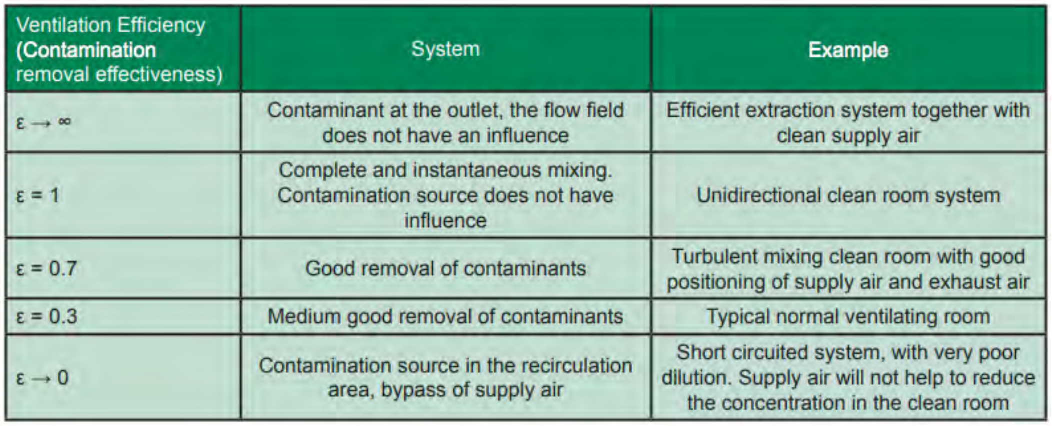
"ε" : is the Ventilation efficiency
(contamination removal effectiveness)
factor

"C_{exit}" : is the particle concentration at the
exhaust (exit) air from the room

"C_s" : is the particle concentration at the inlet
(air supply) of the room
"C(t)" : is the particle concentration in the room

Where:

The Ventilation efficiency is between 0 – 1, but can also be larger than 1 in certain systems, for example when exhaust system removing internal generated dust generation efficiently. Typically the factor 1 is used for efficient unidirectional systems. Typical ventilation efficiencies for different rooms can be seen in Table A (below).



Ventilation Efficiency **(Contamination** removal effectiveness)	System	**Example**
$\varepsilon \to \infty$	Contaminant at the outlet, the flow field does not have an influence	Efficient extraction system together with clean supply air
$\varepsilon = 1$	Complete and instantaneous mixing. Contamination source does not have influence	Unidirectional clean room system
$\varepsilon = 0.7$	Good removal of contaminants	Turbulent mixing clean room with good positioning of supply air and exhaust air
$\varepsilon = 0.3$	Medium good removal of contaminants	Typical normal ventilating room
$\varepsilon \to 0$	Contamination source in the recirculation area, bypass of supply air	Short circuited system, with very poor dilution. Supply air will not help to reduce the concentration in the clean room

The factor depends on what cleaning equipment is installed and position in the room. The spread of contaminants, how large and the position of the sources as well as the operation of the clean room are other important parameters.

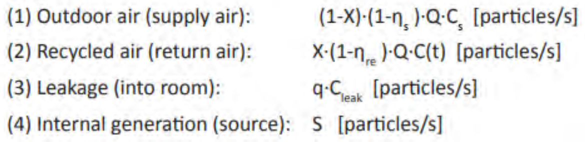
As a result of turbulence or presence of non-moving air, high concentrations of contaminants can exist in certain areas of a clean room. The ventilation efficiency factor can under those circumstances be set so it would simulate these differences.

It may be difficult to accurately estimate this factor without a thorough analysis, never the less the estimation according to figure 1 may serve as a good guideline for a first evaluation.

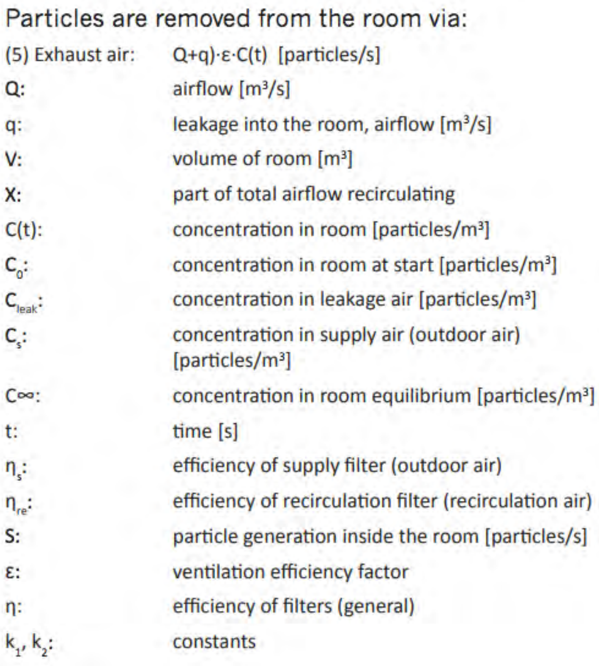
Particle Balance Equations

The following mathematical relations can be used to describe the particle balance in a general clean room, see figure 2.

Particles are supplied to the room via:



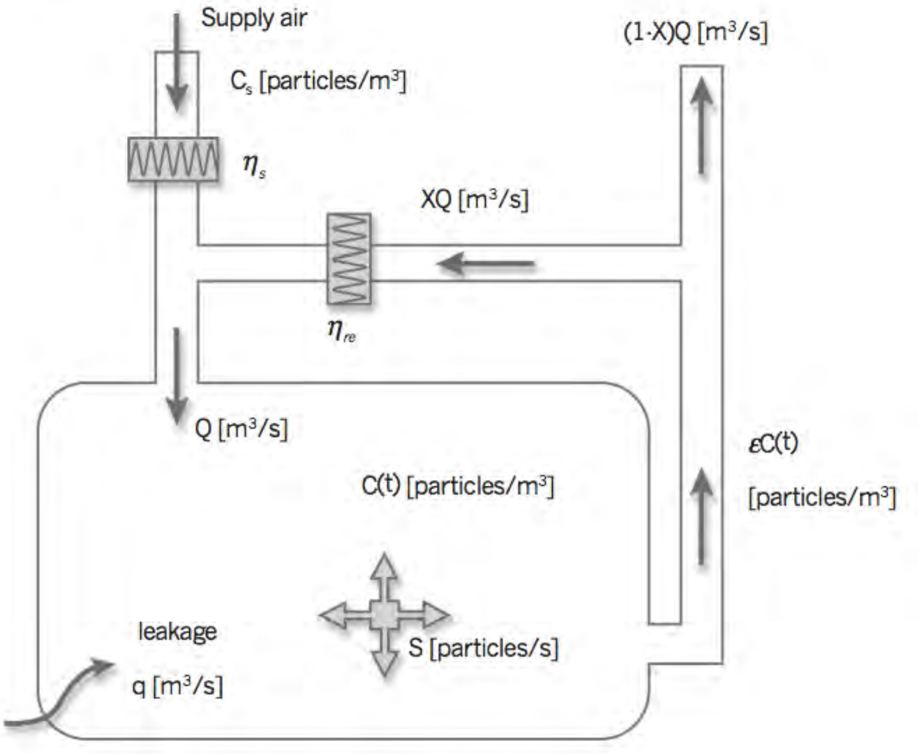
(1) Outdoor air (supply air): $(1\text{-}X)\cdot(1\text{-}\eta_s)\cdot Q\cdot C_s$ [particles/s]
(2) Recycled air (return air): $X\cdot(1\text{-}\eta_{re})\cdot Q\cdot C(t)$ [particles/s]
(3) Leakage (into room): $q\cdot C_{leak}$ [particles/s]
(4) Internal generation (source): S [particles/s]



Particles are removed from the room via:

(5) Exhaust air: $Q+q)\cdot\varepsilon\cdot C(t)$ [particles/s]
Q: airflow [m³/s]
q: leakage into the room, airflow [m³/s]
V: volume of room [m³]
X: part of total airflow recirculating
C(t): concentration in room [particles/m³]
C_0: concentration in room at start [particles/m³]
C_{leak}: concentration in leakage air [particles/m³]
C_s: concentration in supply air (outdoor air) [particles/m³]
$C\infty$: concentration in room equilibrium [particles/m³]
t: time [s]
η_s: efficiency of supply filter (outdoor air)
η_{re}: efficiency of recirculation filter (recirculation air)
S: particle generation inside the room [particles/s]
ε: ventilation efficiency factor
η: efficiency of filters (general)
k_1, k_2: constants

Figure 2



The difference between the number of particles that are removed and introduced to the room during Δt seconds will change the particle concentration by ΔC. The change in particles in the room is then VΔC, where "V" is the volume of the room and can be expressed as:

$$(6)\quad V\Delta C = |(1-X)\cdot(1-\eta_s)\cdot Q\cdot C_s+X(1-\eta_{re})\cdot Q\cdot\varepsilon\cdot C(t)+q\cdot C_{leak}+S-(Q+q)\cdot\varepsilon\cdot C(t)|\Delta t$$

$$(7)\quad k_1=\varepsilon\cdot Q\cdot[1+\frac{q}{Q}-X\cdot(1-\eta_{re})]$$

$$(8)\quad k_2=(1-X)(1-\eta_s)\cdot Q\cdot C_s+q\cdot C_{leak}$$

If Δt→0 equation (6), (7) and (8) becomes:

$$(9)\quad VdC=(S-k_1\cdot C(t)+k_2)dt$$

Integration of (9) gives:

$$(10)\quad V\int_{C_0}^{C} dC = \int_{t_0}^{t} (S-k_1\cdot C(t)+k_2)dt$$

$$(11)\quad V\int_{C_0}^{C} \frac{dC}{(S-k_1\cdot C(t)+k_2)} = \int_{t_0}^{t} dt$$

For $t_0=0$ and $C=C_0$ the following equations are obtained:

$$(12)\quad t=\frac{V}{k_1}\ \ln\frac{S+k_2-k_1\cdot C}{S+k_2-k_1\cdot C_0}$$

or

$$(13)\quad C=(C_0-\frac{S}{k_1}-\frac{k_2}{k_1})e^{\frac{k_1 t}{V}}+\frac{S}{k_1}+\frac{k_2}{k_2}$$

As can be seen in the equation the particle concentration is composed of two parts. One part that vary with time and another part that is independent of time. The part that has a time dependency may express a dilution process of the particle concentration and describes in that case a declination in concentration with time. When $t \rightarrow \infty$ the time dependent term will approach zero, and thus this term becomes insignificant. This case is describing a stationary clean room process which often is referred to as “the steady state of the system”. However in many cases, it is necessary evaluate transient (time dependent) processes such as variance in internal particle generation or other time dependent events. Thus, for a stationary process ($t \rightarrow \infty$) equation (12) is reduced to:

$$(14) \qquad C_\infty = \frac{S}{k_1} + \frac{k_2}{k_1}$$

The complexity of the equations above can be substantially simplified when one or more terms are dominating. Assumptions like constant internal particle generation, constant outdoor particle concentration (C_s) and constant concentration in leakage air (C_{leak}) are already made. In real life this is not always the case.

Different cleanroom systems

Clean room systems can look very different depending on the operational requirements. Air filters are used in many different places in those applications and therefore the calculation algorithms will vary from case to case.

It is possible to use equation (13) and (14) for all kinds of ventilations systems. However it is necessary to combine and group filters in a suitable manner in order to describe the filter efficiencies in the system correctly. The relation of penetrations for filters mounted in series can be described as:

$$(1-\eta)=(1-\eta_1)\cdot(1-\eta_2)\cdot(1-\eta_3)\cdot\ldots\ \cdot(1-\eta_N)$$

Where:

N: Number of filters in series

$(1-\eta)$: The total penetration of N filters

This general relationship is the key to model the filtration performance in conjunction with ventilation systems.

Air Handling Systems

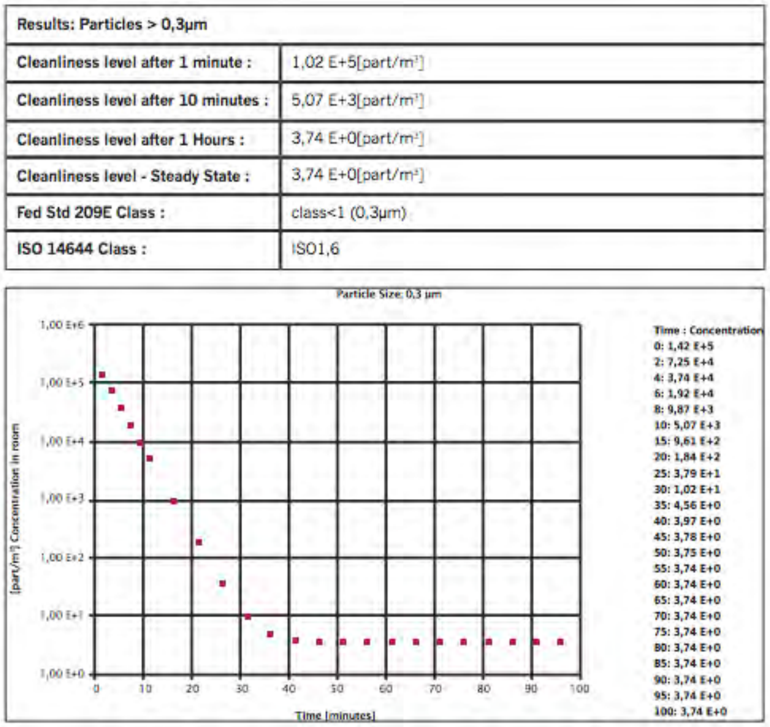
There are many different types of cleanroom designs in the industry today. The analysis tools developed by Cobeal cover three basic designs, ventilating-, turbulent- and unidirectional (laminar) airflow systems. When selecting a system it is important to select the closest model for the real system.

The airflow (recirculation), the amount of supply air, particle composition, the room size and the ventilation efficiency (contamination removal effectiveness) are all important inputs for the modeling of the cleanroom. Further sustainability considerations include: air change rate reduction in a classified space, recirculation in lieu of once through (full fresh) air, and reduction of velocity (down flow/laminar flow).

Air change rate reduction

Air change rate reduction starts with assessing cleanroom performance with ISO-14644-3, specifically classification & recovery.

- Assess risk to product & process
- Select & qualify scheme, qualify scheme by
- looking at the following:
  a. Classification
  b. Recovery
  c. Viables
  d. Activities & Interventions
  e. Cleaning



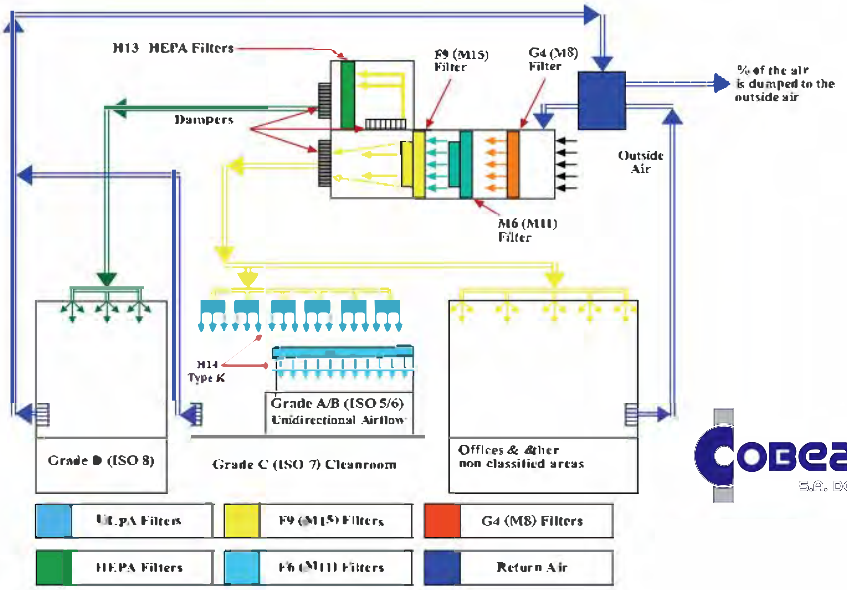
Results: Particles > 0,3μm	
Cleanliness level after 1 minute :	1,02 E+5[part/m^3]
Cleanliness level after 10 minutes :	5,07 E+3[part/m^3]
Cleanliness level after 1 Hours :	3,74 E+0[part/m^3]
Cleanliness level - Steady State :	3,74 E+0[part/m^3]
Fed Std 209E Class :	class<1 (0,3μm)
ISO 14644 Class :	ISO1,6

Cobeal Cleanroom Report (above) showing ‘steady state condition’

Recirculation and reduction of velocity

The hypothesis is that 100% outside air is deemed excessive in all but the most extraordinary cases. Quantitative assessment of the air recirculation risks is possible using a combination of industrial hygiene & air filtration certification standards. An opportunity for the use of more energy efficient filters applies which can be addressed through technical assessments, significant energy saving opportunities have been identified.

Reduction of velocity in clean rooms have been applied for a number of years in the microelectronics industry. The ‘magic’ 90-fpm (0.45m/s) +/- 20% from Willis Whitfield in the 1960’s was a ‘good guess’ but today is not scientifically supported. There are specific concerns and published papers on the impracticality of measuring velocity at working height, again, energy saving opportunities as much as 20% in a Grade A space is thought possible here.



Cobeal air filtration design for a multi-product pharmaceutical manufacturing facility

Cleanroom Design and Construction Costs

Cobeal builds sophisticated systems to ensure the purity of manufacturing processes in cleanrooms. Any combination of design criteria variables will produce a cleanroom of a specific quality. These are the main variables that determine the construction cost of a cleanroom. Depending on the tools, process equipment, and other fittings, the cost can range from USD \$200 ft^2 to \$2800/ft^2.

Cleanroom design and construction are performed under tight time constraints and limited opportunities for options, changes and other in-process improvements. Even the largest companies approach cleanroom design and engineering with “cookie-cutter repeats” in an attempt to avoid potential risks of new design approaches. These standardized cleanroom recipes make the designer’s task easier, but may not improve the project’s overall economics or lower the construction cost. Since requirements of each cleanroom are different in subtle ways, Cobeal addresses all cases with relevant data rather than the same design/build template.

Often clients ask engineers to design their cleanroom with more stringent specifications than are required in the hopes that, if something goes wrong, they will get the basics of what they need. Over-design wastes money, whereas a detailed assessment of real needs saves money. Ultimately it comes down to the mutual trust among the design and construction professionals, cleanroom developers, and client.

To help our clients get what they need at a cost that doesn’t break their budget, Cobeal focuses on the optimal arrangement of the tools and utilities connected to the production equipment, the location of service aisles, chases, corridors, mechanical equipment rooms and utilities rooms, all of which play a major part in cleanroom economy decisions. At the onset of a project, these factors are considered and simultaneously evaluated by Cobeal's team of architects, engineers and contractors, with the client in mind. Clients are treated as equal partners to ensure a thorough and shared understanding of their manufacturing process goals and requirements, which is the key to an economically successful design/build project.

The right selection of features for the type of cleanroom required by the client has a monumental impact on the final cost. There is no "paint by numbers" solution. Cobeal's engineers, architects, contractors, and the client must all understand the cost impact of the selected combination of variables that are not necessarily regulated by standards or ISOs. Cobeal works together with all parties as a team to finalize the goals, needs and expectations before the design activity begins.

Case Studies

Cobeal draws data from a variety of past cleanroom case studies:

- Microelectronic manufacturing facilities with cleanroom ISO Class 3, 5, 7 and 8;
- Pharmaceutical and biopharmaceutical facilities with cleanrooms ISO Class 5 and 7;
- Biopharmaceutical facility ISO Class 4, 5, 7 and 8.

Mechanical (HVAC, process piping) construction cost data was extrapolated and adjusted for site location, labor cost and inflation factors to obtain a unified "snapshot" picture of the mechanical construction cost breakdown per generic cleanroom ISO Class 3, 5, 7 and 8.

All facilities selected for analysis were approximately the same size - between 40,000 and 60,000 ft^2 - with 30 to 40 percent of the facility space occupied by the classified cleanroom, cleanroom corridors and airlocks. Similar arithmetic was applied to mechanical equipment operating costs to obtain the cost breakdown in Table 2. This approach allows unification of the mechanical construction cost without differentiation between microelectronics, pharmaceutical and biopharmaceutical cleanrooms. (The resulting data is shown in Tables 3, 4, 5, 6 and 7.

Based on the tables, the "Key value factor" chart (Figure 1) was constructed with Cleanroom ISO Class 5 mechanical construction cost as a baseline; cost factor variables shown in Table 8 were obtained. These empirical variables may be applied as percent multipliers to the square foot construction cost for different types of cleanrooms, and may be helpful for the initial alternatives cost evaluation.

Table 1: Cleanroom HVAC requirements

(Recommended to meet and exceed Federal Standard 209 E, 209 Class 1 VLF, and ISO 14644-1)

ISO 14644-1 per cubic meter	209 E Intern. (SI)	209 E English (USA) per cubic ft.	Suggested minimum ceiling coverage	Suggested filter type	Suggested minimum air velocity @ ceiling level	Suggested minimum cleanroom air changes
Class 3 Particle counts ≥ 0.1 µm – 1,000 ≥ 0.5 µm – 35	Class M	Class 1 Particle counts ≥ 0.1 µm – 35 ≥ 0.5 µm – 1	100% ceiling coverage	ULPA filters providing efficiency of 99.99995% at 0.12 µm	75 to 90 fpm (0.38 to 0.46 m/sec)	500 to 640 ach
	Class M 1.5	Class 1 Particle counts ≥ 0.1 µm – 35 ≥ 0.5 µm – 1	100% ceiling coverage	ULPA filters providing efficiency of 99.99995% at 0.12 µm	75 to 90 fpm (0.38 to 0.46 m/sec)	450 to 640 ach
	Class M 2	Class 10 Particle counts ≥ 0.1 µm – 99.1 ≥ 0.5 µm – 2.83	100% ceiling coverage	ULPA filters providing efficiency of 99.99995% at 0.12 µm	70 to 80 fpm (0.36 to 0.41 m/sec)	420 to 600 ach
Class 4 Particle counts ≥ 0.1 µm – 10,000 ≥ 0.5 µm – 352	Class M 2.5	Class 10 Particle counts ≥ 0.1 µm – 345 ≥ 0.5 µm – 10	100% ceiling coverage	ULPA filters providing efficiency of 99.99995% at 0.12 µm	70 to 80 fpm (0.36 to 0.41 m/sec)	420 to 600 ach
	Class M 3	Class 100 Particle counts ≥ 0.1 µm – 991 ≥ 0.5 µm – 28.3	80% ceiling coverage	HEPA filters providing efficiency of 99.999% at 0.12 µm	50 to 70 fpm (0.26 to 0.36 m/sec)	300 to 480 ach
Class 5 Particle counts ≥ 0.1 µm – 100,000 ≥ 0.5 µm – 3,520	Class M 3.5	Class 100 Particle counts ≥ 0.1 µm – 3,450 ≥ 0.5 µm – 100	75% ceiling coverage	HEPA filters providing efficiency of 99.999% at 0.12 µm	50 to 70 fpm (0.26 to 0.36 m/sec)	300 to 480 ach
Class 6 Particle counts ≥ 0.1 µm – 1,000,000 ≥ 0.5 µm – 35,200	Class M 4.5	Class 1000 Particle counts ≥ 0.1 µm – 34,500 ≥ 0.5 µm – 1,000	40% ceiling coverage	HEPA filters providing efficiency of 99.999% at 0.12 µm	30 to 50 fpm (0.15 to 0.25 m/sec)	180 to 300 ach
Class 7 Particle counts ≥ 0.5 µm – 352,000	Class M 5.5	Class 10,000 Particle counts ≥ 0.1 µm – 345,000 ≥ 0.5 µm – 10,000	30% ceiling coverage	HEPA filters providing efficiency of 99.99% at 0.3 to 0.5 µm	20 to 30 fpm (0.10 to 0.15 m/sec)	60 to 100 ach
Class 8 Particle counts ≥ 0.5 µm – 3,520,000	Class M 6.5	Class 100,000 Particle counts ≥ 0.1 µm – 3,450,000 ≥ 0.5 µm – 100,000	15% ceiling coverage	HEPA filters providing efficiency of 99.99% at 0.3 to 0.5 µm	15 to 20 fpm (0.08 to 0.10 m/sec)	36 to 90 ach

Note: Air changes developed for cleanroom heights 9' to16'

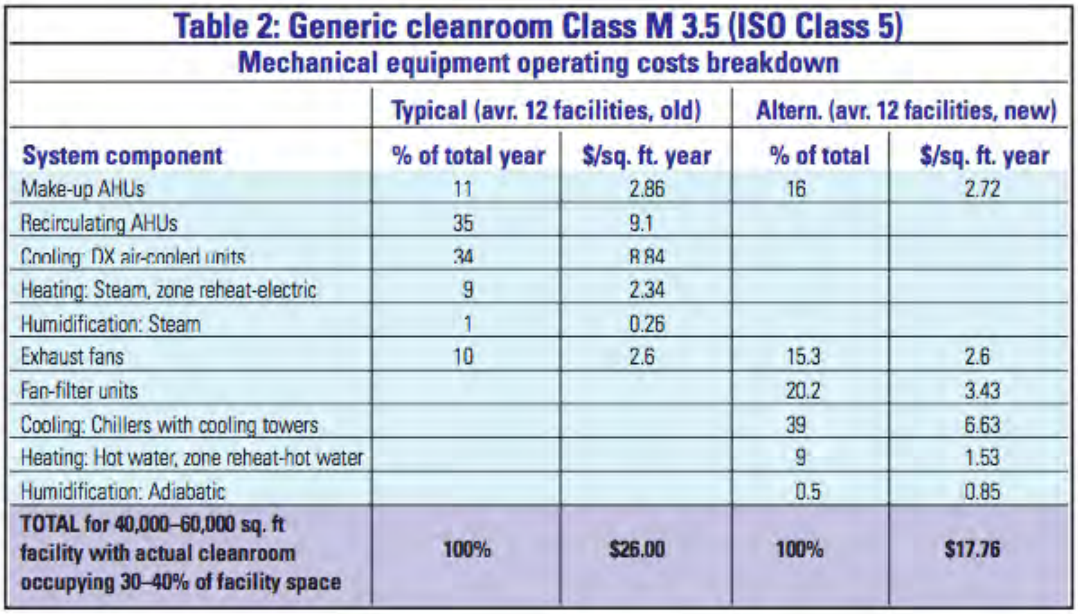


Table 2: Generic cleanroom Class M 3.5 (ISO Class 5)

Mechanical equipment operating costs breakdown

	Typical (avr. 12 facilities, old)		Altern. (avr. 12 facilities, new)	
System component	**% of total year**	**$/sq. ft. year**	**% of total**	**$/sq. ft. year**
Make-up AHUs	11	2.86	16	2.72
Recirculating AHUs	35	9.1		
Cooling: DX air-cooled units	34	8.84		
Heating: Steam, zone reheat-electric	9	2.34		
Humidification: Steam	1	0.26		
Exhaust fans	10	2.6	15.3	2.6
Fan-filter units			20.2	3.43
Cooling: Chillers with cooling towers			39	6.63
Heating: Hot water, zone reheat-hot water			9	1.53
Humidification: Adiabatic			0.5	0.85
TOTAL for 40,000–60,000 sq. ft facility with actual cleanroom occupying 30–40% of facility space	**100%**	**$26.00**	**100%**	**$17.76**

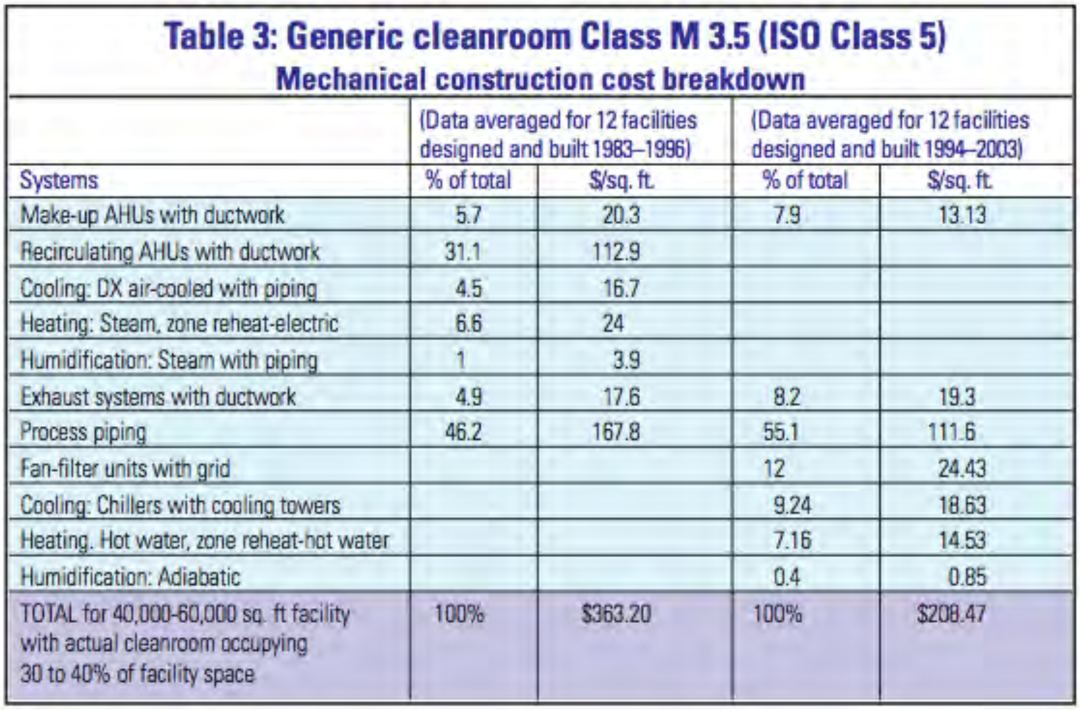


Table 3: Generic cleanroom Class M 3.5 (ISO Class 5)

Mechanical construction cost breakdown

	(Data averaged for 12 facilities designed and built 1983–1996)		(Data averaged for 12 facilities designed and built 1994–2003)	
Systems	% of total	$/sq. ft.	% of total	$/sq. ft.
Make-up AHUs with ductwork	5.7	20.3	7.9	13.13
Recirculating AHUs with ductwork	31.1	112.9		
Cooling: DX air-cooled with piping	4.5	16.7		
Heating: Steam, zone reheat-electric	6.6	24		
Humidification: Steam with piping	1	3.9		
Exhaust systems with ductwork	4.9	17.6	8.2	19.3
Process piping	46.2	167.8	55.1	111.6
Fan-filter units with grid			12	24.43
Cooling: Chillers with cooling towers			9.24	18.63
Heating. Hot water, zone reheat-hot water			7.16	14.53
Humidification: Adiabatic			0.4	0.85
TOTAL for 40,000-60,000 sq. ft facility with actual cleanroom occupying 30 to 40% of facility space	100%	$363.20	100%	$208.47

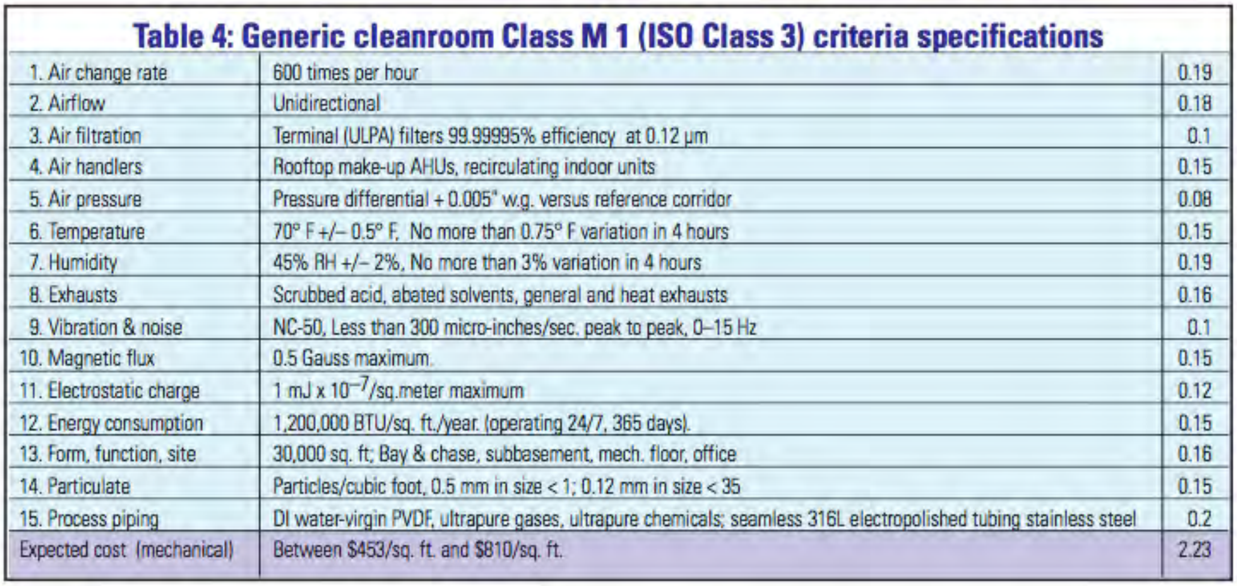


Table 4: Generic cleanroom Class M 1 (ISO Class 3) criteria specifications

1. Air change rate	600 times per hour	0.19
2. Airflow	Unidirectional	0.18
3. Air filtration	Terminal (ULPA) filters 99.99995% efficiency at 0.12 µm	0.1
4. Air handlers	Rooftop make-up AHUs, recirculating indoor units	0.15
5. Air pressure	Pressure differential + 0.005" w.g. versus reference corridor	0.08
6. Temperature	70° F +/– 0.5° F. No more than 0.75° F variation in 4 hours	0.15
7. Humidity	45% RH +/– 2%, No more than 3% variation in 4 hours	0.19
8. Exhausts	Scrubbed acid, abated solvents, general and heat exhausts	0.16
9. Vibration & noise	NC-50, Less than 300 micro-inches/sec. peak to peak, 0–15 Hz	0.1
10. Magnetic flux	0.5 Gauss maximum.	0.15
11. Electrostatic charge	1 mJ x 10^{-7}/sq.meter maximum	0.12
12. Energy consumption	1,200,000 BTU/sq. ft./year. (operating 24/7, 365 days).	0.15
13. Form, function, site	30,000 sq. ft; Bay & chase, subbasement, mech. floor, office	0.16
14. Particulate	Particles/cubic foot, 0.5 mm in size < 1; 0.12 mm in size < 35	0.15
15. Process piping	DI water-virgin PVDF, ultrapure gases, ultrapure chemicals; seamless 316L electropolished tubing stainless steel	0.2
Expected cost (mechanical)	Between $453/sq. ft. and $810/sq. ft.	2.23

Table 5: Generic cleanroom Class M 3.5 (ISO Class 5) criteria specifications

1. Air change rate	300 times/hour	REF.
2. Airflow	Unidirectional	REF.
3. Air filtration	Terminal HEPA filters 99.999% efficiency at 0.12 µm	REF.
4. Air handlers	Rooftop make-up AHUs, 15,000 cfm e.a. recirculating indoor units	REF.
5. Air pressure	Pressure differential + 0.05" w.g. versus reference corridor	REF.
6. Temperature	70° F +/– 1.0° F, No more than 1.5° F variation in 4 hours	REF.
7. Humidity	45% RH +/– 5%, No more than 3% variation in 4 hours	REF.
8. Exhausts	Scrubbed acid, abated solvents, general and heat exhausts	REF.
9. Vibration & noise	NC-55, Less than 500 micro-inches/sec. peak to peak, 0–15 Hz	REF.
10. Magnetic flux	1.5 Gauss max.	REF.
11. Electrostatic charge	3 mJ x 10 ±/sq.meter.	REF.
12. Energy consumption	800,000 BTU/sq. ft./year. (operating 24/7, 365 days).	REF.
13. Form, function, site	30,000 sq. ft. floor. Bay & chase, subbasement, mech. floor, office	REF.
14. Particulate	Particles per cubic foot, 0.5 mm in size < 100; 0.12 mm in size < 3,450	REF.
15. Process piping	DI water-virgin PVDF, ultrapure gases, ultrapure chemicals; seamless 316L electropolished tubing stainless steel	REF.
Expected cost (Mechanical)	Between $203 sq. ft. and $363 sq. ft.	1

Table 6: Generic cleanroom Class M 5.5 (ISO Class 7) criteria specifications

1. Air change rate	90 times per hour	0.072
2. Airflow	Turbulent	0.067
3. Air filtration	Terminal HEPA filters 99.99% efficiency at 0.3 to 0.5 µm	0.028
4. Air handlers	Rooftop make-up AHUs, 15,000 cfm e.a. recirc. indoor units	0.063
5. Air pressure	Pressure differential + 0.05" w.g. versus reference corridor	0.033
6. Temperature	70° F +/– 2.0° F, No more than 3.5° F variation in 4 hours	0.026
7. Humidity	45% RH +/– 5%, No more than 5% variation in 4 hours	0.032
8. Exhausts	Scrubbed acid, abated solvents, general and heat exhausts	0.028
9. Vibration & noise	NC-65, less than 500 micro-inches/sec. peak to peak, 0 to 15 Hz	0.025
10. Magnetic flux	1.5 Gauss max.	0.036
11. Electrostatic charge	3 mJ x 10^{-7}/sq. meter	0.036
12. Energy consumption	600,000 BTU/sq. ft./year (operating 24/7, 365 days)	0.015
13. Form, function, site	30,000 sq. ft. floor, ballroom, mechanical room, office	0.035
14. Particulate	Per cubic foot, 0.5 mm in size < 10,000; 0.12 mm in size < 345,000	0.035
15. Process piping	DI Water-virgin PVDF, pure gases, pure chemicals; seamless 316L stainless steel, copper type "L", 304 SS	0.011
Expected cost (mechanical)	Between $93/sq. ft. and $167/sq. ft.	–0.054

Table 7: Generic cleanroom Class M 6.5 (ISO Class 8) criteria specifications

1. Air change rate	60 times per hour	
2. Airflow	Turbulent	–0.07
3. Air filtration	Terminal HEPA filters 99.99% efficiency at 0.3–0.5 µm	–0.07
4. Air handlers	Rooftop make-up AHUs, 15,000 cfm e.a. recirculating indoor units	–0.07
5. Air pressure	Pressure differential + 0.05" w.g. versus reference corridor	–0.041
6. Temperature	70° F +/– 2.0° F, No more than 3.5° F variation in 4 hours	–0.032
7. Humidity	45% RH +/– 5%, No more than 5% variation in 4 hours	–0.034
8. Exhausts	Scrubbed acid, abated solvents, general and heat exhausts	–0.031
9. Vibration & noise	NC-65, less than 700 micro-inches/sec. peak to peak, 0 to 15 Hz	–0.027
10. Magnetic flux	3.5 Gauss max.	–0.037
11. Electrostatic charge	3 mJ x 10^{-7}/sq. meter	–0.037
12. Energy consumption	600,000 BTU/sq. ft./year (operating 24/7, 365 days)	–0.017
13. Form, function, site	30,000 sq. ft. floor, ballroom, mechanical room, office	–0.038
14. Particulate	Per cubic foot, 0.5 mm in size < 100,000; 0.12 mm in size < 3,450,000	–0.04
15. Process piping	DI Water-virgin PVDF, pure gases, pure chemicals; seamless 316L stainless steel, copper type "L", 304 SS	0.021
Expected cost (mechanical)	Between $93/sq. ft. and $167/sq. ft.	–0.61

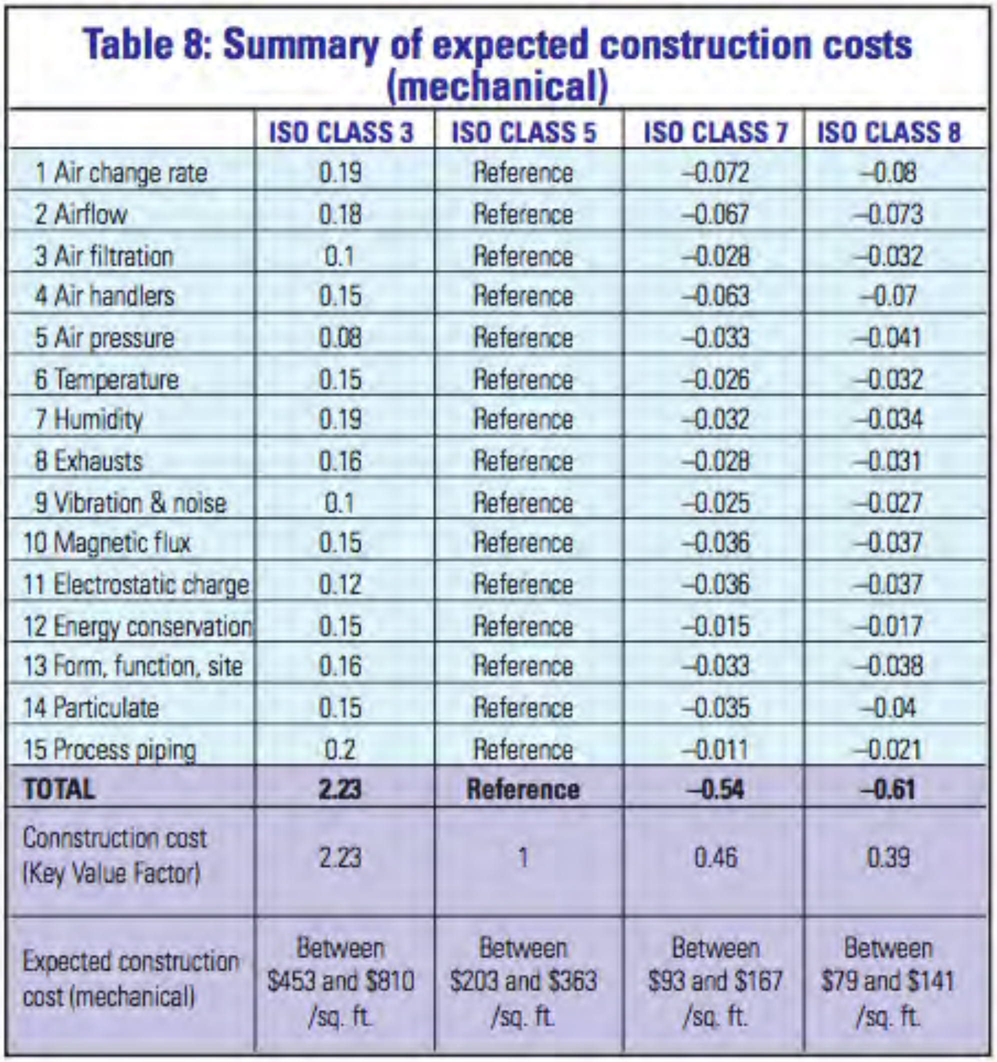


Table 8: Summary of expected construction costs (mechanical)

	ISO CLASS 3	ISO CLASS 5	ISO CLASS 7	ISO CLASS 8
1 Air change rate	0.19	Reference	–0.072	–0.08
2 Airflow	0.18	Reference	–0.067	–0.073
3 Air filtration	0.1	Reference	–0.028	–0.032
4 Air handlers	0.15	Reference	–0.063	–0.07
5 Air pressure	0.08	Reference	–0.033	–0.041
6 Temperature	0.15	Reference	–0.026	–0.032
7 Humidity	0.19	Reference	–0.032	–0.034
8 Exhausts	0.16	Reference	–0.028	–0.031
9 Vibration & noise	0.1	Reference	–0.025	–0.027
10 Magnetic flux	0.15	Reference	–0.036	–0.037
11 Electrostatic charge	0.12	Reference	–0.036	–0.037
12 Energy conservation	0.15	Reference	–0.015	–0.017
13 Form, function, site	0.16	Reference	–0.033	–0.038
14 Particulate	0.15	Reference	–0.035	–0.04
15 Process piping	0.2	Reference	–0.011	–0.021
TOTAL	**2.23**	**Reference**	**–0.54**	**–0.61**
Connstruction cost (Key Value Factor)	2.23	1	0.46	0.39
Expected construction cost (mechanical)	Between $453 and $810 /sq. ft.	Between $203 and $363 /sq. ft.	Between $93 and $167 /sq. ft.	Between $79 and $141 /sq. ft.

Using the following cost factor variables, Cobeal is able to reduce the facilities construction cost by maintaining the live database of design alternatives, staying close to facilities needs and engineering valuable improvements to the base cleanroom design and criteria. Cobeal applies these methods for successful cleanroom design-build projects for pharmaceutical, biopharmaceutical, microelectronics and food processing industries.

Air Changes

COST FACTOR VARIABLES: 0.08 to 0.19

Air distribution devices in cleanrooms (usually ceiling filters) are designed to provide a uniform “shower” of pure, filtered air. The quantity of air supplied to the room can be related to a fire hydrant as opposed to an ordinary shower-head.

American Federal Standard 209E, Japanese JIS B9920, and ISO 14644-1 entitled “*Cleanrooms and associated controlled environments - Part 1: Classification of air cleanliness,”* provides guidelines for cleanroom parameters, classification and testing, but do not tell you how to deliver these systems economically. This is because each process and, therefore, cleanroom requirement are different; desired conditions may be reached utilizing different quantities of recirculating air.

There are always at least five different “possible” designs to achieve the desired results; however, there is only one design that “fits” best. Finding the optimal and most economical solution for the project is Cobeal’s fundamental goal of in determining the project concept for cleanroom air changes.

As shown in Table 1, the air changes and quantity of recirculation vary significantly even for the given room class. The cleanroom Class M2, for example, may be achieved with 300 air changes, or 540 air changes may not be enough.

The rate of room contamination and live particles generation is one of the major factors in cleanroom air quantity selection. The rate of particles removal from the room may be very important for one manufacturing process but may not have any effect on another. Other variables that may impact the quantity of recirculating air include: room configuration, equipment location, equipment surface temperature, convective flux, type of the air flow (unidirectional over sensitive areas only or over the entire room), room operations and protocol, materials and chemicals used, etc.

The room may need to be certified at rest only, certified at working conditions, validated for the process, or cGMP-validated (quality assurance validation program for pharmaceutical/biotech product or process). Federal standard 209(e), set by the General Services Administration, suggests that air in a Class 100 cleanroom shall be at 90 cfm/ft^2 or 90 fpm; however, it is possible to build a better than Class 100 room with lower air movement. In fact, Cobeal has done it with as low as 45 cfm/ft^2.

Unidirectional, turbulent, vertical, or horizontal airflow

COST FACTOR VARIABLES: 0.073 to 0.18

For most applications, unidirectional flow is only necessary over small, sensitive areas of the cleanroom and may be handled with mini-environments. Source of contamination may be localized with Cobeal glove boxes and filtration modules, etc. The majority of cleanrooms designed for total unidirectional flow can achieve unidirectional flow only at rest without workers, equipment, and room exhausts. The choice of vertical or horizontal airflow depends on room configuration and equipment layout. In many facilities, turbulent airflow with properly engineered exhaust and return air locations works fine for contamination removal.

Raised floors were developed to help distribution of electrical wires, communication cables, utilities, piping, etc. between tools, equipment and utility sources. Subsequently, for economy purposes, they were utilized for returning air from the bays to the chases in bay-and-chase cleanroom configurations. In a pure unidirectional cleanroom, the particles are expected to flow from the working space to toward the holes in the floor. Cobeal has successful installations of Class 10 and Class 100 spaces with low wall returns and without raised floors, and the cleanroom airflow is designed to be turbulent.

Another option is to isolate an ultra-clean area with a thin air jet moving at 500 to 800 fpm; it functions exactly the same way as the plastic curtain.

Air Filtration

COST FACTOR VARIABLES: 0.032 to 0.10

Incoming air is filtered with HEPA filters, providing efficiency of 99.99% at 0.3 to 0.5 μm and 99.999% at 0.12 μm, or ULPA filters providing efficiency of 99.99995% at 0.12 μm.

Other devices may also be required depending on cleanroom purpose, such as HEPA filtration in recirculating and make-up air handlers, VOC absorption with charcoal type or similar synthetic filters, electrostatic filtration chambers, etc.

Fan-filters provide an excellent and economical solution for many high-level cleanrooms - especially in buildings with ceiling height limitations. Applying higher-grade terminal filters should be economically justified and weighted against cost and lower pressure drop of more expensive filter media. *It is not always obvious that lower grade filters with higher pressure drops are more economical in the long run, through the life of the cleanroom.*

Air Handlers

COST FACTOR VARIABLES: 0.07 to 0.15

Make-up AHUs: Make-up air handling units (primary AHUs) provide the necessary make-up air for the recirculating air-handling units (secondary AHUs). The make-up air AHUs consist of draw-through centrifugal, vane axial or plug fans with filters, hot water coils for preheat and reheat, chilled water coils for cooling and dehumidification, and steam or adiabatic humidifiers. Add-ons and variations include static air mixers, steam preheat coils, ultrasonic humidifiers, brine, Dx or glycol sub-cooling coils for dehumidification, VOC absorption filters, sound attenuators, and VFD drives.

Cobeal provides reliable and economical fan systems, which are very quiet and consume 20% less energy in comparison to conventional centrifugal or plug fans assigned for the same duty.

Make-up AHUs typically discharge into a common header with ductwork laterals balanced to supply the required make-up air to the recirculation AHUs. Air measuring stations are installed in the primary and secondary air supply main ducts to modulate the supply fans, VFDs, or inlet vane dampers to maintain constant air flow. Magnahelic gauges monitor the loading of HEPA filters, bag filters and pre-filters located at each air-handling unit. In situations where ceiling fan filters are provided, the make-up air is to be evenly distributed in the space above. Air from the make-up AHUs enters draw-through recirculation AHUs.

Recirculation AHUs. Each recirculation AHU typically consists of an energy-efficient centrifugal fan with filters and sensible (dry) cooling coils. Add-ons and variations include reheat coils for zone temperature control, steam or ultrasonic humidifiers for zone humidity control, and constant volume control boxes. Cobeal fan systems used for this application prove to be cost-saving and energy-conscientious selections.

Multiple recirculation AHUs discharge into supply ducts feeding the cleanroom through ULPA or HEPA filters, which typically cover 100% of the ceiling in the Class 10 and Class 1 areas. This vertical unidirectional flow passes down through the room, through the perforated raised floor tile into the return air space under the floor, and then up through vertical return air shafts, which are open to the ceiling fan-filters, the sensible cooling may be provided by water or cooled fan units located in the ceiling space above the fan filters.

Air pressure differential

COST FACTOR VARIABLES: 0.041 to 0.08

Cleanroom pressurization is necessary to protect the cleanroom against contamination from adjacent areas, control the flow of unwanted contaminants, prevent cross-contamination between areas, and help maintain temperature and humidity at required levels.

Typical air pressure differential between cleanroom and reference corridor and other areas of the facility is maintained at 0.25 to 0.005 in w.g. The higher number is usually more applicable to pharmaceutical facilities, with cascading air pressures between areas to avoid cross-contamination. Such areas normally require a series of cascading airlocks between them, plus pharmaceutical doors that allow air to escape at a high velocity, creating a pressure differential. A well-designed microelectronics cleanroom normally operates at 0.02 to 0.005 in w.g. with a semi-hermetic air lock at the cleanroom entrance. The cloth change and gowning areas often serve as airlocks. Mechanical air showers at the entrance are more a question of facility culture and cleanroom protocol than necessity.

Most microelectronics and photolithography cleanrooms operate successfully with passive air pressure control, and maintain only minimum air velocity of 50 to 100 fpm over the entrance with the door fully open. Some biopharmaceutical facilities require an active differential pressure control and supplement air escaping through the door (when the door is being opened) with make-up air automatically.

Differential pressure monitors, such as those provided by Cobeal, may be used for this task. Monitors may be mounted outside the cleanroom with a small LED inside the cleanroom, having an audible alarm and two indicators to show when pressure is normal or abnormal. The device detects negative pressure in biocontainment areas common in biopharmaceuticals, as well as the positive pressure common to electronic facilities. It has a digital differential pressure display with resolution of 0.001-in w.c. and pressure/vacuum range of 0.5-in w.c. Differential pressure is indicated by illuminated LEDs and an audio alarm. An internal adjustable time delay prevents activation of the audible alarm with the door is opened.

Temperature Control

COST FACTOR VARIABLES: 0.032 to 0.15

Temperature and humidity variations cause process equipment misalignment, impact the repeatability of the developed process, and eventually reduce the product's useful output, while increasing the quantity of waste. It is understandable that the goal is the most stringent cleanroom temperature requirements, but the cost often dictates otherwise.

In an attempt to lower construction costs, engineers are asked to design a precise temperature control area within a large space where the temperature is allowed to swing +/- 4 to 6 degrees Fahrenheit (i.e., the warehouse area with roll-up doors). But without hard walls and airlocks, it may be a very expensive alternative, with virtually uncontrollable variations of humidity. Common sense says that cascading levels of cleanliness, temperature, humidity and pressure are easier to achieve and maintain. The allowable tolerance should be carefully evaluated.

Mechanical equipment and control systems for cleanrooms with stringent temperature control requirements (+/- 0.1 degrees F) may cost 20 to 50 percent more than a cleanroom with typical requirements (68 to 72 degrees F) and setpoint (70 degrees F, +/- 2.0 degrees).

A zone thermostat controls the design temperature in each cleanroom zone. It actuates the duct-mounted zone reheat or re-cool coil to satisfy the room's sensible load conditions. In the case of fan coil units, the zone thermostat controls the temperature of air leaving the coils in the zone.

Humidity control

COST FACTOR VARIABLES: 0.034 to 0.19

The relative humidity for each cleanroom is controlled by a zone humidistat. If there is a high relative humidity in the room, the humidistat lowers the cooling coil discharge air temperature to provide more dehumidification. At the same time, the reheat coil provides heat to maintain the room temperature. If the relative humidity of any cleanroom falls below the design limit, the zone humidistat actuates the duct-mounted zone humidifier. When precise humidity control is required, it can typically be achieved with adiabatic humidification of make-up air in the air handler, and by maintaining the cleanroom dew point.

Local variation in humidity levels may be handled with ultrasonic humidifiers located in the ductwork plenum before the filtration terminals. These work well, with RO-DI water quality and water resistivity near 3 to 5 mgm. If the relative humidity falls below the design limit, the humidistat actuates the humidifier to increase the supply air's moisture content. If there is a high relative humidity, the humidistat lowers the make-up air handlers' cooling coil discharge air dew point temperature to provide more dehumidification.

Exhaust Systems

COST FACTOR VARIABLES: 0.031 to 0.16

Process exhaust systems include: acid, solvents and VOC, toxic, heat, and general room exhaust. If ammonia is present in the exhaust air stream, some facilities prefer to run a separate ductwork and abatement for fumes. The most common abatement for acid exhausts is a horizontal or vertical scrubber. Solvents and VOC exhausts require absorption, concentration and removal of condensed solvents or on-site incineration. Toxic exhaust is usually abated by in-place or on-site high temperature destruction. Cobeal carefully determines the abatement types and the quantities of required exhaust air streams.

Cobeal recommends good facility air management to help minimize quantities of exhaust air and, therefore, lower construction cost and energy waste during operation. It is important to maintain balance between potential needs for increase of exhaust quantity and expansion and economical value of installing such provisions. Far too often, oversized, expensive, lined stainless steel or FRP exhaust systems have been built in consideration for future expansion in cleanrooms while other utilities and mechanical systems (make-up air and cooling, for example) couldn't support such expansion. It is also common that acid exhaust systems have been built without consideration for future need, where velocity in the ductwork exceeds 4,000 fpm with added airflow and new ductwork branches. Such systems were difficult or impossible to balance and expensive to operate.

Vibration and noise control

COST FACTOR VARIABLES: 0.027 TO 0.10

Equipment size and weight affect vibration transfer and control. Concrete “waffle” slabs under the cleanroom floor work well for keeping equipment vibration from transferring to other areas of production or to metrology tools.

Waffle slabs remain rigid even if holes are drilled in the floor for piping and conduit access to the cleanroom. Because the strength of the floor is in the grid system, rearrangement is feasible; additional holes can be punched in the floor without adversely affecting vibration considerations.

All mechanical equipment should be vibro-isolated with springs, flexible connections, and isolated foundations to minimize the vibration effect. Cobeal’s quiet, energy-efficient fans and motors allow maintenance of the desired NC level in the cleanroom. Cobeal verifies mechanical and architectural concepts for vibration and noise control. Ignoring these systems could be very expensive to fix going forward. Many potentially costly measures can be eliminated, or replaced with more economical solutions when considered from the beginning of the project and by involving experienced architects, mechanical engineers, client and specialized consultants.

Magnetic and electromagnetic flux

COST FACTOR VARIABLES: 0.037 to 0.15

Magnetic flux has been proposed to be the flow of the background oceanic particles of the galaxy. Galactic rotation is also proposed to be electromagnetic in nature. The word “flux” means flow. Consider magnetic field lines as lines of some type of fluid flow through an imaginary surface. The magnetic field magnitude is like a rate of flow, and its direction is the direction of flow. The magnetic flux is akin to the total volume of flow through the surface. Simply put, think of magnetic flux as the number of field lines passing through the surface.

At a given speed, this force is greatest when the particle moves perpendicular to the magnetic field, and zero when the motion is parallel to the magnetic field.

At the most basic level, magnetic forces are exerted on moving charges by other moving charges, just as electrostatic forces are exerted by electric charges on other electric charges—whether or not they are moving.

It appears from comparative studies of planets that the Earth has a strong field because it rotates and has a molten metallic core. In theory, the field arises in internal electric currents that are induced by the Earth's rotation and by circulation in its fluid core. Magnetic flux density (instead of “Newton's per Amp-meter”) has its own unit—the Tesla. The typical value of the Earth's field near its surface is about half of a gauss, which is about one 200,000th of a Tesla. Occupational safety and health requirements limit magnetic field strength in areas open to the public to the 5 Gauss limit.

Magnetic shielding of a cleanroom can be very expensive. For example, 4 to 5-mm thick shielding on the envelope of the cleanroom with magnetic (Fe-Si) steel (M15 type) may lower the strength of magnetic flux from MRI equipment to 1.3 to 2.6 Gauss. But 14-mm of ordinary low-carbon steel shielding may not be sufficient. Semiconductor, metrology and communication laboratories require the strength of magnetic flux in the area to be limited to 0.05 Gauss or less.

A very expensive cleanroom was once shut down shortly after it was built because it was constructed on a site with high magnetic flux. Another cleanroom process failure was attributed to a high-capacity, high-voltage cable buried many feet under the production floor. Again, these things should be assessed at the onset of the project so remedies may be found and time and costs saved. Indeed, the cost of magnetic shielding should also be considered.

Electrostatic charge of air and surfaces

COST FACTOR VARIABLES: 0.037 to 0.12

“Static electricity” is present when surfaces in contact are separated. If the charge that arises from differences between the surfaces cannot escape to Earth quickly enough, then it is trapped and the charge will spread out over a material's surface—it is “static.”

Retained electrostatic charge creates risks and causes problems in many areas of the industry. It can cause ignition of flammable gases and even shock personnel. It can make thin films and light fabrics cling, attract airborne dust and debris, damage semiconductor devices and upset the operation of microelectronic equipment.

The hazard concerning flammable gases, vapors and powders relates both to the capacitively-stored energy in relation to minimum ignition energies, and to the breakdown voltage of the minimum gap from which an ignition will propagate.

Typically, the minimum ignition energies of common hydrocarbon gas/air mixtures are 0.2 millijoule (mJ) with a few kV minimum breakdown voltages. With powders, minimum ignition energies start at a few mJ.

Shocks from electrostatic discharges become discernible around 1 mJ and are likely to be uncomfortable in the 10 to 100-mJ range. They will cause major muscular contraction above 1J. Mechanical handling problems arise when electro-static forces become comparable to gravitational or other constraining forces. This relates to the strength of local electric fields and, hence, on insulators to surface-charge density.

In general, electrostatic forces are weak, but dust will be attracted to surfaces at charge densities less than a few mJ x 10^{-7} per m^{-2}. Electrostatic charge will be generated on people by such normal activities as walking across carpets, getting up from chairs, rubbing clothing against surfaces, etc. The levels of charge will be higher in low humidity environments and where artificial fibers are extensively used. Body potentials up to 15 kV may be expected.

Electrostatic discharges will occur from charged fabrics, a charged body, and any metal objects held in the hand, etc. These electrostatic discharges may involve high potentials and so may be able to jump several millimeters of air through gaps in equipment casings directly to internal circuitry. The discharges can involve currents up to several amps and involve frequency spectra extending up to several hundred megahertz—particularly where a metal conductor acts as the source of the discharge.

Static damage to semiconductor devices is very dependent on the device type and design. CMOS devices and fine geometry structures are especially susceptible. The risks may be expressed in relation to the voltage involved with a “human body model” discharge, although damage is more likely related to discharge energy and voltage. Damage sensitivities down around 50 volts may be experienced. Problems with the upset of microelectronic systems are also usually expressed in relation to a human body model discharge. System immunities of several kilovolts (kV) are likely to be needed (preferably over 15 kV for uncontrolled environments) as high potentials can readily be generated on personnel in normal working environments by movements across flooring, etc.

To minimize risk and avoid potential problems, it is necessary to ensure that static charge can dissipate more quickly than it is generated. For normal, manual-handling and body motion activities, this means the charge decay time needs to be .25 second or less. A new concept, relevant to risk control, is that if static charge experiences a high capacitance on a material, then only low surface voltages will be observed and potential problems and harm will be prevented.

Cobeal has taken precautions against static by recommending the installation of conductive floors and work surfaces, personnel earth bonding via wrist straps, and using anti-static or conductive bags for storing and transporting components and assemblies. The basic way to avoid electrostatic discharges affecting microelectronic systems is to mount the equipment within an enclosure, providing good electrostatic and magnetic shielding, and to suitably decouple all input and output connections.

Energy and operating cost

COST FACTOR VARIABLES: 0.017 to 0.15

As seen in Table 2, the operating costs of of recirculating AHU fans and air-cooled units each contribute significantly—approximately 35 percent—to the total HVAC operating cost. An operating cost savings was achieved on newly designed facilities by using fan filters, VFD drives, energy efficient motors, a cooling system with cooling towers, hot water zone reheat, and adiabatic humidification.

The stringent cleanliness requirements for cleanrooms are coupled with their inherent high operating costs; however, Cobeal helps client cut costs by planning ahead:

- Precisely define the class of cleanroom desired, making sure it fits the process requirement.
- Precisely define the room operating air temperature and humidity, making sure it fits the process requirement.
- The amount of air exhausted from the cleanroom should be the minimum required by the process. Imbed the exhaust air management program from the beginning. Start with providing

flow and differential pressure indicating instruments at all process exhaust air ductwork branches and tools.

- Limit ductwork and piping pressure drops by establishing maximum and minimum air velocities for the facility, and following these guidelines through construction.
- Use mini-environments, glove boxes, vacuum chambers and modular enclosures; reduce the need for large ballroom space and, therefore, reduce operating cost.
- Use energy-efficient motors with VFD drives.
- Loop supply and exhaust systems to reduce pressure drop and save space.

Form and Function

COST FACTOR VARIABLES: 0.038 to 0.16

Generally speaking, 20,000 to 30,000 sq. ft. of cleanroom space requires a 60,000 to 90,000 sq.ft. structure. The building height may be 21 to 26 ft. in order to accommodate an interstitial space of approximately 10 ft. in height. Another 12 to 16 ft. may be added for mechanical equipment above or below the cleanroom level.

For maximum flexibility, there should not be any columns inside the cleanroom. The roof structure should have a minimum depth and designed for loads of 100 to 200 pounds per sq./ft. to support the piping, ductwork and air-handling equipment that could be suspended from the overhead structure.

Frequently, the interstitial space must be used as a return air plenum, so the room and the building should be constructed of non-combustible material. The interstitial space, as well as the space below the ceilings, should be sprinklered.

NFPA codes should be followed to the letter, along with local safety codes. Obtaining permits for the construction (permitting process) may be long, expensive and frustrating if all building and fire safety codes are not followed. Also, all exempts and interpretations need to be documented and discussed with permitting officials ahead of time.

The cleanroom may be located against an interior wall with sufficient space provided outside the cleanroom to accommodate mechanical and process equipment, such as chillers, heat exchangers, pumps, DI water equipment, storage tanks, etc. Ideally, the floor slab in the cleanroom should not be poured until the designer and owner determine the requirements for process piping trenches and the location of vibration-sensitive equipment. A basement and or sub-basement space may be required for process and utilities piping, and cable distribution to tools and equipment, exhaust and return ductwork.

Extremely large electrical service with special redundancy features is often required, in which case it is necessary to confirm that adequate utilities are available.

The high water usage associated with semiconductor and pharmaceutical fabrication also requires waste treatment capacity and sewer lines large enough to handle the expected effluent. Minimizing wastewater discharge is always a goal. Today, zero-discharge facilities are commonplace—no longer a state-of-the-art feature.

Cobeal’s experienced architect provide valuable input into cleanroom facility design and cannot be overstated or overlooked. It will have a tremendous impact on the quality and cost-efficiency of your facility. The high-tech facility thrives with a thorough understanding of its function. Like the need for speed determines the size and shape of a race car, the cleanroom's specifics determine the correct architectural design of the facility.

Cobeal’s cleanroom architects have a solid knowledge of facility processes as well as present and future needs. Teamed with our qualified mechanical cleanroom design engineers, structural and electrical experts, and client process groups, the combination forms a critical element of every successful design.

Particulate

COST FACTOR VARIABLES: 0.040 to 0.15

Process Piping

COST FACTOR VARIABLES: 0.021 to 0.20

Particulate and process piping factors should not be eliminated from the discussion of their effect on cost. At the same time, because these variables are particularly specific to each facility, it is best not to generalize; they are, however, addressed within the included tables.

The process of cleanroom facility design is dynamic and creative. It is possible that cleanrooms as we know them today will continue to evolve.

Summary

Standards continue changing and evolving to meet the complex needs of our changing society and subsequent technological advancements. Some of us are still accustomed to using Fed Standard 209D (Class 100, 10,000, etc.). The ISO terminology enables engineers to speak a common language on a global basis, but it is adherence to case specific factors and variables that make the cleanroom.

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