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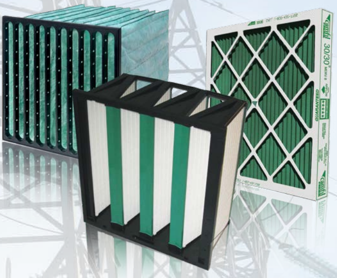
THE ENERGY & FILTER FACT HANDBOOK



Technical Guide on Energy Reduction by Choosing The Right Air Filter

Includes:
MERV References
Filter Application Guidelines
Handy HVAC Formulas
Conversion Formulas
HVAC Rules of Thumb

Clean Air Solutions

Contents

Publications with additional detail on items referenced in this pamphlet:

ASHRAE - American Society of Heating, Refrigeration and Air-Conditioning Engineers (www.ashrae.org), Various Handbooks and Standards

HVAC Equations, Data & Rules of Thumb, Arthur A. Bell, Publisher: McGraw Hill

Institute of Environmental Sciences & Technology, Various published Recommended Practices (www.iest.org))

Industrial Ventilation, Manual of Recommended Practices, ACGIH

Historical materials as published by Camfil, the Cambridge Filter Company and Farr Company.

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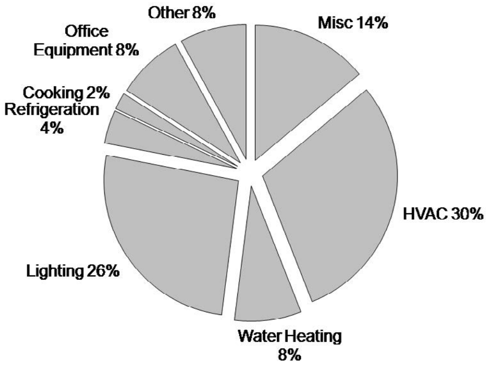
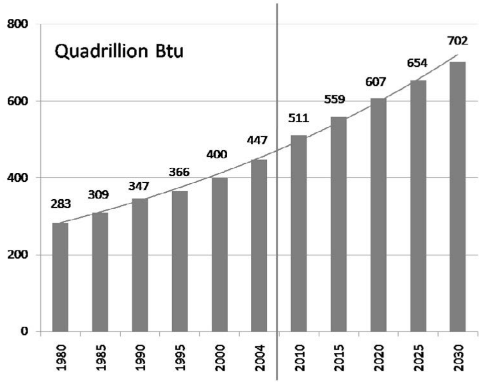
Energy - The Driving Force

Heating, ventilating and air conditioning systems (HVAC) account for more than 40% of the total energy used in North America and 30% worldwide. While each building will have varying costs based upon geography, climate and utility cost for each Kilowatt hour, we are all feeling the effects of global economics and the ever fluctuating prices of fuels.



Commercial Building Primary Energy Consumption Breakdown (from BTS, 2001; ADL, 1999; ADL, 2001)

Additionally, as we all know from a personal standpoint, energy prices are predicted to increase without a leveling in sight. The following chart notes the predicted energy increase in all forms through 2030. If we are going to practice sustainablity and move towards the 'green' concept, we need to reduce energy consumption in any area feasibly possible.



Energy Information Administration (EIA), International Energy Annual 2004 (May-July 2006), web site www.eia.doe.gov/iea.

In a standard HVAC system a filter may be responsible for up to 60% of the energy cost to move air through the system. An air filter creates resistance to airflow which makes the fan work harder to move the air required to heat and cool the building.

As the air filter becomes dirty it will increase in resistance thus requiring the fan to work even harder using even more energy. Some systems are further energy challenged because they require multiple stages of filtration to protect a process, such as a semiconductor or pharmaceutical manufacturing facility where higher grades of filtration are used because of the cleanliness requirement of the end product. These facilities use HEPA filters which have very dense media and require three to four times the power to move air through the filters. Hospital operating suites would also have these high efficiency filtration requirements and would use similar amounts of energy.

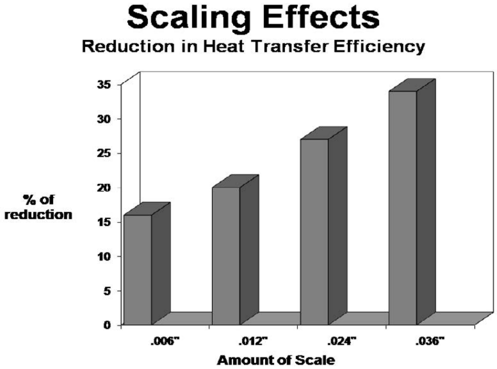
Maintaining the Building Intent

To control future expenditures it is important that a building's HVAC system be maintained and operated under the intent of the original design engineer. When a building undergoes major modification, or use changes, the HVAC system is often overlooked. Before any major modification, or building use change, the HVAC system should be examined by an HVAC engineer to ensure that cooling and heating demand may be met and that the comfort of the occupants is not compromised because of reduced ventilation air, or a reduction in the removal of contaminants by air filtration. Additional ventilation, or filtration, may be required if additional pollution generating components are added to the structure (IE: high volume laser printers or copiers).

The HVAC system should also be maintained as close as possible to its original pristine condition where the duct work and coils are free of contamination, sludge, or fouling. Moisture control is also paramount in maintaining the performance of the system and ensuring the proper indoor air quality (IAQ) of the building. A coil should be protected from airborne contaminants by a filter that has at least a minimum efficiency reporting value of 6 (MERV 6) per ASHRAE Standard 52.2, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.

The filter should also fit securely in the frame so filter air bypass is all but eliminated. Dirty systems are often the result of poorly fitting filters, not the filters themselves, as a 1/4″ gap around a 24″ by 24″ filter can equal as much as 18% bypass.

We also need to remember that air filters were originally installed in equipment to protect the equipment, not the environment or people. We have learned the hazards of poor environments so our HVAC systems were the natural choice to install higher efficiency filtration to protect building occupants.



The chart above notes the percent of reduction of heat transfer (R-22 type AC coil) with minimum scaling contamination.

Types of Air Filters

Given the multitude of building uses, varying climates and geographical environmental air quality, it is no wonder there are so many different types of filters. What type of filter should you apply in your building to protect the integrity of the HVAC system and of course, the building occupants?

The filter on the left has 6 pockets, the filter on the right has 8 pockets, and both are the same length. The filter on the right has 30% more media area and will last longer and use less energy in its life within the system. At 10¢ a kilowatt hour the filter on the left will cost $95.00 per year to operate and the filter on the right will cost $56.00 (2000 cfm per filter & 60% fan efficiency). Some bag filters can cost up to $227.00 per year in energy.

Are you selecting a filter to control contaminants from an industrial process? Are you selecting filters to protect an office building and reduce absenteeism of employees? Are you protecting a critical process that requires ultra-clean air? Will you change your filters on a preventative maintenance schedule, or will you use increasing pressure drop as a barometer?

Your filter supplier can provide guidance. Their representatives work with filtration every day. Filters are a small part of your overall responsibility, so capitalize on their experience.

The American Society of Heating, Refrigeration and Air-Conditioning Engineers recommends specific filter efficiencies for certain types of buildings and has assigned values to allow easier selection of the appropriate filter. The following chart notes some common filter applications.

Application	MERV
Light duty residential for coil or heat exchanger protection, light commercial for protection of HVAC and industrial equipment.	1 to 4
Superior residential for removal of allergens, light duty commercial, split systems and roof tops.	5 to 8
Superior residential for removal of allergens, commercial office buildings and institutional.	9 to 11
Superior commercial office buildings, superior institutional, removal of respirable particles.	12 to 13
General hospital areas, low-level surgical suites, smoke removal, superior commercial buildings.	14 to 15
High risk surgical suites, hazardous material capture, clean rooms, HEPA level protection.	16 to HEPA
General recommendations. Consult ASHRAE Systems & Equipment Handbook or www.camfil.com for specific application guidance.	

The following chart allows you to compare the current MERV values from manufacturers' literature to other standards that may be referenced in other literature or specifications.

Filter Efficiencies & Corresponding Values of Current Filter Testing Standards			
MERV ASHRAE 52.2	Dust Spot Efficiency ASHRAE 52.1 (defunct Standard)	Arrestance ASHRAE 52.2	Selected Eurovent EN779 Values
1	< 20	>65	G1
2	< 20	≥65	G2
3	< 20	≥70	
4	< 20	≥75	
5	20	80	G3
8	30-35	92	M5
9	40-45	94	
11	60-65	97	M6
13	80-85	99	F7
14	90-95	100	F8
16	99	100	F9

MERV is Minimum Efficiency Reporting Value per ASHRAE 52.2, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size

Dust Spot Efficiency and Arrestance are values from ASHRAE 52.1, Gravimetric & Dust Spot Procedures for Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter

EN779 is the European Filter Testing Standard, *Particulate Air Filters for General Ventilation.*

Selecting the Right Filter

Once the required filter efficiency has been established through guidance from cognizant authorities, how do you select from the multitude of configurations available? Do you select a flat panel pad, a fiberglass throw-away, or a pleated panel as a prefilter? For your final filter, do you select an extended surface pocket filter (bag) and, if so, how many pockets, what length and what type of media? If you select a rigid box style filter, do you select one with glass mat media, or high-lofted media, in a deep pleat or mini-pleat design, with fine fiber media which removes particles through a mechanical process, or coarse fiber media that enhances its performance with an electret charge?

The answers are not always straight-forward as each filter manufacturer probably has a system somewhere where it may prove to be the best selection. You should always review your options, for your unique application, with your filter supplier, or preferred filter manufacturer.

We will concentrate herein on recommendations for selecting a filter based upon its actual cost of ownership. This includes the cost of the filter, the amount of time it will last in the system, if it will maintain particle capture efficiency throughout its life, and perhaps the most critical factor, the amount of energy that it will use in its period of operation.

For product considerations we should always look at the amount of media area, the type of media used to capture the contaminant and the configuration of the media and filter pack. From a low efficiency panel filter to the highest grade HEPA filter the more media area exposed to the airflow in a given space, the more value the filter will have in terms of lasting longer and using less energy in its lifetime. The concept is analogous to duct selection. When a larger duct is selected to move a given amount of air, the resistance to airflow though the larger duct will be less, resulting in less required horsepower to move the air. As an example, a 6˝ round supply duct will offer 110 cfm of air per 100 feet of duct with a resistance to airflow of 0.10˝ w.g. An 8˝ round duct under the same parameters will have a resistance to airflow of only 0.025˝ w.g., only 25% of the 6˝ round duct. The fan will require less horsepower to move air through the 8˝ duct as opposed to the 6˝ duct.

An air filter with 15 pleats per linear foot exposes over 30% more media to the airflow than a filter in the same configuration with only 10 pleats per linear foot. The filter with the increased media area has more paths for the air to move through the media, creating less resistance to airflow over its lifetime thus requiring less horsepower and less energy.

A 2˝-deep pleated panel filter with 10 pleats per linear foot will not last as long as another pleated panel filter with 15 pleats per linear foot. The filter with fewer pleats will also use more energy while in operation as it will increase in resistance at a much faster rate with dirt loading.

Final filters are available with as little as 40 square feet of media to well over 200 square feet of media. Without considering the

Both filters are 24˝ by 24˝ by 12˝, the filter on the right has double the media area of the filter on the left. The filter on the right will last longer and offer significant energy savings. At 10¢ a kilowatt hour the filter on the left will cost $127.90 per year to operate and the filter on the right will cost $53.50 (2000 cfm per filter & 60% fan efficiency). Some bag filters can cost up to $238.60 per year in energy.

extended life of the product with the higher amount of media, the additional energy cost to move air through the filter with less media can be well over $100 per year.

Another determining factor for longer life and lower energy usage relates to configuration losses. Each filter has construction components that restrict airflow. A properly manufactured filter does not have air pockets that can cause turbulent airflow and increase resistance. Additionally, media spacing must be dynamically optimized so air flows through the filter freely even as the filter loads with contaminant. It is also important to maintain media exposure while loading with contaminant through the use of

- tapered pockets on bag filters
- tapered deep pleats on box filters
- and, radially configured pleats as opposed to v-style pleats on medium efficiency prefilters.

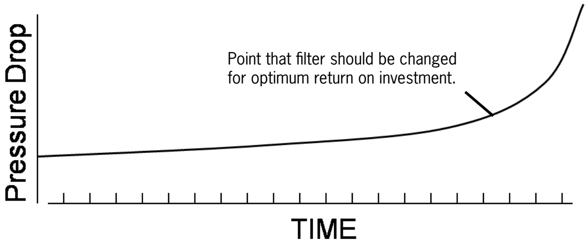
Filters are only one component of an HVAC system, albeit one of the most important. Reducing the pressure drop through the air filters can increase airflow to the space and save energy while ensuring that the occupants of the building are protected from contaminants.

Reducing energy and maintaining efficiency will contribute to the requirements of LEED certification. LEED is a registered trademark of the United States Green Building Council. Please refer to www.usgbc.org for additional information on LEED.

Filters will use additional energy as they become loaded with contaminants. If allowed to operate to published final resistance levels, a MERV 14 filter may use up to 50% of the total energy required to operate the fan. Operating to a filter's published final pressure drop rarely has an economic advantage as the energy penalty to move air through a dirty filter far outweighs the cost of replacing the filters. Final recommended pressure drop, as published in manufacturers' literature is a maximum.

Ideally filters should always be evaluated using pressure drop versus the actual air velocity of the system. Your manufacturer can provide additional guidance here because your actual values, in your system, can vary widely.

The easiest rule of thumb is to change the filter when the pressure drop has doubled. Consistent from pleated panel filters to HEPA filters, this rule of thumb offers the best return on your filtration investment as it balances filtration efficiency.



The final resistance as published in manufacturers' literature is a guide as to maximum point to which a filter may be operated without concern for filter failure. Actual changeout point varies from system to system. For the best value a filter should be changed at the point where it becomes a detriment to the system and the use of energy outweighs the value of more life from the filter.

Critical HVAC Components on the Air Side

Every component within an air handling system creates resistance to airflow which requires more power from the fan to meet the requirements for heating and cooling a building. The following chart notes some of those components and an approximate percentage of their share of the energy requirement load.

HVAC Component	Estimated use of fan power as a percentage of total available (approx.)
Supply grille or register	3%
Return grilles or registers	13-20%%
Dampers	6%
Flexible duct	3%
Solid wall duct	6%
Elbows or turns	13-20%
Cooling or heating coil	8-12%
Heat exchanger	10% to 16% (clean filters)
Single stage filters (MERV 13)	10% to 16% (clean filters)
Second stage filters (MERV 14)	16% to 33% (clean filters)
Actual values will vary based upon design velocity, component selection and the intricacy of the entire system. Values are shown for example purposes.	

Energy Calculation

To calculate the energy cost to move air through any component in your system, the following equation applies:

1. Volumetric Flow Rate "Q", stated in ft^3/min (cubic feet per minute).
2. Total Pressure in inches of water (resistance due to friction of ducts, coils, filters, etc.), and ΔP of the component under consideration.
3. Density factor of the gas being collected "df" (dimensionless).
4. Efficiency of the fan, "η" (dimensionless).

These are combined into the air power equation:

Power (horsepower) = (Q) (TP) (df) (η) (6356).

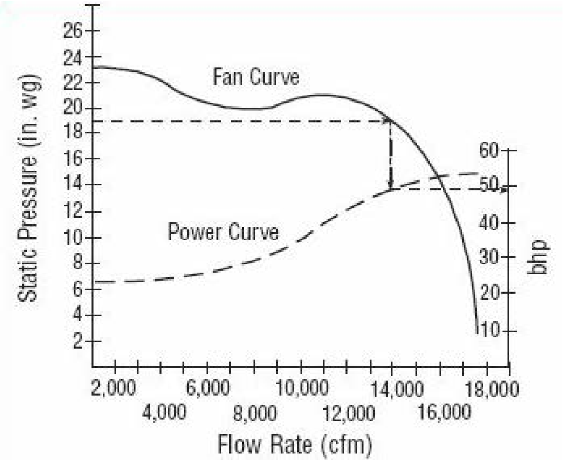
Small reductions in the numerator can have a significant cost impact.

Following the rule of thumb of changing the filter when it doubles its initial pressure drop can also provide significant energy savings. As a filter loads with dirt, its resistance to airflow increases, forcing the fan to work harder to deliver the air for heating and cooling requirements. This change in filter resistance can affect the balance of the system, increasing energy costs.

Fan performance is typically defined by a plot of static pressure and power required over a range of fan-generated airflow. Understanding this relationship is essential to initial design and proper selection of components, and replacement components such as air filters. Fan efficiency is the ratio of the power imparted to the airstream to the power delivered by the motor. The power of the airflow is the product of the pressure and the flow, corrected for units consistency. The equation for total efficiency is:

$$\text{Total Efficiency} = \frac{\text{Total Pressure x Airflow}}{\text{bhp x 6.362}}$$

Where:
Total Pressure is in inches of water
Airflow is in cubic feet per minute (cfm)
bhp is brake horsepower



An important aspect of a fan performance curve is the best efficiency point (BEP), where a fan operates most cost effectively in terms of both energy efficiency and maintenance considerations. Operating a fan near its BEP improves its performance and reduces wear, allowing longer intervals between repairs. Moving a fan's operating point away from its BEP increases bearing loads and noise.

On the above fan curve, the optimum operating range is within the intersecting points where the straight dotted line intersects the fan curve. Variance in either direction can translate into higher energy costs. This graph is fan specific and the curve and intersections will vary from fan to fan. Consult your fan manufacturer for model specific fan curves.

Each fan manufacturer can provide a fan curve that allows a technician to adjust fan operating parameters to provide maximum air at a minimal energy investment. In most modern systems, fan adjustment is handled automatically by a variable frequency drive (VFD). The VFD can reduce the motor speed when full flow is not required, thereby reducing the power and the electrical energy used. The intent of a VFD is to match system airflow to actual heating and cooling demands. Most HVAC systems are designed to keep the building cool on the hottest days and warm on the coldest days. Therefore, the HVAC system needs to work at full capacity only on the 10, or so, hottest days and the 10, or so, coldest days of the year. On the other 345 days, the HVAC system can operate at a reduced capacity. A variable air volume system with variable speed drives adjusts the motor speed enabling closer matching of motor output to load with resultant energy savings.

VFDs decrease energy losses by lowering overall system flow.

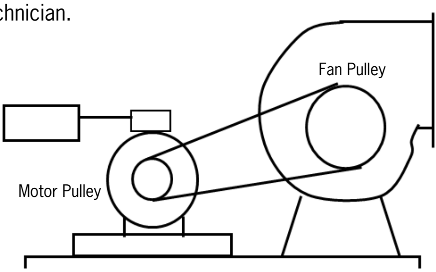
By slowing the fan and lessening the amount of unnecessary energy imparted to the airstream, VFDs offer substantial savings with respect to the cost-per-unit volume of air moved. When fan speed decreases, the curves for fan performance and brake horsepower move toward the origin. Fan efficiency increases, providing an essential cost advantage during periods of low system demand. Keeping fan efficiency as high as possible across variations in the system's flow requirements reduces fan operating costs. VFDs eliminate the reliance on mechanical components, providing an attractive operational advantage, especially in “dirty” airstreams. A system with a VFD will adjust to the filter’s resistance to airflow even as the filter loads with contaminants.

For initial design purposes a design engineer should calculate:

- Initial resistance at airflow plus 0.20″ for prefilters
- Initial resistance at airflow plus 0.30″ w.g. for final filters

...as part of the overall system average resistance to airflow.

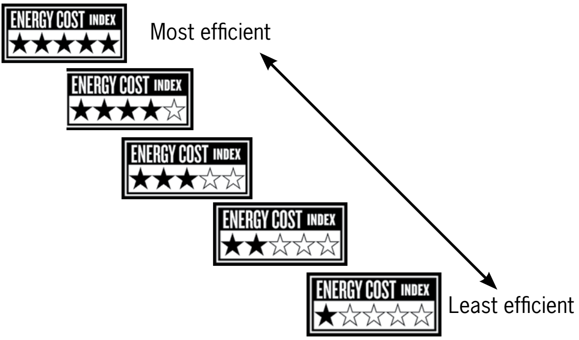
If a building uses a constant-volume air handling system with no variable speed drives, the system runs at full speed all the time. If optimal energy savings are to be obtained by using air filters with a lower system resistance, then some mechanical modifications may have to be made. Usually this involves a simple pulley change. We recommend that these changes be made by a qualified technician.



On older belt-driven systems a motor pulley must be changed or chived to ensure that the fan is operating within the parameters of the fan’s curve. Changing system components on this type of system without taking this step could actually cause the system to use more energy.

Energy Cost Index (ECI)

Another item that should be considered when selecting a filter is whether that filter will provide the efficiency as published throughout the life of the filter. Some filters use an electret charge to enhance efficiency, but the charge dissipates over time, and the filter’s efficiency drops. The Energy Cost Index (ECI) looks at a filter’s energy use over its expected life and includes a factor that penalizes the filter rating, if it drops in efficiency. The Energy Cost Index (ECI) is an easy way to compare the energy efficiency of one manufacturer’s filter against another and then choose the one that will work best for you. Based on a five-star scale, the ECI is an indicator of what the filter will cost over its lifetime. The best rating—five stars—indicates that the filter is one of the most energy-efficient, longest-lasting filters available.



Handy Industry Conversions

ATMOSPHERES — atm (Standard at sea-level pressure)

x 101.325 = Kilopascals (kPa) absolute

x 14.696 = Pounds-force per square inch absolute (psia)

x 76.00 = Centimeters of mercury (cm Hg) at 0°C

x29.92 = Inches of mercury (inHg) at 0°C

x 33.96 = Feet of water (ft H_2O) at 68°F

x 1.01325 = Bars (bar) absolute

x 1.0332 = Kilograms-force per square centimeter (kg/cm^2) absolute

x 1.0581 = Tons-force per square foot ($tonf/ft^2$) absolute

x760 = Torr (torr) (= mm Hg at 0°C)

BARRELS, LIQUID, U.S. — bbl

x 0.11924 = Cubic meters (m^3)

x 31.5 = U.S. gallons (U.S. gal) liquid

BARRELS, PETROLEUM — bbl

x 0.15899 = Cubic meters (m^3)

x 42 = U.S. gallons (U.S. gal) oil

BARS — bar x 100

x 14.504 = Kilopascals (kPa)

x 33.52 = Pounds-force per square inch (psi) = Feet of water (ft H_2O) at 68°F

x 29.53 = Inches of mercury (in. Hg) at 0°C

x 1.0197 = Kilograms-force per square centimeter (kg/cm^2)

x 0.98692 = Atmospheres (atm) sea-level standard

x 1.0443 = Tons-force per square foot ($tonf/ft^2$)

x 750.06 = Torr (torr) (= mm Hg at 0°C)

BRITISH THERMAL UNITS — Btu

x 1055 = Joules (J)

x 778 = Footpounds-force (ft • lbf)

x 0.252 = Kilocalories (kcal)

x 107.6 = Kilogram-force-meters (kgf • m)

x 2.93×10^{-4} = Kilowatt-hours (kW • h)

x 3.93×10^{-4} = Horsepower-hours (hp • h)

BRITISH THERMAL UNITS PER MINUTE — Btu/mln

x 17.58 = Watts (W)

x 12.97 = Foot-pounds-force per second (ft • lbf/s)

x 0.02358 = Horsepower (hp)

CENTARES

x 1 = Square meters (m)

CENTIMETERS — cm

x 0.3937 = Inches (in)

CENTIMETERS OF MERCURY — cm Hg at 0°C

x 1.3332 = Kilopascals (kPa)
x 0.013332 = Bars (bar)
x 0.4468 = Feet of water (ft H_2O) at 68°F
x 5.362 = Inches of water (inH_2O) at 68°F
x 0.013595 = Kilograms-force per square centimeter (kg/cm^2)
x 27.85 = Pounds-force per square foot (lb f/ft^2)
x 0.19337 = Pounds-force per square inch (psi)
x 0.013158 = Atmospheres (atm) standard
x 10 = Torr (torr) (= mm Hg at 0°C)

CENTIMETERS PER SECOND — cm/s

x 1.9685 = Feet per minute (ft/min)
x 0.03281 = Feet per second (ft/s)
x 0.03600 = Kilometers per hour (km/h)
x 0.6000 = Meters per minute (m/min)
x 0.02237 = Miles per hour (mph)

CUBIC CENTIMETERS — cm^3

x 3.5315×10^{-5} = Cubic feet (ft^3)
x 6.1024×10^{-2} = Cubic inches (in^3)
x 1.308×10^{-6} = Cubic yards (yd^3)
x 2.642×10^{-4} = U.S. gallons (U.S. gal)
x 2.200×10^{-4} = Imperial gallons (imp gal)
x 1000×10^{-3} = Liters (l)

CUBIC FEET — ft^3

x 0.02832 = Cubic meters (m^3)
x 2.832×10^4 = Cubic centimeters (cm^3)
x 1728 = Cubic inches (in^3)
X 0.03704 = Cubic yards (yd^3)
x 7.481 = U.S. gallons (U.S. gal)
x 6.229 = Imperial gallons (imp gal)
x 28.32 = Liters (l)

CUBIC FEET PER MINUTE — cfm

x 472.0 = Cubic centimeters per second (cm^3/s)
x 1.699 = Cubic meters per hour (m^3/h)
x 0.4720 = Liters per second (l/s)
x 0.1247 = U.S. gallons per second (U.S. gps)
x 62.30 = Pounds of water per minute (lb H_2O/min) at 68°F

CUBIC FEET PER SECOND — cfs

x 0.02832 = Cubic meters per second (m^3)
x 1.699 = Cubic meters per minute (m^3/min)
x 448.8 = U.S. gallons per minute (U.S. gpm)
x 0.6463 = Million U.S. gallons per day (U.S. gpd)

CUBIC INCHES — In^3

x 1.6387×10^{-5} =	Cubic meters (m^3)
x 16.387 =	Cubic centimeters (cm^3)
x 0.016387 =	Liters (l)
x 5.787×10^{-4} =	Cubic feet (ft^3)
x 2.143×10^{-5} =	Cubic yards (yd^3)
x 4.329×10^{-3} =	U.S. gallons (U.S. gal)
x 3.605×10^{-3} =	Imperial gallons (imp gal)

CUBIC METERS — m^3

x 1000 =	Liters (l)
x 35.315 =	Cubic feet (ft^3)
x 61.024×10^{3} =	Cubic inches (in^3)
x 1.3080 =	Cubic yards (yd^3)
x 264.2 =	U.S. gallons (U.S. gal)
x 220.0 =	Imperial gallons (imp gal)

CUBIC METERS PER HOUR — m^3/h

x 0.2778 =	Liters per second (l/s)
x 2.778×10^{-4} =	Cubic meters per second (m^3s)
x 4.403 =	U.S. gallons per minute (U.S. gpm)

CUBIC METERS PER SECOND — m^3/s

x 3600 =	Cubic meters per hour (m^3/h)
x 15.85×10^{-3} =	U.S. gallons per minute (U.S. gpm)

CUBIC YARDS — yd^3

x 0.7646 =	Cubic meters (m^3)
x 764.6 =	Liters (l)
x 7.646×10^{5} =	Cubic centimeters (cm^3)
x 27 =	Cubic feet (ft3)
x 46,656 =	Cubic inches (in^3)
x 201.97 =	U.S. gallons (U.S. gal)
x 168.17 =	Imperial gallons (imp gal)

DEGREES ANGULAR — (°)

x 0.017453 =	Radians (rad)
x 60 =	Minutes (′)
x 3600 =	Seconds
x 1.111 =	Grade (gon)

DEGREES PER SECOND, ANGULAR — (°/s)

x 0.017453 =	Radians per second (rad/s)
x 0.16667 =	Revolutions per minute (rpm)
x 2.7778×10^{-3} =	Revolutions per second (rps)

DRAMS — (dr)

x 1.7718 =	Grams (g)
x 27.344 =	Grains (gr)
x 0.0625 =	Ounces (oz)

FATHOMS

x 1.8288 =	Meters (m)
x 6 =	Feet (ft)

FEET — ft

x 0.3048 =	Meters (m)
x 30.480 =	Centimeters (cm)
x 12 =	Inches (in)
x 0.333 =	Yards (yd)

FEET OF WATER — ft H^2O at 68°F

x 2.984 =	Kilopascals (kPa)
x 0.02984 =	Bars (bar)
x 0.8811 =	Inches of mercury (in. Hg) at 0°C
x 0.03042 =	Kilograms-force per square centimeter (kg/cm^2)
x 62.32 =	Pounds-force per square foot (lbf/ft^2)
x 0.4328 =	Pounds-force per square inch (psi)
x 0.02945 =	Standard atmospheres

FEET PER MINUTE

x 0.5080 =	Centimeters per second (cm/s)
x 0.01829 =	Kilometers per hour (km/h)
x 0.0051 =	Meters per second (mps)
x 0.3048 =	Meters per minute (m/min)
x 0.016667 =	Feet per second (ft/s)
x 0.01136 =	Miles per hour (mph)

FEET PER SECOND PER SECOND — ft/s^2

x 0.3048 =	Meters per second per second (m/s^2)
x 30.48 =	Centimeters per second per second (cm/s^2)

FOOT-POUNDS-FORCE — ft • lbf

x 1.356 =	Joules (J)
x 1.285×10^{-3} =	British thermal units (Btu)
x 3.239×10^{-4} =	Kilocalories (kcal)
x 0.13825 =	Kilogram-force-meters (kgf • m)
x 5.050×10^{-7} =	Horsepower-hours (hp • h)
x 3.766×10^{-7} =	Kilowatt-hours (kW • h)

GALLONS U.S — U.S. gal

x 3785.4 =	Cubic centimeters (cm^3)
x 3.7854 =	Liters (l)
x 3.7854 x 10-3 =	Cubic meters (m^3)
x 231 =	Cubic inches (in^3)
x 0.13366 =	Cubic feet (ft^3)
x 4.951 x 10-3 =	Cubic yards (yd^3)
x 8 =	Pints (pt) liquid
x 4 =	Quarts (qt) liquid

GALLONS U.S — U.S. gal (continued)

x 0.8327 =	Imperial gallons (Imp gal)
x 8.328 =	Pounds of water at 60°F in air
x 8.337 =	Pounds of water at 60°F in vacuum

GALLONS, IMPERIAL — Imp gal

x 4546 =	Cubic centimeters (cm^3)
x 4.546 =	Liters (l)
x 4.546×10^{-3} =	Cubic meters (m^3)
x 0.16054 =	Cubic feet (ft^3)
x 5.946×10^{-3} =	Cubic yards (yd^3)
x 1.20094 =	U.S. gallons (U.S. gal)
x 10.000 =	Pounds of water at 62°F in air

GALLONS, PER MINUTE, U.S. — U.S. gpm

x 0.22715 =	Cubic meters per hour (m^3h)
x 0.06309 =	Liters per second (l/s)
x 8.021 =	Cubic feet per hour (cfh)
x 2.228×10^{-3} =	Cubic feet per second (cfs)

GRAINS — gr av. or troy

x 0.0648 =	Grams (g)

GRAINS PER CUBIC FOOT

x 2288.1 =	milligrams per cubic meter (mg/m^3)

GRAINS PER U.S. GALLON — gr/U.S. gal at 60°F

x 17.12 =	Grams per cubic meter (g/m^3)
x 17.15 =	Parts per million by weight in water
x 142.9 =	Pounds per million gallons

GRAINS PER IMPERIAL GALLON — gr/Imp gal at 62°F

x 14.25 =	Grams per cubic meter (g/m^3)
x 14.29 =	Parts per million by weight in water

GRAMS — g

x 15.432 =	Grains (gr)
x 0.035274 =	Ounces (oz) av
x 0.032151 =	Ounces (oz) troy
x 2.2046×10^{-3} =	Pounds (lb)

GRAMS-FORCE — gf

x 9.807×10^{-3} =	Newtons (N)

GRAMS—FORCE PER CENTIMETER — gf/cm

x 98.07 =	Newtons per meter (N/m)
x 5.600×10^{-3} =	Pounds-force per inch (lbf/in)

GRAMS PER CUBIC CENTIMETER — g/cm^3

x 62.43 =	Pounds per cubic foot (lb/ft^3)
x 0.03613 =	Pounds per cubic inch (lb/in^3)

GRAMS PER LITER — g/l

x 58.42 =	Grains per U.S. gallon (gr/U.S. gal)
x 8.345 =	Pounds per 1000 U.S. gallons
x 0.06243 =	Pounds per cubic foot (lb/ft^3)
x 1002 =	Parts per million by mass (weight) In water at 60°F

HECTARES — he

x 1.000×10^4 =	Square meters (m^2)
x 1.0764×10^6 =	Square feet (ft^2)

HORSEPOWER — hp

x 745.7 =	Watts (W)
x 0.7457 =	Kilowatts (kW)
x 33,000 =	Foot-pounds-force per minute (ft • lbf/min)
x 550 =	Foot-pounds-force per second (ft • lbf/s)
x 42.43 =	British thermal units per minute (Btu/min)
x 10.69 =	Kilocaiories per minute (kcal/min)
x 1.0139 =	Horsepower (metric)

HORSEPOWER — hp boiler

x 33,480 =	British thermal units per hour (Btu/h)
X 9.809 =	Kilowatts (kW)

HORSEPOWER-HOURS — hp • h

x 0.7457 =	Kilowatt-hours (kW • h)
x 1.976×10^6 =	Foot-pounds-force (ft • lbf)
x 2545 =	British thermal units (Btu)
x 641.5 =	Kilocalories (kcal)
x 2.732×10^6 =	Kilogram-force-meters (kgf • m)

INCHES — In

x 2.540 =	Centimeters (cm)

INCHES OF MERCURY — In Hg at 0°C

x 3.3864 =	Kilopascals (kPa)
x 0.03386 =	Bars (bar)
x 1.135 =	Feet of water (ftH_2O) at 68°F
x 13.62 =	Inches of water (In H_2O) at 68°F
x 0.03453 =	Kilograms-force per square centimeter (kg/cm^2)
x 70.73 =	Pounds-force per square foot (lbf/ft^2)
x 0.4912 =	Pounds-force per square inch (psi)
x 0.03342 =	Standard atmospheres

INCHES OF WATER — In H_2O at 68°F

x 0.2487 =	Kilopascals (kpa)
x 2.487×10^{-3} =	Bars (bar)
x 0.07342 =	Feet of water (ft H_2O) at 68°F
x2.535×10^{-3} =	Inches of mercury (in Hg) at 0°C
x 0.5770 =	Ounces-force per square inch (ozf/in^2)

INCHES OF WATER — In H_2O at 68°F (Continued)

x 5.193 =	Pounds-force per square foot (lbf/ft^2)
x 0.03606 =	Pounds-force per square inch (psi)
x 2.454 x 10^{-3} =	Standard atmospheres

JOULES — J

x 0.9484 x 10^{-3} =	British thermal units (Btu)
x 0.2390 =	Calories (cal) thermochemical
x 0.7376 =	Foot-pounds-force (ft • lbf)
x 2.778 x 10^{-4} =	Watt-hours (W • h)

KILOGRAMS — kg

x 2.2046 =	Pounds (lb)
x 1.102 x 10^{3} =	Tons (ton) short

KILOGRAMS-FORCE — kgf

x 9.807 =	Newtons (N)
x 2.205 =	Pounds-force (lbf)

KILOGRAMS-FORCE PER METER — kgf/m

x 9:807 =	Newtons per meter (N/m)
x 0.6721 =	Pounds-force per foot (lbf/ft)

KILOGRAMS-FORCE PER SQUARE CENTIMETER — kgf/cm^2

x 98.07 =	Kilopascals (kPa)
x 0.9807 =	Bars (bar)
x 32.87 =	Feet of water (ft H20) at 68°F
x 28.96 =	Inches of mercury (in Hg) at 0°C
x 2048 =	Pounds-force per square foot (lbf/ft^2)
x 14.223 =	Pounds-force per square inch (psi)
x 0.9678 =	Standard atmospheres

KILOGRAMS-FORCE PER SQUARE MILLIMETER — kgf/mm^2

x 9.807 =	Megapascals (MPa)
x 1.000 X 10^{6} =	Kilograms-force per square meter (kgf/m^2)

KILOMETERS PER HOUR — km/h

x 27.78 =	Centimeters per second (cm/s)
x 0.9113 =	Feet per second (ft/s)
x 54.68 =	Feet per minute (ft/min)
x 16.667 =	Meters per minute (m/min)
x 0.53996 =	International knots (kn)
x 0.6214 =	Miles per hour (mph)

KILOMETERS PER HOUR PER SECOND — km • h^{-1} • s^{-1}

x 0.2778 =	Meters per second per second (m/s^2)
x 27.78 =	Centimeters per second per second (cm/s^2)
x 0.9113 =	Feet per second per second (ft/s^2)

KILOMETERS PER SECOND — km/s

x 37.28 =	Miles per minute (mi/min)

KILOPASCALS — kPa

x 10^3 =	Pascals (Pa) or newtons per square meter (N/m^2)
x 0.1450 =	Pounds-force per square inch
x 0.010197 =	Kilograms-force per square centimeter (kg/cm^2)
x 0.2953 =	Inches of mercury (in Hg) at 32°F
x 0.3351 =	Feet of water (ft H_2O) at 68°F
x 4.021 =	Inches of water (in H_2O) at 68°F

KILOWATTS — kW

x 4.425 x 104 =	Foot-pounds-force per minute (ft • lb/min)
x 737.6 =	Foot-pounds-force per second (ft • lbf/s)
x 56.90 =	British thermal units per minute (Btu/min)
x 14.33 =	Kilocalories per minute (kcal/min)
x 1.3410 =	Horsepower (hp)

KILOWATT-HOURS — kW • h

x 3.6 x 10^6 =	Joules (J)
x 2.655 x 10^6 =	Foot-pounds-force (ft • lbf)
x 3413 =	British thermal units (Btu)
x 860 =	Kilocalories (kcal)
x 3.671 x 10^5 =	Kilogram-force meters (kgf • m)
x 1.3410 =	Horsepower-hours (hp • h)

KNOTS — kn (International)

x 0.5144 =	Meters per second (m/s)
x 1.151 =	Miles per hour (mph)

LITERS — l

x 1000 =	Cubic centimeters (cm^3)
x 0.035315 =	Cubic feet (ft^3)
x 61.024 =	Cubic inches (in^3)
x 1.308 x 10^3 =	Cubic yards (yd^3)
x 0.2642 =	U.S. gallons (U.S. gal)
x 0.2200 =	Imperial gallons (imp gal)

LITERS PER MINUTE — l/mln

x 0.01667 =	Liters per second (l/s)
x 5.885 x 10^{-4} =	Cubic feet per second (cfs)
x 4.403 x 10^{-3} =	U.S. gallons per second (U.S. gals)
x 3.666 x 10^{-3} =	Imperial gallons per second (imp gal/s)

LITERS PER SECOND — l/s

x 10^{-3} =	Cubic meters per second (m^3/s)
x 3.600 =	Cubic meters per hour (m^3/h)
x 60 =	Liters per minute (l/min)
x 15.85 =	U.S. gallons per minute (U.S. gpm)
x 13.20 =	Imperial gallons per minute (imp gpm)

MEGAPASCALS — MPa

x 10^6 =	Pascals (Pa) or newtons per square meter (N/m^2)
x 10^3 =	Kilopascals (kPa)
x 145.0 =	Pounds-force per square inch (psi)
x 0.1020 =	Kilograms-force per square millimeter (kgf/mm^2)

METERS — m

x 3.281 =	Feet (ft)
x 39.37 =	Inches (in)
x 1.0936 =	Yards (yd)

METERS PER MIN — m/min

x 1.6667 =	Centimeters per second (cm/s)
x 0.0600 =	Kilometers per hour (km/h)
x 3.281 =	Feet per minute (ft/min)
x 0.05468 =	Feet per second (ft/s)
x 0.03728 =	Miles per hour (mph)

METERS PER SECOND — m/s

x 3.600 =	Kilometers per hour (km/h)
x 0.0600 =	Kilometers per minute (km/min)
x 196.8 =	Feet per minute (ft/min)
x 3.281 =	Feet per second (ft/s)
x 2.237 =	Miles per hour (mph)
x 0.03728 =	Miles per minute (mi/min)

MICROMETERS — um (micron)

x 0.000001 =	Meters (m)

MILES — mi

x 1.6093 x 10^3 =	Meters (m)
x 1.6093 =	Kilometers (km)
x 5280 =	Feet (ft)
x 1760 =	Yards (yd)

MILES PER HOUR — mph

x 44.70 =	Centimeters per second (cm/s)
x 1.6093 =	Kilometers per hour (km/h)
x 26.82 =	Meters per minute (m/min)
x 88 =	Feet per minute (ft/min)
x 1.4667 =	Feet per second (ft/s)
x 0.8690 =	International knots (kn)

MILES PER MINUTE — ml/min

x 1.6093 =	Kilometers per minute (km/min)
x 2682 =	Centimeters per second (cm/s)
x 88 =	Feet per second (ft/s)
x 60 =	Miles per hour (mph)

MINUTES, ANGULAR — (′)

x 2.909×10^{-4} =	Radians (rad)

NEWTONS — N

x 0.10197 =	Kilograms-force (kgf)
x 0.2248 =	Pounds-force (lbf)
x 7.233 =	Poundals
x 10^{5} =	Dynes

OUNCES — oz av

x 28.35 =	Grams (g)
x 2.835×10^{-5} =	Tonnes (t) metric ton
x 16 =	Drams (dr) av x 437.5
x 0.06250 =	Pounds (lb) av
x 0.9115 =	Ounces (oz) troy
x 2.790×10^{-5} =	Tons (ton) long

OUNCES — oz troy

x 31.103 =	Grams (g)
x 480 =	Grains (gr)
x 20 =	Pennyweights (dwt) troy
x 0.08333 =	Pounds (lb) troy
x 0.06857 =	Pounds (lb) av.
x 1.0971 =	Ounces (oz) av.

OUNCES — oz U.S. fluid

x 0.02957 =	Liters (l)
x 1.8046 =	Cubic inches (in)

OUNCES-FORCE PER SQUARE INCH — ozf/in^2

x 43.1 =	Pascals (Pa)
x 0.06250 =	Pounds-force per square inch (psi)
x 4.395 =	Grams-force per square centimeter (gf/cm^2)

PARTS PER MILLION BY MASS — mass (weight) in water

x 0.9991 =	Grams per cubic meter (g/m^3) at 15°C
x 0.0583 =	Grains per U.S. gallon (gr/U.S. gal) at 60°F
x 0.0700 =	Grains per imperial gallon (gr/imp gal) at 62°F
x 8.328 =	Pounds per million U.S. gallons at 60°F

PASCALS — Pa

x 1 =	Newtons per square meter (N/m^2)
x 1.450×10^{-4} =	Pounds-force per square inch (psi)
x 1.0197×10^{-5} =	Kilograms-force per square centimeter (kg/cm^2)
x 10^{-3} =	Kilopascals (kPa)

PENNYWEIGHTS — dwt troy

x 1.5552 =	Grams (g)
x 24 =	Grains (gr)

POISES — P

x 0.1000 =	Newton-seconds per square meter ($N \bullet s/m^2$)
x 100 =	Centipoises (cP)
x 2.0886×10^{-3} =	Pound-force-seconds per square foot ($lbf \bullet s/ft^2$)
x 0.06721 =	Pounds per foot second ($lb/ft \bullet s$)

POUNDS-FORCE — lbt av

x 4.448 =	Newtons (N)
x 0.4536 =	Kilograms-force (kgf)

POUNDS — lb av.

x 453.6 =	Grams (g)
x 16 =	Ounces (oz) av
x 256 =	Drams (dr) av
x 7000 =	Grains (gr)
x 5×10^{-4} =	Tons (ton) short
x 1.2153 =	Pounds (lb) troy

POUNDS PER CUBIC FOOT

x 7000 =	Grams/cubic ft. (g/ft^3)
x1.6×10^7 =	Grams/cubic meter (g/m^3)

POUNDS = lb troy

x 373.2 =	Grams (g)
x 12 =	Ounces (oz) troy
x 240 =	Pennyweights (dwt) troy
x 5760 =	Grains (gr)
x 0.8229 =	Pounds (lb) av
x 13.166 =	Ounces (oz) av
x 3.6735×10^{-4} =	Tons (ton) long
x 4.1143×10^{-4} =	Tons (ton) short
x 3.7324×10^{-4} =	Tonnes (t) metric tons

POUNDS-MASS OF WATER AT 60°F

x 453.98 =	Cubic centimeters (cm^3)
x 0.45398 =	Liters (l)
x 0.01603 =	Cubic feet (ft^3)
x 27.70 =	Cubic inches (in^3)
x 0.1199 =	U.S. gallons (U.S. gal)

POUNDS OF WATER PER MINUTE AT 60°F

x 7.576 =	Cubic centimeters per second (cm^3/s)
x 2.675×10^{-4} =	Cubic feet per second (cfs)

POUNDS PER CUBIC FOOT — lb/ft^3

x 16.018 =	Kilograms per cubic meter (kg/m^3)
x 0.016018 =	Grams per cubic centimeter (g/cm^3)
x 5.787×10^4 =	Pounds per cubic inch (lb/in^3)

POUNDS PER CUBIC INCH — lb/in^3

x 2.768 x 10^4 =	Kilograms per cubic meter (kg/m^3)
x 27.68 =	Grams per cubic centimeter (g/cm^3)
x 1728 =	Pounds per cubic foot (lb/ft^3)

POUNDS-FORCE PER FOOT — lbf/ft

x 14.59 =	Newtons per meter (N/m)
x 1.488 =	Kilograms-force per meter (kgf/m)
x 14.88 =	Grams-force per centimeter (gf/cm)

POUNDS-FORCE PER SQUARE FOOT — lbf/ft2

x 47.88 =	Pascals (Pa)
x 0.01605 =	Feet of water (ft H_20) at 66°F
x 4.882 x 10^4 =	Kilograms-force per square centimeter (kgf/cm^2)
x 6.944 x 10^4 =	Pounds-force per square Inch (psi)

POUNDS-FORCE PER SQUARE INCH — psi

x 6.895 =	Kilopascals (kPa)
x 0.06805 =	Standard atmospheres
x 2.311 =	Feet of water (ft H_20) at 68°F
x 27.73 =	Inches of water (in H_20) at 68°F
x 2.036 =	Inches of mercury (in Hg) at 0°C
x 0.07031 =	Kilograms-force per square centimeter (kgf/cm^2)

QUARTS — qt dry

x 1101 =	Cubic centimeters (cm^3)
x 67.20 =	Cubic inches (in^3)

QUARTS — qt liquid

x 946.4 =	Cubic centimeters (cm^3)
x 57.75 =	Cubic inches (in^3)

QUINTALS — obsolete metric mass term

x 100 =	Kilograms (kg)
x 220.46 =	Pounds (lb) U.S. av
x 101.28 =	Pounds (lb) Argentina
x 129.54 =	Pounds (lb) Brazil
x 101.41 =	Pounds (lb) Chile
x 101.47 =	Pounds (lb) Mexico
x 101.43 =	Pounds (lb) Peru

RADIANS — rad

x 57.30 =	Degrees (°) angular

RADIANS PER SECOND — rad/s

x 57.30 =	Degrees per second (°/s) angular

STOKES — St

x 10^4 =	Square meters per second (m^2/s)
x 1.076 x 10^4 =	Square feet per second (ft^2/s)

TONS-MASS — tonm long

x 1016 =	Kilograms (kg)
x 2240 =	Pounds (lb) av
x 1.1200 =	Tons (ton) short
TONNES —	t metric ton, miller
x 1000 =	Kilograms (kg)
x 2204.6 =	Pounds (lb)

TONNES-FORCE — tf metric ton-force

x 980.7 =	Newtons (N)

TONS — ton short

x 907.2 =	Kilograms (kg)
x 0.9072 =	Tonnes (t)
x 2000 =	Pounds (lb) av
x 32000 =	Ounces (oz) av
x 2430.6 =	Pounds (lb) troy
x 0.8929 =	Tons (ton) long

TONS OF WATER PER 24 HOURS AT 60°F

x 0.03789 =	Cubic meters per hour (m^3h)
x 83.33 =	Pounds of water per hour (lb/h H_20) at 60°F
x 0.1668 =	U.S. gallons per minute (U.S. gpm)
x 1.338 =	Cubic feet per hour (cf/h)

WATTS — W

x 0.05690 =	British thermal units per minute (Btu/min)
x 44.25 =	Foot-pounds force (ft- lb/min)
x 0.7376 =	Foot-pounds-force per second (ft- lbf/s)
x1.341 x10^{-3} =	Horsepower (hp)
x 0.01433 =	Kilocalories per minute (kcal/min)

WATT-HOURS — W • h

x 3600 =	Joules (J)
x 3.413 =	British thermal units (Btu)
x 2655 =	Foot-pounds-force (ft • lbf)
x 1.341 x 10^{-3} =	Horsepower-hours (hp • h)
x 0.860 =	Kilocalories (kcal)
x 367.1 =	Kilograms-force-meters (kgf • m)

APPROXIMATE METRIC EQUIVALENTS

1 decimeter =	4 inches
1 liter =	1.06 quarts liquid, 0.9 qt. dry
1 meter =	1.1 yards
1 kilometer =	5/8 of a mile
1 hektolite =	2 5/8 bushels
1 hectare =	2 1/2 acres
1 kilogram =	2 1/5 pounds
1 metric ton =	2,204.6 pounds

TEMPERATURES (Fahrenheit)

Milk Freezes 30° above Zero

Water Freezes 32° above Zero

Olive Oil Freezes 36° above Zero

Wines Freeze 20° above Zero

Vinegar Freezes 28° above Zero

Alcohol Boils at 173° above Zero

Water Boils at 212° above Zero

Eggs Hatch 104° above Zero

Petrol Boils at 360° above Zero

Blood Heat 98.4° above Zero

Linear measure

1 foot =	12 inches
1 yard =	3 feet
1 rod =	5 1/2 yards
1 furlong =	40 rods
1 stat mile =	8 furlongs
1 stat mile =	5,280 feet
1 naut mile =	6,080 feet
1 league =	3 miles

Circular measure

1 minute =	60 seconds
1 degree =	60 minutes
1 circle =	4 quadrants = 2 π radians or 360 degrees
1 radian =	57.296 degrees
1 quadrant =	90°

Square measure

144 sq. in. =	1 sq. ft.
9 sq. ft. =	1 sq. yd.
30 1/4 sq. yd. =	1 sq. rod
160 sq. rods =	1 acre
43,560 sq. ft. =	1 acre
640 acres =	1 sq. mile

Liquid measure

1 pint =	4 gills
1 quart =	2 pints
1 gallon =	4 quarts
1 barrel =	31 1/2 gallons
1 hogshead =	2 barrels
1 Imp. gal. =	1.2 gal. (U.S.)

Volume

1 cu. foot =	7.48 gallons
1 gallon =	231 cu. inches
1 gal./hr. =	2.135 oz./ min.

Avoirdupois weight

1 dram =	27.3437 grains
1 ounce =	16 drams
1 pound =	16 ounces
1 quarter =	25 pounds
1 hundredweight =	4 quarters
1 short ton =	2,000 pounds
1 long ton =	2,240 pounds
1 pound =	7,000 grains

Heat and energy units

1 ton (ref rig.) =	200 Btu/ min.

Apothecaries' weight

1 scruple =	20 grains
1 ounce =	8 drams
1 dram =	3 scruples
Grain =	0.0648 g
Oz. =	28.3495 g
Lb . =	0.4536 kg
1 pound =	12 ounces
Ton (sht.) =	907.1848 kg.
Ton (sht.) =	0.9072 ton (met.)
Ton (lg.) =	1.0160 ton (met.)

Pressure

1 kg. per sq. cm. =	14.223 lb. per sq. in.
1 lb. per sq. in. =	0.0703 kg. per sq. cm.
1 kg. per sq. m. =	2048 lb. per sq. ft.
1 lb. per sq. ft. =	4.8824 kg. per sq. m.
1 kg. per sq. cm. =	0.9678 normal atmosphere

Heat & Energy Units

1 kw-hr.	1,000 watts per hour (w/hr)
	1.3410 horsepower per hour (hp-hr)
	2,655,217 foot/pounds (ft-lb)
	3,600,000 Joules
	3,413 British thermal units (Btu)
	860 kg-cal
	367,098 kg-m
	0.235 pounds of carbon oxidized with perfect efficiency
	3,518 pounds of water evaporated from and at 212º F
	22.76 pounds of water raised from 62º to 212º F

Heat & Energy Units

1 hp-hr.	0.7457 kilowatt hour (kw-hr)
	1,980,000 foot pounds (ft-lb)
	2,545 British thermal units (Btu)
	273,745 kg-m
	0.1849 pounds of carbon oxidized with perfect efficiency
	2.622 pounds of water evaporated at 212º F
	16.96 pounds of water raised from 62º to 212º F
1 pound of carbon oxidized with perfect efficiency	14,520 British thermal units (Btu)
	1.1085 pounds anthracite oxidized (varies)
	2.315 pounds of dry wood oxidized (varies)
	26.4 cubic feet manufactured gas (varies)
	12.9 cubic feet natural gas
	14.255 kilowatt hour, 5.709 horsepower hour, 11,300,000 foot pounds
	14.97 pounds of water raised from 62º to 212º F
1 pound of water evaporated from and at 212º F	0.2844 kilowatt hour
	0.3814 horsepower hour
	970.2 British thermal units (Btu)
	104,400 kg-m
	1,023,500 Joules
	756,500 foot pounds
	0.0668 pounds of carbon oxidized with perfect efficiency

1 kg.-cal. =	3.9685 Btu
1 Btu =	0.2520 kg.-cal.
1 kg.-cal. per kilogram =	1.8000 Btu per lb.
1 Btu per pound =	0.5555 kg.-cal. per kg.
1 kg.-cal. per liter =	112.37 Btu per cu. ft.
1 Btu per cu. ft. =	0.0089 kg.-cal. per lb.
1 kg.cal. per cu. m. =	0.1124 Btu per cu. ft.
1 Btu per cu. ft. =	8.8987 kg.-cal. per cu. m.

Pressure equivalents

1 Atmosphere

= 14.696 lb. per sq.in. =	2116.3 lb. per sq.ft.
= 33.96 ft. of water =	407.52 in. water
= 29.92 in. of mercury =	760 mm. mercury
= 234.54 oz. per sq. in. =	10,340 mm. water

1 In. water (H_2O)

= 0.0361 lb. per sq. in. =	5.196 lb. per sq. ft.
= 0.0735 in. mercury =	1.876 mm. mercury
= 0.002456 atmospheres =	0.5774 oz. per sq. in.
= 25.4 mm. of water =	0.08333 ft. of water

1 In. mercury

= 0.491 lb. per sq. in. =	70.70 lb. per sq. ft.
= 25.4 mm. mercury =	7.86 oz. per sq. in.
= 0.03342 atmospheres =	345.6 mm. water
= 13.61 in. water =	1.134 ft. water

1 mm. mercury

= 0.01934 lb. per sq. in. =	2.789 lb. per sq. ft.
= 0.3094 oz. per sq. in. =	0.001316 atmospheres
= 0.5357 in. water =	0.04464 ft. water
= 13.61 mm water =	0.03937 in. mercury

1 lb. per sq. in.

= 144 lb. per sq. ft. =	16 oz. per sq. in.
= 51.71 mm. mercury =	2.036 in. mercury
= 0.06804 atmospheres =	703.7 mm. water
= 27.70 in. water =	2.309 ft. water

= 0.06895 megabars (or megadynes) per sq. cm.

= 0.0703 kg. per sq. cm.

1 oz. per sq. in.

= 0.0625 lb. per sq. in. =	9.00 lb. per sq. ft.
= 1.733 in. water =	0.1441 ft. water
= 0.1272 in. mercury =	3.23 mm. mercury
= 0.00425 atmospheres =	44.02 mm. water

Additional Tidbits

1 in. of water resistance lowers wt. per cu. ft. of air by 1/4 of 1%.

1 in. of mercury represents 900 ft. difference in elevation at sea level to 4,000 ft.

1 in. of mercury represents 1,000 ft. difference in elevation at 4,000 to 6,000 ft. elevation.

1 in. of water represents 66 ft. difference in elevation at sea level to 4,000 ft.

1 in. of water represents 74 ft. difference in elevation at 4,000 to 6,000 ft. elevation.

1,000 ft. difference in elevation at sea level represents 1.11 in. of mercury.

1,000 ft. difference in elevation at 4,000 ft. represents 1 in. of mercury.

1,000 ft. difference in elevation at sea level represents 15.2 in. water.

1,000 ft. difference in elevation at 4,000 ft. represents 13.6 in. water.

1 gm. per sq. cm. = 0.394 in. water = 0.02896 in. mercury

TROY WEIGHT

24 grains =	1 pwt.
20 pwt =	1 ounce
12 ounces =	1 pound

CLOTH MEASURE

2 1/8 inches =	1 nail
4 nails =	1 quarter
4 quarters =	1 yard

CUBIC MEASURE

1,728 cubic inches =	1 cubic foot
27 cubic feet =	1 cubic yard
128 cubic feet =	1 cord (wood)
40 cubic feet =	1 ton (shipping)
2,150.42 cubic inches =	1 standard bushel
231 cubic inches =	1 U.S. standard gal.
1 cubic foot =	about 4/5 of a bushel

DRY MEASURE

2 pints =	1 quart
8 quarts =	1 peck
4 pecks =	1 bushel
36 bushels =	1 chaldron

MARINERS' MEASURE

6 feet =	1 fathom
120 fathoms =	1 cable length
7 1/2 cable lengths =	1 mile
5,280 feet =	1 statute mile
6,080.2 feet =	1 nautical mile

SURVEYORS' MEASURE

7.92 inches =	1 link
25 links =	1 rod
4 rods =	1 chain
10 sq. chains or 160 sq. rod =	1 acre
640 acres =	1 sq. mile
36 sq. miles (6 miles sq) =	1 township

TIME MEASURE

60 seconds =	1 minute
60 minutes =	1 hour
24 hours =	1 day
7 days =	1 week
28, 29, 30 or 31 days =	1 calendar month
30 days =	1 month in compound interest
365 days =	1 year
366 days =	1 leap year

MISCELLANEOUS

3 inches =	1 palm
4 inches =	1 hand
6 inches =	1 span
18 inches =	1 cubit
21.8 inches =	1 Bible cubit
2 1/2 feet =	1 military pace

MEASURE OF VOLUME

1 cubic centimeter =	0.061 cu. inch
1 cubic Inch =	16.39 cubic cent.
1 cubic decimeter =	0.0353 cubic foot
1 cubic foot =	28.317 cubic dec.
1 cubic meter =	1.308 cubic yards
1 cubic yard =	0.7646 cubic meter
1 stere =	0.2759 cord
1 cord =	3.624 steres
1 liter =	0.908 qt. dry / 1.0567 qt. liq.
1 quart dry =	1.101 liters
1 quart liquid =	0.9463 liter
1 dekaliter =	2.6417 gals - 1.135 pecks
1 gallon =	0.3785 dekaliter
1 peck =	0.881 dekaliter
1 hektoliter =	2.8375 bushels
1 bushel =	0.3524 hektoliter

Industry Terms

µm - Micrometer or micron, one-millionth of a meter

Absolute Zero - Absolute zero is the temperature at which molecular activity ceases. Absolute zero equals 0 Kelvin, -273.15°C, and –459.67°F. All material properties change according to temperature.

ACFM - Actual Cubic Feet per Minute. This is a measure of airflow referenced to the current density of the gas. The mass flow rate of the air equals the ACFM multiplied by the air density.

Aerosols - Solid and liquid airborne particles, typically ranging in size from 0.001 to 100 µm.

Ambient - In our discussion, refers to room conditions, particularly room temperature.

Amperes - Units for measuring the amount of electrical current. Electrical current is analogous to a rate of flow such as gallons per minute (liquid flow) or cubic feet per minute (airflow).

Arrestance - Ability of a filter to capture a mass fraction of coarse test dust.

Axial Fan - A fan that propels air in a direction parallel to its axis of rotation. Virtually all fans used in computers today are of this type. The alternative is a centrifugal (or radial) fan.

Bioaerosols - A suspension of particles of biological origin.

Breakthrough Concentration - Saturation point of downstream contaminant buildup, which prevents the collection ability of a sorbent to protect against gases and vapors.

Breakthrough Time - Elapsed time between the initial contact of the toxic agent at a reported challenge concentration on the upstream surface of the sorbent bed and the breakthrough concentration on the downstream side.

CBR Agent - Airborne chemical, biological, or radiological contaminant.

Celsius (Centigrade) - A temperature scale. Pure water freezes at 0° C and boils at 100° C (at one atmosphere of pressure). To convert °C to °F, multiply by 1.8 and add 32. Celsius and Kelvin have the same scale, but are offset from one another by 273.15. i.e.: 0° K equals –273.15° C and 273.15° K equals 0° C.

cfm - Cubic feet per minute. This is a general measure of volumetric ~ ow rate. Fans are normally rated in terms of CFM. In order for fan ratings to have meaning, they must be tested under identical, rigidly controlled conditions.

Challenge Concentration - Airborne concentration of the hazardous agent entering the sorbent.

Channelling - Air passing through portions of the sorbent bed that offer low airflow resistance due to non-uniform packing, irregular particle sizes, etc.

Chemisorption - Sorbent capture mechanism dependent on chemically active medium (involves electron transfer).

Collection Efficiency - Fraction of entering particles that are retained by the filter (based on particle count or mass).

Composite Efficiency Value - Descriptive rating value for a clean filter to incrementally load different particle sizes.

Convection - Heat transfer from a solid into a liquid or gas. The energy transferred through the heat sink leaves via convection to air or water. Convection increases with increasing temperature differential, increasing surface area, and increasing convection coefficient.

Convection Coefficient - A measure of how efficiently a fluid (liquid or gas) transfers heat to or from a solid. This value depends on many factors including fluid density, fluid speed, fluid viscosity, solid geometry, and a few others not mentioned here.

Decibels - A logarithmic scale used in measuring sound.

Differential Temperature - The difference between two temperatures. Convection between a solid and liquid depends on temperature differential. To convert a differential temperature in °C to °F, multiply by 1.8. To convert a differential temperature in °F to °C, divide by 1.8. Do not add or subtract 32 when converting differentials. You need only add or subtract 32 when converting absolute temperatures.

Diffusion - Particle colliding with a fiber due to random (Brownian) motion.

Dust Spot Efficiency - Measurement of a filter's ability to remove large particles (the staining portion of atmospheric dust).

Dust Holding Capacity - Measurement of the total amount of dust a filter is able to hold during a dust-loading test.

Electrostatic Attraction - Small particles attracted to fibers, and after being contacted, retained there by a weak electrostatic force.

Electrostatic Filter - A filter that uses electrostatically enhanced fibers to attract and retain particles.

Energy - Energy has units of force multiplied by distance. It is commonly referred to as “work”. If you weigh 200 pounds and climb straight up a ten foot ladder, you do 200*10 foot-pounds of work. In metric units, the common units are called “joules”. One joule equals one Newton-meter. In metric units, if you weigh 850 Newtons and climb straight up a 3 meter ladder, you do 2550 N-m of work. Energy divided by time is called “power”.

Fahrenheit - A temperature scale. Pure water freezes at 32°F and boils at 212°F (at one atmosphere of pressure). To convert °F to °C, subtract 32 and divide by 1.8. Fahrenheit and Rankine have the same scale, but are offset by 459.67 relative to one another. ie: 0°R equals –459.67°F and 0°F = 459.67°R.

Fan Laws - Equations used to calculate fan flow, pressure, and power at different fan speeds, different air temperatures, and different air pressures.

Filter Bypass - Airflow around a filter or through an unintended path.

Filter Face Velocity - Air stream velocity just prior to entering the filter.

Filter Performance - A description of a filter’s collection efficiency, pressure drop, and dust-holding capacity over time.

High Efficiency Filter - Primarily used to collect particles <1 micrometer.

Gas - Formless fluids which tend to occupy an entire space uniformly at ordinary temperatures.

Gas-Phase Filter - Composed of sorbent medium, e.g., natural zeolite, alumina-activated carbon, specialty carbons, synthetic zeolite, polymers.

Impaction - Particle colliding with a fiber due to particle inertia.

Large Particle - Particles greater than 1 micrometer in diameter.

Life-Cycle Cost - Sum of all filter costs from initial investment to disposal and replacement, including energy and maintenance costs.

Low Efficiency Filter - Primarily used to collect particles >1 micrometer.

Mass Transfer Zone - Adsorbent bed depth required to reduce the chemical vapor challenge to the breakthrough concentration.

Mechanical Filter Collection Mechanism - Governs particulate air filter performance.

Packing Density - Ratio of fiber volume to total filter volume.

Particulate Filter - Collects particles only—mechanically or electrostatically.

Particle Size Efficiency - Descriptive value of filter performance loading based upon specific particle sizes.

Personal Protective Equipment (PPE) - Devices worn by workers to protect against environmental hazards (i.e., respirators, gloves, hearing protection, etc.).

Physicochemical Properties - Physical and chemical characteristics of sorbents (pore size, shape, surface area, affinities, etc.). Characteristics of sorbent medium, e.g., pore size, shape, surface area, etc.

Polarized Filter - Contains electrostatically enhanced fibers.

Pressure Drop - The difference in static pressure measured at two locations in a ventilation system. A measure of airflow resistance through a filter.

Power - A measure of how quickly work is performed. Work divided by time equals power. Electrical power in DC devices is simply voltage multiplied by current.

Residence Time - Length of time that a hazardous agent spends in contact with the sorbent.

SCFM - Standard Cubic Feet per Minute. An absolute measure of air flow rate. “Standard” defines the air density by specifying a temperature of 70°F (-21.1°C) and pressure of one atmosphere (14.7 psi, 101.3 kPa). SCFM equals ACFM only when the temperature is 70°F (21.1°C) and pressure equals one atmosphere (101.3 kPa). A fan producing 38 CFM at standard conditions produces 38 ACFM in Denver, but only about 31 SCFM.

Sorbent - Porous medium that collects gases and vapors only.

Sound Power Level - The amount of power dissipated in the form of sound.

Sound Pressure Level - The localized air pressure fluctuation due to a specific sound source. For a given sound power level, the sound pressure level drops as distance to the sound source increases.

Static Pressure - Static pressure (abbreviated SP) is the uniform force exerted equally in all directions by a liquid or gas. It does not include any force from motion or acceleration of the liquid or gas. It is akin to the potential energy of a system.

Steady State - A condition of equilibrium where all things are constant. Power consumption and temperatures no longer change once steady-state occurs. In actuality, computers never truly reach steady-state; although, they tend to get pretty close. Contrast this against “transient”.

Total Pressure - Total pressure is the sum of static and velocity pressure. Not including temperature changes, it is the sum energy potential of liquid or gas.

Vapor - The gaseous form of substances that are normally solid or liquid at ambient temperatures.

Vapor Pressure - Partial pressure of a liquid’s vapor required to maintain the vapor in equilibrium with the condensed liquid or solid.

Velocity Pressure - Velocity pressure is the energy associated with a liquid or gas based upon its velocity and density. Velocity pressure is proportional to the square of velocity. It is akin to the kinetic energy of a system.

Industry Abbreviations

AC – Air Conditioning

ACGIH - American Conference of Governmental Industrial Hygienists, www.acgih.org

ACH – Air Changes per Hour

AHU – Air Handling Unit

ANSI - American National Standards Institute, www.ansi.org

ARI - Air-Conditioning and Refrigeration Institute, www.ari.org

ASHRAE - American Society of Heating, Refrigeration and Air Conditioning Engineers, www.ashrae.org

ASME – American Society of Mechanical Engineers, www.asme. org

ASTM - American Society for Testing and Materials

ASZM -TEDA - U.S. military carbon: copper-silver-zinc-molybdenum triethylenediamine

°C - Degrees Celsius

CAV – Constant Air Volume

CBR - Chemical, biological, or radiological

CDC - Centers for Disease Control and Prevention, www.cdc.gov

CFC - Chlorinated fluorocarbons CO – Carbon Monoxide

cfm - Cubic feet per minute; a volumetric measurement used to size fans and duct work.

CFR - Code of Federal Regulations (Federal, OSHA)

CIF - Chemically impregnated fibers

CO_2 – Carbon Dioxide

DARPA - Defense Advanced Research Projects Agency, www. darpa.mil

DOD - Department of Defense, www.defenselink.mil

DOE – US Department of Energy, www.energy.gov

DP – Differential Pressure, also shown as ΔP

EPA - Environmental Protection Agency, www.epa.gov

fpm - Feet per minute; a measurement of air velocity used in calculating cfm requirements.

FV – Face Velocity

HAZMAT - Hazardous materials HCHO - Formaldehyde

HEPA - High-efficiency particulate arrestor (also high efficiency particulate air)

HP - Horsepower

HVAC - Heating, Ventilation, and Air Conditioning

IAQ – Indoor Air Quality

IEST - Institute of Environmental Sciences and Technology, www. iest.org

Kw – Kilowatt

kWh – Kilowatt Hour

m/s - Meters per second

m^2 - Square meters

m^2/g - Square meters per gram

m^3/min - Cubic meters per minute

MERV - Minimum efficiency reporting value

mm - Millimeters

mph - Miles per hour

MPPS - Most penetrating particle size

N95 - 95% efficient respirator filter for use in a non-oil mist environment

NAAQS – National Ambient Air Quality Standards (US), www.epa. gov/air/criteria.html

NAFA - National Air Filtration Association

NFPA - National Fire Protection Association, www.nfpa.org

NBC - Nuclear, biological, and chemical

NIOSH - National Institute for Occupational Safety and Health, www.cdc.gov/niosh/

nm - Nanometers, one-billionth of a meter

Nox – Nitrogen Oxide

O^2 - Oxygen

OA – Outdoor Air

OEM – Original Equipment Manufacturer

OHS - White House Office of Homeland Security

OSHA – U.S. Occupational Safety and Health Administration, www.osha.gov

Pa - Pascals

PCC - Policy Coordinating Committee

PEL - Permissible Exposure Level; a standard level of exposure levels set by government regulations.

PM – Particulate Matter

PPE - Personal protective equipment

ppm - Parts per million

PSE - Particle size efficiency

PSI – Pounds per Square Inch

PTAC – Packaged terminal air conditioner

R&D – Research and Development

SA – Supply air

SCF – Standard Cubic Foot

SCFM – Standard Cubic Foot per Minute

SEM - Scanning electron microscope

SMACNA – Sheet Metal and Air Conditioning Contractors National Association, www.smacna.org/

SO^2 – Sulfur Dioxide

TIC - Toxic industrial complex

TIM - Toxic industrial material

TWA - Time Weighted Average; an average exposure calculated over a specific time period, such as eight hours.

UL – Underwriters Laboratories, www.ul.com

VAV – Variable air volume

VFD – Variable Frequency Drive

VOC – Volatile Organic Compound

VP – Velocity Pressure

Handy Formulas & Tidbits

1 HP is 1 ton of cooling

12,000 BTU to a ton

Offices - 30 to 40 BTUs per square foot

Hospitals - 30 to 50 BTUs per square foot

Meeting Rooms - 60 to 120 BTUs per square foot

Computer Rooms - 120 to 150 BTUs per square foot

Homes - 15 to 25 BTUs per square foot

Airborne Contaminants

Classifications of particles

Fine	<2.5 microns
Course	2.5 microns
Respirable	<10.0 microns
Nonrespirable	10.0 microns

Relative Sizes

Micron = 1 millionth of a meter (0.000001 meter) or 39 millionths of an inch (0.000039 inch)

Visible to the Naked Eye	25 microns
Human Hair	100 microns
Dust	25 microns
Optical Microscope	0.25 micron
Scanning Electron Microscope	0.002 micron
Macro Particle Range	25 microns & larger
Micro Particle Range	1.0 to 25 microns
Molecular Macro Range	0.085 to 1.0 micron
Molecular Range	0.002 to 0.085 micron
Ionic Range	0.002 microns & smaller

Standard CFM Values

400 cfm per ton for cooling applications

500 cfm per ton for heat pump applications

350 cfm per ton for heating applications

1 cfm per square foot of floor area (8’ ceilings, 7-1/2 ach)

Energy Use Formula

$$HP = \frac{\text{cfm x static pressure (″ w.g.) x 5.2}}{\text{33,000 x system efficiency}}$$

Kilowatt Hours = HP x .746 x operating hours

Operating Costs = Kilowatt hours x energy Cost per kWh

Air Change Rate

$$\frac{\text{Air change}}{\text{Hour}} = \frac{\text{cfm x 60}}{\text{Space volume ft}^3}$$

$$\text{cfm} = \frac{\text{Air change x space volume ft}^3}{\text{Hour}}$$

Thermal Mass Balance Equation

$$\text{Outside Air \%} = \frac{T_{RA} - T_{MA}}{T_{RA} - T_{OA}} \times 100$$

where:

T_{RA} = Temperature of return air

T_{MA} = Temperature of mixed air

T_{OA} = Temperature of outside air

T = Temperature

Average Air Velocities

350-700 fpm for disposable filters

250 fpm for HEPA filters

500 fpm for electronic air cleaners

400 fpm minimum, 600 fpm maximum for evaporators 1000 fpm for condenser

700 fpm for hot water coils

Duct Section Airflow

	Offices	Residential	Quiet Areas
Mains	1200	1000	800
Branch	800	600	500
Register	700	600	400

(the same formula can be used using CO2 levels, substitute CO2 level for T value.)

1 ppm is relative to:

1 inch in 16 miles

1 minute in 2 years

1 ounce in 31 tons

1 drop of vermouth in 80 “fifths” of gin

1 ppb is relative to:

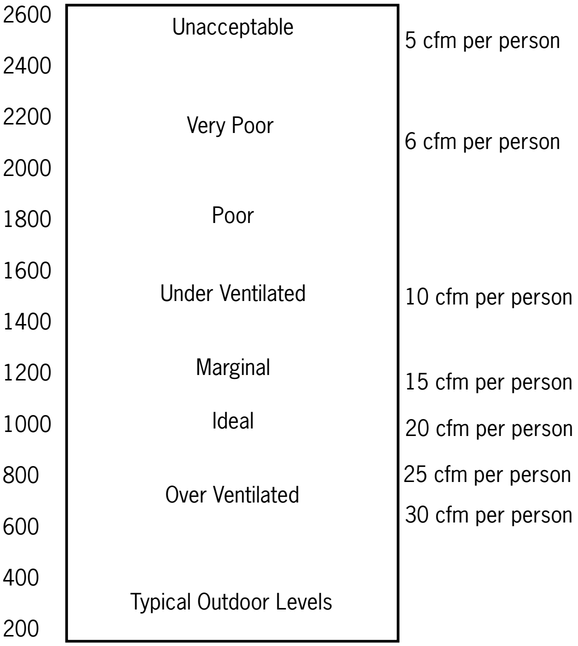
1 inch in 16,000 miles

1 second in 32 years

1 pinch of salt in 10 tons of potato chips 1 drop of vermouth in 500 barrels of gin.

Air changes per hour	Minutes required for a removal efficiency of:		
	90%	99%	99.9%
6	23	46	69
10	14	28	41
15	9	18	28
20	7	14	21
30	5	9	14
40	3	7	10
50	2	6	8

Condition of indoor air as a function of ventilation



CO_2 is a surrogate for evaluating air quality when ventilation air is the major factor in fresh air changes to the conditioned space. The CO_2 level has no value when filtration has been used to reduce the outside air to save the energy that would be typically used to heat and cool the incoming ventilation air.

Convert fpm to mph

$$\frac{100\text{ feet}}{\text{minute}} \times \frac{60\text{ minutes}}{\text{hour}} \times \frac{\text{mile}}{5280\text{ ft}} \times \frac{1.15}{\text{hour}}$$

Camfil - clean air solutions

Camfil is the world's largest and leading manufacturer of filters and clean air solutions. There is a good chance that you are at this very moment breathing fresh air that has passed through an air filter manufactured by us. We can be found everywhere from offices to clean rooms for sensitive electronics production, pharmaceuticals, mines, factories, hospitals and nuclear power stations.

Camfil is a global company with 29 subsidiaries, 23 production plants and agents throughout Europe, North America and Asia — but we are also very much a local force. This is a real must, given that air pollution always has local origins, but can often have global consequences.

Our success is based on a collaborative development process with our customers and suppliers. Maintaining an open dialogue is essential if the end result, clean air, is to be optimized and achieved. We know that a filter solution must always be customized and optimized for each new environment. We are convinced that a perfect clean air solution will always protect the environment and make everyone feel and perform better.

For you as a customer, this means that you stand to benefit from our global knowledge bank and the resources that a world-leading company constantly invests in research and development. At the same time, you stand to benefit from personal contact with your local Camfil office, which will be only too pleased to provide you with the right filter solution for your particular needs.

Some Camfil Trademarks	
Farr 30/30®	Absolute®
Aeropac®	Aeropleat®
Cam-Flo®	Camsorb®
Campure®	Durafil®
Dynavane®	Filtra 2000™
Gigacheck™	Gigalam™
Gigapleat®	Glide/Pack®
Hi-Flo®	HP®
Micretain®	Opti-Pac®
PharmaSeal®	Riga-Flo®
Riga-RP®	Riga-Sorb®
Sidelock®	Turbopac®
Ultra-Pac®	

Thank you for your interest in improving indoor air quality and for your support of Camfil.

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