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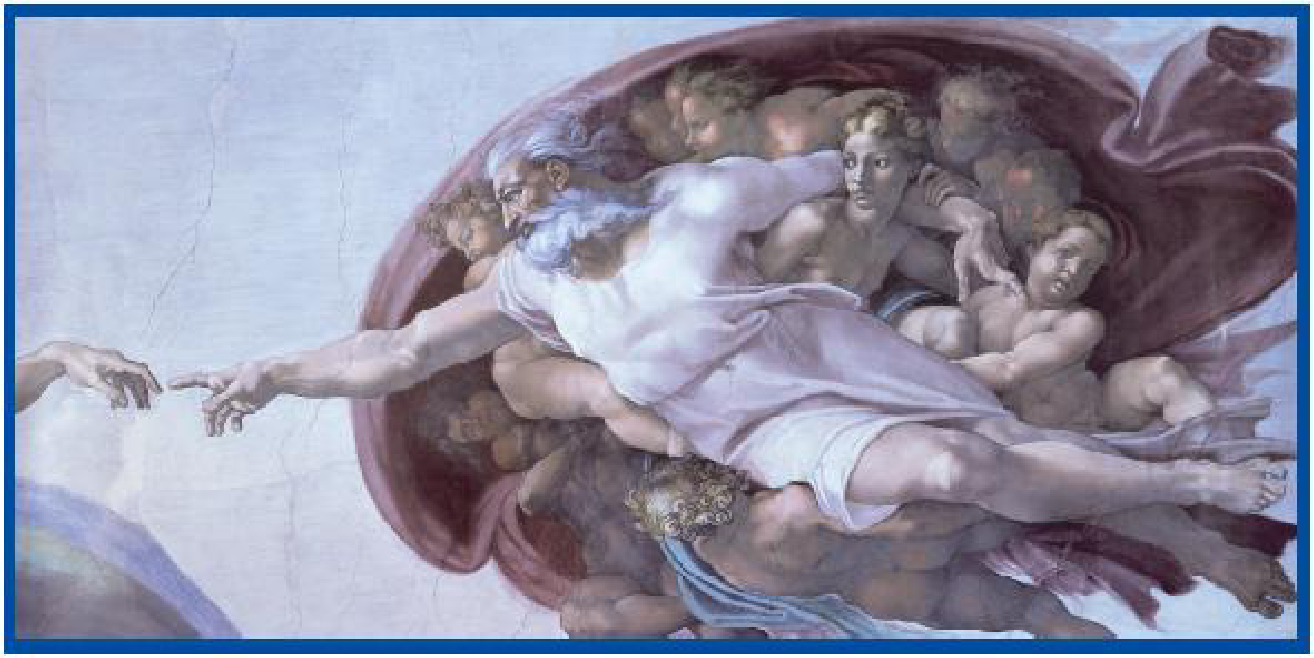

Environmental Control for Museums, Libraries, and Archival Storage Areas

PURAFIL

First...in clean air

Purafil, Inc. Technical Bulletin-600A

Environmental Control for Museums, Libraries and Archival Storage Areas

Purafil, Inc.

This document was prepared by the staff of Purafil, Inc. in response to the growing need for a comprehensive environmental pollutant control guide for museums, libraries and archival storage areas. It represents a compilation of work in the area of environmental standards research with an emphasis on the control of gaseous contaminants — an area in which PURAFIL has been the leader for more than 30 years. As warranted, this document will be updated to reflect changes and advances in environmental control in these environments.

The use of this document should allow one to become familiar with those parameters critical in maintaining these environments and the recommended control levels for each parameter. Applicable PURAFIL equipment for gaseous contaminant control are described. A list of PURAFIL systems currently operating in these environments is included at the end of this document.

Any questions, comments or requests for further information or documentation regarding the preparation of this document or the use of PURAFIL media or equipment to maintain these environments should be directed to Chris Muller, Manager of Gas Technology, at **1-800-222-6367** or **770-662-8545**.

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INTRODUCTION

The conservation of artifacts and buildings has a long history, but the positive emergence of conservation as a profession can be said to date from the foundation of the International Institute for the Conservation of Historic and Artistic Works (IIC) in the early 1950's. The role of the conservator as distinct from that of the restorer had been emerging from work in years prior. Now, there existed an organization that recognized this distinction.

Since this time, many other organizations have become involved and are responsible for much of the information contained in this document(1)(1). Research performed and/or sponsored by these organizations has led to a tremendous increase in the current level of knowledge in this discipline. Among the leaders in these efforts have been the National Institute for Science and Technology (NIST, formerly the National Bureau of Standards (NBS), the Public Buildings Service (PBS), the General Services Administration (GSA), the American National Standards Institute (ANSI), the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), the Library of Congress, the Newberry Library, the Canadian Conservation Institute (CCI), the Royal Ontario Museum, and the British Museum Library.

The use of the term **conservation** refers to the whole subject of the care and treatment of valuable artifacts both movable and immovable, but within the discipline conservation has a meaning, which is distinct from that of restoration. Conservation used in this specialized sense has two aspects: firstly, the control of the environment to minimize the decay of artifacts and materials; and, secondly, their treatment to arrest decay and to stabilize them where possible against further deterioration. This document shall focus on the first of these two aspects - control of the environment.

DESIGN SUMMARY

In these environments there are four contributing factors, three of which are interrelated, that have a direct effect on the degradation of materials and objects. These are **Particulates**, **Temperature**, **Humidity**, and **Gaseous Pollutants**; the last three having a measurable synergy. Control specifications for all four are summarized below. Although PARTICULATES, TEMPERATURE, and HUMIDITY are within the scope of and may be controlled by Purafil, Inc. technology and systems, only the control of those GASEOUS POLLUTANTS - specifically **sulfur dioxide, oxides of nitrogen**, and **ozone** - will be discussed in depth. Major effects and suggested control specifications and methods will be offered for the other three.

Particulates: ≤75 $\mu g/m^3$ for all areas within all facilities.

Temperature: The temperature should be in the given range and not vary more than the control values. **Category 1**: 18-24ºC ±1ºC (65-75ºF ±2ºF); **Category 2**: 10-13ºC ± 0.5ºC (50-55º±1ºF); **Category 3**: -29ºC ±1ºC (-20ºF ±1ºF). **Relative Humidity**: The relative humidity should be in the given range and not vary more than the control values. **Category 1:** 40-55% ± 5%; **Category 2**: 25-35% ± 3%; **Category 3**: 20-25% (should be sealed at this RH).

Gaseous Contaminants: Direct gas monitoring - SO_2, ≤0.35 ppb; Ozone, ≤0.94 ppb; NO_2, ≤2.65 ppb; CO_2, ≤2.50 ppm; Hydrogen chloride, acetic acid, formaldehyde, and metallic fumes - use best control technology. Corrosion monitoring (total silver), <300Å / 90 days.

ENVIRONMENTAL CONSIDERATIONS

Four environmental factors - **Particulates, Temperature, Humidity,** and **Gaseous Pollutants** - have been shown to cause the deterioration of historical artifacts and materials. Of these, GASEOUS POLLUTANTS are the most destructive. However, because of the synergistic effects of temperature and humidity, controlling gaseous pollutants alone may not prevent deterioration. Higher temperatures and/or humidity will accelerate the chemical reactions of sulfur dioxide, nitrogen dioxide, ozone, etc., on materials. Thus the total environment, external and internal, must be considered to accurately assess the potential for damage from environmental factors and adequate control measures must be

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(1) Many references were used in the preparation of this document and almost all were used more than once. We do wish to give due credit where appropriate, however, normal referencing techniques would have detracted from an easy assimilation of the subject matter. Therefore, no reference notations will be found in the body of the text. All references are listed in a separate section at the end of this document.

employed for all four. Anything less in a control strategy could result in the damage or destruction of materials that can never be replaced or restored.

Degradation from Particulates - The effects of particulates have apparently not been well studied, but some effects are obvious and others can be hypothesized. There is abundant evidence of the visible damage such as soiling of books and documents. Not only are exteriors disfigured by dust and soot, but also perspiration and skin oils have caused dust to become irremovably embedded. Fine, or respirable particles, can carry adsorbed sulfur dioxide and nitrogen oxides, and can also stain books. Viable particles such as fungal spores and mycelia, bacteria and molds can result in the deterioration of books and documents, especially if the temperature and humidity are not properly controlled.

Degradation from Temperature - Heat, either by itself or in combination with insufficient or excessive moisture, damages paper and other materials. The deterioration of paper becomes more rapid as the temperature is increased. Fluctuations in temperature causes materials to alternately expand and contract which may ultimately lead to cracking. Heat causes water, solvents, and plasticizers to be driven off. It also can increase the reaction rate of pollutants with materials, change acidity and promote microbiological activity.

Degradation from Humidity - There are three different modes of deterioration that are influenced by relative humidity: (1) changes in size and shape; (2) chemical reaction; and (3) biodeterioration. One could say that these are the physical, chemical, and biological modes. A change in relative humidity causes changes in size and shape of virtually all moisture-containing materials. Paper and virtually all other materials used in records absorb moisture and this moisture content has profound effects on them. Metal corrosion, warping, splitting, and bacterial growth caused by high humidity levels (65-70% RH) are not the only way materials can be damaged. Low humidity levels (<40% RH) can also be detrimental, causing some materials to dry and shrink. Natural adhesives, parchment, and leather products are especially subject to desiccation and embrittlement.

Referring to (2) above there are two quite different classes of chemical reactions that are favored by high humidity: (a) the corrosion of metals, and (b) the fading of dyes and the weakening of paper and textiles. Certain less common reactions of museum materials are also known to be affected by moisture, i.e. weeping glass and other materials.

Degradation from Gaseous Pollutants - Gaseous pollution is caused overwhelmingly by the burning of fuels in power stations, factories, commercial and domestic buildings, and automobiles. Before the "age of the car" it appeared there were two main types of gaseous urban air pollution: acidic and oxidizing. Acidic pollution was associated with coal burning, oxidizing with cars. As cities became more crowded with cars these two types have merged. Now the three main pollutant gases found everywhere in the industrialized world are sulfur dioxide, nitrogen dioxide, and ozone. The chemical reactions that form these pollutants and their byproducts as well as other sources of these materials are outlined in **TABLES 1 and 2**.

TABLE 1 - CHEMICAL REACTIONS OF ATMOSPHERIC POLLUTANTS

Sulfur Dioxide (SO_2) Reactions:

S (sulfur - in all fuels) + O_2 (oxygen*) → SO_2 (sulfur dioxide gas)

$2SO_2$ (sulfur dioxide) + O_2 (more oxygen*) → $2SO_3$ (sulfur trioxide gas)

SO_3 (sulfur trioxide) + H_2O (water) → H_2SO_4 (sulfuric acid)

Nitrogen Dioxide (NO_2) Reactions:

$2NO_2$ (nitrogen dioxide) + H_2O (water) → HNO_2 (nitrous acid) + HNO_3 (nitric acids)

HNO_3 (nitric acids) + air → HNO_3 (nitric acid)

Ozone (O_3) Reactions:

O_2 (oxygen molecule) + UV radiation (sunlight) → O + O (oxygen atoms - highly reactive)

O (oxygen atom) + O_2 (oxygen molecule) → O_3 (ozone)

* Oxygen can be supplied by oxidizers such as ozone and nitrogen dioxide

TABLE 2 - COMMON MATERIALS THAT ARE SOURCES OF GASEOUS POLLUTANTS

Wood (particularly oak, birch, beech)	acetic and other carboxylic acids, aldehydes, alcohol
Protein-based glues, wool	volatile sulfides
Vulcanized rubber	volatile sulfides (some dyes may release sulfur compounds)
Cellulose nitrate	oxides of nitrogen
Polyvinyl chloride	hydrochloric acid
Polyurethanes are suspect	

Sulfur dioxide - The chief materials to suffer from sulfur dioxide pollution are calcium carbonate (marble, limestone, frescoes, alkaline sandstones), cellulose (paper, cotton, linen, wood veneers), silk, iron and steel. Leather, parchment and wool are also attacked. Many other materials, including certain bronze alloys, synthetic rubbers, dyes and textiles may be affected.

All cellulose, whether paper, cotton or linen, is attacked by sulfuric acid from sulfur dioxide. Light, and even more, UV radiation, increases the damage. Poor quality paper deteriorates more quickly than rag paper, firstly because it contains more acid materials introduced during manufacturing, and secondly because it absorbs acidic gaseous pollutants more strongly because of the lignin that is also present.

A few modern dyes and pigments have been found to be specifically sensitive to sulfur dioxide. Certain elastomers' (synthetic rubbers) elasticity can be destroyed. Paints are affected.

Iron is the chief metal to suffer from the presence of sulfur dioxide. Iron corrodes to rust electrolytically. This means that both moisture and an electrolyte must be present on the iron surface. All water-soluble salts, acid, and alkalis form electrolytes. Those electrolytes that attract moisture, form soluble corrosion products, and are non-volatile, are the most corrosive. Sulfuric acid and the ammonium sulfate to which it is often partly converted fulfill all these conditions.

Ozone - Ozone has a specific and complete action on unsaturated organic compounds; it will break every carbon double bond with which it comes into contact. This destroys the material. This is why cracks appear in rubber bands, which then snap when stretched. By being a powerful oxidant, ozone can destroy almost all organic materials. One hardly needs reminding that paintings, textiles, archival materials, furniture, biological specimens, leather, fur, feathers, etc., are all made wholly or predominantly of organic materials, and that, therefore, ozone is extremely dangerous in the museum. Ozone may also increase the oxidation rate of silver and iron and the sulfidation of silver and copper.

Nitrogen dioxide - Since nitrogen dioxide dissolves in water eventually to form nitric acid, an acid as strong as sulfuric, and on top of that a strong oxidizing agent, all the same problems encountered with sulfuric acid will be seen, particularly the corrosion of metals, hydrolysis of cellulose, and attack on calcareous stone and murals.

Nitric acid is volatile in nature and therefore cannot be entrained on dry surfaces. This requires that it must react on contact. Because of this it is probably a lesser menace than sulfuric acid.

Chlorides - Although not one of the "big three", chlorides whether as chlorine or hydrogen chloride, are a dangerous contaminant for metals. Mostly, only coastal areas will be affected. However, corrosive levels have been found far inland, particularly in heavily industrial areas.

CONTROL SPECIFICATIONS

Particulate Control Specifications - Particulates are controlled by a combination of filtration devices, which trap particulates in outside and recirculated air and eliminate infiltration of particulates in storage areas. A prefilter should filter all outside air drawn into the air-handling system. Intermediate and final filters should filter all air handled by the system, both outside and recirculated. Although there are varied particulate removal efficiency specifications for these applications, for the purposes of this document the standards outlined in **TABLE 3** will apply. Electrostatic precipitators should not be used in museums since they emit the very undesirable contaminant ozone. They also aid in the conversion of sulfur dioxide to sulfuric acid.

TABLE 3 - PARTICULATE STANDARDS

System Filter Locations	Prefilter*	Intermediate Filter**	Final Filter**
ASHRAE Weight Arrestance Efficiency, %	≥80	≥95	N.A.
ASHRAE Atmospheric Dust Spot Efficiency, %	≥30	≥80	≥90
MIL-STD 282 Efficiency	≥5	≥50	≥75

* For outside or make-up air

**For supply (both outside and recirculated) air

Temperature Control Specifications - Storage areas should be maintained at the lowest possible temperature as consistent with such other considerations as the need for human access. (Although, technically, the entire library or museum may be thought of as a storage area, this term will refer to those areas with limited access and containing those materials which are infrequently used.) The use areas are usually kept at more "traditional" temperature levels. However, too great a temperature difference between storage and use areas could result in condensation (-related) damage when materials are brought from the former to the latter. This distinction between areas must be kept in mind when reviewing control specifications.

Although each of the above-mentioned organizations adhere to different temperature limits, these may be summarized as follows. **The maximum acceptable temperature is between 19°C (66°F) and 25°C (77°F) with a monthly permissible changeover of 5°C (±9°F).** This is based on human comfort; to prevent deterioration, lower temperatures would be tolerable. These standards will be presented with those of humidity in **TABLE 4**.

Humidity Control Specifications - Unlike other factors, there is no agreement on what constitutes an optimum relative humidity level for the preservation of museum materials. At temperatures normally encountered in these environments, relative humidities are generally in the range of 30-65% with an average of around 50%. This 50% level appears to be acceptable as long as it remains relatively stable. Diurnal fluctuations in relative humidity of 2-6% do not appear to be damaging. Larger fluctuations of up to 12% may be acceptable if the cycling occurs over extended periods of time. To maintain humidity levels in an acceptable range, room or building humidity control may need to be used. For humidification, an evaporative type of humidifier should be chosen. For dehumidification in warm climates use a refrigerative type of dehumidifier, and in cold climates a desiccant type. Proper air mixing and regular maintenance are very important in room humidity control. Extreme limits for relative humidity and temperature levels are outlined in **TABLE 4**. For the most effective preservation strategy regarding humidity control, materials should be broken down into several groups. **Unbound records** may be kept at a slightly lower relative humidity than bound ones in order to obtain some advantage in chemical stability. **Bound records** require a somewhat higher humidity level to maintain dimensional stability and to maximize flexibility in order to reduce structural breakdown when in use. **Parchment and vellum** require even higher relative humidities to prevent shrinking and becoming hard and inflexible. **Preservation collections** can stand lower humidities, at the expense of some flexibility, if use can be severely restricted. **Metal only collections** can be maintained acceptably at a lower relative humidity as well. **Textiles** exposed to light appear to do the best at slightly lower than the average level listed above. This is summarized in **TABLE 5** below.

TABLE 4 - TEMPERATURE AND RELATIVE HUMIDITY STANDARDS

* Sealed at the RH before freezing

EXTREME LIMITS								
UNBOUND RECORDS				BOUND RECORDS				
General		Preservation Collections		General		Preservation Collections		Vellum & Parchment
Temp.	RH	Temp.	RH	Temp.	RH	Temp.	RH	RH
65-70°F	25-35%	55-65°F	25-30%	65-70°F	40-55%	55-65°F	30-40%	45-55%
		45-55°F	25-30%			45-55°F	20-35%	
		35-45°F	20-25%			35-45°F	20-25%	
		0°F	20-25%*			0°F	20-25%*	

TABLE 4 (cont.) - VARIATIONS FROM TARGET STANDARD WITHIN RANGE ABOVE

	Temperature	Relative Humidity
Diurnal	±2°F	2%
Seasonal changes, max. per month	±3°F	5%

TABLE 5 - CHOICE OF RH LEVEL ACCORDING TO CLIMATE

65%	Acceptable for mixed collections in the humid tropics. Too high, however, to ensure the stability of iron and chloride-containing bronzes. Air circulation very important.
55%	Widely recommended for paintings, furniture, and wooden sculptures in Europe, and satisfactory for mixed collections. May cause condensation and frosting difficulties in old buildings, especially in inland areas of Europe and the Northern part of North America.
45-50%	A compromise for mixed collections and where condensation may be a problem. May well be the best level for textiles and paper exposed to light.
40-45%	Ideal for metal-only collections. Acceptable for museums in arid zones exhibiting local material.

Note: International exhibits and loans require mutual agreement on RH levels, and introduce a bias towards the median level of 50-55% RH.

Gaseous Pollutants Control Specifications - Pollutant levels typically found in these environments lend themselves well to removal by dry-scrubbing, or gas-phase, air filtration. The highest levels encountered would be by a system used to filter the outside or make-up air. Systems that are used to recirculate the air within an area would be subject to much lower pollutant concentrations.

For dry-scrubbing air filtration, only two media are in common use: activated carbon and activated alumina. Silica gel, synthetic zeolites, and other materials are sometimes used in small room-type air purifiers sold in the consumer market. However, these latter materials are not generally available or particularly effective when used in central HVAC systems.

Activated alumina is used only with chemical impregnations (potassium permanganate); however activated carbon may be used with or without impregnation, depending on the application. **TABLES 6 and 7** summarize the actions of these media.

TABLE 6 - SUMMARY OF ACTIONS OF ACTIVATED ALUMINA (Al_2O_3)

Impregnation	Mode of Action	Reversible?
None (alumina only)	Removes water in preference to other vapors. Not applicable for air cleaning.	Yes
Potassium permanganate ($KMnO_4$)	As an oxidizing agent; it is reduced to MnO_2. Color changes from purple to brown. Effective for formaldehyde (HCHO) and sulfur dioxide (SO_2). For reaction to occur, some moisture must be present, because the action is electrolytic. $KMnO_4$ is reduced to MnO_2 which is a catalyst for air oxidation, so some easily oxidizable contaminants will continue to be oxidized, but reactions are slow.	No
Sodium carbonate (Na_2CO_3) or bicarbonate ($NaHCO_3$)	Reacts with SO_2 by acid-base neutralization. $SO_2 + Na_2CO_3 \rightarrow Na_2SO_3 + CO_2$	No

TABLE 7 - SUMMARY OF ACTIONS OF ACTIVATED CARBON

Impregnation	Mode of Action	Reversible?
None (carbon only)	Physical adsorption and capillary condensation. Applicable to a broad range of organic contaminants, generally with a molecular weight (MW) greater than 80. Also adsorbs SO_2. Some catalytic oxidation ($H_2S \rightarrow$ sulfur).	Yes - except for the oxidation
Sodium hydroxide or potassium hydroxide (NaOH or KOH)	Neutralization of acidic gases; SO_2, H_2S, NO_2, HCl, acetic acid. Reaction is for all practical purposes, instantaneous. Used extensively for removal of H_2S from sewer gases. Capacity depends on the type and amount of caustic used in impregnation, but can be enhanced by some catalytic oxidation on the carbon surface.	No

The compromise between the objectives of effective contaminant removal and minimizing resistance to air flow is achieved by selecting dry-scrubbing air filtration media in the size range of 6 to 8 mesh (or approximately 1/16 inch). With such media size, the half-life of a molecule in the gas phase (before it reaches the surface of the media) is about 0.01 second. Then, if an air stream that contains a concentration of contaminant, $\mathbf{C_r}$, enters such a media bed, the concentration of contaminants that have never reached the surface of the media after **n** seconds of residence time, $\mathbf{C_n}$, is:

$$\mathbf{C_n = C_r(2^{-100n})} \quad (1)$$

The ratio of $\mathbf{C_n/C_r}$ is the penetration, **P**, of the media bed. Thus, the contact efficiency, **E**, (fraction of contaminant molecules that have contacted the surface of the media) is:

$$\mathbf{E = 1 - (2^{-100n})} \quad (2)$$

It must be noted that the contact efficiency is not the same as the removal efficiency. The contact efficiency is the percentage of total contaminant molecules that have come into contact with the media. Removal efficiency is that fraction of the contaminant that is removed either by physical or chemical means. However, higher contact efficiencies will result in higher removal efficiencies until such time where the media approaches its total removal capacity for the contaminant(s). Examples of the relationship between residence time, **n**, and contact efficiency of a media bed are shown in **TABLE 8**.

TABLE 8 - RELATIONSHIP BETWEEN RESIDENCE TIME, n, OF A GASEOUS MOLECULE IN A GRANULAR MEDIA BED AND THE CONTACT EFFICIENCY, E, OF THE BED

Residence Time (sec.)	2^{-100n}	$E = (1 - 2^{-100n}) \times 100\%$
0.01	0.500	50.0%
0.02	0.250	75.0
0.03	0.125	87.5
0.04	0.0625	93.75
0.05	0.03125	96.88
0.06	0.01562	98.84
0.07	0.00781	99.22
0.20*	0.00000095	99.9999

* Recommended residence time for dry-scrubbing air filtration media

Testing performed on dry-scrubbing air filtration media has shown single-pass removal efficiencies in excess of 95% for nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). Different media have been shown effective against ozone, and satisfactory with typical levels of hydrogen sulfide. It should be noted that recirculation will raise efficiency considerably. This will be discussed in detail in the section on gaseous pollutant specification levels that follows.

Up to now we have assumed a ducted system, but room units and show-case air purifiers for dealing with both particulates and gaseous pollutants can be just as effective. Such a unit would consist of a filter or filters mounted in an enclosure with a fan to draw the room air through the filter.

Let us assume the 95% efficiency as for sulfur dioxide above and a fan which passes a volume of air equal to the room volume through the filters 10 times an hour (10 air changes per hour). With outside ventilation completely shut off, tests have shown that the concentration can be brought down to quite low levels in an hour.

Just as with **Particulates**, **Temperature**, and **Humidity**, there is wide variation in just what are acceptable levels for these contaminants. The British Museum Library specifies that sulfur dioxide, nitrogen dioxide, and ozone are to be removed completely. Other sources recommend levels from fractional parts-per-billion up to the low parts-per-million. These are shown in **TABLE 9**.

TABLE 9 - GASEOUS POLLUTANT STANDARDS

Contaminant	Recommended Control Levels
Sulfur dioxide	≤0.35 up to ≤3.8 ppb
Nitrogen dioxide	≤2.65 up to ≤5.3 ppb
Ozone	≤0.94 up to ≤12.75 ppb
Carbon dioxide	≤2.5 ppm
Hydrogen chloride	Use best control technology
Acetic acid	Use best control technology

One might argue that although there is considerable variation in the recommended allowable pollutant levels, at least attempts have been made to set standard levels. Whether or not they are realistic in the levels specified or their attainability is another question.

There has been little, if any, research done to determine what levels actually cause deterioration of historical artifacts and archival materials. Experience has come from the determination of the normal background levels of the pollutants to which these materials have been exposed over the years. Some postulate that more deterioration has occurred in the last fifty years than in the previous two thousand. As stated at the beginning of this section, it was not until the industrial revolution, and more distinctly, "the age of the car" that global pollutant levels dramatically increased. "Normal" background pollutant levels measured in non-industrial versus industrial areas today frequently show differences of two orders of magnitude. This is illustrated in **TABLE 10**.

TABLE 10 - COMMON LEVELS OF GASEOUS POLLUTANTS

Pollutant	Normal Background Concentrations	Peak Concentrations (Urban Areas)
Sulfur dioxide	6-30 ppb	100-750 ppb
Nitrogen dioxide	1.0-1.5 ppb	40-100 ppb
Ozone	0.4 ppb	20-40 ppb

Referring back to the example of a single-pass efficiency of 95% on dry-scrubbing media for sulfur dioxide, let us assume the outside concentration to be 360 ppb. (This the midpoint of actual SO_2 measurements taken in Washington, D.C.) A system filtering the outside air could reduce this level to 18 ppb with one pass. If this concentration reached an area with a room air cleaner (containing media), the corresponding reduction in sulfur dioxide levels would be to just under 1 ppb. This is within the range shown in **TABLE 9**, but still almost three times higher than the lowest published standard level for this pollutant. The same results could be achieved by adding a second pass of media to the outside air filtration system. Using this method, room air cleaners would only be used to "polish" the air in a specific area.

The above example does not mention the effects recirculation would have on pollutant concentrations in a building. As stated previously, recirculation will raise efficiency considerably. If the recirculation rate was set at 80%, dilution alone could reduce the pollutant concentration to 72 ppb (360 ppb x 0.2). This would deliver air that would normally be acceptable for most applications. However, the recommended pollutant levels for museum and library environments are so low that dilution alone is not adequate for control. The normal background level for sulfur dioxide averages between 8 and 85 times higher than the recommended standards. So even when the ambient concentration returns to "normal" after an episode of peak concentration, the make-up air would still be of unacceptable quality. This is why dry-scrubbing air filtration is employed.

With a bed of dry-scrubbing media, the 72 ppb could be lowered to 3.6 ppb, which is just inside the upper limit of published control levels. A second pass would reduce this to 0.18 ppb which would be acceptable by all standards. This example illustrates only one of the possible scenarios for the application of dry-scrubbing air filtration. It represents a situation having high pollutant concentration (outside air) and low air volume (20% of total air handling system capacity). Other possibilities could include: low concentration (within a room), high volume ("x" air changes per unit time within the space); and high concentration (sources within the space), high volume.

It should be fairly obvious that dilution, or increased ventilation, alone is not sufficient to bring gaseous pollutant levels down to standard levels. Because the make- up air will most often be of unacceptable quality, some other method must be employed in conjunction with simple dilution. Dry-scrubbing air filtration has been shown to be effective in a properly designed system. With the choice of different media, almost any combination of commonly found pollutants can be controlled to extremely low levels. This again brings up the concern about the attainability of these levels.

The biggest problem today is not whether these levels can be reached, but whether they can be accurately measured to assure compliance with any standard. The research and studies that have been used as the foundation for this document have had access to sophisticated analytical devices that would not normally be found in a museum or library. Not only would the cost of the equipment be prohibitive, but a full-time professional would also be needed for operation and maintenance. This is usually beyond the budget of most of these institutions. Therefore, it is always the best decision to allow the purchaser to be responsible for determining how best to certify a system.

It has been stated throughout this document that there are many different standard levels from many different sources regarding these pollutants. Although each institution may go by a different set of standards, it is felt that **TABLE 11** presents a good general summary of specifications that would produce a benign environment. However, it is those who are responsible for these historical artifacts and materials that will ultimately decide what are the optimum conditions for their storage and preservation.

TABLE 11 - SUMMARY OF CONTROL SPECIFICATIONS

Environmental Factor	Standard Levels(1) Category 1	Category 2	Category 3
Public Access	yes	no	no
Duration of Storage	short-long(2)	short-long(2)	long(3)
Frequency of Access	often	often	seldom
Dry-bulb Temperature Range	18-24°C (65-75°F)	10-13°C (50-55°F)	-29°C (-20°F)
Temperature Control(4)	±1°C (±2°F)	±0.5°C (±1°F)	±1°C (±2°F)
Relative Humidity Range(5)	40-55%	25-35%	20-25%(6)
Gaseous Contaminants			
Sulfur dioxide	≤0.35 ppb	≤0.35 ppb	≤0.35 ppb
Nitrogen dioxide	≤2.65 ppb	≤2.65 ppb	≤2.65 ppb
Ozone	≤0.94 ppb	≤0.94 ppb	≤0.94 ppb
Carbon dioxide	≤2.50 ppm	≤2.50 ppm	≤2.50 ppm
Hydrogen chloride Acetic acid Formaldehyde Metallic Fumes	Use best control technology	Use best control technology	Use best control technology
Corrosion Levels(7)			
Copper Corrosion	<150Å/30 days	<150Å/30 days	<90 Å/30 days
Silver Corrosion	<100Å/30 days	<100Å/30 days	<40 Å/30 days
Particulates - Tsp(8)	≤75 μg/m^3	≤75 μg/m^3	≤75 μg/m^3
Air Flow Rate(9)	Ceiling height under 10 feet - 8 air changes per hour Ceiling height under 15 feet - 6 air changes per hour Ceiling height under 23 feet - 4 air changes per hour		

1. **Category 1** - facilities with unrestricted public access; **Category 2** - areas with access restricted to authorized personnel only, but in which materials must be removed and replaced frequently; **Category 3** - areas with highly restricted access, and in which materials will be removed and replaced infrequently.
2. Short-long storage is defined in this cases as a wide range of time storage. Materials may be removed and replaced daily or stored fro many years depending on requests for their use.
3. Long-term storage is defined in this case as a time of storage intended to be 50-100 years or more. Materials designed for this type of storage would be those of “intrinsic value” and designated for preservation as long a possible.
4. Temperature should be in the given range and not vary more than these control values.
5. Relative humidity should be in the given range and not vary more than these control values.
6. Should be sealed at this relative humidity before freezing. Otherwise use a 2% RH at normal room temperature. At the temperature of storage, -20°F, the water vapor in the sealed storage container is close to saturation (i.e., 100% RH).
7. Environmental classifications may be determined via corrosion monitoring. This involves the exposure of specially prepared metal strips, usually silver, to the local environment. The amount of corrosion which has formed on the metal can be measured using electrolytic reduction techniques. Alternatively, real-time corrosion monitoring may be performed using electronic devices employing metal-plated quartz crystal microbalances. These devices are available under the tradename **OnGuard**®.
8. Total suspended particulates: the weight of particulates suspended in a unit volume of air when collected by a high volume air sampler.
9. Can be reduced to half during periods of non-occupancy

BASIC ROOM DESIGNS - SYSTEM EXAMPLE

Steady-State Model for Air Quality Control - A simple, steady-state expression for a one-compartment model of the storage facility is helpful in identifying the three methods of control most commonly employed for thermal and air quality control: **source control**, **removal control**, and **dilution control**. A mass-balance for the model shown in **Figure 1** may be expressed as:

$$\Delta C = \frac{N - E}{V_o} \qquad (3)$$

where:

$\Delta C = C_r - C_o =$ the difference between the uniformly-mixed indoor air concentration, C_r, and the outdoor air concentration, **Co**.

$N = Q - S =$ the net generation rate of the contaminant where **Q** is the source strength (i.e., gross generation or emission rate), and **S** is the sink strength (i.e., settling or sorption rate within the controlled space).

$E = eV_mC_u =$ the removal rate of a contaminant in the air cleaner;

$e =$ the efficiency of the air cleaner rate in terms of the contaminant removed;
$V_m =$ volumetric flow of recirculated air;
$C_u =$ concentration of the contaminant upstream of the air cleaner, and;
$C_d =$ the concentration of the contaminant downstream of the air cleaner (see **Figure 1**).

$V_o =$ volumetric flow rate of outdoor air for dilution control.

In the model, the dilution rate, V_o, represents infiltration, natural ventilation, or mechanical ventilation with outdoor air. The removal rate, **E**, represents fan-filter modules commercially available, or filtered 100% recirculated air commonly used in forced air systems. In **Figure 1**, V_r represents volumetric flow rate of indoor air for dilution control.

Although Eq. (3) was derived from a simple model, it serves to identify some control strategies and their limitations for indoor air quality control:

- If removal control is not employed, the indoor (air) contaminant concentration will exceed the outdoor concentration unless the source is removed or an infinite dilution rate is provided.

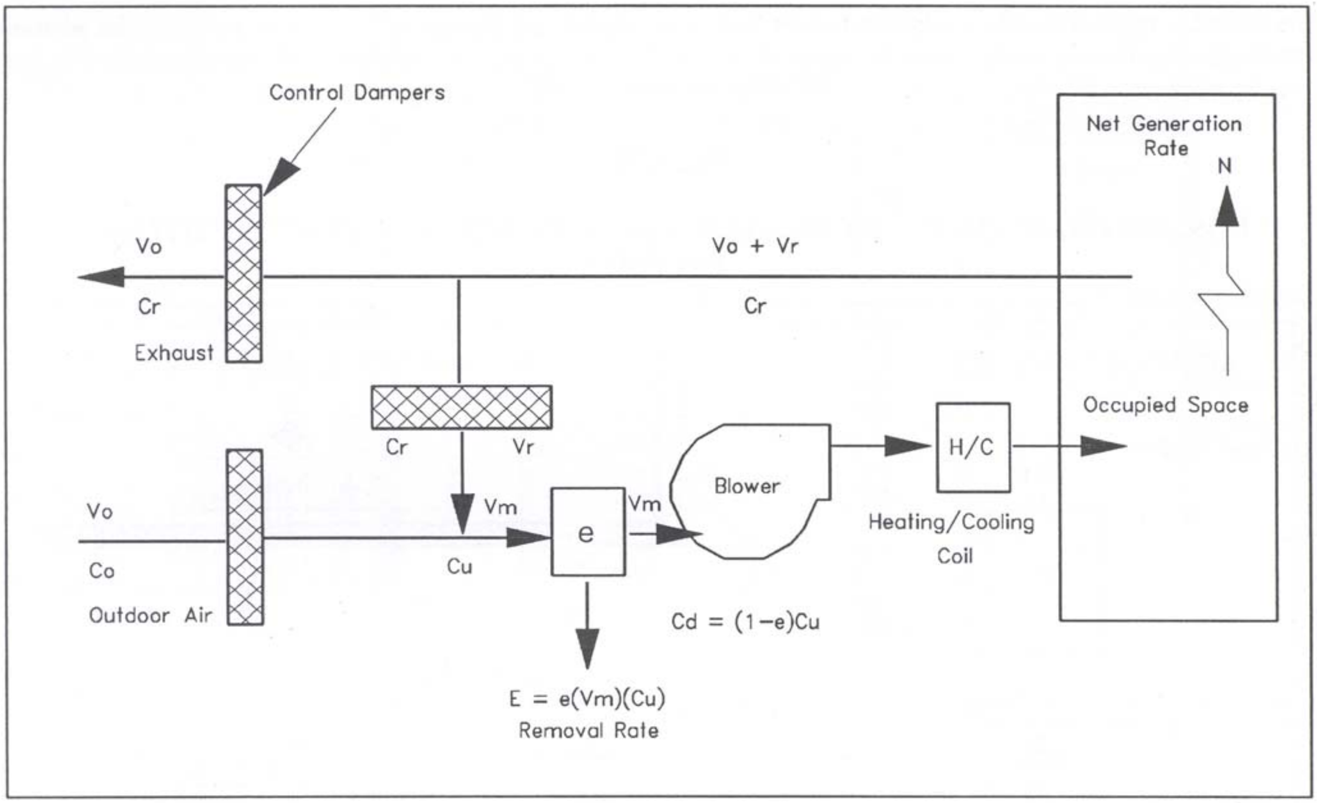
- If the indoor contaminant concentration is to be less indoors than outdoors and the dilution rate is finite, the removal rate, **E**, must exceed the net generation rate, **N**.

- Outdoor air required for dilution control may be reduced, if alternative source control and removal control strategies are sufficient to provide the same quality of indoor air as would be achieved by dilution control.

- To achieve an acceptable **ΔC**, economically, a combined strategy of source, removal, and dilution control may be required.

Whether an indoor air quality control strategy employs an open- or closed-loop system, Eq.(3) indicates that the contaminant concentrations, C_r and C_o, must be known or specified and that the net generation rate, **N**, must be known or estimated if indoor air quality is to be controlled directly. In this regard, it should be noted that Eq. (3) is analogous to an energy balance in which **N** may be compared to the cooling load within an occupied space; **ΔC** to the change in enthalpy required to cool the supply air; and V_o to the volumetric rate of supply air.

FIGURE 1 - ONE-COMPARTMENT, UNIFORMLY-MIXED, STEADY-STATE MODEL FOR INDOOR AIR QUALITY CONTROL

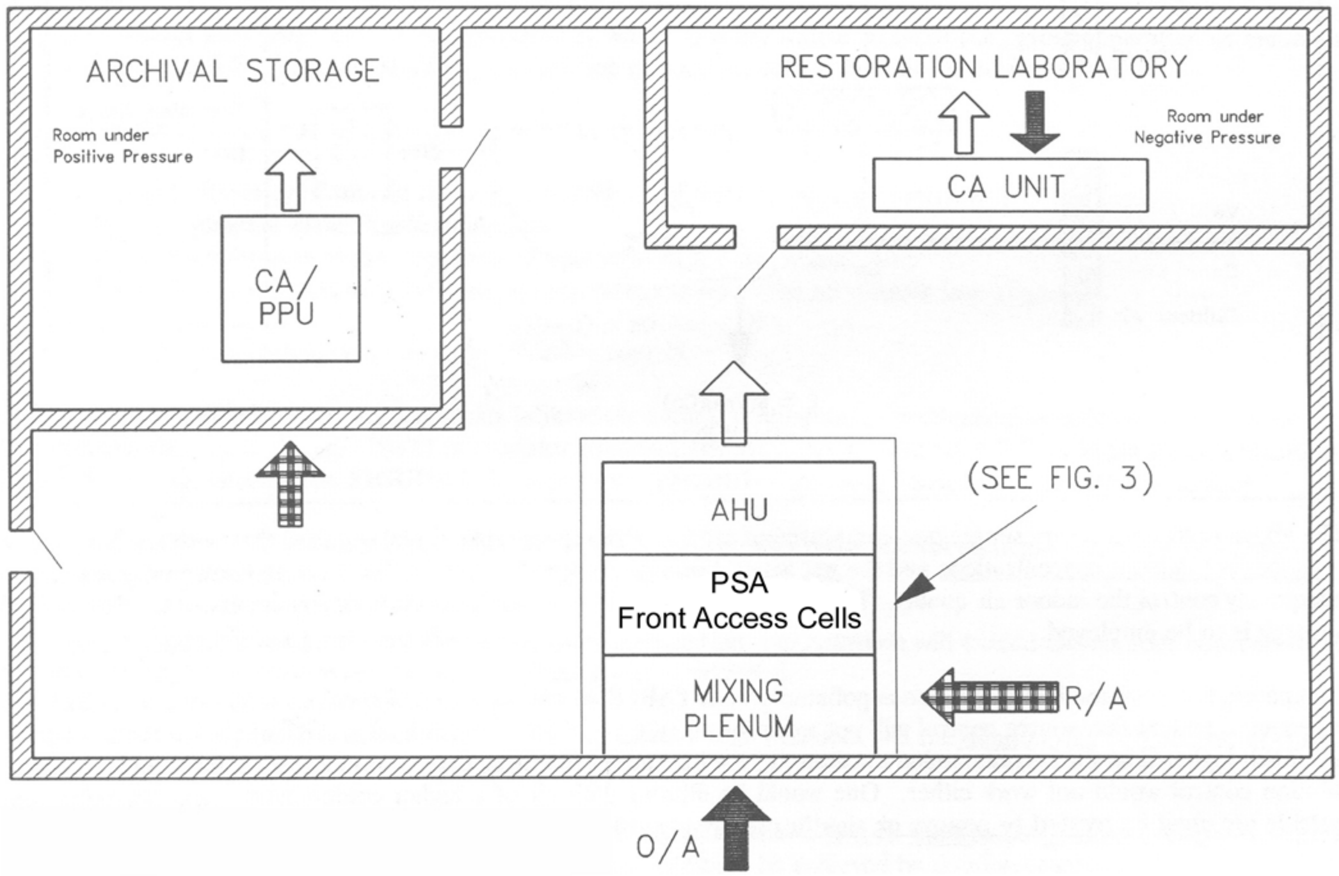


The above represents a very simple one-compartment model. Even this simple model requires that both the indoor and outdoor contaminant concentrations and the net generation rate from within the facility must be known or estimated to adequately control the indoor air quality. These three variables are the most important determinants as to what control strategy is to be employed.

Comparing the common levels of gaseous pollutants from **TABLE 10** with the control specifications listed in **TABLE 11**, it becomes evident that source control will not work for outside air. These "normal" background levels, for the most part, are much higher than the recommended maximums. And because even these background levels would be unacceptable, dilution control would not work either. One would be diluting with air of a higher contaminant load. **Therefore, the outside air must be treated to remove or significantly reduce these levels.**

Once inside the facility, there is greater leeway as to which control strategy may be employed. **FIGURE 2** shows how different Purafil air purification systems may be employed for direct control of indoor air quality through a combination of source, removal, and/or dilution control. Because the amount of outside air cannot be increased for dilution control, most of the air must be recirculated back through the filtration media. This strategy is good for treating the general-use areas of the facility as long as the net contaminant generation rate from within does not exceed the contaminant levels in the outside air. Low internal levels might be adequately treated within the main filtration system. However, many times it is preferable to keep the challenge levels to the main system as low as possible with localized source control. If point sources can be identified, these may be treated by their own stand-alone systems. In the example shown in **FIGURE 2**, there are two areas that would benefit from this strategy.

FIGURE 2 - POSSIBLE LOCATIONS OF PURAFIL AIR PURIFICATION SYSTEMS WITHIN A FACILITY



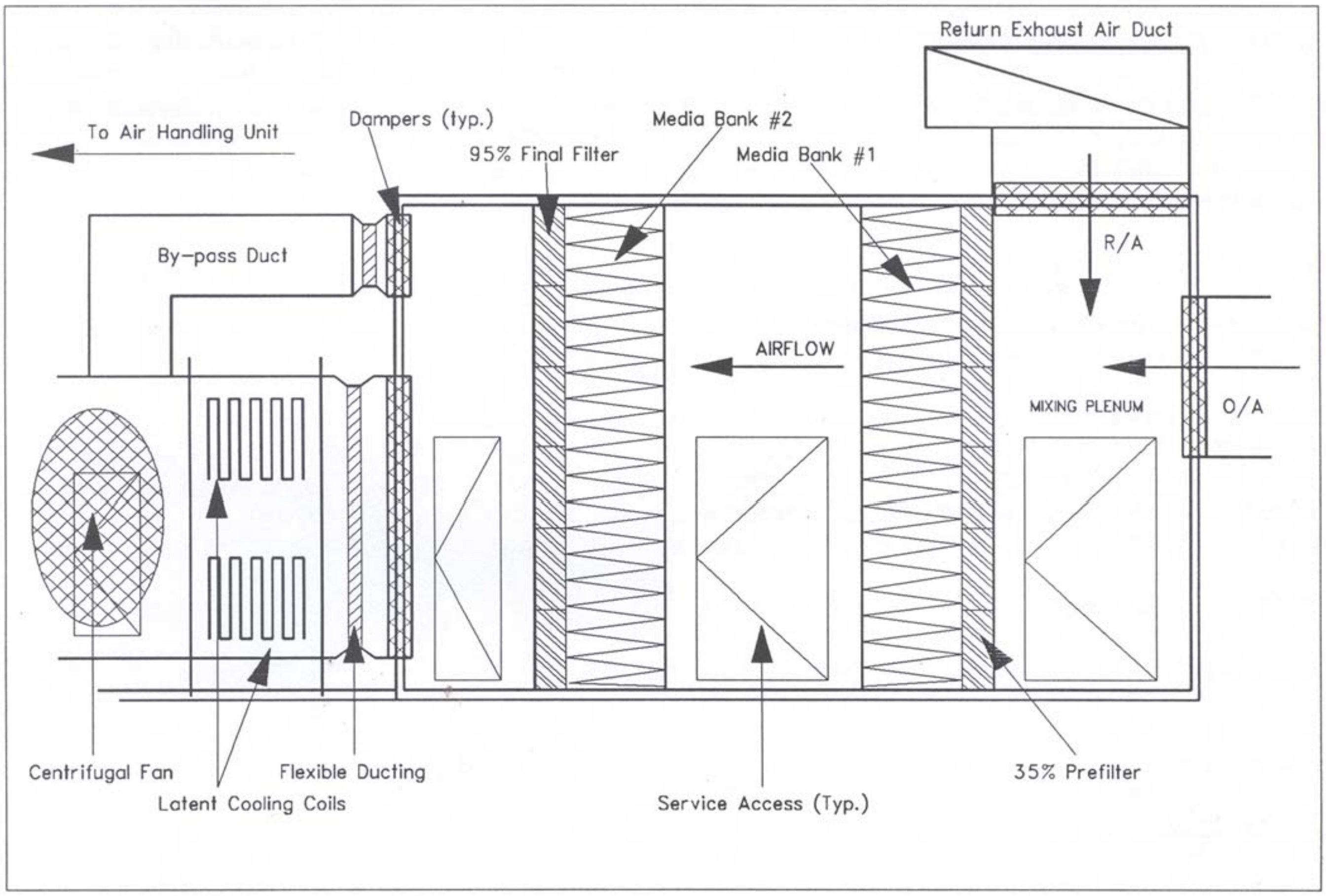
The above shows how different Purafil air purification systems may be employed for direct control of indoor air quality. (These systems are described in the following section.) Outside air is treated by dry-scrubbing air filtration media contained in a variety of gas-phase air filtration equipment designs. Because the amount of outside air cannot be increased for dilution control, most of the air must be recirculated back through the filtration media. This strategy is good for treating the general-use areas of the facility as long as the net generation rate from within does not exceed the levels in the outside air. Low internal levels might be treated adequately within the main air filtration system. However, many times it is preferable to keep the challenge levels to the main system as low as possible with localized source control. If point sources can be identified, these may be treated by their own stand-alone systems. In the example shown in **FIGURE 2**, there are two areas that would benefit from this strategy.

The first, a limited-access archival storage area, may see increased levels of pollutants due to off-gassing from stored materials (low levels, long term) or introduction from the exterior (high levels, short term). Recirculation should be employed to control those internal pollutants and positive pressure should be maintained to prevent infiltration. **Positive Pressurization Units (PPU's)** could be used where both pressurization and recirculation is required. **Corrosive Air (CA)** units could be used where recirculation alone is required.

The second, a restoration lab, would also benefit from recirculation, but positive pressurization would not be advisable. The levels of pollutants inside would be higher than the exterior and positive pressure could introduce these to other areas by exfiltration. A slight negative pressure would be more desirable in this case. This could be done with a **CA unit**.

As stated previously, because the amout of outside air cannot (usually) be increased for dilution control, most of the air must be recirculated back through the facility's main air filtration unit(s). These units are integrated into the main air handling unit(s) (AHU). As illustrated in **FIGURE 2**, the air filtration unit, designated **PSA/Front Access Cells**, is located downstream of the outside air/return air mixing plenum. This allows both outside and recirculated air to be treated by the dry-scrubbing air filtration media, assuring virtually contaminant-free air as long as proper maintenance is provided for the entire air handling system. An illustration of how air filtration may be employed in part a typical air handling unit is shown in **FIGURE 3** and described in detail in the following section.

FIGURE 3 - TYPICAL AIR FILTRATION / AIR HANDLING UNIT

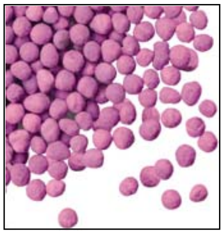


GAS-PHASE AIR FILTRATION SYSTEMS

Chemical Media - The heart of Purafil' air purification systems is the dry-scrubbing, or gas-phase, air filtration media. Based upon the contaminant gases present and their concentrations, systems can be designed around the specific media required to do the job.

PURAKOL® Activated Carbon: Activated carbons provide excellent adsorption characteristics on gaseous contaminants having higher molecular weights. Purakol media is a premium grade carbon with a surface area of 1100-1200 m^3/gm, with a performance criterion qualitatively and quantitatively tested.

All urban/industrial atmospheres contain a combination of various contaminant gases. Purakol media will adsorb a wide spectrum of contaminants and is used for the control of chlorine, aromatic and aliphatic hydrocarbons, chlorinated hydrocarbons, as well as two gases of great concern to those concerned with the preservation of archival and historical materials - ozone and nitrogen dioxide.



PURAFIL® SELECT: Purafil Select media is a broad-spectrum media used to control a variety of gaseous contaminants. The media accomplishes this through a unique combination of adsorption, absorption, and oxidation processes. Reactive gases are converted to non-corrosive solids, which remain in/on the pellet. This media is particularly effective against lower molecular weight compounds, such as sulfur dioxide, hydrogen sulfide, and hydrogen chloride, and is UL Classified Class 1.

SELECT CP BLEND: Most applications have complex air challenges and require multi-stage filtration systems to ensure removal of all contaminants. In applications where space limitations prohibit multiple media stages, Purafil offers Select CP Blend, a blend of both Purakol and Purafil Select media. Select CP Blend media removes the broadest range of contaminants in a single pass and is UL Classified Class 2.

Purafil Equipment - Purafil manufactures a broad line of equipment to handle distinct air purification requirements. Equipment is grouped into two main categories: HVAC integrable and self-contained systems.

The building blocks of these systems are the Purafil modules. Purafil disposable MediaPAK™ modules are constructed of recyclable polystyrene plastic and have a distinctive "V" shaped media bed, which decreases resistance to airflow. Purafil offers the following MediaPAK™ module designs:

PK-18: Designed for airflows up to 500 ft/min (2.54 m/sec), the PK-18 measures 24" wide x 6" high x 18" deep (610 x 152 x 457 mm), features a one-inch (25.4 mm) bed depth and contains 0.5 ft^3 of Purafil media.

PK-12: Designed for airflows up to 250 ft/min (1.27 m/sec), the PK-12 measures 24" wide x 12" high x 12" deep (610 x 305 x 305 mm), features a three-inch (76.2 mm) bed depth and contains 1 ft^3 of Purafil media.

CK-12/24: Designed for airflows up to 500 ft/min (2.54 m/sec), the CK-12/24 module features a one-inch (25.4 mm) bed depth and contains 0.5 ft^3 of Purafil media. The CK-12/24 module features an integral one-inch header to fit any 12-inch (305 mm) headered filter section, box filter section or universal frame with no alterations to the air handling system. The CK-12 module measures 12" wide x 24" high x 12" deep (305 x 610 x 305 mm). The CK-24 module measures 24" wide x 12" high x 12" deep (610 x 305 x 305 mm).

HVAC Integrable Systems - Some Purafil systems are designed to be integrated into the overall HVAC system. This system approach offers the confidence that all parts of the air purification/HVAC systems will work together. Integrated systems typically require there be mechanical or machine rooms in which they can be placed. **NOTE**: Unless redundancy is built in, the air purification system will only operate when the central HVAC system in is operation.

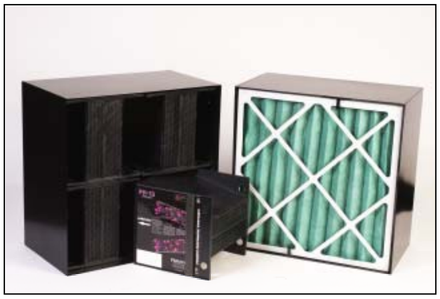
PURAFIL SIDE ACCESS UNIT (PSA) - The PSA is a versatile system designed to achieve virtually any efficiency rating desired. The unit is used to filter low to medium concentrations of gaseous pollutants contained in outside air. In addition, the unit may also be used for recirculation. As the outside air will already have been filtered, the PSA unit used for recirculation purposes will clean and polish very low gas levels to maintain those levels as required for a particular application.

As a working tool for the designer, Purafil air cleaners are available in a complete line of side access units. Standard housing construction is of 14 gage (1.9 mm) galvanized steel with thorough support bracing. These housings are offered with a full range of size options, prefilter sections, final particulate alternatives, and up to four passes of Purafil MediaPAK™ modules. Although the 2" prefilter is most often specified, other extended media options are available. Final filters can range from the rigid frame type to deep pocket bag filter...any of which can be provided by Purafil, Inc.

The PSA offers Purafil's patent-pending J-Track™ technology, which features slanted tracking to support Purafil's MediaPAK™ modules via a corresponding angled notch in the modules' frame. The weight of the module forces it against the channel and creates a positive seal with the tracking. The J-Track™ technology ensures self-sealing pressure to prevent air bypass and enhance filtration efficiency.

PSA units are available in any size to house most commercially available filters and match dimensionally with most air handling equipment. Prefilters, chemical media modules, and final filters may be contained in separate or combination housings. Special metals and finishes are also available as options.

FRONT ACCESS SYSTEM - The Purafil Front Access System consists of holding cells with Purafil media modules. Cells are designed for permanent installation in banks in sizes of 4x4' and larger. Modules slide into the cell on individual tracks and are held in place against sealant gaskets by quick turn fasteners allowing cells to mount for either up- or downstream access. The frames accommodate particulate filters for pre- or post filtration. Filter banks smaller than 4x4' or not having appropriate front access plenum space should employ the Purafil Side Access (PSA) pre-assembled housing.



Self-contained Systems - Self-contained systems consist of the housing to hold the media as well as a blower section to move the air through the system. These systems are totally separate from the HVAC system. Self-contained systems allow for easier retrofits, the use of standard air handlers, easier service of the system, and less complex air balancing. Additionally, some self-contained systems contain greater amounts of media and are thus able to handle higher gaseous pollutant levels. **NOTE**: Noise levels on some of the indoor systems may be increased due to the use of multiple fans and blowers. These systems may also be more costly.

POSITIVE PRESSURIZATION UNIT (PPU) - The ultimate control for any space requiring high air quality standards involves positive pressurization. The PPU is an all-in-one packaged air filtration machine for indoor use. Both particulate and chemical filtration are integrated into one unit, complete with a self-contained blower. It is used to filter low to medium concentrations of gaseous pollutants while providing continuous positive pressure within the space.

The PPU cabinet is constructed of seam-welded 14 gauge steel and includes a prefilter, two banks of Purafil MediaPAK™ modules, an optional 90% final filter, a blower section, and an adjustable damper for control of pressurization air. A maximum of 50% of the unit's total airflow capacity may be used for pressurization air.

CORROSIVE-AIR (CA) UNIT - The CA unit, also designed to be located within the protected space, is an air purification machine with recirculation as its primary function. The unit is used to further filter and polish the room air to maintain very low pollutant levels. It offers a number of advantages not present in filtration systems that are integral with the HVAC systems. Both particulate and chemical filtration and a self-contained blower are combined in one unit.

While designed to stand alone, CA units cannot be used for pressurization and thus are often used in combination with the PPU. For larger rooms it may be necessary to use several CA units to fully recirculate all the air within the room.

The CA unit is constructed of seam- welded 14 gauge steel and includes a prefilter, two banks of Purafil MediaPAK™ modules, a blower section, and a 90% final filter.

Systems Components - Particulate Filtration - An integral feature of all Purafil air purification systems is particulate filtration: a prefilter for large particulate matter and a final filter for the smaller, microscopic particulate matter.

A MERV 6 prefilter is used upstream of all Purafil media banks. The filter removes 20-30% of all particles greater than 1 micron in size and 80-90% of all particles larger than 10 microns. This is the required minimum efficiency to prevent atmospheric dust from clogging the chemical filtration media.

A MERV 13 or MERV 14 final filter is used to insure the removal of extremely small particles from the airstream.

FACILITIES DESIGN & CONSTRUCTION REQUIREMENTS

In order to assure reliable performance of any air purification system, it is imperative to minimize the introduction of contaminated outdoor air, while simultaneously maintaining a slight positive pressure with the protected space.

A controlled atmosphere depends on air contaminant capture and containment. It is assumed that the rooms/buildings considered in this document have people-related internal sources of contamination such as tobacco smoke, off-gassing from clothing, etc., and the outdoor air as the major external source.

Rigid adherence to the following requirements will allow Purafil air cleaning systems to effectively and economically protect materials and artifacts contained within the facility.

- Seal the area to be protected as tightly as possible.
- Install gaskets and heavy door closers on all doors. Avoid roll-up access doors or seal with heavy plastic when not in use.
- Where windows are required, install well-sealed stationary windows. Seal shut existing operational windows.
- Seal permeable construction materials such as concrete block with an impermeable paint, plaster, or paneling. (A concrete block will leak over 0.15 cfm/ft^2 at 0.05 iwg.)
- When suspended ceilings are employed, the space above the ceiling must be considered as part of the protected space, and must be sealed just as carefully as the rest of the facility.
- Cracks around infrequently used doors, etc. should be sealed with tape, caulking, plastic sheeting or other materials.
- Toilet ventilation should be ducted into the return air of the Purafil system.
- Light duty, infrequently used laboratory hoods should be ducted into the return air of the Purafil system(s) rather than exhausted outdoors.
- Select cleaning compounds with care to avoid acidic or chlorinated materials from being introduced into the protected space.

FACILITES MANAGEMENT & MAINTENANCE REQUIREMENTS

Restrict access to **Category 2** and **Category 3** facilities/ areas to authorized personnel only. Restrict facility/area usage from secondary purposes.

Rooms that are not ordinarily occupied must be locked in order to restrict access to unauthorized personnel and traffic.

Storage batteries for emergency power should be located in a separately ventilated room without interior connections.

The engineering/maintenance staff should be assigned the following tasks:

- Develop an inspection checklist for the types of filter systems used, and perform inspections periodically.
- Establish a Purafil media sampling schedule. Maintain records on life cycles and replacement dates.
- Supervise the routine replacement of Purafil media and particulate filters.

Purafil, Inc. will, on a service contract basis, handle routine inspections, media sampling, and other functions to provide advance warning of media replacement and maintenance requirements. This service will permit continuous protection and optimum performance.

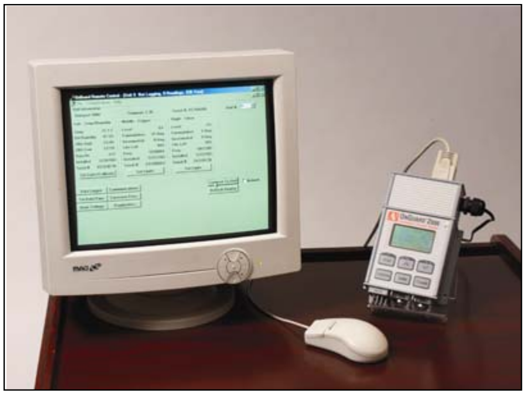
TESTING AND MONITORING

Environmental Classification Services - Purafil' Environmental Classification service is designed to characterize the corrosive potential of a environment. The growth of various corrosion films on specially prepared copper, silver, and/or gold coupons gives an excellent indication of the type(s) and level(s) of any and all corrosive gaseous pollutants present in the local environment.

ENVIRONMENTAL REACTIVITY COUPONS - Although originally developed for the classification of environments for computers and control rooms, these **Environmental Reactivity Coupons (ERC's)** may be used to indicate the presence of sulfur dioxde, nitrogen dioxide, hydrogen sulfide, and chlorine compounds, which can cause deterioration of metals, cellulose, and/or calcium carbonate within museums, libraries, and similar environments. These ERC's normally contain copper-only or copper in combination with other coupons to provide an environmental assessment. However, recent studies have shown that while copper coupons are good indicators of corrosive gases in an industrial environment, they are not sufficiently sensitive to contaminants ubiquitous to most urban environments - the same environments in which most museums, etc. are located.

Purafil, in response to this, developed a silver ERC that allows for the identification of contaminants not reactive with copper. Both copper and silver coupons will provide a realistic assessment of "average" conditions over time. Purafil, Inc. will take these results and maintain a database categorized by facility type, location, etc.

The ability to compare results with other museums and archives will provide important information on individual institutional performance. The museum database will summarize the test results by type and general location of the facility, average outdoor conditions, present type of climate control system(s), and locations of the coupons within the building. While individual institutional results will be kept confidential, the database will provide a useful tool for comparing present performance and for projecting improvements through the installation of gas-phase air filtration.



ELECTRONIC MONITORING - Another tool has been developed and is currently being used in museums and archives around the world. The **OnGuard® 2000 Atmospheric Corrosion Monitor** is the first electronic instrument that provides real-time information on the amount of corrosion occurring due to the presence of corrosive gases in the subject environment. The unit monitors corrosion on a continuous basis and calculates cumulative and incremental corrosion rates. This allows for preventive action to be taken before serious damage due to atmospheric corrosion has occurred. It also measures the temperature and relative humidity of the subject environment, both of which can cause increases in the rates of corrosion.

The **OnGuard® 2000** may be operated by itself, using the visual information displayed on corrosion severity levels, temperature and relative humidity, or wired directly into a central computer system. All measurements can be easily viewed on the Liquid Crystal Display, and the parameters can be easily configured using the menu-based keypad, or the same features can be accessed through OnGuard's Remote Control software. By making use of the **OnGuard® 2000's** ability to interface with computers, up-to-the-minute information on these important environmental parameters can be obtained. Environmental corrosion databases can be established and maintained to provide historical data to those charged with the maintenance and preservation of artifacts.

For real-time corrosion monitoring, Purafil also offers the **OnGuard® Environmental Reactivity Monitor (ERM).** Like the OnGuard® 2000, the OnGuard® ERM provides real-time information on the amount of corrosion occurring due to the presence of corrosive gases. While OnGuard 2000 measurements are viewed on the monitor's LCD or read remotely via a central computer system, ERM measurements are transmitted to the building management system via a 4-20 mA output signal.

Both the OnGuard® 2000 and the OnGuard® ERM feature copper and silver Quartz Crystal Microbalance (QCM) sensors for the detection of contaminant concentrations as low as one part per billion.

ENVIRONMENTAL CLASSIFICATION - Both Environmental Reactivity Coupons and OnGuard® Monitors measure environmental reactivity in Angstroms, a unit of length equal to one ten-billionth of a meter. Purafil's understanding of the environmental challenges facing museums and archives has led to the following environmental classification scheme whereby monitoring results correlate to varying degrees of air quality.

Environmental Classification for Preservation Environments **Silver Reactivity Monitoring**		
Class	**Air Quality Classification**	**Reactivity Rate (Å/30 Days)**
S1	Extremely Pure	<40
S2	Pure	<100
S3	Clean	<200
S4	Slightly Contaminated	<300
S5	Polluted	≥300
Environmental Classification for Preservation Environments **Copper Reactivity Monitoring**		
Class	**Air Quality Classification**	**Reactivity Rate (Å/30 Days)**
C1	Extremely Pure	<90
C2	Pure	<150
C3	Clean	<250
C4	Slightly Contaminated	<350
C5	Polluted	≥350

ENVIRONMENTAL RECOMMENDATIONS -Based on the above-mentioned environmental classifications, Purafil recommends the following levels of air quality for locations within the museum or archive:

- Class S1/C1: Archives, Metal Collections, Rare Books
- Class S2/C2: Museums, Museum Storage, Libraries
- Class S3/C3: Historic Houses
- Class S4/C4: Short Term Acceptable
- Class S5/C5: Not Acceptable

While each museum or archive may follow a unique set of standards for environmental control, provided on the following page is a general summary of specifications that would produce a benign environment. These specifications include recommended levels for gaseous contaminants, as well as temperature, relative humidity, particulates and air flow rate.

Environmental Factors	**Standard levels (1)**		
	Category 1	**Category 2**	**Category 3**
Public Access	yes	no	no
Duration of Storage	short-long (2)	short-long (2)	long (3)
Frequency of Access	often	often	seldom
Dry-bulb temperature range	65-75°F (18-24°C)	50-55°F (10-13°C)	-20°F (-29°C)
Temperature Control (4)	±2°F (±1°C)	±1°F (±0.5°C)	±2°F (±1°C)
Relative Humidity Range (5)	40-55%	25-35%	20-25%
Gaseous Contaminants			
Sulfur dioxide	≤0.35 ppb	≤0.35 ppb	≤0.35 ppb
Nitrogen dioxide	≤2.65 ppb	≤2.65 ppb	≤2.65 ppb
Ozone	≤0.94 ppb	≤0.94 ppb	≤0.94 ppb
• Hydrogen chloride • Acetic acid • Formaldehyde • Metallic Fumes	Use best control technology	Use best control technology	Use best control technology
Particulates - TSP (7)	≤75 μ/m3	≤75 μ/m3	≤75 μ/m3
Air Flow Rate (8)	• Ceiling height under 10 ft - 8 air changes/hour • Ceiling height under 15 ft - 6 air changes/hour • Ceiling height under 23 ft - 4 air changes/hour		

1. Category 1 - facilities with restricted public access; Category 2 - areas with access restricted to authorized personnel only, but in which materials must be removed and replaced frequently; Category 3 - areas with highly restricted access, and in which materials will be removed and replaced infrequently
2. Short-long storage is defined in this case as a wide range of time storage. materials may be removed and replaced daily or stored for many years depending on requests for their use.
3. Long-term storage is defined in this case as a time of storage intended to be 50-100 years or more. materials designed for this type of storage would be those of intrinsic value and designated for preservation as long as possible.
4. Temperature should be in the given range and not vary more than these control values.
5. Relative humidity should be in the given range and not vary more than these control values.
6. Should be sealed at this relative humidity before freezing. Otherwise use a 2% RH at normal room temperature. At the temperature storage of -20° F, the water vapor in the sealed storage container is close to saturation.
7. Total suspended particulates: the weight of particulates suspended in a unit of volume of air when collected by a high volume air sampler.
8. Can be reduced to half during non-occupancy.

Pressurization and Air Quantities - Since the quantity of outside air and the degree of pressurization are critical to the performance of a filtration system, an air volume measuring device should be installed in the outside air duct. Gauge units to display outside air quantity and room pressure should be located where they can be easily observed, and operating personnel should be instructed to report readings that are out of specifications.

Temperature and Humidity - The actual temperature and relative humidity, as well as the rates of change of both greatly affect the environment within these facilities. Transient out-of-spec conditions indicate that corrective action is desirable. Long-term or frequent short-term deviations from standard specifications will encourage corrosive damage.

Temperature and relative humidity may be recorded using simple methods such as manually reading and logging values from wet/dry bulb thermometers or by using a rotating drum hygrothermograph. Most of these latter devices require chart replacements at 7 to 31 day intervals.

SUGGESTED SPECIFICATION AREAS

The environmental conditions required for protection of materials and artifacts contained in museums, libraries, and archival storage facilities involve every facet of the construction process:

- Facility design
- Ventilation system design and installation
- Temperature and humidity control systems
- Particulate contamination control system
- Gaseous pollutants control system
- Programmed maintenance system

Owners, consultants, and contractors are urged to contact Purafil, Inc. for specific design recommendations and mutually agreed upon control specifications and methods for particulates, temperature, humidity and gaseous pollutants.

DEFINITIONS

Absorption - the penetration of one substance into the inner structure of another.

Acceptable Air Quality - (a) air in which there are no known contaminants at harmful concentrations. (b) ambient air in which there are no known contaminants and corrosion, deterioration, or other faults are unlikely.

Adsorption - The process by which one substance is attracted to and held on the surface of another.

Air Cleaner - a device used to remove airborne impurities such as dusts, vapors, fumes, and smoke.

Air Cleaner Bank - a group of identical air cleaning devices arranged in parallel so the air volume flowing through each is equal to the total airflow divided by the number of devices in the bank.

Air Conditioning - the process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, cleanliness, and distribution.

Air, Ambient - air of naturally occurring composition surrounding an object.

Air, Exhaust - air removed from a space and not reused therein.

Air, Makeup - outdoor air supplied to replace that amount lost to exhaust air and exfiltration.

Air, Outdoor - air making up the external atmosphere.

Air, Purged - air that is exhausted to the outside (usually) through cracks, crevices, ceilings, floors, and walls of a space or building.

Air, Room Pressurization - outside air supplied to a space to create positive pressure within that space.

Air, Room Recirculation - air removed from a space to be recirculated, usually back through an air handling/ filtration unit.

Air, Supply - air delivered to the conditioned space.

Air, Ventilation - supply air plus any recirculated air that has been treated for the purpose of maintaining acceptable indoor air quality.

Angstrom - a unit of distance equal to $1x10^{-10}$ meter.

Artifact - a characteristic product of human activity.

ASHRAE - the initials of the American Society of Heating, Refrigeration, and Air-Conditioning Engineers. It is a professional organization which has established test methods and standards for rating the efficiency of particulate filters. The particulate filter efficiencies referred to in this document are in accordance with ASHRAE Standard 52.

Chemisorbent - a material that adsorbs and/or absorbs gaseous pollutants, then chemically reacts with them - preventing desorption.

Concentration - the quantity of one substance dispersed in a defined amount of another.

Conservation - a careful preservation and protection of something. In this case, it refers to the whole subject of the care and treatment of valuable artifacts both movable and immovable.

Contaminant - an unwanted (air borne) constituent.

Corrosion - used here to mean the deterioration of a substance (usually a metal) due to a reaction with its environment.

Coupon - specially prepared strips of metal (usually copper or silver) used to evaluate the corrosivity of a specific environment.

Coupon Reactivity Test - an environmental test in which copper and/or silver coupons are exposed to the atmosphere for a predetermined time and then analyzed in accordance with a specific analytical procedure. When the results are correlated with a known data base, the integrated average corrosivity of the environment may be predicted.

Exfiltration - air leakage outward through cracks, crevices, ceilings, floors, and walls of a space or building.

Dust - fine particulate matter usually with particle size < 100 μm.

Fumes - giving off of a smoke (particles), vapor, or gas.

Gas - a state of matter in which substances exist in the form of nonaggregated molecules (usually a superheated vapor).

Infiltration - air leakage inward through cracks, crevices, ceilings, floors, and walls of a space or building.

Internally-Generated Contaminants - particulates and/or gases found inside a space whose sources are within the space.

Media, Dry-Scrubbing (or Gas-Phase) - a granular substance used to remove (usually) gaseous pollutants from the air.

Micrometer - a unit of distance equal to $1x10^{-6}$ meter.

Module - a perforated plastic or metal container used to hold a measured quantity of a granular air cleaning medium in a moving airstream. Usually formed in a "v"shape to minimize air resistance and reduce cross sectional area while maximizing the surface area available for ad- absorption.

Oxidation - the reaction of oxygen with another element; to turn into an oxide.

Particulate - a vary small piece of matter. Airborne particulate matter is typically in the size range of 0.01 to 100 μm.

PURAFIL SELECT® Media - a dry scrubbing air filtration media manufactured by Purafil, Inc. for adsorbing, adsorbing ,and chemically oxidizing (or otherwise reacting with) gaseous pollutants.

PURAKOL® - a family of activated (coconut shell) carbons exhibiting a high surface area with or without chemical impregnants marketed by Purafil, Inc.

Synergy - combined action or operation. Where two or more agents working together produces an effect greater than the sum of the individual effects.

Total Suspended Particulate (TSP) - the weight of particulates suspended in a unit volume of air when collected by a high volume air sampler.

Vapor - A substance in gas form.

Ventilation - the process of supplying and removing air by natural or mechanical means to and from any space. Such air may or may not be conditioned.

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