CONTROL OF VOLATILE ORGANIC COMPOUNDS AND PARTICULATE MATTER IN INDOOR ENVIRONMENTS OF AIRPORTS BY BIPOLAR AIR IONIZATION

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ABSTRACT:

Modern airports are a potpourri of indoor and outdoor spaces serving commercial and public demands much like small cities. These include: administration; ticketing and baggage handling; lounges and waiting areas; hotels, restaurants, and shops; air traffic control; surface transportation; and aircraft maintenance. These facilities experience environmental challenges from a variety of volatile, particulate, and microbial air contaminants arising from natural and human sources. These contaminants affect comfort and health aspects of indoor air environments. They include general pollutants (smoke, dust, pollen, odors), specific chemicals (unburned hydrocarbons, carbon monoxide), and microbials (bacteria, molds).

The objectives for environmental management of indoor air systems at airports are multiple: minimizing pollutant sources, providing good air handling, and improving Indoor Air Quality (IAQ). Treating air contaminants depends upon the nature of the contaminants, relative concentrations, technical approaches used, and results to be achieved. Technologies involve filtration, adsorption, and electronic processes. Electronic devices, including bipolar air ionizers, electrostatic precipitators, and ozone generators, are functionally related, but have distinct differences in their modes of operation. Bipolar air ionization involves creation of clusters of negative and positive ions by applying electrical energy to air molecules without heating the bulk gas. Reactive species are created that oxidize volatile organic compounds (VOCs) and agglomerate fine particulate matter (PM_x).

Demands for more complete treatment of indoor air environments has led to the development of practical engineered systems based upon bipolar air ionization. Air ionization units are tailored to particular facilities depending upon sources and strengths of VOCs and PM_x. Air ionization modules are fitted directly into central air handling units to treat entire airflows to meet challenges from external sources. Modules also can be fitted into existing ductwork immediately downstream of central HVAC systems. Freestanding devices can also be placed in individual room spaces to meet immediate demands from internal sources.

Field applications of bipolar air ionization systems require optimization of up to eight process variables of the physical air handling system and the air quality demand. The central process control unit is programmed for fixed situation design parameters (ion level, power capacity, and airflow area), and for monitored demand parameters (airflow, humidity, outside and return air quality, and ozone). Case histories, including ticketing and baggage handling facilities at a major international airport, several FAA control towers, and a number of passenger lounges, will be discussed in terms of process design, unit performance, and IAQ evaluation.

1.0 MANAGEMENT OF AIR SPACES.

The management of air quality is dependent on the uses and needs of the living-breathing “space” under consideration. Modern airports are a potpourri of indoor and outdoor spaces serving commercial and public demands much like small cities. These include: administration; ticketing and baggage handling; lounges and waiting areas; hotels, restaurants, and shops; air traffic control; surface transportation; and aircraft maintenance. In addition, the cabin environments of aircraft, like those of other transport vehicles, are enclosed spaces that in a sense are “movable buildings”. For all of these spaces, the quality of the indoor air is intimately associated with the quality of the surrounding outdoor (ambient) air. For purposes of this discussion, emphasis will be put on “inner” enclosed spaces vis-à-vis “outer” open spaces.

The FAA Air Quality Handbook (Draper et al., 1997) provides guidance, procedures, and methodologies for conducting air quality assessments, emission inventories, dispersion analysis, confirmatory determinations, and mitigation and control procedures at civilian airports and military air bases. It contains updated guidance on recent changes in the Clean Air Act and other laws, regulations, and directives, and references. A recently completed study by the National Academy of Science (NAS, 2001) and sponsored by the FAA was directed at assessment of air quality conditions, associated health effects, and contributing factors in passenger cabins of commercial aircraft equipped with environmental control systems (ECSs) that provide a suitable indoor environment. A new standard for air quality within commercial aircraft is under development (ASHRAE, 2001).

Development of engineered solutions to mitigate Indoor Air Quality (IAQ) problems in enclosed spaces requires an understanding of several factors: (1) the types, sources, and interactions of space contaminants; (2) the nature and activities of space occupants; (3) the design and operation of space HVAC equipment, and (4) the impact of indoor and outdoor space climates. Control strategies can be both passive and active. Passive control strategies include implementation of proactive measures to limit sources and exposures to potential contaminants. Active control strategies include reactive responses to actual contaminants through management of ventilation and air cleaning systems. An ordered hierarchy of control strategies is usually applied: source control, exposure control, ventilation, and air cleaning (EPA, 1990; ALA, 1997). The management of air, especially engineering design for indoor environments, requires interpretations of both perception and reality (Daniels, 1999; Daniels 2000).

What do we want to accomplish? Perception: a safe, healthy air environment free of dangerous, toxic, harmful, hazardous constituents. Reality: a workable compromise balancing safety, health benefits, comfort needs, and costs. Airflow, temperature, and humidity can be managed using recognized engineering standards and guidelines for design, construction, and procedures for building operation. Management decisions then are made that "trigger" responses: alert, evacuation, control, removal, or remediation of specific contaminants.

A three-fold question begs answers; (i) why do we ventilate spaces, (ii) why do we ventilate the way we do, and (iii) how much ventilation is needed and for what purposes? There have been a series of four paradigms in ventilation theory (Fanger, 1998). For almost 200 years, it has been assumed that human beings were the exclusive polluters in occupied indoor spaces.

The first paradigm (1800's) assumed that people exhaled a highly toxic substance that required ventilation to avoid poisoning themselves. Identification of this toxin ranged from carbon dioxide (harmless at indoor air concentrations) to "anthropotoxin" (a hypothetical substance never identified chemically). A second paradigm shift (early 1900's) assumed that people emitted "contagion". Concentrations of disease-causing microorganisms were diluted by ventilation to decrease risk.

A third paradigm shift gradually evolved (1920's - 1930's). Factors other than ventilation were found more important in the transfer of contagion. This shift was made toward "comfort". It was directed toward dilution of human bioeffluents (respiration, halitosis, perspiration, and flatulence) and tobacco smoke. A fourth paradigm shift toward the building itself is now underway in the new millennium (2000+). Efforts are focused on avoiding or reducing superfluous contaminants in spaces using engineered solutions directed specifically at controlling VOCs and PM_x from diverse sources. The Products of Anyone’s Fertile Imagination (PAFIs) of the past are now assuming real identities. The conventional IAQ parameters of temperature, humidity, and airflow, now include: VOCs, PM_x, microbials, and combinations, thereof.

2.0 AIR CONTAMINANTS IN INDOOR SPACES.

Airport facilities, like other spaces, experience environmental challenges from a variety of volatile, particulate, and microbial air contaminants arising from natural and/or human sources. These contaminants affect both comfort and health aspects of indoor air environments. They include general pollutants (smoke, dust, pollen, odors), specific chemicals (unburned hydrocarbons, carbon monoxide), and microbials (bacteria, molds). The introduction, persistence, and removal of such contaminants may be a combination of inadvertent and intentional actions resulting from normal (and sometimes abnormal) human activities. Some air constituents have positive connotations (fresh coffee, bread baking); others have negative connotations (body odors, garbage, molds, pet dander); a few are equivocal (perfumes, candles).

Data on aircraft cabin contaminants, collected by FAA and others, and means for improving cabin air quality have been reviewed (NAS, 2001). Contaminants of concern include pathogens and substances used in maintenance, operation, or treatment of aircraft, and those that may result from seasonal changes in fuels and the use of deicing fluids. The study considered design and operation of cabin air supply systems. The toxicological properties of contaminants, byproducts, and degradation products, and other factors, such as temperature and relative humidity, establish health effects. Measurements of contaminants in cabin air during domestic and foreign air transportation are compared with measurements taken in public buildings, including airports. Potential approaches for improving cabin air quality are addressed.

Space comfort, like beauty obviously is in the eyes (and noses!) of the beholders. Air quality is maintained within a suitable "comfort" zone for most people most of the time. Management of potentially hazardous trace constituents ("nasties") is also attempted with qualified successes. This is done in several ways: (i) minimizing entrance of "nasties" from point sources in the first place, (ii) maintaining a vigilance for "nasties" that might appear from natural or incidental sources, and (iii) removing any "nasties" found to be present to below predetermined “action” levels. We need to know what “nasties” are most significant; how to detect them in different environmental media; which methods to apply for their control, and what levels of controls to apply and evaluate. We need to be prudent and make pretty darn good "guess-timates" to set priorities for management of the really important "nasties" if present in indoor air environments, to avoid treating all the “goodies” to the same extent as all the “nasties”, and squandering our limited resources. Control of air contaminants in spaces is akin to air traffic control albeit at microscopic levels!

“Average” (impure) air is hypothetical. Air is a complex system with its constituents in dynamic equilibrium, all varying by many orders of magnitude in time, space, and composition. It is "constantly changing" over very short times (literally with each breath), and over very long (geologic) times. Weather (which is really changing air conditions) can change in our backyards or across the globe. Relative concentrations of air constituents can range from almost 80 % by volume to as little as a few atoms or molecules (depending upon the method of detection). These constituents must be placed in proper perspective regarding their significance to our well-being.

"Pure" air would be all (100 %) oxygen and bone-dry (0 % water) (Daniels and Fox, 2000). It would be devoid of major (N_2) and minor (Ar, Ne, He, Kr, Rn) inert ingredients. Major carbonaceous constituents (CO_2 and CH_4) from anthropogenic and biogenic origins would be gone. There would be no oxides of other common elements (SO_x and NO_x). Nor would it contain any “dust”, solid particulate matter (PM_X); or “fumes”, organic compounds (VOCs), in any form. It would be utterly tasteless and odor-free (no pleasant or obnoxious smells; no corrosive [acid] or caustic [alkaline] constituents). There would be no dust or haze, no clouds, no precipitation (fog, rain, snow), no rainbows, and no gorgeous sunsets. Besides being rather boring, “pure” air would be toxic to all living things!

3.0 VENTILATION VS. TREATMENT OF AIR IN SPACES.

The objectives for environmental management of spaces and indoor air systems at airports is multiple: minimizing contaminant sources, providing good air handling, and improving Indoor Air Quality (IAQ). Treating air contaminants depends upon the nature of the contaminants, their relative concentrations, the technical approaches used, and the results to be achieved. There is a balance among most everyday air handling, but extremes to handle the unusual event or the unthinkable contaminant must also be considered.

Which then, is of greater concern - a brand-spanking "new" building or vehicle, or a well-aged, comfortable-as-an-old-shoe, really no-too-shabby "old" one? Perception vs. Reality might favor vs. disfavor the "new" vs. "old". The "new" space might not be fully “degassed” of VOCs (or “departiculated” of PM_x) after manufacture or construction, painting, carpeting, furnishing, and cleaning. The "old" space may have accumulated a certain patina of age, including the debris of years of occupancy: dust and dirt, smoke, dead "bugs", moisture, molds and other microbes, rust and rot, and other organic/inorganic residues all contributing their part to the "impurity" of the air. Both "old" and "new" spaces are candidates for ventilation and air cleaning.

Non-engineered controls of general sources and exposures are mostly passive and prescriptive. Engineered controls of specific contaminant classes, such as VOCs and PM_x, are more active and descriptive. The former is more “hands-off” management; the latter is more “hands-on” management. Engineered controls are directed at design and operational aspects of ventilation and air cleaning. Ventilation is the historic approach for control of airborne contaminants. It is essentially a dilution of contaminated “dirty” air with fresh “clean” air, and/or separation and venting of “dirty” air. Air cleaning, by contrast, is treatment through removal and/or conversion of individual air contaminants.

Air cleaning devices have been perceived historically as being simple commodities for controlling nonspecific “odors” and “dusts”. General-purpose functionalities of these devices have included: protection of HVAC equipment components, protection of furnishings and décor, reduction of building and vehicular maintenance, reduction of fire hazards (flammables), improvement of general well-being of workers, and improvement of the quality of sensitive products. These are generally applied based upon generic contaminant characteristics, such as particle size, flammability, toxicity, etc. More recently, attention has been focused more on specific functionalities that are more responsive to characteristics of specific chemical, physical, or biological classes of contaminants or to specific contaminants themselves. Interactions of VOCs and PM_x, and their speciation in indoor environments have been reviewed from a risk assessment standpoint (Daniels, 2000).

4.0 TECHNOLOGIES FOR CONTROL OF AIR IN SPACES.

Technologies available for control of contaminants by cleaning the air in spaces are cataloged by their functionality and specificity for removal and/or destruction (EPA, 1990; ALA, 1997; Priest et al., 1995, Daniels, 2001a). They include: (i) physical, (ii) physicochemical, and (iii) electronic processes, and various combinations of all three (Table I). With regard to the contaminants, these technologies fall into five overlapping classifications: (1) filtration of PM_x, (2) electrostatic precipitation of PM_x, (3) reaction of negative ions with PM_x and VOCs, (4) sorption of VOCs onto solid sorbents, and (5) oxidation of VOCs. Each classification will be described in the present context of specific applicability to VOCs and/or PM_x.

Filtration of PM_x (1) is probably the most common technology. It involves a physical or mechanical collection of particles on porous or fibrous media. The mechanisms of removal are impaction, settling, and diffusion. In some less common, but more specific applications, especially for finer particles, filtration may be aiding by electrostatic precipitation of PM_x (2). This technology involves collection of the PM_x on electrically charged plates, or less commonly on charged fibrous media.

Another common technology is sorption of VOCs onto solid sorbents (4) (sometimes referred to as “gas-phase filtration”.). Activated carbon is the most common adsorbent. The process involves sorption of VOCs onto surfaces, and into pores of solid media, with or without chemical reactions. It can remove a variety of VOCs, as gases and vapors, but is not efficient for low molecular weight constituents. Catalytic oxidation includes solid media with imbedded catalysts or photocatalytically active materials. Special sorbents also have been used for the oxidation of VOCs (5). These include chemisorbents, which are impregnated with chemically active ingredients, such as an oxidant (potassium permanganate), or a solid catalyst (copper, iron, or other metallic oxide), or a photo-catalytic material activates by light or UV.

Electronic air cleaners are cataloged by types of ionization and modes of operation. They include: bipolar air ionization, ozone generation, and electrostatic precipitation (Table 1) (Daniels, 2001b, Daniels 2001c). Bipolar air ionization devices are the simplest form of electronic air cleaner. These devices produce local clusters of bipolar (negative and positive) ions. Cluster ions electrically charge PM_x thereby facilitating their removal by filtration. Cluster ions also chemically react and destroy VOCs. This process, although similar to many familiar oxidation processes, is more subtle and complex. It can be effected at ambient temperature without the need for solid catalysts. Air ionization forms "nonthermal" plasmas, i.e. the electron and ion clusters may be highly but uniformly energized. The bulk of the surrounding gases remains at ambient temperature. Thermally speaking, the mixture is in nonequilibrium. Air ionizers are quite distinct from both electrostatic precipitators and ozone generators (Table 1). In air ionization, PM_x becomes electrically charged through direct contact with the air ions, vis-à-vis attraction to electrically charged surfaces in the case of electrostatic precipitation. In air ionization, the primary active species are clusters of negative and/or positive air ions, vis-à-vis nascent ozone in the case of ozone generation.

Air ionizers are distinct from electrostatic precipitators in that PM_x becomes electrically charged through direct contact with air ions vis-à-vis attraction to electrically charged surfaces. Air ionizers also are distinct from ozone generators in that the active species are clusters of negative and/or positive air ions and not nascent ozone which is restricted in indoor environments. Air ionizers are unlike devices that intentionally introduce air fresheners or odor maskers. Air ionization is used with other technologies, such as filtration and adsorption.

The benefits of air cleaning by air ionization are multiple. They include low energy costs and minimal bulk deposition of PM_x on room surfaces, and less hazardous byproducts. Air ionization has several direct and indirect advantages: destruction, transformation, and removal of potentially hazardous VOCs and PM_x, extended and improved performance of conventional technologies (filtration and adsorption), and possible associated health benefits. The technology of air ionization, although well advanced, is just now entering the field of treatment of specific VOCs and PM_x. It has been applied in diverse fields ranging from control of electrostatic discharges in sensitive manufacturing operations, to destruction of hazardous air contaminants. Related technologies include oxidation in pulsed-corona reactors (Nunez et al., 1993).

As in all technologies of air cleaning, it is important to establish well-engineered installation of systems, to obtain certifications of proper operation, and to validate performance. The ability to make up- and down-stream measurements of HVAC processes accurate at trace-levels to evaluate and optimize performance should not be underestimated (Daniels et al., 1998). Effectiveness has been established in a number of applications. Further validation is underway in additional areas of application. Standards are available for related technologies of air cleaning, including: ab/adsorption, destruction, and filtration. There are occupational levels (PELs, TLVs, RELs) for VOCs, limited IAQ levels for VOCs, workplace levels for dusts, and clean room levels for PM_x, and clean air delivery rates for specific contaminant classes.

5.0 MITIGATION OF SPECIFIC CONTAMINANTS.

Demands for more complete treatment of indoor air environments has led to the development of practical engineered systems based upon bipolar air ionization. Air ionization units are tailored to particular facilities depending upon sources and strengths of VOCs and PM_x. Air ionization modules are fitted directly into central air handling units to treat entire airflows. Modules also can be fitted into existing ductwork downstream of central HVAC systems. Freestanding devices can also be located in individual room spaces to meet immediate demands.

Field applications of permanent in-duct systems require optimization of up to eight process variables of the physical air handling system and the air quality demand. The central process control unit is programmed for fixed situation design parameters (ion level, power capacity, and airflow area), and for monitored demand parameters (airflow, humidity, outside and return air quality, and ozone). Installations of bipolar air ionization systems have included: airport hospitality suites, ticketing and billing facilities, and several FAA control towers. The following case histories are illustrative:

5.1. Airport Hospitality Suites.

Air passengers travelling through at airports share common concerns for IAQ. One application determined the feasibility of bipolar air ionization to reduce odor and smoke in smoking lounges within the hospitality suites of a major carrier at two large mid-western airport (DTW and MSP). The major IAQ complaints at both locations was tobacco smoke. The goal was to improve IAQ for transient passengers and ground staff. Independent appliance systems (Model 7-D-2, ionair® system, Midland, MI) were installed in both lounges. Although repeatedly challenged by the intermittent entry of new smokers, overall air quality was improved to the point that non-smoking staff could tolerate the environment. Fuel and exhaust odors from planes and support vehicles which often enter these facilities in the outside air were also reduced.

5.2. Airport Billing Facilities.

A number of support facilities are associated with any major airport. The VISA Center at Glattbrugg/Zurich provides billing services to customers. The indoor air quality was adversely affected by aircraft exhaust from the nearby Zurich International Airport and odors from a wastewater treatment plant in close proximity. Reductions in total VOCs (including benzene, toluene, and iso-octane) of over 50% were achieved. The entire four-story building is now equipped with in-duct ionization units and controls (ionair®, LK Luftqualitat AG).

5.3. Airport Control Towers.

Indoor air quality complaints received from air traffic controllers (ATCs) prompted consideration for improving IAQ. Several applications of bipolar air ionization have been made at FAA facilities having no previous IAQ controls. Independent appliance systems were installed in the control towers at the airports serving Midland, MI and Pontiac, MI. IAQ from aircraft taxi and take-off operations was determined to be poor according to the controllers' personal built-in VOC meters - their noses!

In the TRACON room of the MBS FAA ATC Tower the air before treatment was very stale, dry, and full of dust. After one week of ionization the air was noticeably improved according to occupants who had prior histories of allergies and rhinitus. A completely ducted system is now being considered to remove VOCs from the air prior to entering the cab since ionization would be distributed more evenly. Control would be further improved by enhanced on-line monitoring and internet capability. Bipolar air ionization system also are under consideration at other airports to replace existing gas-phase adsorption systems.

5.4. Airport Life-Cycle Cost Analysis.

Once IAQ problems have been identified, design and cost comparisons are made. Life-cycle cost analysis (LCA) involves assessment of equipment costs of the basic air handling units (AHUs) and remedial components, and annual system operating costs. The HVAC system for the airport control tower and administrative base building at Port Columbus (Ohio) International Airport (CMH) requires new construction. The basic design includes three AHUs designed to control VOCs and improve IAQ. Two systems for VOC removal are compared in Table 2: (1) gas-phase adsorption with activated carbon in cartridge filters, and (2) bipolar air ionization with in-duct units.

There are additional factors to consider. According to the manufacturer of the AHU: “Controlling VOC concentrations is particularly challenging: hundreds of them are present, few are unique to any one source, and there are many potential sources, some of which emit several VOCs. Gas-phase filters must be designed (‘tuned’) for the specific contaminants to be removed.” Bipolar air ionization systems are more universally applicable and do not require being “tuned” for specific VOCs. Ionization will reduce concentrations of many VOCs associated with poor indoor air quality, as well as those commonly encountered in outdoor air.

High humidity in the outside air passing through the gas-phase filters mounted upstream of the cooling coils of the AHUs will reduce their efficiency for removing VOCs. The ionization system is mounted downstream from the AHU and will monitor and adjust to changes in humidity. Reducing the AHUs operating static pressure will reduce equipment fatigue and failures, and system sound power levels. Cost savings are realized by using less energy to operate the fans. The LCA shows that an ionization system will initially be a greater first-cost investment than gas-phase filtration, but will reduce VOCs, conserve energy, and minimize maintenance expenses over time. It will also not create hazardous byproducts and a need for disposal or regeneration of spent carbon sorbent.

6.0 ADDITIONAL CONSIDERATIONS.

Engineered solutions require knowledge of the specific contaminants to be controlled, an ability to determine their distributions of contaminants in time and space, and an understanding of the degree of control achievable by a particular technology. Combinations of new technologies using multipoint monitoring systems coupled with low-level, real-time detectors now allow for greatly improved quantitation of control strategies and technologies. Several perspectives regarding the mitigation of VOCs and PM_x are worthy of consideration.

While it is impractical to fit diapers on every pigeon in the park, it appears prudent at first glance to consider placing controls on specific fractions of PM_x. The crux of the problem lies in the determination of just which fraction to control without imposing excessively stringent limits on all PM_x from all sources. Obviously, there are many shades of gray that color the scenario. There are those who advocate control of PM_x down to zero levels. It might be possible to sort really big from small PM_x, but almost impossible to separate a “bad” from a “good” PM_x, especially if they are essentially the same size. It would also be impractical, impecunious, and impossible to remove all PM_x to levels of computer chip clean rooms.

Both coarse and fine PM_x in airborne suspensions (aerosols) are of health concern, since they may penetrate into the deepest and most sensitive regions of the respiratory tract, where they may become deposited and aggravate many respiratory illnesses, inc. asthma, bronchitis, and emphysema. The mitigation of PM_x is most dependent upon particle size. Coarse PM_x ($PM_{2.5}$ to PM_{10}) are easily removed by gravitational sedimentation. Their atmospheric lifetimes range from minutes to hours. Fine PM_x ($\leq PM_{2.5}$) are more difficult to remove. They require a concerted effort of filtration through various types of fibrous or porous media, possibly augmented by aqueous scrubbers or electrostatic precipitators (Daniels & Fox, 1999; Offerman et al., 1985). The atmospheric lifetimes of PM_x can extend from days to weeks. Standard tests have been applied to determine the efficacy of commercially available filters and devices in which standardized aerosols are used to challenge the units (ASHRAE, 1999).

Concerns for Volatile Organic Compounds (VOCs) focus on both environment and public health. The regulation of risks potentially posed by VOCs is as diverse as the interpretations of just what comprises VOCs. The distinctions usually made are twofold: (i) most VOCs are considered to be emitted from regulatable point sources (stacks or vents, specific industrial manufacturing operations, fuel or waste combustion, wastewater treatment, etc.), and (ii) any emissions become part of the outdoor (ambient) air environment. Historically, risks from VOCs have been associated with identifiable sources of rather broadly defined air pollutant classes. The risk of a toxic effect exerted by a specific VOC is a function of exposure, i.e. a function of availability, as dictated by volatility, mediated by sorption to, and reaction with PM_x.

There is no consensus on just how to manage VOCs in indoor environments, although the U.S. EPA, OSHA, and others have considered the issue. The American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE, 2001), which historically has directed attention to air flow, temperature, and humidity. reaffirmed that ASHRAE standards should and do consider health impacts when setting the criteria for acceptable indoor air environment. Some standards have been set for VOCs emitted from building materials by other societies. There have been many studies attempting to link cause and effect for VOCs. Most of the attention to date on mitigation of VOCs has been directed toward elimination, reduction, and control of specific groupings of VOCs from identifiable large point sources from industrial processes. (Rathmanian, 1988; U.S. EPA, 1995; Peral et al., 1997). As the universe of identifiable sources is expanded, the magnitudes of their contributions become ever smaller and more diffuse.

Microbes are consistently reported as the single most significant indoor pollutant affecting productivity and health of building residents and workers (Daniels et al., 1999). Unfortunately, environments comfortable for people are also well suited for microbes, which interact with sources, amplification sites, and transport media within buildings to cause deterioration and staining of walls, ceilings, and floors; and coverings, furnishings and fixtures through attachment to surfaces. Adverse effects include: offensive odors, physical discomforts, general malaise, irritations, allergenic responses, toxic reactions, hypersensitivities, respiratory problems, and specific diseases. Microbes and associated MVOCs may adversely affect indoor air quality (IAQ) and reduce work efficiency or endanger human health.

Microorganisms can be present in indoor environments both as particulates (cells, spores) and as microbial VOCs (MVOCs). Mitigation, therefore, may require combinations of processes to effect removal and destruction. Microbes prefer to attach to almost any surface. Attempts are made to create and maintain “sanitary”, microbially-clean surfaces, e.g. painted and tiled surfaces, and smooth ducts and piping. No surface is ever completely free of microbes, although special laboratories and biologically “clean” rooms for handling potent disease agents approach “zero” limits. Sterilization can be physical (heating, freezing) or chemical (disinfectants, germicides, antimicrobials.

Processes applicable for controlling VOCs (and MVOCs) include: odor masking, combustion, ventilation, and gas-phase filtration (Daniels & Fox, 1999; Ramanathan et al. 1988). Sorption of VOCs to a solid, such as activated carbon, requires regeneration or replacement. Chemisorption of VOCs to a reactive solid phase, such as activated alumina impregnated with potassium permanganate, allows for reaction and destruction. Gas-phase contaminants adsorb onto the surface and absorb into the interior of the solid phase. These processes have been available for many years, but applications for mitigation of specific VOCs have been limited. Concerns have included: limited applicability, retentivity of contaminants, byproduct formation, and cost-effectiveness under typical, adverse (e.g. high humidity), and dynamic (cycling of high and low contaminant concentrations) conditions.

VOCs, MVOCs, and some permanent gases can be chemisorbed to various extents to permanganate-impregnated activated alumina. Some VOCs also adsorb to activated carbon. The former is a reducing environment; the latter is an oxidizing environment. The combined sorption/oxidation process is broadly applicable. Separation by adsorption, however, does not assure destruction by oxidation. Some gases and VOCs may be only partially sorbed and/or oxidized. Products of partial or incomplete oxidation may be of concern. Vapor-phase adsorption of VOCs can be expected to cover several orders of magnitude in concentration.

7.0 SUMMARY.

Increased attention is being directed at the management of indoor air quality in airport facilities, such as administration; ticketing and baggage handling; lounges and waiting areas; hotels, restaurants, and shops; air traffic control; surface transportation; and aircraft maintenance. These facilities are subjected to environmental challenges from a variety of volatile, particulate, and microbial contaminants. A catalogue of engineered solutions to IAQ problems associated with indoor spaces at airport facilities is briefly outlined in for five overlapping classifications: (1) filtration of PM_x, (2) electrostatic precipitation of PM_x, (3) reaction of negative ions with PM_x and VOCs, (4) sorption of VOCs onto solid sorbents, and (5) oxidation of VOCs. Electronic air cleaners, cataloged by types of ionization and modes of operation, include: bipolar air ionization, ozone generation, and electrostatic precipitation. The general applicabilities of bipolar air ionization to airport facilities are illustrated by selected case histories.

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Table 1. COMPARISON OF AIR CLEANING SYSTEMS.

System	Bipolar Air Ionization	Ozone Generation	Electrostatic Precipitation	Gas-Phase Filtration	Solid Media Filtration
Function	Electronic	Electronic	Electronic	Physicochemical	Physical
Principle	Dielectric Barrier Discharge (DBD).	Sparking Discharge.	High-voltage wire and plate	Sorption and reaction.	Flat, pleated, or HEPA media.
Process	(+) & (-) Ion generation.	Ozone generation.	Charging of particulate matter.	Sorption and reaction.	Collection on porous media.
Active Species	Bipolar ions and radicals ($O_2\bullet^-$)	Ozone (O_3).	Charged particles	Sorption and reaction sites.	High surface area.
Products	CO_2, H_2O; larger PM_x.	CO_2, H_2O, O_3.	Larger PM_x.	Less VOCs.	Less PM_x.
Byproducts	Minimal byproducts, O_3 if not controlled. **	Significant O_3, atm. reactants.	O_3, if not cleaned regularly.	Spent media with contaminants.	Spent filters & contaminants.
Health Concerns	O_3, limited by control. **	High ozone exposure.	Exposure to high voltages and O_3.	Saturation, capacity, disposal.	Contaminated filters, disposal.
VOCs	Chemical oxidation.	Chemical oxidation	Sorption of VOCs on PM_x	Ad/absorption	NA
PM_x	Agglomeration.	NA	Collection on plates.	Collection in media.	Impact, settling & diffusion.
Odors	Oxidation	Oxidation.	NA	Ad/absorption	NA
Microbes	Inactivation.	Inactivation.	Particle removal.	NA	Particle remova
Control	Ions on demand.	Continuous generation.	Process design.	Process design.	Process design.
Costs	Low	Low	Moderate	High	High
Energy Need	Low	Moderate	High	NA	NA
Energy Loss	Low	Low	Low	High	High
Maintenance	Tubes.*	Elements	Plates	Media	Filters

`*  Does not apply to needlepoint bipolar ionization systems`

`** If the manufacturer used has UL 2998, it is an ozone free technology`

Table 2. **LIFE- CYCLE COST ANALYSIS (*).**

System Components/Costs, $	**(1)** **Carbon Filtration** (1)	**(2)** **Air Ionization** (2)	**Needlepoint** **Air Ionization**
1. Admininstrative Base Building Conventional AHU (AHU-1B) Variable air volume = 23,450 cfm			
Initial Equipment Costs	$ 30,246	$ 21,234	$ 9,900
Annual System Operating Costs*	42,553	6,850	98
Total Costs (10-year)	545,890	34,934	980
Cost Savings		510,956	556,244
Break-Even Time		~ immediate	~ immediate

*Includes fan KW and power for electronics