DESIGN CONSIDERATIONS FOR VENTILATING A LARGE AIRCRAFT PAINT FACILITY USING RECIRCULATION

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ABSTRACT

This paper describes the design development of the ventilating and air-handling systems in a corrosion control facility for large aircraft, including the new C-17 cargo plane. It is based on the findings of a study conducted for the U.S. Air Force to determine the most cost-effective method for performing corrosion control processes on large aircraft. The research team was a multi-disciplinary group with expertise in architecture, spray painting, industrial hygiene, fire protection, and industrial ventilation.

INTRODUCTION

This paper is based on the findings and recommendations of a study conducted for the U.S. Air Force (1987) to determine the most cost-effective method for performing corrosion control processes on large aircraft, up to the size of the new C-17 cargo plane. The research team was a multi-disciplinary group with expertise in architecture, spray painting, industrial hygiene, fire protection, and ventilation.

The study included design development of optimal ventilating and air-handling systems that met USAF requirements. It was based on information obtained from several sources, including a USAF Project Book prepared in the concept design for a corrosion control facility at Robins Air Force Base, Georgia; data obtained in telephone interviews with operators of several corrosion control facilities for large commercial and military aircraft; data obtained in visits to several existing corrosion control facilities for large commercial and military aircraft; review of design documents for a new large aircraft painting facility for an airframe manufacturer; review of codes, guides, and standards for industrial hygiene and industrial ventilation; and group discussions of findings of the research study team from the above sources.

The research focused on the concept of performing all of the corrosion control processes in one building, including depainting or stripping old finishes. New findings as to the toxicity of certain materials found in stripping compounds, principally methylene chloride, have made it necessary to remove the depainting functions to a separate area.

Steps in the Corrosion Control Process

The corrosion control process for large aircraft is composed of multiple steps, and each requires a different mode of operation for the ventilating and air-handling systems in the corrosion control facility. The four modes of operation on which the study was based are preparation, stripping, painting, and curing. The ventilation rate for dilution of contaminants and the air-handling rate for removal of contamination from the point of application are different for each of the four operating modes. Several of the modes have sub-modes that are selected by the automatic control system. A standby mode is required to maintain the facility at a minimum temperature to prevent freezing during periods when the facility is not in operation. A manually controlled ventilating mode is required to allow the paint hangar bay to be purged of contaminants in case of a fuel spill or a spill of materials used in the corrosion control process or to clear the air between normal operating modes. A brief description of each step of the process follows:

Preparation In this step the aircraft is positioned in the hangar bay of the corrosion control facility for operations to prepare it for processing. The operations may include removing control surfaces for separate stripping, sealing openings, masking glass areas, and masking other areas that are not to be stripped and are not expected to produce measurable contamination. This step may require work on only one shift for an aircraft the size of the C-141.

Stripping In this step the aircraft is stripped of all paint by use of chemical stripping compounds. The operation requires multiple applications of a viscous liquid stripper to the surfaces; a reaction time for each application of stripper to soften the paint; removal of the stripper and softened paint by squeegee; and spot applications of stripper to areas that were not completely stripped, followed by a heated water washdown and cleaning of all surfaces. This step is highly productive of gaseous contaminants that must be diluted by the ventilating system to maintain the ambient air level below the maximum acceptable contamination level. This step may require work on twelve shifts for an aircraft the size of the C-141.

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Painting In this step the aircraft is brought to the facility after periodic maintenance work is completed elsewhere and is positioned in the hangar bay. The aircraft surfaces are washed with an alkaline detergent and coated with an etching compound, then painted with a prime coat and several top coats, with the number of applications depending on the requirements for final finish. This step is highly productive of particulate contaminants that must be removed from the point of application and of gaseous contaminants that must be diluted by the ventilating system to maintain the ambient air level below the maximum acceptable contamination level. The maximum application rate is about 85 gallons in an eight-hour shift with about 600 gallons total required for a C-141. This step may require work on 10 shifts for a C-141 sized aircraft.

Curing In this step the aircraft with newly painted surfaces is allowed to air dry for a period of time that varies with the ambient air temperature and humidity. During hot and moist summer weather, ventilation with outdoor air is adequate to produce drying in a reasonable time. During other outdoor weather conditions, curing may be accelerated by supplying heated and humidified air to the facility. During the initial cure to "tack free," no work is done on the newly painted surfaces. After the surfaces are "tack free," the last jobs of applying decals, painting operating limit placards, and painting insignia and identification marks are done during the final curing stage. This step is moderately productive of gaseous contaminants in the early stages, and they must be diluted by the ventilating system to maintain the ambient air level below the maximum acceptable contamination level. This step may require work on four shifts for an aircraft the size of the C-141.

A complete cycle for one large aircraft may take an average of 27 shifts. Table 1 lists the operating time of the ventilating and air-handling system on each operating mode in a facility working three shifts a day, seven days a week, with twelve days a year in standby mode for holidays.

TABLE 1
Annual Operating Time in Each Ventilating Mode

Mode	Preparation	Stripping	Painting	Curing	Standby	Total
Shifts	39.2	470.7	392.2	756.9	36.0	1095
Time, hrs	314	3766	3138	1255	288	8760
Time, %	3.6%	43.0%	35.8%	14.3%	3.3%	100%

Air-Handling System Design Criteria

The required air-handling capacity of the ventilating and air-handling system is determined by these criteria:

1. Air movement during paint application

a) Overspray removal from point of application to provide required visibility and to minimize exposure of the paint crews.

b) Air velocity high enough to move overspray particles from point of application to paint arrestors. Velocity threshold at which overspray is not carried to arrestors appears to be about 100 fpm. If velocity is below the threshold, particles will drop out of the airstream before the air reaches the paint arrestors. Optimum velocity appears to be about 125 fpm.

2. Ventilation for contamination control

a) Control of volatile organic contaminant (VOC) concentrations in atmospheric discharges.

b) Control of VOC concentrations in recirculated air to work areas.

c) Dilution of VOC and other contaminant concentrations in work areas.

d) Removal of particulate contaminants in recirculated air to work areas.

3. Ventilation for explosion control required by code.

a) NFPA Standard 33 (NFPA 1985) includes provisions for spray booths and spray rooms, with 100 fpm velocity required in spray booths but no velocity requirement for spray rooms.

b) ANSI Standard 100 specifically excludes entire aircraft from spray booth requirements (Article 5-1.3).

c) ANSI Standard 100 requirements for spray rooms include a requirement for dilution ventilation to 25% of lower explosive limit (LEL) value for VOCs.

4. Air handling for building pressure control

a) Maintain positive pressure in hangar bay to prevent infiltration of atmospheric contaminants, including dust and pollen.

b) Maintain pressure differential between hangar bay and attic to prevent accumulation of dirt in cracks and crevices in ceiling.

Air Distribution System Configurations for Paint Hangar Bays

The following four basic configurations of air flow were considered in this study for use in large aircraft hangar bays:

1. Horizontal or laminar flow: Horizontal flow systems employ full face wall air supply with return either in full face wall or in floor trenches. When full face wall return is used, the flow is termed "laminar."

2. Vertical laminar flow: Vertical laminar flow systems employ full ceiling air supply and full floor return.

3. Downdraft flow: Downdraft flow systems employ ceiling air supply with return through floor trenches or low wall returns or a combination of the two methods. The primary air supply may be concentrated in slots over the planform of the aircraft, with a secondary "entrained air" supply through the remaining ceiling area to prevent overspray reaching the ceiling, where it would be entrained with the primary air supply and delivered to newly processed surfaces.

4. Mixed flow or hybrid systems: Mixed flow, or hybrid, systems employ a downdraft flow system over fuselage, wing, and tail, with an additional horizontal air supply introduced along the leading edges of wings. Return air may be taken through either floor trenches or low wall returns or a combination of the two methods. Entrained air supply from areas of the ceiling not over the aircraft planform may be employed in conjunction with the primary air supply.

Comparison of Air Distribution System Configurations

There is a diversity of opinion among the operators of large aircraft corrosion control facilities about the most effective configuration of air distribution systems. Each of the four system configurations has distinct advantages and disadvantages, which are presented below:

1. Horizontal or laminar flow type system

Advantages:

a) Horizontal airflow over aircraft from nose to tail most closely follows airflow around the aircraft when in flight and makes use of the aerodynamics of the surfaces to move air along the point of paint application.

b) A horizontal flow system requires a total air volume that is less than any other system to provide a given air velocity through the hangar bay.

c) A horizontal flow system is best suited to low-velocity return through dry-type paint arrestors in a full face wall configuration.

Disadvantages:

a) Horizontal airflow causes problems when one paint crew must work downstream from another paint crew.

b) Horizontal airflow causes problems due to the aerodynamics of airflow over surfaces such as wing flaps. During the painting operation, the aircraft's flaps and high-lift devices are extended, which causes overspray to be diverted to the floor and separated from the airflow by the inertia of the particles. Those particles form a buildup on the floor with a resulting fire hazard unless provision is made for a constant removal of overspray particles from the floor.

c) Horizontal airflow requires more complex layout in order to achieve the desired nose-to-tail airflow pattern. It is necessary to provide either air supply or return through a movable plenum made up of two sets of hangar doors or to provide a complex system of tracks and trolleys or turntables in order to position the aircraft for airflow between supply outlets and return inlets on two fixed walls.

2. Vertical laminar flow system

Advantages:

a) The vertical airflow pattern allows paint crews to work side by side without exposure of the second crew when the first crew is painting.

b) The vertical airflow pattern carries overspray downward, where it is captured by high-velocity airstreams through floor grates over trenches that connect through underfloor tunnel or duct systems into an air filtration system. This minimizes the buildup of overspray particles on the floor and the resulting fire hazard.

Disadvantages:

a) A vertical laminar flow system requires the largest total air volume of any system in order to provide 100 fpm air velocity over the hangar bay.

b) Airflow in a vertical laminar flow system does not follow the patterns of the aircraft when in flight and causes turbulent airflow under the planform of the aircraft.

c) Vertical laminar airflow causes exposure problems when one paint crew must work below another paint crew.

d) Vertical laminar airflow is not suited to low-velocity return through dry-type paint arrestors in a full face wall configuration.

e) Vertical laminar flow requires full face floor return with an underfloor tunnel system to conduct airflow to an air filtration system.

f) In a vertical laminar flow system, floor returns installed in facilities used for both stripping and painting must carry waste from water washdown during the stripping cycle, requiring greater maintenance than for wall return systems.

g) Vertical laminar airflow does not allow the desired nose-to-tail airflow pattern.

h) In a vertical laminar flow system, floor trenches and tunnels in facilities used for processing aircraft that have not been defueled present an additional fire protection problem with greater maintenance requirements and increased exposure to fire hazards.

3. Downdraft flow system

Advantages:

a) Downdraft flow system airflow allows paint crews to work side by side without exposure of the second crew when the first crew is painting.

b) Total air volume in a downdraft flow system is less than for a laminar flow system or hybrid system in order to provide a 100 fpm air velocity over the areas of paint application, provided the overall hangar bay is not required to have a 100 fpm minimum velocity.

c) Downdraft flow system airflow carries overspray downward, where it is captured by high-velocity airstreams into floor grates on trenches connecting underfloor to an air filtration system. This minimizes the fire hazard from buildup of overspray particles on the floor.

Disadvantages:

a) A downdraft flow system does not allow airflow to follow the airflow patterns of the aircraft when it is in flight and causes turbulent airflow under the planform of the aircraft.

b) Downdraft airflow causes exposure problems when one paint crew must work below another paint crew.

c) Downdraft airflow is not suited to low-velocity return through dry-type paint arrestors in a full face wall configuration.

d) A downdraft flow system requires an underfloor tunnel system to conduct airflow to an air filtration system.

e) In a downdraft flow system in facilities used for both stripping and painting, floor trenches must carry waste from water washdown during the stripping cycle, requiring greater maintenance than for wall return systems.

f) Downdraft airflow does not allow the desired nose-to-tail airflow pattern.

g) In a downdraft flow system, the primary air supply through high-velocity air outlets along the aircraft planform causes a secondary flow of room air containing overspray particles toward the ceiling. Unless an "entrained air" system is used, when the air velocity is reduced at the ceiling, the heavier overspray particles separate out of the airflow by gravity and fall on the newly prepared or painted surfaces below. The remaining overspray particles are induced into the supply airstream and delivered to the point of paint application.

4 Mixed flow, or hybrid, system

Advantages:

a) A hybrid system's vertical airflow pattern on the fuselage and vertical tail allows several paint crews to work side by side without exposure of downstream crews when any crew is painting.

b) A hybrid system's horizontal airflow pattern along the wings allows several paint crews to work side by side without exposure of crews downstream.

c) The vertical airflow component carries overspray downward, where it is captured by high-velocity airstreams through floor grates into trenches connecting underfloor to an air filtration system. The horizontal airflow component may be carried to low wall returns. This tends to minimize the fire hazard from buildup of overspray particles on the floor.

Disadvantages:

a) Hybrid system airflow does not follow the airflow patterns of the aircraft when it is in flight.

b) A hybrid system requires air volume greater than horizontal flow or downdraft flow systems to provide a 100 fpm air velocity over the areas of paint application in both horizontal and vertical planes.

c) Hybrid system airflow is not suited to low velocity return through dry-type paint arrestors in a full face wall configuration.

d) A hybrid system requires an underfloor tunnel system to conduct airflow to the air filtration system.

e) Hybrid system floor trenches in facilities used for both stripping and painting must carry waste from water washdown during the stripping cycle, requiring greater maintenance than for wall return systems.

f) The hybrid system airflow pattern does not allow the desired nose-to-tail airflow pattern.

g) The vertical airflow component, through high-velocity air outlets used for supply along the aircraft planform, causes a secondary flow of room air containing overspray particles toward the ceiling. Unless an entrained air supply is used, as the air velocity reduces at the ceiling, the heavier overspray particles separate out of the airflow by gravity and fall on the newly prepared or painted surfaces below. Other overspray particles are induced into the supply airstream and delivered to the point of paint application.

h) Hybrid systems with floor trenches in facilities used for processing aircraft that have not been defueled present an additional fire protection problem with greater maintenance requirements and increased exposure to fire hazards.

Design Analysis for Airflow System Types

Air Volume Design Criteria Two basic air volumes must be determined for a ventilating and air-handling system operating in each of the four operational modes. The overall air-handling volume is that required for the specific needs of each mode. The total air-handling volume for the paint application mode is based on a 100 fpm velocity found to be the minimum required for removal of contaminants from the work position and to carry overspray to the filter system. The dilution ventilation air volume was determined by the industrial hygienist on the team as the volume required for dilution of flammable vapors to 25% of the threshold limit value (TLV) as given in *Industrial Ventilation* (ACGIH 1976). Analysis by methods established in *Industrial Ventilation*, Section 2, "Dilution Ventilation," determined the required ventilation rate during the normal processes of the painting and curing modes to be 100,000 cubic feet per minute (cfm). This is applicable to compounds not listed by OSHA as carcinogens or suspected carcinogens, which may not be recirculated. Other modes that do not produce flammable vapors or VOCs require only the ventilation air needed for CO_2 dilution, oxygen supply, and odor dilution, about 25 cfm per worker.

Air Volume Requirements The architectural design established hangar bay dimensions at 195 ft width, 180 ft length, 62 ft height, with a flat ceiling, giving 35,100 ft^2 of floor area and a volume of 2,106,000 ft^3. The hangar door opening is 195 ft wide by 62 ft high, giving an area of 12,090 ft^2.

The total air supply quantities for each system type, based on a velocity of 100 fpm over the paint application surface, are:

1. Horizontal laminar airflow, based on airflow across the width and height of the hangar bay, is 12,090 ft^2 of cross-sectional area times 100 fpm or 1,209,000, say, 1,200,000 ft^3/min.

2. Vertical laminar airflow, based on airflow across the width and length of the room, is 35,100 ft^2 of floor area at 100 ft/min or 3,510,000, say, 3,500,000 ft^3/min.

3. Vertical downdraft airflow, based on airflow down along the planform of the aircraft, is 15,000 ft^2 of planform at 100 ft/min plus entrainment airflow over 20,100 ft^2 of ceiling at 25 ft/min for a total airflow of 2,002,500, say, 2,000,000 ft^3/min.

4. Hybrid airflow, based on airflow down along the planform of the aircraft and horizontally across the profile of the wings, is 15,000 ft^2 of planform and 5850 ft^2 of wing profile at 100 ft/min plus entrained air over 20,100 ft^2 of ceiling at 25 ft/min for a total airflow of 2,587,500, say, 2,600,000 ft^3/min.

The ventilation air supply quantities are the same for all system types but will vary between operating modes. The outdoor air quantities required for ventilation in each mode are:

1. Preparation mode—The ventilation supply, based on 25 ft^3/min per human occupant and 100 occupants, is 2500 ft^3/min. The air leakage rate through closed dampers will produce a ventilation airflow of about 4% of the total air handled, or about 3000 cfm for 75,000 cfm total air.

2. Stripping mode—The ventilation air supply, based on dilution of contaminants released by the maximum amount of stripping compounds used in the process, is 300,000 ft^3/min. As mentioned above, this is applicable only to compounds not listed by OSHA as carcinogens or suspected carcinogens.

3. Painting mode—The ventilation air supply, based on dilution of contaminants released from the maximum amount of paint used in the process, is 100,000 ft^3/min.

4. Curing mode—The ventilation air supply, based on dilution of contaminants released from the maximum amount of paint applied to aircraft, is 100,000 ft^3/min.

The air-handling air supply will be monitored in all modes by the indoor air quality monitoring system, which utilizes a gas chromatograph to sense about five of the expected contaminants. It operates through the automatic control system to, first, increase the volume of ventilating air to the maximum flow rate when contaminant concentration in the work areas reaches the preprogrammed low-limit value and, second, to initiate an alarm and stop flow of air to the process equipment when contaminant concentration in the work areas exceeds the high-limit value.

HVAC Design Conditions for Corrosion Control Facilities

Design conditions for environmental systems providing temperature and humidity control in hangar bays of corrosion control facilities are mandated by Air Force regulations and technical bulletins.

Inside design conditions are given in Air Force technical bulletins. The painting cycle requires control of the space temperature and humidity to maintain conditions within a given range as required to permit paint application without use of additives. The additives, which are required to modify the paint to allow application at nonstandard conditions, adversely affect the durability of the finishes. The curing mode requires control of temperature and humidity in a normal comfort range for natural curing. Rapid curing requires the addition of heat and humidity to maintain elevated temperature and humidity during the curing cycle. Other operating modes do not require cooling, dehumidification, or humidification.

Outdoor design conditions are obtained from AFM 88-29, *Engineering Weather Data* (USAF 1978). The indoor and outdoor design conditions for each operating mode are tabulated in Table 2.

TABLE 2
Design Conditions for Summer and Winter by Modes

Operating Mode	Preparation	Stripping	Painting	Curing
Inside, Summer				
Dry-bulb	*	*	80°F	*
Relative humidity	*	*	60%	*
Outdoor, Summer				
Dry-bulb	95°F	95°F	95°F	95°F
Wet-bulb	76°F	76°F	76°F	76°F
Inside, Winter				
Dry-bulb	55°F	55°F	70°F	70°F
Relative humidity	**	**	50%	**
Outdoor, Winter				
Dry-bulb	25°F	25°F	25°F	25°F
Wet-bulb	**	**	21°F	**

* Mechanical cooling and dehumidification not authorized.
** Humidification not authorized.

Cooling and Heating Load Calculations

The cooling and heating loads for operation at minimum and maximum outdoor design temperatures have been calculated for each mode of operation at minimum outdoor air and for 100% outdoor air using a microcomputer-based load calculation program. They are tabulated in Tables 3 through 6.

TABLE 3
Cooling and Heating Loads—Horizontal Flow System

Operating Mode	Preparation	Stripping	Painting	Curing
Total Air, cfm	75,000	1,200,000	1,200,000	75,000
Outdoor Air, cfm *	3000	****	100,000	3000
Chiller Load,				
Tons, Recirc.	**	**	550	**
Tons, 100% OA	**	**	2239	**
Boiler Load, Btu/h				
Space heating	487,000	487,000	731,000	731,000
OA tempering				
Recirc.	105,000	****	4,898,000	4,898,000
100% OA	2,625,000	39,180,000	58,776,000	14,100,000
Humidification				
Recirc.	***	****	3,540,000	***
100% OA	***	***	42,480,000	***
Total load, Btu/h				
Recirc.	592,000	****	9,169,000	5,629,000
100% OA	3,112,000	39,667,000	101,987,000	15,694,000
Boiler HP				
Recirc.	18	****	277	170
100% OA	94	1198	3079	474

* Outdoor air volume for recirculating operation.
** Mechanical cooling not authorized.
*** Humidification not authorized.
**** Recirculation not authorized, use 100% outdoor air. Warmup/cooldown cycle for 60 minutes at 75,000 cfm.
Initial cure cycle for 60 minutes at 1,200,000 cfm total air with 100,000 cfm outdoor air.

TABLE 4
Cooling and Heating Loads—Vertical Laminar Flow

Operating Mode	Preparation	Stripping	Painting	Curing
Total Air, cfm	75,000	3,500,000	3,500,000	75,000
Outdoor Air, cfm *	3000	****	100,000	3000
Chiller Load,				
Tons, Recirc.	**	**	1666	**
Tons, 100% OA	**	**	10,815	**
Boiler Load, Btu/h				
Space heating	487,000	487,000	731,000	731,000
OA tempering				
Recirc.	105,000	****	4,898,000	4,898,000
100% OA	2,625,000	114,278,000	172,200,000	14,694,000
Humidification				
Recirc.	***	****	3,060,000	***
100% OA	***	***	107,100,000	***
Total load, Btu/h				
Recirc.	592,000	****	9,169,000	5,629,000
100% OA	3,112,000	115,089,000	279,300,000	15,425,000
Boiler HP				
Recirc.	18	****	156	170
100% OA	94	3475	5548	[illegible]

* Outdoor air volume for recirculating operation.
** Mechanical cooling not authorized.
*** Humidification not authorized.
**** Recirculation not authorized, use 100% outdoor air. Warmup/cooldown cycle for 60 minutes at 75,000 cfm.
Initial cure cycle for 60 minutes at 3,500,000 cfm total air with 100,000 cfm outdoor air.

Available Energy Conservation and Heat Recovery Systems

Review of the cooling and heating loads indicates that it is not economically feasible to build and operate the ventilating and air-handling systems in the facility on the basis of 100% outdoor air. It will be necessary to incorporate some method or combination of methods to provide energy-conservative operation, including

TABLE 5
Cooling and Heating Loads—Downdraft Flow System

Operating Mode	Preparation	Stripping	Painting	Curing
Total Air, cfm	75,000	2,000,000	2,000,000	75,000
Outdoor Air, cfm *	3000	****	100,000	3000
Chiller Load,				
Tons, Recirc.	**	**	1035	**
Tons 100% OA	**	**	3689	**
Boiler Load, Btu/h				
Space heating	487,000	487,000	731,000	731,000
OA tempering				
Recirc	105,000	****	4,898,000	4,898,000
100% OA	2,625,000	65,789,000	97,200,000	14,694,000
Humidification				
Recirc	***	***	3,060,000	***
100% OA	***	***	61,200,000	***
Total boiler load				
Recirc	592,000	****	8,689,000	5,629,000
100% OA	3,112,000	66,276,000	159,131,000	15,425,000
Boiler HP				
Recirc.	18	****	262	170
100% OA	94	2001	4805	466

* Outdoor air volume for recirculating operation.
** Mechanical cooling not authorized.
*** Humidification not authorized.
**** Recirculation not authorized, use 100% outdoor air. Warmup/cooldown cycle for 60 minutes at 100,000 cfm.
Initial cure cycle for 60 minutes at 2,000,000 cfm total air with 100,000 cfm outdoor air.

TABLE 6
Cooling and Heating Loads—Hybrid Flow System

Operating Mode	Preparation	Stripping	Painting	Curing
Total Air, cfm	75,000	2,600,000	2,600,000	75,000
Outdoor Air, cfm *	3000	****	100,000	3000
Chiller Load,				
Tons Recirc.	**	**	1275	**
Tons, 100% OA	**	**	8002	**
Boiler Load, Btu/h				
Space heating	487,000	487,000	731,000	731,000
OA tempering				
Recirc	105,000	****	4,898,000	4,898,000
100% OA	2,616,000	39,181,000	127,348,000	14,694,000
Humidification				
Recirc.	***	***	3,540,000	***
100% OA	***	***	79,560,000	***
Total boiler load				
Recirc	592,000	****	9,169,000	5,629,000
100% OA	3,103,000	39,668,000	207,639,000	15,425,000
Boiler HP				
Recirc.	18	****	277	170
100% OA	94	1198	6269	466

* Outdoor air volume for recirculating operation.
** Mechanical cooling not authorized.
*** Humidification not authorized.
**** Recirculation not authorized, use 100% outdoor air. Warmup/cooldown cycle for 60 minutes at 100,000 cfm.
Initial cure cycle for 60 minutes at 2,600,000 cfm total air with 100,000 cfm outdoor air.

heat recovery. A number of energy conservation and energy recovery methods are suitable for use in this facility. The principal methods are:

1. Recirculation of air from space in conjunction with dilution ventilation for control of gaseous contaminants and filtration of particulate contaminants.

2. Water-to-water heat recovery between spray-filled air washers in the supply airstream and wet scrubbers in exhaust airstreams.

3. Air-to-air heat recovery in rotary total heat exchangers or sensible heat exchangers.

4. Air-to-air heat recovery in heat-pipe-type sensible heat exchangers.

5. Air-to-air heat recovery in plate-type sensible heat exchangers.

6. Air-to-air heat recovery in runaround cycle heat exchange coil loop with glycol piping system.

The method of recirculating of air from space in conjunction with dilution ventilation for control of contaminants has the lowest owning and operating cost and the lowest first cost. However, recirculation cannot be employed with certain chemical stripping compounds, including those using methylene chloride, the most effective compound for removing polysulfide-based primers used by the military. The recirculation method requires the addition of automatic air quality monitoring controls and recirculating connections to the duct system.

The method of air-to-air heat recovery in heat-pipe-type sensible heat exchangers requires positive medium-efficiency air filtration. Failure of the air filtration system will cause the narrow air passages through the finned surface of the heat exchange coils to be plugged up with particulates. The relatively thin aluminum sheets used in the finned surface of the heat transfer coils will not stand the forces generated in cleaning with high-pressure water spray. The owning and operating costs are relatively high due to cleaning and maintenance of the finned surface coils. The first costs for this method are relatively high due to the expense of arranging duct systems for counterflow of exhaust and outdoor air and to the cost of the heat pipe units.

The method of air-to-air heat recovery in plate-type sensible heat exchangers requires positive medium-efficiency air filtration. Failure of the air filtration system will cause the internal air passages through the closed heat transfer plates to be plugged up with particulates. The arrangement of the heat transfer surfaces in the plate-type heat exchanger will not allow access for cleaning with high-pressure water spray. The owning and operating costs are relatively high due to the air pressure drop through the plate-type exchanger and to the periodic replacement of the plate-type exchanger when it is fouled. The first costs for this method are relatively high due to the expense of arranging duct systems for counterflow of exhaust and outdoor air and to the cost of the plate-type heat exchange units.

The method of air-to-air heat recovery in a runaround cycle heat exchange coil loop with a glycol piping system requires positive medium-efficiency air filtration. Failure of the air filtration system will cause the narrow air passages through the finned surface of the heat exchange coils to be plugged up with particulates. The relatively thin aluminum sheets used in the finned surfaces of the heat-transfer coils will not stand the forces generated in cleaning with high-pressure water spray. The owning and operating costs are relatively high due to cleaning and maintenance of the finned surface coils, operation of the glycol pumping system, increased fan power due to high pressure drop through coils, and maintenance of the glycol heat-transfer fluid. The first costs for this method are relatively high due to the expense of the glycol piping system between sets of coil and to the cost of the runaround coils.

Selection of System Type for Value Analysis

The scope of the study was to compare the ventilating and air-handling systems found to be best suited for use in a corrosion control facility for large aircraft with a previous design for a corrosion control facility that had been carried through documentation at the 35% completion level.

This paper has outlined four systems of ventilating and air handling. In the judgment of the research team, the system best suited for use in Air Force corrosion control facilities for large aircraft is the horizontal laminar flow type. The recirculating method of heat recovery is deemed to be the best method of energy conservation for use in this project.

This design analysis is based on use of recirculating systems with dilution ventilation of the volume determined by calculations in the appendix.

It is necessary to provide safety functions through an indoor air quality monitoring system. The monitoring system must provide an alarm when the gaseous contaminant level reaches the lower-limit value programmed into the system by the industrial hygienists, at which point the ventilating system must be energized to exhaust a maximum volume of air from the hangar bay to purge the contaminants from the facility. The monitoring system must provide a second alarm at a higher action level, where the process must be stopped, the compressed air serving the process equipment shut off, and workers evacuated from the facility.

CONCLUSIONS

Review of the air-handling requirements and the calculated cooling, heating, and electrical power system capacities for the four air distribution types shows that the horizontal laminar flow system has the lowest requirements of all the systems studied. Similarly, the cooling, heating, and electrical power system requirements are proportionately less.

The horizontal laminar flow system of air distribution is recommended on the basis of three cost considerations: (1) cost for installation of equipment; (2) cost for construction of mechanical equipment room space; and (3) operating cost for air-handling, cooling, heating, and electrical power systems.

The research on which this paper is based was intended to provide a design basis for future corrosion control facilities and also for a specific new facility. Changes in the environmental regulatory climate caused the Air Force to delete the requirements for paint-stripping operations from the overall system design, and a new project was commissioned to design the specific facility. That project is expected to be completed in mid-1990. The design data obtained in the study were incorporated into the design of a larger paint facility for a commercial client, which was completed in mid-1989. That facility is sized to accommodate aircraft up to the size of 747-300 models.

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APPENDIX

DETERMINATION OF DILUTION VENTILATION AIR VOLUME

Methodology

The determination of dilution ventilation air volume is based on a number of variable factors, some of which are empirical in nature. Section 2 of *Industrial Ventilation, A Manual of Recommended Practice* (ACGIH 1976), hereinafter called "the Manual," covers dilution ventilation. Under the heading "Dilution Ventilation for Health," a procedure is given for calculating the required dilution ventilation rate subject to four limiting factors: (1) the quantity of contaminant must not be too great or the dilution air volume will be impractical; (2) workers must be far enough away from contaminant evolution or evolution of contaminant must be in sufficiently low concentrations so that workers will not have an exposure in excess of the established TLV value; (3) the toxicity of the contaminant must be low; and (4) the evolution of contaminants must be reasonably uniform.

Painting operations in a large aircraft paint facility do not fall within the bounds of all the limiting factors, but the procedure appears to be reasonable to follow when it is considered that painters wear supplied-air respirators and that the toxicity of the contaminants is deemed to be moderate, with TLVs equal to or greater than 100 parts per million (ppm).

The dilution ventilation calculation is based on a formula that considers the specific gravity (SG) of the contaminant, the evolution rate of the contaminant (the rate at which the contaminant is applied) in pints per hour, the molecular weight (MW) of the contaminant, the TLV of the contaminant, and an empirical factor, K, to account for the evolution rate of the contaminant and the ventilation effectiveness of the paint room. The factor K is a judgment factor ranging from 3 to 10, with 3 being assigned for low evolution rates and high ventilation effectiveness and 10 being assigned for high evolution rates and low ventilation effectiveness. In the Air Force project, a value of $K = 4$ was assigned.

The contaminants in aircraft finishes vary with the type of paint job to be done. In military facilities, camouflage paint schemes are applied with a polysulfide-based prime coat and a gray top coat with accents of black, green, blue, and red. Glossy decorative finishes in commercial facilities are applied with a polysulfide-based prime coat and a white top coat with trim in various colors.

Review of the composition of basic paints used by the Air Force found typical percentages of contaminants to include:

Polysulfide-based primers	
Methyl ethyl ketone (MEK)	15%
Toluene	15%
Polyurethane coating, white, 2-part	
Base	
Cellosolve acetate	20%
Ethyl acetate	10%
Methyl ethyl ketone (MEK)	10%
Catalyst	
Cellosolve acetate	20%
Methyl ethyl ketone (MEK)	40%

Polyurethane coating, blue, 2-part
Base
Ethyl acetate 20%
Methyl ethyl ketone (MEK) 15%
Catalyst
Cellosolve acetate 20%
Methyl ethyl ketone (MEK) 40%
Polyurethane coating, thinner
Cellosolve acetate 40%
Methyl ethyl ketone (MEK) 30%
n-Butyl acetate 10%
Toluene 12%

Only one accent-color coating is listed. Colored coatings have a broad range of contaminants, including heavy metals, which become a problem for particulate contaminant control.

A listing of the principal contaminants expected in the finishes and values of SG, MW, and TLV for each includes:

Contaminant	SG	MW	TLV*
Amyl Acetate	130.18	0.879	100
Cellosolve Acetate	132.16	0.975	**
Methyl Ethyl Ketone (MEK)	72.10	0.805	200
n-Butyl Acetate	116.12	0.882	150
Toluene	92.13	0.866	100
Xylene	106.16	0.881	100

* 1975 TLVs, as were used in original calculations.
** TLVs for cellosolve acetate vary with exact compound from 25 to 50.

The amount of each type of finish varies for the aircraft size and the finish type, i.e., camouflage or airline colors. In each type of finish material, the proportion of each contaminant varies. In two-part systems, the catalyst may be a relatively small part of the mixed compound, in the range of 10% to 25%.

The fraction of each gaseous contaminant that goes into the ventilating airstream varies in relation to many factors, including indoor temperature and humidity conditions, type of spray apparatus, air pressure supplied to spray apparatus, and ventilating system effectiveness. For solvents, the drying time factor varies in relation to ethyl ether at 1 through ethyl acetate at 17.5, distilled water at 55 to cellosolve actate at 65.

The maximum volume of paint expected to be applied during one eight-hour shift when painting a C-141-sized aircraft was stated to be 85 gallons, which would be either all primer, all gray base camouflage coat, or a mixture of accent colors.

The equation for dilution ventilation in ft³/h is:

$$cfh = \frac{403 \times SG \times 1{,}000{,}000 \times \text{pints contaminant/hour} \times K}{\text{contaminant MW} \times \text{Contaminant TLV}}$$

in which 403 is a conversion factor for the units in the equation and 1,000,000 is a conversion for the TLV that is stated in ppm.

When a compound contains more than one toxic contaminant, the volume of dilution ventilation must be determined for each contaminant, and the sum of the dilution ventilation volumes for the individual constituents becomes the total dilution ventilation volume required for the compound.