

INDUSTRIAL VENTILATION

A Manual of Recommended Practice
*for Operation and
Maintenance*

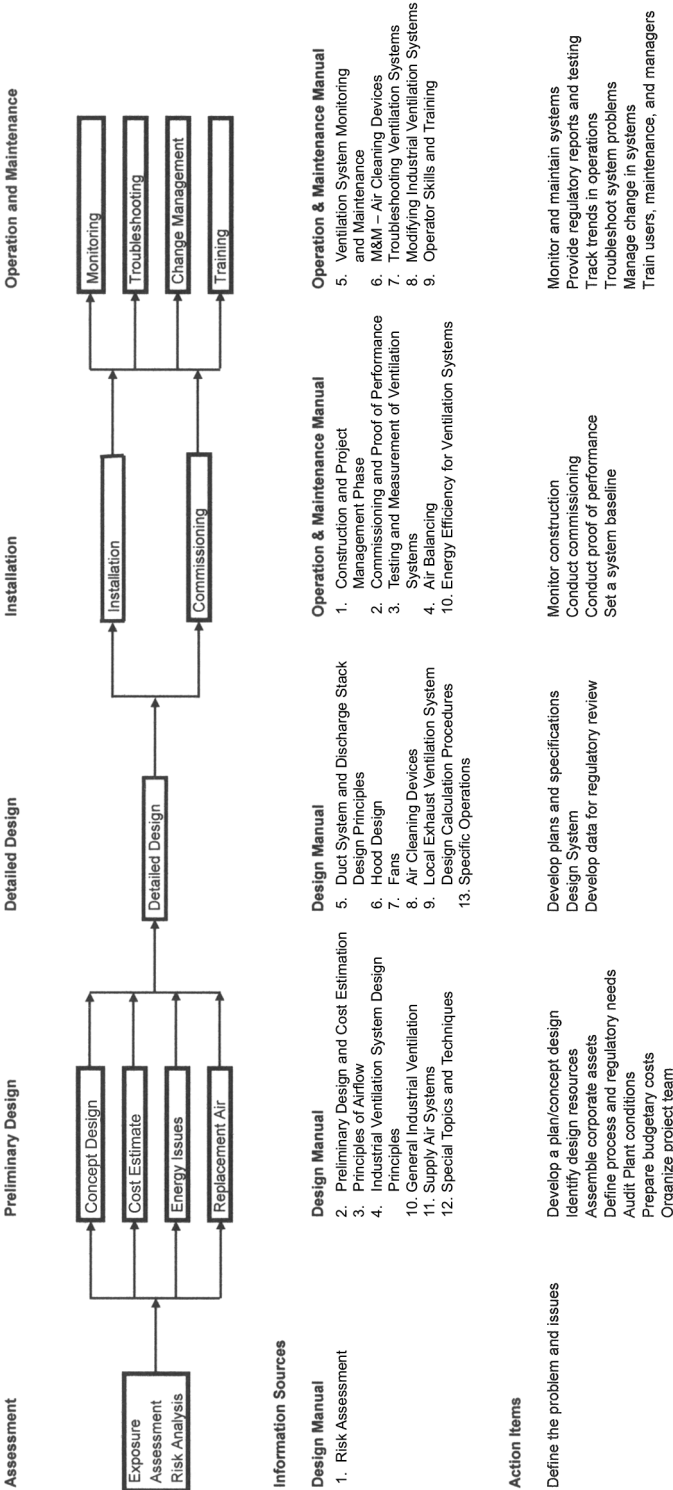
2nd Edition



Defining the Science of
Occupational and Environmental Health®

Signature Publications

LIFE CYCLE OF AN INDUSTRIAL VENTILATION SYSTEM



INDUSTRIAL VENTILATION

A Manual of Recommended Practice
*for Operation and
Maintenance*

2nd Edition



*Defining the Science of
Occupational and Environmental Health®*

Signature Publications

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by

American Conference of Governmental Industrial Hygienists (ACGIH®)

ISBN: 978-1-607261-14-8

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FOREWORD

Since its first edition in 1951, *Industrial Ventilation: A Manual of Recommended Practice for Design* (the Ventilation Manual) has been used by engineers, industrial hygienists and other practitioners to both design and evaluate/repair industrial ventilation systems. This Manual entitled *Industrial Ventilation: A Manual of Recommended Practice for Operation and Maintenance* (the O&M Manual) is written as a companion document to the Design Manual and is intended to complement its information. The Industrial Ventilation Committee has found a need in the public forum for further consideration of a number of burgeoning issues that would benefit practitioners of this art. Consequently, the two Manuals can be considered as a whole entity even while they will generally address different subjects.

To facilitate navigation between the two volumes, an insert on the front, inside cover shows how the chapters are related. The two Manuals are divided into several topics, which generally follow the timeline for the development of an industrial ventilation system.

- Concept Design
 - Risk Assessment – Design Manual – Chapter 1
 - Preliminary Design and Cost Estimation – Design Manual – Chapter 2
 - Special Topics and Techniques – Design Manual – Chapter 12
- Detailed Design
 - Principles of Airflow – Design Manual – Chapter 3
 - General Industrial Ventilation – Design Manual – Chapter 10
 - Duct System and Discharge Stack Design Principles – Design Manual – Chapter 5
 - Hood Design – Design Manual – Chapter 6
 - Fans – Design Manual – Chapter 7
 - Air Cleaning Devices – Design Manual – Chapter 8
 - Local Exhaust Ventilation System Design Calculation Procedures – Design Manual – Chapter 9
 - Supply Air Systems – Design Manual – Chapter 11

- Specific Operations – Design Manual – Chapter 13
- Installation
 - Construction and Project Management Phase – O&M Manual – Chapter 1
- Commissioning
 - Commissioning and Proof of Performance – O&M Manual – Chapter 2
 - Testing and Measurement of Ventilation Systems – O&M Manual – Chapter 3
 - Air Balancing – O&M Manual – Chapter 4
- Monitoring and Maintenance of a Ventilation System
 - Ventilation System Monitoring and Maintenance – O&M Manual – Chapter 5
 - M&M – Air Cleaning Devices – O&M Manual – Chapter 6
 - Energy Efficiency for Ventilation Systems – O&M Manual – Chapter 10 (New chapter)
- Managing Ventilation Systems
 - Troubleshooting Ventilation Systems – O&M Manual – Chapter 7
 - Modifying Industrial Ventilation Systems – O&M Manual – Chapter 8
 - Operator Skills and Training – O&M Manual – Chapter 9

Information provided as a guideline can be influenced by other factors in an industrial environment (material handling techniques, cross-drafts and replacement air, work practices, and housekeeping, etc.), therefore formulae developed in the laboratory and at other sites may need to be altered further for actual field conditions. In many cases, ranges of values are shown, leaving final selection to be based on the experience of the practitioner and appropriate field conditions. Hence, the practitioner should always evaluate the effectiveness of hoods and other parts of the system after installation and be prepared to make changes as needed. Indeed, due to process changes, work-practice changes, and to the effects of the aging of the system, practitioners should continually evaluate and modify systems throughout their life cycles.

This Manual is intended to be used as a guide, not as an official standard. It is designed to present current information with

regard to the subject matter covered. It is distributed with the understanding that the Industrial Ventilation Committee and its members, collectively or individually, assume no responsibility for any inadvertent misinformation, for inadvertent omissions, or for the results in the use of this publication.

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ACKNOWLEDGMENTS

Industrial Ventilation is a true Committee effort. It brings into focus useful practical ventilation data from all parts of the world in one source. The Committee membership of industrial ventilation engineers and industrial hygienists represents a diversity of experience and interests that ensures a well-rounded cooperative effort.

From the First Edition in 1951, this effort has been successful as witnessed by the acceptance of the “Ventilation Manual” throughout industry, by governmental agencies, and as a worldwide reference and text.

As indicated in the Foreword, we now have two volumes of the Manual; the Operation and Maintenance (O&M) Manual and the Design Manual. We are extremely grateful to the external contributors listed at the end of the Foreword for their con-

tributions to the sixth chapter of the O&M Manual.

We are also grateful for the faith and firm foundation provided by past Committees and members listed below. A special acknowledgment on this Manual is made to Ms. Rita Williams. Ms. Williams’ assistance as editor and in the production of this Manual has been invaluable for many years.

Many figures in Chapters 1, 5, 6, 7 and 9 of the O&M Manual are courtesy of The Procter & Gamble Company (P&G). To P&G and many other individuals and agencies who have made specific contributions and have provided support, suggestions, and constructive criticism, our special thanks.

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DEFINITIONS

Aerosol: An assemblage of small particles, solid or liquid, suspended in air. The diameter of the particles may vary from 100 microns down to 0.01 micron or less, e.g., dust, fog, smoke.

Air Cleaner: A device designed for the purpose of removing atmospheric airborne impurities such as dusts, gases, mists, vapors, fumes, and smoke. (Air cleaners include air washers, air filters, electrostatic precipitators, and charcoal filters.)

Air Filter: An air cleaning device that removes light particulate loadings from normal atmospheric air before introduction into the building. Usual range: loadings up to 3 grains per thousand cubic feet (0.003 grains per cubic foot). Note: Atmospheric air in heavy industrial areas and in-plant air in many industries have higher loadings than this, and dust collectors are then indicated for proper air cleaning.

Air Horsepower: The theoretical horsepower required to drive a fan if there were no losses in the fan; that is, if its efficiency were 100 percent.

Aspect Ratio: The ratio of the width to the length; $AR = W/L$.

Aspect Ratio of an Elbow: The width (W) along the axis of the bend divided by depth (D) in the plane of the bend; $AR = W/D$.

Blast Gate: Sliding damper.

Blow (throw): In air distribution, the distance an air stream travels from an outlet to a position at which air motion along the axis reduces to a velocity of 50 fpm. For unit heaters, the distance an air stream travels from a heater without a perceptible rise due to temperature difference and loss of velocity.

Brake Horsepower: The horsepower actually required to drive a fan. This includes the energy losses in the fan and can be determined only by actual test of the fan. (This does

not include the drive losses between motor and fan.)

Capture Velocity: The air velocity at any point in front of the hood or at the hood opening necessary to overcome opposing air currents and capture the contaminated air at that point by causing it to flow into the hood.

Comfort Zone (Average): The range of effective temperatures over which the majority (50% or more) of adults feel comfortable.

Convection: The motion resulting in a fluid from the differences in density and the action of gravity. In heat transmission this meaning has been extended to include both forced and natural motion or circulation.

Deflagration: A propagation of a combustion zone that occurs at a velocity that is less than the speed of sound in the unreacted medium.

Density: The ratio of the mass of a specimen of a substance to the volume of the specimen. The mass of a unit volume of a substance. When weight can be used without confusion, as synonymous with mass, density is the weight of a unit volume of a substance.

Density Factor: The ratio of actual air density to density of standard air. The product of the density factor and the density of standard air (0.075 lb/ft^3) will give the actual air density in pounds per cubic foot; $\text{Density} = df \times 0.075 \text{ lb/ft}^3$ (the density of standard air).

Dust: Small solid particles created by the breaking up of larger particles by processes, i.e., crushing, grinding, drilling, explosions, etc. Dust particles already in existence in a mixture of materials may escape into the air through such operations as shoveling, conveying, screening, sweeping, etc.

Dust Collector: An air cleaning device to remove heavy particulate loadings from exhaust systems. Usual range of particulate loading: 0.003 grains per cubic foot or higher.

Entry Loss: Loss in pressure caused by air flowing into a duct or hood (inches H₂O).

Fumes: Small, solid particles formed by the condensation of vapors of solid materials.

Gases: Formless fluids which tend to occupy an entire space uniformly at ordinary temperatures and pressures.

Hood: A shaped inlet designed to capture contaminated air and conduct it into the exhaust duct system.

Hood Flow Coefficient: The ratio of flow caused by a given hood static pressure compared to the theoretical flow which would result if the static pressure could be converted to velocity pressure with 100 percent efficiency. *NOTE: This was defined as Coefficient of Entry or C_e in previous editions.*

Humidity, Absolute: The weight of water vapor per unit volume, pounds per cubic foot or grams per cubic centimeter.

Humidity, Relative: The ratio of the actual partial pressure of the water vapor in a space to the saturation pressure of pure water at the same temperature.

Inch of Water: A unit of pressure equal to the pressure exerted by a column of liquid water one inch high.

Lower Explosive Limit: The lower limit of flammability or explosibility of a gas or vapor at ordinary ambient temperatures expressed in percent of the gas or vapor in air by volume. This limit is assumed constant for temperatures up to 250 F. Above these temperatures, it should be decreased by a factor of 0.7 since explosibility increases with higher temperatures.

Manometer: An instrument for measuring pressure; essentially a U-tube partially filled with a liquid, usually water, mercury or a light oil, so constructed that the amount of displacement of the liquid indicates the pressure being exerted on the instrument.

Micron: A unit of length, the thousandth part of 1 mm or the millionth of a meter (approximately 1/25,000 of an inch).

Minimum Design Duct Velocity: Minimum air velocity required to move the particulates in the air stream (fpm).

Mists: Small droplets of materials that are ordinarily liquid at normal temperature and pressure.

Plenum: Pressure equalizing chamber.

Pressure, Static: The potential pressure exerted in all directions by a fluid at rest. For a fluid in motion, it is measured in a direction normal to the direction of flow. Usually expressed in inches water gauge when dealing with air. (The tendency to either burst or collapse the pipe.)

Pressure, Total: The algebraic sum of the velocity pressure and the static pressure (with due regard to sign).

Pressure, Vapor: The pressure exerted by a vapor. If a vapor is kept in confinement over its liquid so that the vapor can accumulate above the liquid, the temperature being held constant, the vapor pressure approaches a fixed limit called the maximum or saturated vapor pressure, dependent only on the temperature and the liquid. The term vapor pressure is sometimes used as synonymous with saturated vapor pressure.

Pressure, Velocity: The kinetic pressure in the direction of flow necessary to cause a fluid at rest to flow at a given velocity. Usually expressed in inches water gauge.

Radiation, Thermal (Heat): The transmission of energy by means of electromagnetic waves of very long wave length. Radiant energy of any wave length may, when absorbed, become thermal energy and result in an increase in the temperature of the absorbing body.

Replacement Air: A ventilation term used to indicate the volume of controlled outdoor air supplied to a building to replace air being exhausted.

Slot Velocity: Linear flow rate of contaminated air through a slot, fpm.

Smoke: An air suspension (aerosol) of particles, usually but not necessarily solid, often originating in a solid nucleus, formed from combustion or sublimation.

Specific Gravity: The ratio of the mass of a unit volume of a substance to the mass of the same volume of a standard substance at a standard temperature. Water at 39.2 F is the standard substance usually referred to. For gases, dry air, at the same temperature and pressure as the gas, is often

taken as the standard substance.

Standard Air: Dry air at 70 F and 29.92 (in Hg) barometer. This is substantially equivalent to 0.075 lb/ft³. Specific heat of dry air = 0.24 BTU/lb/F.

Temperature, Effective: An arbitrary index which combines into a single value the effect of temperature, humidity, and air movement on the sensation of warmth or cold felt by the human body. The numerical value is that of the temperature of still, saturated air which would induce an identical sensation.

Temperature, Wet-Bulb: Thermodynamic wet-bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicated by a wet-bulb psychrometer constructed and used according to specifications.

Threshold Limit Values (TLVs®): The values for airborne toxic materials which are to be used as guides in the control of health hazards and represent time-weighted concentrations to which nearly all workers may be exposed 8 hours per day over extended periods of time without adverse effects (see Appendix).

Transport (Conveying) Velocity: See Minimum Design Duct Velocity.

Turn-Down Ratio: The degree to which the operating performance of a system can be reduced to satisfy part-load conditions. Usually expressed as a ratio; for example, 30:1 means the minimum operation point is 1/30th of full load.

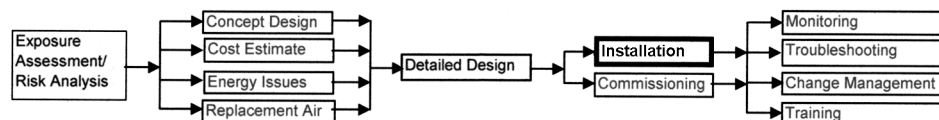
Vapor: The gaseous form of substances that are normally in the solid or liquid state and that can be changed to those states either by increasing the pressure or decreasing the temperature.

ABBREVIATIONS

A	area	HVAC	heating, ventilation, and air conditioning
acfm	actual flow rate	in	inch
AHP	air horsepower	in ²	square inch
AR	aspect ratio	lb	pound
A _s	slot area	lbm	pounds mass
B	barometric pressure	LEL	lower explosive limit
BHP	brake horsepower	ME	mechanical efficiency
BHP _a	brake horsepower, actual	mg	milligram
BHP _s	brake horsepower, standard air	min	minutes
BTU	British Thermal Unit	mm	millimeters
BTUh	BTU per hour	MRT	mean radiant temperature
C _e	hood flow coefficient	MW	molecular weight
CLR	centerline radius	ρ	density of air
d	diameter	ppm	parts per million
df	density factor	psi	pounds per square inch
df _e	elevation density factor	PWR	power
df _m	moisture density factor	Q	flow rate
df _p	pressure density factor	Q _{corr}	corrected airflow rate
df _t	temperature density factor	R	degrees, Rankin
ET	effective temperature	RH	relative humidity
f	Moody diagram friction coefficient	RPM	revolutions per minute
F	degrees, Fahrenheit	scfm	standard cubic feet per minute
F _{el}	elbow loss factor	sfp _m	surface feet per minute
F _{en}	entry loss factor	SG	specific gravity
F _h	duct entry loss factor	SP	static pressure
fpm	feet per minute	SP _{gov}	governing static pressure
fps	feet per second	SP _h	hood static pressure
F _s	slot loss factor	SP _s	SP, system handling standard air
ft ²	square foot	STP	standard temperature and pressure
ft ³	cubic foot	TLV®	Threshold Limit Value
g	gravitational force, ft/sec/sec	TP	total pressure
gpm	gallons per minute	V	velocity
gr	grains	V _d	duct velocity
h _e	overall hood entry loss	VP	velocity pressure
h _{el}	elbow loss	VP _d	duct velocity pressure
h _{en}	entry loss	VP _r	weighted-average velocity pressure
h _f	loss in straight duct run	VP _s	slot or opening velocity pressure
h _h	hood entry loss	V _s	slot velocity
HEPA	high-efficiency particulate air	V _t	duct transport velocity
H _f	duct loss coefficient	w	watt
hp	horsepower	ω	moisture content
hr	hour	"wg	inches water gauge
h _s	slot or opening entry loss	z	elevation above sea level
HV	humid volume (ft ³ mix/lbm dry air)		

Chapter 1

CONSTRUCTION AND PROJECT MANAGEMENT PHASE



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1.1 INTRODUCTION

The construction and installation of the local exhaust system is often the User's initial introduction to the system hardware. The system has been designed and reviewed and is now being installed in the plant. Because most local exhaust ventilation systems also must meet environmental and safety and health regulations, the proper control and management of the construction process is the first important phase of operation and management.

1.1.1 Organization of the Chapter. The principals in a typical industrial ventilation construction project (both new work and renovations) include the Owner and the **General Contractor** (hereafter called Contractor), with the designer taking a less dominant role. This chapter focuses on activities of the Contractor and the Owner's on-site representatives.

A diagram showing the relationship of all of the parties from concept and design through construction is shown in Figure 1-1. In this diagram, the Project Team takes a central role in the communication of design needs among all of the parties. Note that the 'team' may actually be one person for smaller projects but can have 20 or more members on complex projects and/or those impacting plant operations. Team members can include the Owner's own employees and/or outside consultants specifically hired for the project. Typical members include personnel with expertise in plant production requirements, maintenance, safety, permits, design, purchasing and operators. Details of the functions and tools for the operation of the Project Team will be further discussed in Chapters 2 and 4 of *Industrial Ventilation: A Manual of Recommended Practice for Design*, 30th Edition (the Design Manual).

1.2 GOALS AND OBJECTIVES DURING CONSTRUCTION

The primary objectives in the construction of the ventilation system are:

- 1) Meet ventilation system success criteria
- 2) Meet exposure control criteria
- 3) Meet building code and other regulatory criteria
- 4) Protect contractor and plant personnel during construction
- 5) Deliver project on time
- 6) Contain costs

1.2.1 Meet Ventilation System Success Criteria. From the Construction Contractor's perspective the project is a success if it meets the design requirements, i.e., correct airflow and capture velocity at the hoods, sufficient duct velocities in the branches and the main, appropriate fans and compliant air pollution control equipment. The commissioning agent testing, adjusting and balancing (TAB) agency must test both the exhaust and supply system and the relationship (balance) between the two systems. The commissioning or TAB agency's role is to ensure that the mechanical system is oper-

ating as designed. TAB agencies typically do not conduct exposure monitoring.

1.2.2 Meet Exposure Control Criteria. The primary purpose for an industrial ventilation system is to protect workers from occupational stressors, typically in the form of airborne contaminants. Refer to Chapter 1 of the Design Manual, entitled Risk Assessment, to establish acceptable values. The facility Safety and Health Staff or an outside contractor can determine if the industrial ventilation system is controlling the stressor. Occasionally industrial ventilation alone cannot fully control the stressor. Facility management must employ other methods of contaminant control.

1.2.3 Meet Building Code and Other Regulatory Criteria. Because local exhaust ventilation systems transport materials that could be hazardous, system construction and operation are subject to numerous regulations ranging from local community building codes to national consensus codes such as National Fire Protection Association (NFPA), American National Standards Institute (ANSI), and Sheet Metal and Air Conditioning Contractors National Association (SMACNA). Most countries have a set of standards that they use as the industrial facility design and operation basis. Many standards are codified into the local community codes. Communities will adopt others, such as the International Mechanical Code and American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) codes or standards in whole or in part.

The air pollution control system is considered part of the industrial ventilation system. Since material is conveyed away from the worker and potentially deposited to the outdoors, environmental protection regulations are a critical part of the project. Obtaining environmental permits is a critical task that should be initiated as soon as possible in the project's lifecycle.

1.2.4 Protect Contractor and Plant Personnel During Construction. In the past, owners left occupational safety and health issues to the contractor, but owners cannot avoid becoming involved due to increasing third party legal cases and insurance issues. Aggressive use of past safety performance (e.g., total recordable injury rates, lost time injury rates, etc.) and other contract clauses, improves the pool of eligible contractors. This chapter addresses some of those issues.

Construction operations have somewhat different safety and health considerations than industrial operations, primarily since the project is transient. However, more injuries and deaths occur on a construction site than in general industry due to accidents from slips, falls, ergonomic, electrical, etc. Responsibility for job safety on a construction site lies with the contractor, not the owner or the designer. The owner must identify unusual safety concerns (e.g., flammability, toxicity, etc.) in the contract and review the contractor's safety plan. The owner's on-site representative and construction inspector may observe the safety operations but should not stop the work. Unless there is imminent danger such as unstable