

NAFA GUIDE TO AIR FILTRATION



Sixth Edition, 2021

National Air Filtration Association
www.nafahq.org

Publication Information

The *NAFA Guide to Air Filtration, Sixth Edition* is published by the National Air Filtration Association (NAFA). NAFA is a nonprofit, industry-supported trade association whose members include air filter sales and service companies, manufacturers and distributors of air filtration products, as well as those associated with the air filtration industry.

The appearance of any technical products or equipment in this text does not constitute endorsement, warranty, or guaranty by NAFA.

Additional copies of *NAFA Guide to Air Filtration, Sixth Edition* are available from the NAFA store at www.nafahq.org.

First Edition, 1993

Second Edition, 1996

Third Edition, 2001

Fourth Edition, 2007

Fifth Edition, 2014

Sixth Edition, 2021

Copyright National Air Filtration Association 2021, 2014, 2007, 2001, 1996, 1993.

All rights reserved. No part of this book may be reproduced by photocopy, recording, or by any other means, or stored, processed, or transmitted in or by any computer or other system without prior permission from NAFA.

ISBN No: 978-0-938423-22-5

NAFA encourages architects, engineers and end-users to contact NAFA member companies for air filter information, products and services. NAFA Members subscribe to the NAFA Code of Ethics, study and pass a thorough international examination to achieve accreditation (CAFS: Certified Air Filter Specialist, and/or NCT I or NCT II: NAFA Certified Technician, Level I or II), and receive continuing education and training on “best practice” applications and emerging technologies in the air filtration industry.

A complete list of NAFA Members can be found at the NAFA website at www.nafahq.org.

NAFA Membership

Membership in NAFA is open to individuals involved in the sales, service, manufacture, and distribution of air filter products and service. In addition, NAFA has other categories of involvement for those associated in any way with clean indoor air. For further information, log onto the NAFA website at www.nafahq.org.

Foreword

Air filtration is one of the most important components in an HVAC System. Properly engineered and correctly applied air filtration provides a facility and its occupants with protection from particulate- phase and molecular-phase contaminants that are both a nuisance and can cause illness and even death. It also provides protection to expensive mechanical equipment, interior furniture and fixtures, industrial processes and products that require high levels of cleanliness in manufacture.

This Edition of the NAFA Guide to Air Filtration is the sixth revision since the original edition was printed in 1993. The Technical Committee of the National Air Filtration Association considered a number of factors in this revision that included current state of the industry, intent of the manufacturers and scope of air filter distributors along with the user community's access to internet-based information. It is written in both Inch-Pound (IP) and Standard International (SI) systems of measurement (see Appendix One for Systems, Formulas and Conversions).

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and the International Organization for Standardization (ISO) continues to research and clarify air filter testing guidelines and standards and indoor air quality standards for buildings.

This edition references the latest information from these and other standard and rule making authorities and organizations.

The 6th Edition is required study for those individuals wishing to complete the NAFA Certified Air Filter Specialist (CAFS) accreditation. The international test available in both English and Spanish is administered periodically throughout the year in order to further the educational quality in connection with sales and distribution of air filter products and services.

For additional information or comments and questions about the information in this book, or for a listing of NAFA Members in your area, please go to the NAFA web site at www.nafahq.org.

Acknowledgments

Special recognition and acknowledgment for publication of the 6th Edition must be given to the following groups and individuals:

All Members of the National Air Filtration Association

Contributors to Previous Editions:

Harry Allen, CAFS	Todd Hensley	Rick Peckham, CAFS (Des.)
Robert Avery (Des.)	Jeff Gentry, CAFS	Bill Rasmussen, CAFS, NCT (Des.)
Todd Brisendine	Skiter Kowalski, CAFS (Ret.)	Leslye Sandberg, CAFS
David Books, CAFS	Rupert Langston, CAFS	Dave Sickels, CAFS
Bob Buckley, CAFS	Jack Manns	Jim Solis, CAFS
William Down (Des.)	Dave Matela	George Spottswood, CAFS
Harry C. Elinsky, Jr., CAFS	Ron Mattson, CAFS	Al Vatine, CAFS
Gerald Festian, CAFS	Chris Muller	Gail Waite, CAFS
Dave Goss, CAFS	Stephen Nicholas, CAFS, NCT II	Rex Wilhoite
Robert Hanson, CAFS	Domenick Orlando, CAFS	Robert Williams, CAFS
Jim Hedback, CAFS	Thomas Ottney (Ret.)	Christopher A. Zaker, CAFS, NCT

The 2021 NAFA Rewrite Committee:

Chair Jay Reese, CAFS J & BR Associates, LLC.	Marisa Jimenez de Segovia, CAFS, NCT, ASHRAE Fellow Air-Care de Mexico
Daniel Baizel, CAFS Columbus Industries, Inc.	Keith Jordan Sanuvox Technologies, Inc.
Michael Beier, CAFS Products Unlimited, Inc.	Tom Justice, CAFS, NCT Zene
Michael Corbat, CAFS Rensa Filtration	Paula Levasseur, CAFS LMF Services LLC
Kevin Delahunt, CAFS BGE Indoor Air Quality Solutions Ltd.	Phil Maybee (Ret.)
Jeron Downing, CAFS Dave Downing & Associates	Mike Reidy, CAFS Roto Aire Filter Sales & Service
Joe W. Fly, CAFS Joe W. Fly Co., Inc.	Tom Riddel, CAFS, NCT II Air Filter Sales & Service
Jon Holmes, CAFS Camfil USA, Inc.	Jim Rosenthal, CAFS TEX-AIR Filters/Air Relief Technologies
Jeff Holt, CAFS, NCT Airflow Products Co., Inc.	Mr. Tavatchai (Alex) Satiennattanakul, CAFS 3V Engineering Solutions Company Limited
	Gail Waite, CAFS Roto Aire Filter Sales & Service

A special thanks to the following people who contributed their scientific, technical skills and knowledge to specific chapters:

Kathleen Owen

Jeff Siegel

Brent Stephens

R. Vijayakumar

A special thanks to NAFA Association Partners and other organizations who cooperated by allowing parts of their standards, guidelines and references to be used in this text:

- American Biological Safety Association (ABSA)
- American Conference of Governmental Industrial Hygienists (ACGIH)
- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)
- Institute of Environmental Science and Technology (IEST)
- International Organization For Standardization (ISO)
- National Sanitation Foundation (NSF)
- Underwriter's Laboratories, Inc. (UL)

NAFA Headquarters Staff:

Michelle Czosek, CAE
Executive Director

Chris Caple
Meetings Manager

Terry Driscoll
Association Coordinator / Graphic Designer

Nathan Florek
Marketing Coordinator

Tony Veroeven
Director of Marketing

Table of Contents

Chapter 1: The Importance of Air Filtration	1.1
Introduction	1.1
The Air We Breath	1.1
Aerosols.....	1.2
Solid Particles	1.2
Liquid Particles	1.3
Compound Particles.....	1.3
Measuring Particle Contamination.....	1.3
Particle Size Chart	1.4
Effect of Measuring Method	1.5
Airborne Gases	1.6
Source of Gases.....	1.6
Measurement of Concentration of Gases.....	1.6
The Importance of Air Filtration.....	1.6
System Filters	1.8
Filter Efficiency.....	1.9
Modeling of Filtration Systems.....	1.9

Addendum 1.1

Addendum 1.1.1

HVAC Filtration and Wells-Riley: Assessing risks of infectious airborne diseases

Chapter 2: The Principles of Air Flow, Air Pressure and Air Filtration

2.1

Principles of Air Flow	2.1
Principles of Air Pressure	2.1
Principles of Particulate Air Filtration	2.3
Three Types of Air Filter Categories	2.3
Mechanical Air Filters.....	2.3
Impingement	2.3
Interception	2.4
Diffusion	2.4
Straining.....	2.4
Impingement Filters.....	2.4
Use of Adhesives.....	2.5
Interception and Diffusion Filters.....	2.5
Disruptive Forces.....	2.6
Filter Equilibrium.....	2.6
Factors Affecting Interception and Diffusion	2.6
Mixed-Type Mechanical Filters.....	2.6
Factors Affecting Mechanical Filter Selection	2.6
Electrostatically Charged Media.....	2.7
Electronic Air Cleaners.....	2.8

Chapter 3: Impingement Filters	3.1
Definition	3.1
General Categories	3.1
Panel Filters	3.1
Materials of Construction	3.1
Metals	3.1
Spun-glass fiber media.....	3.2
Synthetic fiber media.....	3.2
Natural Blend Fibers	3.3
Dry Plastic Media	3.4
Media Performance	3.4
Method of Renewal	3.5
Filter Holding Systems.....	3.5
Ring Panels and Link Panels	3.5
Side Access Housing Installation.....	3.6
Automatic Roll Filters.....	3.6
Media Advancing	3.7
Roll Filter Media.....	3.7
Special Particulate Removal.....	3.7
Lint Filters.....	3.7
Grease Filters.....	3.7
Chapter 4: Extended Surface Filters	4.1
Definition	4.1
Types of Extended Surface Filters	4.1
Types of Media Used in Extended Surface Filters.....	4.1
Lofted Synthetic Media	4.1
Synthetic Fiber Mats.....	4.2
Lofted Microglass Media	4.2
Wet Laid Microglass Media.....	4.2
Types of Typical Extended Surface Filters.....	4.3
Pleated Filters	4.3
Lofted Synthetic Filters	4.3
Non-Supported Pocket (Bag) Filters	4.3
Rigid Box Filters	4.4
Rigid Cell Filters	4.5
Mini-Pleat Filters.....	4.5
V-Bank Filters	4.6
Filter Installations.....	4.6
Filter Performance.....	4.6
Deep-pleated Residential Filters.....	4.7
Typical Performance Values Chart.....	4.8
Chapter 5: HEPA, ULPA and Super ULPA Filters	5.1
Definition	5.1
General Description of Filter	5.1
Filter Media.....	5.2
Separators	5.3
Mini-pleat.....	5.4

Sealants	5.4
Frames (Cell Sides).....	5.5
Filter Performance.....	5.5
Categories of HEPA and ULPA Filters	5.6
Holding Devices for HEPA Filters	5.7
Individual Holding Frames	5.7
Room Side Replaceable Wall and ceiling framing modules.....	5.7
Disposable HEPA Filter Modules.....	5.8
Side-servicing Housings	5.8
Bag-in, Bag-out	5.8
HEPA “Like” Filters – 95% DOP	5.8
Bag-in, Bag-out Housing for HEPA Filters	5.9
Super ULPA Filters.....	5.10

Chapter 6: Air Cleaners & Residential & Commercial **6.1**

Introduction.....	6.1
Media Air Cleaners	6.1
Self-contained	6.1
Portable units.....	6.2
In-duct units.....	6.2
Electronic Air Cleaners – Electrostatic Precipitators (ESP)	6.3
Self-Contained ESP	6.3
Hybrid Charged Media/Electronic Air Cleaner	6.3
Factors Affecting Electronic Air Cleaner Design and Efficiency.....	6.4
Agglomerator Units.....	6.5
Prefilters.....	6.6
Cleaning ESP Collector Cells.....	6.6
Washable Electronic Air Cleaners.....	6.6
Afterfilters.....	6.7
Industrial Applications	6.7
Service Requirements	6.8
Power Packs.....	6.8
Applications Not Normally Suitable for Electronic Air Cleaners	6.8
Standards for Electronic Air Cleaners	6.8
Underwriter Laboratories Standard UL 867.....	6.8
Underwriters Laboratories Inc. Standard UL 2998 Environmental Claim Validation Procedure (ECVP) for Zero Ozone Emissions from Air Cleaners.....	6.9

Chapter 7: HVAC Filter Testing **7.1**

Filter Testing	7.1
Filter Performance Testing.....	7.1
ASHRAE Test Methods (a short history).....	7.2
ANSI/ASHRAE - 52.2-2012.....	7.2
ANSI/ASHRAE Standard 52.2-2017.....	7.3
ISO 16890 (2016).....	7.3
Comparison to ASHRAE 52.2	7.4
MERV and Typical Applications	7.5
Comparison of ASHRAE 52.2-2012, ISO16890, EN779 and EN1822:2009.....	7.6
Retired Standards	7.7

EN 779: 2012	7.7
Third-Party Testing	7.7
ISO 29462:2013 (in-situ testing).....	7.7
Filter Certification	7.7
Information Available from ASHRAE Filter Test Summary Sheets	7.8
Filter Tests vs Actual Performance.....	7.8
Room Air Cleaners.....	7.8
Fire Resistance	7.9
Classification Service – ANSI/ UL 900.....	7.9
Flame-Exposure Test.....	7.10
Spot-Flame Test	7.10

Addendum 7.1

Addendum 7.1.1

A Brief Description of the ANSI/ASHRAE Standard 52.2 Test Method

Addendum 7.2

Addendum 7.2.1

A Brief Description of ISO 16890

Chapter 8: HEPA and ULPA Filter Testing

8.1

Introduction	8.1
The Hot DOP Efficiency Test Q107 Penetrometer (MIL-STD-282)	8.1
Leakage vs. Penetration (Two-Flow Testing).....	8.3
In-place Leak Testing; Cold DOP Test	8.3
Particle Counters	8.4
Higher Efficiency Air Filters	8.4
ISO 29463 - 1 to 5.....	8.6
Fire Resistance	8.6
UL 586 (HEPA Filters).....	8.6
Aerosol Penetration Test.....	8.8
Heated Air Test	8.8
Moist Air Test.....	8.8
Low Temperature Test.....	8.8
Spot-Flame Test.....	8.8
Confirmation Test.....	8.8
General.....	8.8
HEPA Filter Aging - Life In Service.....	8.8

Chapter 9: Controlled Environments

9.1

Introduction	9.1
Product and Air Cleanliness	9.1
Cleanroom Zones and Cleanrooms.....	9.1
Cleanroom Types	9.2
Non-unidirectional Airflow	9.2
Unidirectional Airflow.....	9.3
Cleanroom Classification	9.4
ISO 14644-1 Classification of Air Cleanliness.....	9.5
Clean Benches.....	9.5
Biological Safety Cabinets	9.5

Replacement HEPA Filters	9.5
Other Typical Controlled Environments	9.6
Pharmaceutical Compounding - Sterile Preparations	9.6
Firing Ranges.....	9.6
Libraries, Archives and Museums	9.6
Nuclear Energy Applications	9.7
Computer Equipment	9.7
Photographic Industry.....	9.7
Breather Filters for Storage Tanks	9.7
Industrial Process Control Rooms	9.8
Sewage Disposal Plants.....	9.9
Textiles	9.9
Gas Turbines.....	9.10
Telecommunication Equipment Rooms.....	9.11
Commercial Kitchen Ventilation Hood Filters.....	9.11
Other Applications	9.12

Chapter 10: Airborne Microorganisms 10.1

Introduction	10.1
Viruses.....	10.1
Bacteria	10.2
Fungi.....	10.2
Filter Efficiency.....	10.2
Removal of Microorganisms From the Airstream Using HEPA Filters.....	10.3
Removal of Microorganisms From the Airstream Using HVAC Filters	10.3
Removal of Microorganisms From the Airstream Using ESP's.....	10.4
Removal and Retention of Mold	10.4
Antimicrobial Agents.....	10.5
Air Washing	10.5
Disease Control	10.5
Healthcare Facilities	10.5
Filter Efficiencies for Healthcare Central Ventilation and Air Conditioning Systems.....	10.6
Specialized Operating Rooms.....	10.7
Airborne Infection Isolation Rooms (AII).....	10.7
Tuberculosis Control.....	10.8
Pathology and Bioresearch Laboratories.....	10.8
Biosafety Level 1	10.9
Biosafety Level 2	10.9
Biosafety Level 3	10.9
Biosafety Level 4	10.9
Biological Safety Cabinets (BSC).....	10.9
Class I.....	10.9
Class II.....	10.10
Class III.....	10.10
HEPA Filter Decontamination	10.10
Food Processing.....	10.11
Cultured Milk Products.....	10.11
Milk Drying and Other Processes.....	10.12
Aseptic Packaging.....	10.12

Pharmaceutical Industry	10.12
Other Applications Involving Microorganisms.....	10.13
General Overview	10.13
Chapter 11: Airborne Molecular Contaminants (AMC)	11.1
Introduction	11.1
Classification of AMC.....	11.1
Corrosive Gases	11.1
Irritant Gases.....	11.2
Odorous Gases	11.2
Methods of Control.....	11.2
Steady-State Model for Air Quality Control.....	11.3
Overview of Molecular Air Filtration Principles	11.3
Adsorption	11.3
Breakthrough Curves	11.5
Contact Efficiency/Residence Time	11.5
Mass Transfer Zone/Critical Bed Depth.....	11.6
Removal Efficiency	11.6
Adsorptive Capacity	11.6
Summary : Efficiency and Capacity	11.6
Contact Efficiency.....	11.6
Residence Time.....	11.6
Adsorption Efficiency.....	11.6
Removal Capacity.....	11.7
Chemisorption.....	11.7
Catalysis.....	11.8
Molecular Filtration Media	11.8
Activated Carbon.....	11.8
CTC Activity	11.8
Particle/Granule Size.....	11.9
Hardness	11.9
Density	11.9
Adsorptive Capacity.....	11.9
Chemically Impregnated Adsorptive Media.....	11.9
Recommended Removal Media for Contaminants	11.10
Catalysts.....	11.10
Media Selection Considerations.....	11.11
Molecular Air Filtration Equipment Designs.....	11.12
Partial Bypass	11.12
Serpentine.....	11.13
Refillable Tray.....	11.13
Refillable or Disposable Modules	11.13
Disposable “V” Cell Modules.....	11.13
Thick-Bed Cells.....	11.13
Thick-Bed Depth “V” Module	11.13
Importance of Prefiltration	11.14
Packed-Bed vs. Carbon Impregnated (CIF) Filters.....	11.14
Service Life of Molecular Air Filtration Media	11.15
Disposal of Spent Molecular Media	11.16
Testing of Molecular Filtration Media-ASHRAE Standard 145.1 & 145.2	11.16

Chapter 12: Indoor Air Quality

12.1

Introduction	12.1
Human Physical Response	12.1
Sick Building Syndrome	12.2
Building Related Illness	12.2
Sources and Identification of Pollutants.....	12.2
Buildings	12.2
Building Mechanical Systems.....	12.2
Building Contents.....	12.3
Air Surrounding Buildings.....	12.3
Building Occupants.....	12.3
Other Sources.....	12.4
ANSI/ASHRAE Standards for Acceptable Indoor Air Quality.....	12.4
ANSI/ASHRAE Standard 62.1-2019.....	12.4
Air Classes and Redesignation	12.5
Class 1.....	12.5
Class 2.....	12.5
Class 3.....	12.5
Class 4.....	12.5
Air Cleaning.....	12.6
The Ventilation Rate Procedure.....	12.6
The Indoor Air Quality Procedure.....	12.6
Natural Ventilation Procedure.....	12.7
Air Filtration and Treatment for Outside Air.....	12.7
Air Filtration and Treatment for Recirculated Air.....	12.7
ANSI/ASHRAE Standard 62.2 – 2019.....	12.8
Pollution Control.....	12.8
Source Removal	12.8
Removal by the HVAC System	12.8
Dilution Ventilation	12.8
Office Buildings	12.9
Museums	12.9
Libraries.....	12.9
Healthcare Facilities	12.10
Schools.....	12.10
Smoking Areas - Environmental Tobacco Smoke (ETS)	12.10
Residential.....	12.10
Monitoring Indoor Air Quality	12.10
Summary	12.10

Chapter 13: Owning & Operating Costs

13.1

Introduction.....	13.1
New System/Replacement System Initial and Installation Costs.....	13.1
Operating Costs.....	13.2
Energy Costs	13.2
Maintenance and Disposal Costs	13.4
Filter Life Estimating	13.4
Factors Affecting Filter Life.....	13.4
Using Prefilters to Extend Filter Life.....	13.5

Underrating and Overrating Filters	13.5
Optimum Final Pressure Drop	13.7
Annual Owning and Operating Costs.....	13.7
Filter Owning and Operating Cost Study Form.....	13.8

Addendum 13.1

Life Cycle Cost Analysis Tool

Addendum 13.1.1

Chapter 14: Ultraviolet Germicidal Irradiation,

Photocatalytic Oxidation

14.1

Ultraviolet Germicidal Irradiation - UVGI	14.1
How UVGI Works	14.2
In Duct UVGI Airstream Disinfection.....	14.4
UVC and Safety Issues	14.5
UVGI System Operation	14.5
UVGI Applications and Standards.....	14.6
Photocatalytic Oxidation (PCO)	14.6
Coated-wall Annular Reactor	14.7
Packed Bed Annular Reactor	14.7
Box Reactor	14.7
Flat Bed Reactor.....	14.7

Chapter 15: Industrial Contaminant Air Filtration

Control Systems

15.1

Metal Working Fluids	15.1
Types of Metal Working Fluids.....	15.2
Straight Oil	15.2
Soluble Oil	15.2
Semi-synthetic Oil.....	15.2
Synthetic Metal Working Fluids	15.2
Oil Mists and Smoke	15.2
Health and Safety Risks	15.3
Oil Mist and Smoke Collection	15.4
System Performance Goals.....	15.4
Oil Mist and Smoke Separator Systems.....	15.5
1. Media-type Filtration Systems	15.5
2. Centrifugal Separators	15.6
3. Electrostatic Precipitators.....	15.7
Summary	15.7
Welding and Other Smoke Removal.....	15.7
Dust Separation	15.8
Types of Dust Separation Equipment	15.8
Cyclone Separators	15.8
Baghouse Separators	15.9
Cartridge Separators.....	15.10

Filter Media Selection	15.10
Fabric Media.....	15.10
Specialized Applications	15.10
Summary	15.11

Chapter 16: Industrial Finishing **16.1**

Introduction	16.1
Finishing Room or Paint Spray Booth.....	16.1
Supply Air Filtration	16.3
Exhaust Air Filtration	16.4
Relationship Between Supply and Exhaust Air	16.5
Balancing Supply and Exhaust Systems.....	16.6
Exhaust Air Cleaning.....	16.6
Paint Arrestor (Overspray Filter) Media and Styles	16.7
Synthetic Media	16.8
Expanded Kraft®	16.8
Baffle Style Filters.....	16.9
Fiberglass	16.9
Combination	16.9
Box Style.....	16.9
Disposal of Overspray Media.....	16.10
Water-wash Systems.....	16.11
Special Coatings Applications.....	16.11
Types of Finishes	16.11

Appendix One

Systems, Formulas and Conversions

Appendix Two

Federal and State Codes and Standards of Industrial Finishing Systems

Appendix Three

Independent Testing Laboratories

Appendix Four

Filter Equilibrium

Appendix Five

Methods of Testing Overspray Filters

Appendix Six

Contaminant Capacity Index

Appendix Seven

Service Life of Molecular Air Filtration Media

Appendix Eight

Steady-State Model for the Control of Gaseous Contaminants

Chapter 17: Glossary

17.1