

# HVAC SYSTEMS APPLICATIONS



**SHEET METAL AND AIR CONDITIONING CONTRACTORS'  
NATIONAL ASSOCIATION, INC.**  
[www.smacna.org](http://www.smacna.org)



# **HVAC SYSTEMS APPLICATIONS**

SECOND EDITION – MARCH, 2010



**SHEET METAL AND AIR CONDITIONING CONTRACTORS'  
NATIONAL ASSOCIATION, INC.**

4201 Lafayette Center Drive  
Chantilly, VA 20151-1209  
[www.smacna.org](http://www.smacna.org)

# **HVAC SYSTEMS APPLICATIONS**

COPYRIGHT © SMACNA 2010  
All Rights Reserved  
by

**SHEET METAL AND AIR CONDITIONING CONTRACTORS'  
NATIONAL ASSOCIATION, INC.**

4201 Lafayette Center Drive  
Chantilly, VA 20151-1209

Printed in the U.S.A.

FIRST EDITION – JANUARY 1987  
SECOND EDITION – MARCH 2010

Except as allowed in the Notice to Users and in certain licensing contracts, no part of this book may be reproduced, stored in a retrievable system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

## FOREWORD

It is the policy of the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) to continually re-visit and update the technical manuals that have become the backbone of the industry.

With this policy in mind, a Task Force was organized and tasked with the purpose of reviewing and bringing up to date the HVAC Systems Applications. This manual is often referred to as one-of-three manuals that constitute SMACNA's approach to HVAC systems. The other two manuals making up this group are the "*HVAC Systems – Duct Design*" manual and the "*HVAC Systems – Testing, Adjusting and Balancing*" manual. It is recommended that this manual be used in conjunction with the latest ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) "*HVAC Applications*" handbook.

Accordingly, the Task Force found areas that were in need of updating, primarily due to the advancement of technology, since the manual was last revised. This included hardware as well as software improvements. In addition, the science and methodology of Heating, Ventilating and Air Conditioning has changed, with an increased emphasis on energy efficiency and sustainability.

As you review this 2<sup>nd</sup> edition, you will notice that some chapters have been re-named, others have been deleted, and the order of the remaining chapters presented has been adjusted. However the emphasis is still on Air and Hydronic systems. You will also notice new topics of discussion, *i.e.*:

- Displacement Ventilation
- Variable Flow Refrigerant systems
- Fan Wall Systems
- HVAC Systems as they pertain to Sustainable Buildings
- Updated review of modern Variable Frequency Drives
- Revised/Updated Figures
- Expanded chapters for Smoke Control, Cleanrooms and Laboratory HVAC systems

It is the hope of the Task Force that this revised manual will be of value to those contractors who participate in the Design Build arena, as well as those that are involved with retro-fitting existing building systems. For those working in the retro-fit market, references to systems that may be obsolete by today's standards have been retained to offer an insight into these systems.

Finally, the Glossary has also been updated to reflect these changes.

SHEET METAL AND AIR CONDITIONING CONTRACTORS'  
NATIONAL ASSOCIATION, INC.



# HVAC SYSTEMS APPLICATIONS TASK FORCE

Douglas Ahlberg, *Chairman*  
Arctic Sheet Metal, Inc.  
Portland, OR

Christopher A. Fulton  
Bright Sheet Metal Co., Inc.  
Indianapolis, IN

James E. Hall  
Systems Management & Balancing, Inc.  
Des Moines, IA

James Matthews  
Precision Test & Balance  
Colorado Springs, CO

Peyton Collie, *Staff*  
SMACNA  
Chantilly, VA

Eli P. Howard, *Staff*  
SMACNA  
Chantilly, VA



# NOTICE TO USERS OF THIS PUBLICATION

## 1. DISCLAIMER OF WARRANTIES

- a) The Sheet Metal and Air Conditioning Contractors' National Association ("SMACNA") provides its product for informational purposes.
- b) The product contains "Data" which is believed by SMACNA to be accurate and correct but the data, including all information, ideas and expressions therein, is provided strictly "AS IS," with all faults. SMACNA makes no warranty either express or implied regarding the Data and SMACNA EXPRESSLY DISCLAIMS ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR PARTICULAR PURPOSE.
- c) By using the data contained in the product user accepts the Data "AS IS" and assumes all risk of loss, harm or injury that may result from its use. User acknowledges that the Data is complex, subject to faults and requires verification by competent professionals, and that modification of parts of the Data by user may impact the results or other parts of the Data.
- d) IN NO EVENT SHALL SMACNA BE LIABLE TO USER, OR ANY OTHER PERSON, FOR ANY INDIRECT, SPECIAL OR CONSEQUENTIAL DAMAGES ARISING, DIRECTLY OR INDIRECTLY, OUT OF OR RELATED TO USER'S USE OF SMACNA'S PRODUCT OR MODIFICATION OF DATA THEREIN. This limitation of liability applies even if SMACNA has been advised of the possibility of such damages. IN NO EVENT SHALL SMACNA'S LIABILITY EXCEED THE AMOUNT PAID BY USER FOR ACCESS TO SMACNA'S PRODUCT OR \$1,000.00, WHICHEVER IS GREATER, REGARDLESS OF LEGAL THEORY.
- e) User by its use of SMACNA's product acknowledges and accepts the foregoing limitation of liability and disclaimer of warranty and agrees to indemnify and hold harmless SMACNA from and against all injuries, claims, loss or damage arising, directly or indirectly, out of user's access to or use of SMACNA's product or the Data contained therein.

## 2. ACCEPTANCE

This document or publication is prepared for voluntary acceptance and use within the limitations of application defined herein, and otherwise as those adopting it or applying it deem appropriate. It is not a safety standard. Its application for a specific project is contingent on a designer or other authority defining a specific use. SMACNA has no power or authority to police or enforce compliance with the contents of this document or publication and it has no role in any representations by other parties that specific components are, in fact, in compliance with it.

## 3. AMENDMENTS

The Association may, from time to time, issue formal interpretations or interim amendments, which can be of significance between successive editions.

## 4. PROPRIETARY PRODUCTS

SMACNA encourages technological development in the interest of improving the industry for the public benefit. SMACNA does not, however, endorse individual manufacturers or products.

## 5. FORMAL INTERPRETATION

- a) A formal interpretation of the literal text herein or the intent of the technical committee or task force associated with the document or publication is obtainable only on the basis of written petition, addressed to the Technical Resources Department and sent to the Association's national office in Chantilly, Virginia. In the event that the petitioner has a substantive disagreement with the interpretation, an appeal may be filed with the Technical Resources Committee, which has technical oversight responsibility. The request must pertain to a specifically identified portion of the document that does not involve published text which provides the requested information. In considering such requests, the Association will not review or judge products or components as being in compliance with the document or publication. Oral and written interpretations otherwise obtained from anyone affiliated with the Association are unofficial. This procedure does not prevent any committee or task force chairman, member of the committee or task force, or staff liaison from expressing an opinion on a provision within the document, provided that such person clearly states that the opinion is personal and does not represent an official act of the Association in any way, and it should not be relied on as such. The Board of Directors of SMACNA shall have final authority for interpretation of this standard with such rules or procedures as they may adopt for processing same.
- b) SMACNA disclaims any liability for any personal injury, property damage, or other damage of any nature whatsoever, whether special, indirect, consequential or compensatory, direct or indirectly resulting from the publication, use of, or reliance upon this document. SMACNA makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

## 6. APPLICATION

- a) Any standards contained in this publication were developed using reliable engineering principles and research plus consultation with, and information obtained from, manufacturers, users, testing laboratories, and others having specialized experience. They are subject to revision as further experience and investigation may show is necessary or desirable. Construction and products which com-



ply with these Standards will not necessarily be acceptable if, when examined and tested, they are found to have other features which impair the result contemplated by these requirements. The Sheet Metal and Air Conditioning Contractors' National Association and other contributors assume no responsibility and accept no liability for the application of the principles or techniques contained in this publication. Authorities considering adoption of any standards contained herein should review all federal, state, local, and contract regulations applicable to specific installations.

b) In issuing and making this document available, SMACNA is not undertaking to render professional or other services for or on behalf of any person or entity. SMACNA is not undertaking to perform any duty owed to any person or entity to someone else. Any person or organization using this document should rely on his, her or its own judgement or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstance.

## **7. REPRINT PERMISSION**

Non-exclusive, royalty-free permission is granted to government and private sector specifying authorities to reproduce *only* any construction details found herein in their specifications and contract drawings prepared for receipt of bids on new construction and renovation work within the United States and its territories, provided that the material copied is unaltered in substance and that the reproducer assumes all liability for the specific application, including errors in reproduction.

## **8. THE SMACNA LOGO**

The SMACNA logo is registered as a membership identification mark. The Association prescribes acceptable use of the logo and expressly forbids the use of it to represent anything other than possession of membership. Possession of membership and use of the logo in no way constitutes or reflects SMACNA approval of any product, method, or component. Furthermore, compliance of any such item with standards published or recognized by SMACNA is not indicated by presence of the logo.

# **TABLE OF CONTENTS**



# TABLE OF CONTENTS

<b>FOREWORD</b> .....	<b>iii</b>
<b>HVAC SYSTEMS APPLICATIONS TASK FORCE</b> .....	<b>iv</b>
<b>NOTICE TO USERS OF THIS PUBLICATION</b> .....	<b>v</b>
<b>TABLE OF CONTENTS</b> .....	<b>vii</b>
<b>CHAPTER 1 INTRODUCTION</b>	<b>Page</b>
1.1 INTRODUCTION .....	1.1
1.2 HVAC SYSTEM PURPOSE .....	1.1
1.3 HUMAN THERMAL COMFORT .....	1.1
1.4 BASIC HVAC SYSTEM COMPONENTS .....	1.2
1.5 HVAC SYSTEM OPERATIONAL EFFICIENCY .....	1.6
1.6 GREEN BUILDING RATING SYSTEMS .....	1.9
1.7 HVAC SYSTEM SELECTION PARAMETERS .....	1.10
1.8 SPACE CONDITIONS .....	1.10
1.9 HVAC EQUIPMENT AND SPACE .....	1.10
<b>CHAPTER 2 HVAC SYSTEM APPLICATION FUNDAMENTALS</b>	
2.1 INTRODUCTION .....	2.1
2.2 AIR CHEMISTRY .....	2.1
2.3 MOIST AIR PHYSICAL PROPERTIES .....	2.1
2.4 MOIST AIR ENERGY CONTENT .....	2.2
2.5 ZONE DEFINED .....	2.5
2.6 AIRFLOW DEFINED .....	2.7
2.7 SPACE CONDITIONING METHODS .....	2.7
2.8 HVAC SYSTEMS CATEGORIZED BY PRIMARY HEAT TRANSFER MEDIA .....	2.8
<b>CHAPTER 3 VARIABLE-AIR-VOLUME HVAC SYSTEMS</b>	
3.1 INTRODUCTION .....	3.1
3.2 VAV SYSTEM DESCRIPTION .....	3.1
3.3 VAV VERSUS CONSTANT-AIR-VOLUME HVAC SYSTEMS .....	3.1
3.4 VAV SYSTEM OPERATION .....	3.2
3.5 VAV TERMINAL UNITS .....	3.4
3.6 BASIC VAV TERMINAL UNITS .....	3.8
3.7 FAN-POWERED VAV TERMINAL UNITS .....	3.11
3.8 VAV TERMINAL UNITS WITH REHEAT .....	3.18
3.9 BYPASS VAV TERMINAL UNITS .....	3.18
3.10 VAV TERMINAL UNIT .....	3.21
3.11 HVAC SYSTEMS INCORPORATING VAV .....	3.22
<b>CHAPTER 4 MULTIZONE HVAC SYSTEMS</b>	
4.1 INTRODUCTION .....	4.1
4.2 MULTIZONE HVAC SYSTEM DESCRIPTION .....	4.1
4.3 USE OF A MULTIZONE HVAC SYSTEM .....	4.1
<b>CHAPTER 5 TERMINAL REHEAT HVAC SYSTEMS</b>	
5.1 INTRODUCTION .....	5.1
5.2 SYSTEM DESCRIPTION .....	5.1



5.3	SYSTEM FEATURES .....	5.1
5.4	SYSTEM LAYOUT .....	5.1
5.5	SYSTEM OPERATION .....	5.2
5.6	VAV HVAC SYSTEM WITH TERMINAL REHEAT .....	5.3
<b>CHAPTER 6</b>	<b>DUAL-DUCT HVAC SYSTEMS</b>	<b>Page</b>
6.1	INTRODUCTION .....	6.1
6.2	DUAL-DUCT HVAC SYSTEM DESCRIPTION .....	6.1
6.3	DUAL-DUCT HVAC SYSTEM APPLICATION .....	6.1
6.4	DUAL-DUCT HVAC SYSTEM OPERATION .....	6.5
6.5	DUAL-DUCT HVAC SYSTEM FEATURES .....	6.5
6.6	CENTRAL DUAL-DUCT HVAC SYSTEM EQUIPMENT .....	6.8
6.7	DUAL-DUCT HVAC SYSTEM AIR TERMINAL UNITS .....	6.9
6.8	SYSTEM OPERATION .....	6.12
6.9	IMPROVING EXISTING DUAL-DUCT HVAC SYSTEM PERFORMANCE .....	6.12
<b>CHAPTER 7</b>	<b>INDUCTION REHEAT HVAC SYSTEMS</b>	
7.1	INTRODUCTION .....	7.1
7.2	SYSTEM DESCRIPTION .....	7.1
7.3	INDUCTION TERMINAL UNITS .....	7.1
7.4	SYSTEM OPERATION .....	7.4
7.5	SYSTEM ADVANTAGES AND DISADVANTAGES .....	7.5
<b>CHAPTER 8</b>	<b>UNITARY HVAC SYSTEMS</b>	
8.1	INTRODUCTION .....	8.1
8.2	UNITARY HVAC SYSTEM CHARACTERISTICS .....	8.1
8.3	UNITARY HVAC SYSTEM .....	8.1
8.4	UNITARY HVAC SYSTEM ADVANTAGES AND DISADVANTAGES .....	8.4
8.5	CONVENTIONAL UNITARY HVAC SYSTEM TYPES .....	8.5
8.6	SINGLE-PACKAGED UNITS .....	8.5
8.7	SPLIT SYSTEMS .....	8.8
8.8	PACKAGED TERMINAL AIR CONDITIONERS .....	8.9
8.9	UNITARY HEAT PUMPS .....	8.13
8.10	COMBINATION UNITARY AND CENTRAL HVAC SYSTEMS .....	8.15
<b>CHAPTER 9</b>	<b>CENTRAL COOLING PLANT</b>	
9.1	INTRODUCTION .....	9.1
9.2	CENTRAL COOLING PLANT OPERATION AND COMPONENTS .....	9.1
9.3	CHILLER PURPOSE .....	9.1
9.4	CHILLER REFRIGERATION CYCLE .....	9.1
9.5	REFRIGERANT .....	9.5
9.6	MOTOR-COMPRESSOR UNITS .....	9.6
9.7	MECHANICAL COMPRESSOR OPERATION AND CHARACTERISTICS .....	9.6
9.8	ABSORPTION CHILLERS .....	9.8
9.9	CENTRAL COOLING PLANTS WITH MULTIPLE CHILLERS .....	9.10
9.10	COOLING TOWERS .....	9.11
9.11	CONDENSER WATER SYSTEMS .....	9.15
9.12	EVAPORATIVE COOLING SYSTEMS .....	9.20
<b>CHAPTER 10</b>	<b>CENTRAL HEATING PLANT</b>	
10.1	INTRODUCTION .....	10.1
10.2	FURNACES .....	10.1
10.3	BOILERS .....	10.1
10.4	HOT WATER VERSUS STEAM .....	10.2

10.5	BOILER PLANT OPERATION .....	10.2
10.6	BOILER CONSTRUCTION .....	10.3
10.7	BOILER FUELS .....	10.4
10.8	ELECTRIC BOILERS .....	10.4
10.9	BOILER RATING .....	10.4
10.10	BOILER CONTROLS .....	10.5
10.11	BOILER FEEDWATER AND CIRCULATING PUMPS .....	10.6
10.12	DEAERATORS .....	10.6
10.13	INCREASING CONVENTIONAL BOILER PLANT EFFICIENCY .....	10.6
10.14	CONDENSING BOILERS .....	10.7
10.15	HEAT EXCHANGERS .....	10.8
<b>CHAPTER 11 ENGINEERED HEAT PUMP SYSTEMS</b>		<b>Page</b>
11.1	INTRODUCTION .....	11.1
11.2	HEAT PUMP SYSTEMS .....	11.1
11.3	HEAT PUMP SYSTEM CHARACTERISTICS .....	11.1
11.4	BASIC HEAT PUMP SYSTEM ARRANGEMENTS .....	11.4
11.5	HEAT PUMP SYSTEM TYPES .....	11.6
11.6	WATER-TO-AIR HEAT PUMP SYSTEMS .....	11.7
11.7	WATER-TO-AIR HEAT PUMP SYSTEM DESIGN CONSIDERATIONS .....	11.11
<b>CHAPTER 12 AIR DISTRIBUTION SYSTEMS</b>		
12.1	INTRODUCTION .....	12.1
12.2	AIR DISTRIBUTION SYSTEM PURPOSE .....	12.1
12.3	AIR DISTRIBUTION SYSTEM COMPONENTS .....	12.1
12.4	SMACNA AIR DISTRIBUTION SYSTEM STANDARDS .....	12.1
12.5	AIR DUCTS AND PLENUMS .....	12.2
12.6	AIR TERMINAL UNITS .....	12.4
12.7	AIR OUTLETS AND INLETS .....	12.4
12.8	PROVISIONS FOR TESTING, ADJUSTING, AND BALANCING .....	12.5
<b>CHAPTER 13 FANS AND AIR-HANDLING UNITS</b>		
13.1	INTRODUCTION .....	13.1
13.2	FANS .....	13.1
13.3	AIR DISTRIBUTION SYSTEM OPERATION .....	13.12
13.4	AIR DISTRIBUTION SYSTEM OPERATING POINT .....	13.12
13.5	AIR DISTRIBUTION SYSTEM DYNAMICS .....	13.16
13.6	SYSTEM OPERATING POINT AND FAN SPEED .....	13.16
13.7	SUPPLY FAN AIRFLOW CONTROL .....	13.20
13.8	AIR HANDLING UNITS .....	13.23
<b>CHAPTER 14 AIR FILTRATION AND CLEANING</b>		
14.1	INTRODUCTION .....	14.1
14.2	AIR FILTRATION AND CLEANING .....	14.1
14.3	RATING AIR FILTERS AND CLEANERS .....	14.1
14.4	AIR POLLUTANT CAPTURE METHODS .....	14.2
14.5	CATEGORIES OF AIR FILTERS AND CLEANERS .....	14.3
14.6	PANEL FILTERS .....	14.5
14.7	RENEWABLE MEDIA FILTERS .....	14.7
14.8	ELECTRONIC AIR CLEANERS .....	14.8
14.9	AIR CLEANER AND FILTER LOCATION .....	14.9
14.10	FILTER INSTALLATION .....	14.10
14.11	ODOR REMOVAL .....	14.11



<b>CHAPTER 15</b>	<b>HYDRONIC DISTRIBUTION SYSTEMS</b>	<b>Page</b>
15.1	INTRODUCTION .....	15.1
15.2	HOT WATER DISTRIBUTION SYSTEM OPERATION .....	15.1
15.3	CHILLED WATER DISTRIBUTION SYSTEM OPERATION .....	15.1
15.4	HYDRONIC DISTRIBUTION SYSTEM ADVANTAGES AND DISADVANTAGES .....	15.4
15.5	HYDRONIC PIPING SYSTEM CLASSIFICATION .....	15.5
15.6	HYDRONIC DISTRIBUTION SYSTEM OPERATING TEMPERATURE CLASSIFICATIONS .....	15.5
15.7	HYDRONIC DISTRIBUTION SYSTEM FLOW .....	15.5
15.8	HYDRONIC DISTRIBUTION SYSTEM ARRANGEMENTS .....	15.6
15.9	MULTI-LOOP HYDRONIC DISTRIBUTION SYSTEMS .....	15.15
15.10	CONTROLLING HYDRONIC DISTRIBUTION SYSTEM FLOW .....	15.15
15.11	HYDRONIC DISTRIBUTION SYSTEM COMPONENTS .....	15.19
15.12	HYDRONIC SYSTEM HEAT TRANSFER MODE .....	15.24
15.13	CONVECTION TERMINAL UNITS .....	15.24
15.14	THERMAL FLUIDS .....	15.29
15.15	SIZING CENTRAL EQUIPMENT FOR ALL-WATER SYSTEMS .....	15.30
15.16	HYDRONIC DISTRIBUTION SYSTEM DESIGN .....	15.31
<b>CHAPTER 16</b>	<b>HVAC HYDRONIC PUMPS</b>	
16.1	INTRODUCTION .....	16.1
16.2	PUMPS .....	16.1
16.3	CENTRIFUGAL PUMP OPERATION .....	16.3
16.4	HYDRONIC SYSTEM OPERATION .....	16.6
16.5	EXPANSION OR COMPRESSION TANK .....	16.8
<b>CHAPTER 17</b>	<b>MOTORS AND VARIABLE FREQUENCY DRIVES</b>	
17.1	INTRODUCTION .....	17.1
17.2	ELECTRIC MOTOR TYPES .....	17.1
17.3	INDUCTION MOTOR SIZE CLASSIFICATION .....	17.2
17.4	INDUCTION MOTOR PURPOSE CLASSIFICATION .....	17.2
17.5	INDUCTION MOTOR .....	17.4
17.6	INDUCTION MOTOR SPEED-TORQUE RELATIONSHIP .....	17.5
17.7	INDUCTION MOTOR CHARACTERISTICS .....	17.7
17.8	MOTOR STARTING .....	17.14
17.9	VARIABLE FREQUENCY DRIVES .....	17.16
<b>CHAPTER 18</b>	<b>HVAC SYSTEM CONTROL</b>	
18.1	INTRODUCTION .....	18.1
18.2	CONTROL SYSTEM BASICS .....	18.1
18.3	CONTROL LOOPS .....	18.5
18.4	THERMOSTAT: SIMPLE CONTROL SYSTEM .....	18.6
18.5	TYPES OF CONTROL SYSTEMS .....	18.6
18.6	SENSING ELEMENTS .....	18.14
18.7	CONTROL SIGNAL TRANSMISSION .....	18.15
18.8	BUILDING AUTOMATION AND CONTROL SYSTEMS .....	18.17
18.9	REMOTE HVAC SYSTEM MONITORING AND CONTROL .....	18.17
18.10	OPEN-ARCHITECTURE CONTROL SYSTEMS .....	18.17
18.11	CONTROL SYSTEM APPLICATIONS .....	18.18
18.12	CONTROL SYSTEM LAYOUT AND OPERATIONAL CONSIDERATIONS .....	18.39
<b>CHAPTER 19</b>	<b>SMOKE CONTROL SYSTEMS</b>	
19.1	INTRODUCTION .....	19.1

19.2	SMOKE CONTROL SYSTEMS .....	19.1
19.3	SMOKE MOVEMENT .....	19.1
19.4	SMOKE MANAGEMENT .....	19.4
19.5	SMOKE CONTROL .....	19.4
19.6	SIMPLE STAIRWELL PRESSURIZATION .....	19.7
19.7	COMPLEX STAIRWELL PRESSURIZATION .....	19.9
19.8	ZONED SMOKE CONTROL .....	19.11
<b>CHAPTER 20 CLEANROOM HVAC SYSTEMS</b>		<b>Page</b>
20.1	INTRODUCTION .....	20.1
20.2	CLASSES OF CLEANROOMS .....	20.1
20.3	CLEANROOM HVAC SYSTEMS .....	20.3
20.4	CLEANROOM AIRFLOW PARAMETERS .....	20.5
20.5	DESIGN AND PERFORMANCE CONSIDERATIONS FOR CLEANROOMS .....	20.10
20.6	CONTROL SYSTEMS .....	20.10
20.7	HVAC DUCTWORK .....	20.12
20.8	TYPICAL CLEANROOM SYSTEMS .....	20.13
20.9	CLEANROOM TESTING .....	20.16
<b>CHAPTER 21 LABORATORY HVAC SYSTEMS</b>		
21.1	INTRODUCTION .....	21.1
21.2	LABORATORY ENVIRONMENTAL REQUIREMENTS .....	21.1
21.3	SUPPLY AIR SYSTEMS .....	21.1
21.4	EXHAUST AIR SYSTEMS .....	21.3
21.5	LABORATORY FUME HOODS .....	21.6
21.6	BIOLOGICAL SAFETY CABINETS .....	21.11
21.7	BIOMEDICAL LABORATORIES AND ANIMAL RESEARCH FACILITIES .....	21.14
<b>APPENDIX A DISPLACEMENT VENTILATION</b>		
A.1	DISPLACEMENT VENTILATION OVERVIEW .....	A.1
A.2	DV SYSTEM OPERATION .....	A.1
A.3	DV SYSTEM THERMAL PLUME .....	A.1
A.4	DV SYSTEM ENERGY CONSIDERATIONS .....	A.2
A.5	CEILING HEIGHT .....	A.2
A.6	HEATING WITH DV SYSTEMS .....	A.2
A.7	DV SYSTEMS AND UNDERFLOOR AIR DISTRIBUTION SYSTEMS .....	A.2
A.8	CONCLUSION .....	A.3
<b>APPENDIX B DEDICATED OUTSIDE AIR SYSTEMS</b>		
B.1	DEDICATED OUTSIDE AIR SYSTEMS OVERVIEW .....	B.1
B.2	DOAS ADVANTAGES .....	B.1
B.3	DOAS DISADVANTAGES .....	B.2
B.4	FRACTIONAL AND INTEGRATED DOAS SYSTEMS .....	B.2
<b>APPENDIX C SUSTAINABLE BUILDING HVAC SYSTEMS</b>		
C.1	SUSTAINABLE BUILDINGS .....	C.1
C.2	WHAT IS A SUSTAINABLE BUILDING? .....	C.1
C.3	SUSTAINABLE BUILDING RATING SYSTEMS .....	C.1
C.4	LEED™ GREEN BUILDING CERTIFICATION .....	C.2
C.5	LEED™ CERTIFICATION .....	C.2
C.6	EXAMPLE LEED™ HVAC REQUIREMENTS .....	C.3
C.7	SUSTAINABLE BUILDING INFORMATION FOR THE HVAC CONTRACTOR .....	C.3



**APPENDIX D THERMAL ENERGY STORAGE**

**Page**

D.1 FULL OR PARTIAL STORAGE ..... D.1

**GLOSSARY**



**TABLES**

	<b>Page</b>
10-1 Boiler Rating by Facility Type .....	10.4
11-1 Basic Heat Pump System Arrangements .....	11.4
14-1 Mechanical Air Filter MERV Rating Information .....	14.4
15-1 Physical and Heat Transfer Characteristics .....	15.30
17-1 System and Motor Voltages .....	17.9
17-2 Voltage Tolerance Ranges .....	17.9
17-3 Voltage Impact on Induction Motor's Operation .....	17.10
17-4 Induction Motor Speeds for Specified Poles .....	17.11
20-1 FS 209(D) Cleanroom Classifications .....	20.1
20-2 History of FS 209: Airborne Particulate Cleanliness Classes in Clean Rooms and Clean Zones .....	20.2
20-3 FS 209(E) Cleanroom Classifications .....	20.2
20-4 ISO 14644 Family of Standards .....	20.3
20-5 ISO Cleanroom and Other Associated Controlled Environments Classifications ...	20.4
20-6 Air Pressure Relationship .....	20.10
20-7 Cleanroom Temperature and Humidity .....	20.10
21-1 Typical Characteristics of Biological Safety Cabinets .....	21.12



**FIGURES**

**Page**

1-1	Comfort Zone .....	1.3
1-2	Basic HVAC System Components .....	1.5
1-3	Typical Central HVAC System .....	1.7
1-4	Commercial Building Energy Use .....	1.8
1-5	HVAC System Selection Parameters .....	1.9
2-1	Typical HVAC Psychrometric Chart .....	2.3
2-2	Psychrometric Chart Example .....	2.4
2-3	Commercial Office Building Floor Plan .....	2.6
2-4	All-Air HVAC System .....	2.9
2-5	Air-Hydronic HVAC System .....	2.11
2-6	All-Hydronic HVAC System .....	2.12
3-1	Basic Single-Zone Cooling Only VAV System .....	3.3
3-2	Basic Multi-Zone Cooling-Only VAV System .....	3.5
3-3	VAV Air Terminal Unit Serving Multiple Air Outlets .....	3.6
3-4	Basic VAV Single-Duct Terminal Unit – Functional Diagram .....	3.7
3-5	Basic VAV Single-Duct Terminal Unit – Cutaway View .....	3.7
3-6	VAV Terminal Unit Types, Configurations, and Features .....	3.8
3-7	Single-Duct VAV Terminal Unit Control Strategy .....	3.9
3-8	Basic VAV Dual-Duct Terminal Unit – Functional Diagram .....	3.10
3-9	Basic VAV Dual-Duct Terminal Unit – Cutaway View .....	3.10
3-10	Dual-Duct VAV Terminal Unit Schematic Diagram .....	3.12
3-11	Dual-Duct VAV Terminal Unit – Non-Blending Control Strategy .....	3.13
3-12	Dual-Duct VAV Terminal Unit – Maximum Heating Blending Control Strategy .....	3.13
3-13	Dual-Duct VAV Terminal Unit – Unequal Flow Blending Control Strategy .....	3.14
3-14	Dual-Duct VAV Terminal Unit – Constant Volume Blending Control Strategy .....	3.14
3-15	Fan-Powered VAV Terminal Unit Schematic Diagram .....	3.15
3-16	Parallel Flow Fan-Powered VAV Terminal Unit – Functional Diagram .....	3.17
3-17	Parallel Flow Fan-Powered VAV Terminal Unit – Cutaway View .....	3.17
3-18	Series Flow Fan-Powered VAV Terminal Unit – Functional Diagram .....	3.19
3-19	Series Flow Fan-Powered VAV Terminal Unit – Cutaway View .....	3.19
3-20	VAV Terminal Unit with Reheat – Functional Diagram .....	3.20
3-21	Bypass (Dump) VAV Terminal Unit – Functional Diagram .....	3.20
3-22	VAV Terminal Unit Inlet Multipoint Pressure Sensor .....	3.23
3-23	Multipoint Pressure Sensor .....	3.23
4-1	Multizone HVAC System .....	4.2
5-1	Typical Terminal Reheat HVAC System Functional Diagram .....	5.2
5-2	Constant Volume Terminal Reheat Unit .....	5.3
6-1	Dual-Duct Single-Fan HVAC System .....	6.2
6-2	Dual-Duct Single-Fan HVAC System Schematic Diagram .....	6.3
6-3	Dual-Duct Dual-Fan HVAC System Schematic Diagram .....	6.4
6-4	Dual-Duct Low Velocity System .....	6.6
6-5	Dual-Duct High Velocity System .....	6.7
6-6	Mixing and Volume Control Method Using Self-Actuated Spring-Loaded Volume Regulator for Constant Volume System .....	6.10
6-7	Mixing and Volume Control Method Using Flow Regulator for Constant Volume System .....	6.11
7-1	Induction Reheat System .....	7.2
7-2	Induction Terminal Unit Functional Diagram .....	7.3
7-3	Two-Pipe Induction Terminal Unit Bypass Control .....	7.4
8-1	Mechanical Refrigeration Cycle .....	8.2
8-2	Rooftop Unitary HVAC System .....	8.7
8-3	Split-System Unitary HVAC System .....	8.10
8-4	Through-The-Wall PTAC with Separate Heating and Cooling Chassis .....	8.12
8-5	Through-The-Wall PTAC with Combined Chassis .....	8.12
9-1	Central Cooling Plant Schematic Diagram .....	9.2
9-2	Vapor-Compression Refrigeration Cycle .....	9.3
9-3	Direct-Contact Evaporative Cooling Tower .....	9.13
9-4	Indirect-Contact Evaporative Cooling Tower .....	9.14
9-5	Forced-Draft Cooling Tower with Counterflow .....	9.16
9-6	Induced-Draft Cooling Tower with Counterflow .....	9.16



**FIGURES**

**Page**

9-7	Forced-Draft Cooling Tower with Crossflow	9.17
9-8	Induced-Draft Cooling Tower with Crossflow	9.17
9-9	Double-Entry Induced-Draft Cooling Tower with Crossflow	9.18
11-1	Basic Heat Pump System Arrangements	11.5
11-2	Air-Source Heat Pump System Schematic Diagram	11.8
11-3	Water-Source Heat Pump System Schematic Diagram	11.9
11-4	Closed Loop Water-To-Air Heat Pump System Schematic Diagram	11.10
13-1	Axial-Flow Fan: Propeller Type	13.2
13-2	Axial-Flow Fan: Tube-Axial Type	13.3
13-3	Axial-Flow Fan: Vane-Axial Type	13.3
13-4	Centrifugal Fan: Backward Inclined (Airfoil) Blade	13.5
13-5	Centrifugal Fan: Radial (Straight) Blade	13.5
13-6	Centrifugal Fan: Forward Curved Blade	13.6
13-7(a)	Summary of Fan Categories, Types, and Characteristics	13.7
13-7(b)	Summary of Fan Categories, Types, and Characteristics	13.8
13-8	Fan Curve for Typical Centrifugal Fan: Backward Inclined Blade	13.9
13-9	Family of Fan Curves	13.11
13-10	Fan Law Example Illustrated with Fan Curves	13.13
13-11	System Curve	13.14
13-12	System Curve Change Due To Increased Resistance To Flow	13.15
13-13	System Operating Point	13.17
13-14	Fan Airflow Modulation "Riding The Fan Curve"	13.18
13-15	Varying Fan Operating Points with Fan Speed	13.19
13-16	Supply Fan Airflow Control Methods	13.21
13-17	Fan Power Input Versus Rated Airflow	13.22
13-18	Air Handling Unit Schematic Diagram	13.25
15-1	Simple Hot Water Distribution System	15.2
15-2	Simple Chilled Water Distribution System	15.3
15-3	One-Pipe Hydronic Distribution System	15.7
15-4	Two-Pipe Hydronic Distribution System (Direct Return)	15.8
15-5	Two-Pipe Hydronic Distribution System (Reverse Return)	15.10
15-6	Three-Pipe Hydronic Distribution System	15.11
15-7	Four-Pipe Hydronic Distribution System (Single Coil Convection Terminal Units)	15.12
15-8	Four-Pipe Hydronic Distribution System (Dual Coil Convection Terminal Units)	15.14
15-9	Multi-Loop Hydronic Distribution System	15.16
15-10	Constant Volume Hydronic Distribution System (Diverting Valve)	15.17
15-11	Diverting Valve	15.18
15-12	Constant Volume Hydronic Distribution System (Mixing Valve)	15.20
15-13	Mixing Valve	15.21
15-14	Single-Seated Two-Way Valve	15.22
15-15	Double-Seated Two-Way Valve	15.22
15-16	Passive Chilled Beam	15.28
15-17	Active Chilled Beam	15.28
16-1	Typical Centrifugal Pump Performance Curves	16.2
16-2	Typical Centrifugal Pump Performance Curves Supplied By Pump Manufacturers	16.5
16-3	Pump and System Curves	16.7
16-4	Correct Pump Connection To Expansion Tank	16.9
16-5	Incorrect Pump Connection To Expansion Tank	16.9
17-1	Typical Integral Horsepower Squirrel Cage Induction Motor	17.3
17-2	Typical Squirrel Cage Induction Motor Rotor	17.3
17-3	Induction Motor Speed-Torque Curve	17.6
17-4	NEMA Design Letter Torque-Speed Curves	17.13
17-5	Typical Full-Voltage Motor Starter	17.15
17-6	HVAC System VFD Use	17.17
17-7	VFD Drive System Functional Diagram	17.18
17-8	Fan and Pump Operation as a Function of Speed	17.20
18-1	Generic HVAC Control System Block Diagram	18.2
18-2	VAV Terminal Unit Control Block Diagram	18.3



**FIGURES**

	<b>Page</b>
18-3	Control Loop . . . . . 18.6
18-4	Example HVAC Closed Loop Control System . . . . . 18.7
18-5	Typical Pneumatic Control System . . . . . 18.9
18-6	Typical Pneumatic Control Valves . . . . . 18.10
18-7	Automatic Multiblade Dampers . . . . . 18.11
18-8	Typical Bleed Type Thermometer and Operator . . . . . 18.13
18-9	Thermostat Flapper-Nozzle-Bimetal Assembly . . . . . 18.14
18-10	Static Pressure Control of Outdoor Air . . . . . 18.20
18-11	Basic Economy Cycle for Control of Outdoor Air . . . . . 18.20
18-12	Enthalpy Control of Outdoor Air . . . . . 18.21
18-13	Outdoor Air Control of Preheat Coil . . . . . 18.22
18-14	Preheat Secondary Pump and Three-Way Valve . . . . . 18.22
18-15	Preheat Secondary Pump and Two-Way Valve . . . . . 18.23
18-16	Heating Coil and Two-Way Valve . . . . . 18.23
18-17	Electric Coil with Solid-State Controller . . . . . 18.25
18-18	Cooling and Dehumidification: Practical Low Limit . . . . . 18.25
18-19	Cooling and Dehumidification with Reheat . . . . . 18.26
18-20	Evaporative Cooling Process . . . . . 18.27
18-21	Evaporative Cooling with an Air Washer . . . . . 18.27
18-22	Pan humidifier Control . . . . . 18.28
18-23	Mixed Loads with Demand Reset . . . . . 18.29
18-24	Coil Control Using a Three-Way Valve . . . . . 18.30
18-25	Pump and System Curves with Valve Control . . . . . 18.31
18-26	Two-Way Valve with Pump Bypass . . . . . 18.32
18-27	Two-Pipe Central Plant System . . . . . 18.33
18-28	Control of a Hot Water Boiler . . . . . 18.34
18-29	Hydronic System Load and Zone Control . . . . . 18.36
18-30	Stem-To-Hot Water Heat Exchange Control . . . . . 18.36
18-31	Duct Heater Control . . . . . 18.37
18-32	Dead Band Control System . . . . . 18.40
19-1	Smoke Control System Design Factors . . . . . 19.2
19-2	Air Movement Due to Normal and Reverse Stack Effect . . . . . 19.3
19-3	Smoke Control System Using Pressure Differential Across a Smoke Barrier To Prevent Smoke Migration From The Low- to the High-Pressure Side . . . . . 19.5
19-4	Smoke Backflow Against Low Air Velocity Through an Open Doorway . . . . . 19.5
19-5	No Smoke Backflow with High Air Velocity Through an Open Doorway . . . . . 19.6
19-6	Top Injection Stairwell Pressurization . . . . . 19.8
19-7	Multiple Injection with Ground Level Fan . . . . . 19.8
19-8	Multiple Injection with Roof Mounted Fan . . . . . 19.9
19-9	Stairwell Pressurization with Air Supply at Each Floor . . . . . 19.10
19-10	Stairwell Pressurization with Bypass Around Supply Fan . . . . . 19.11
19-11	Typical Smoke Control Zone Arrangements . . . . . 19.13
20-1	Conventional Flow Cleanroom . . . . . 20.6
20-2	Cross Flow Laminar Flow Cleanroom . . . . . 20.6
20-3	Down Flow Laminar Flow Cleanroom . . . . . 20.7
20-4	Laminar Flow Workstations . . . . . 20.8
20-5	Typical Secondary Air Location: Cross Flow Laminar Flow Cleanroom . . . . . 20.8
20-6	Conventional Cleanroom with Bypass Fan . . . . . 20.9
20-7	Conventional Cleanroom with Packaged Fan/HEPA Units . . . . . 20.9
20-8	Cleanroom Mechanical Design Considerations . . . . . 20.11
20-9	Typical ISO Class 4 Cleanroom . . . . . 20.14
20-10	Typical ISO Class 5 Cleanroom . . . . . 20.15
20-11	Typical ISO Class 7 Cleanroom . . . . . 20.17
21-1	Typical Process Fume Hood . . . . . 21.8
21-2	Typical Bypass Fume Hood with Vertical Sash and Bypass Air Inlet . . . . . 21.9
21-3	Typical Auxiliary Fume Hood . . . . . 21.10
21-4	Typical Class I Biological Safety Cabinet . . . . . 21.12
21-5	Typical Class II Type A Biological Safety Cabinet . . . . . 21.13
21-6	Typical Class II Type B Biological Safety Cabinet . . . . . 21.14
21-7	NIH Design Requirements Manual Contents . . . . . 21.16



**CHAPTER 1**

**INTRODUCTION**



## 1.1 INTRODUCTION

This chapter provides an introduction to heating, ventilating, and air conditioning (HVAC) applications. This chapter starts with stating the purpose of HVAC systems followed by a discussion of human thermal comfort and the industry standards that are used to establish the operating parameters for HVAC systems. Basic HVAC system components are then identified and discussed and a typical central HVAC system is presented. The importance of HVAC operating efficiency is addressed along with discussion of energy codes and standards. Energy codes and standards, green building rating systems and their relationship to HVAC system applications are also covered. This chapter closes by addressing various issues that should be considered when selecting, designing, and installing HVAC systems.

## 1.2 HVAC SYSTEM PURPOSE

The purpose of an HVAC system is to provide a suitable thermal environment in a defined space that meets the needs of the occupants and the activity that takes place in the space. Most HVAC systems are installed to establish an indoor environment within which building occupants can live, work, and play. The indoor environment impacts the quality of life, productivity, and well being of building occupants. As people spend an increasing amount of time inside buildings HVAC systems and their associated control systems are becoming more important. To address this growing need this manual focuses on HVAC equipment that creates human comfort indoors. Energy use in buildings is becoming increasingly important and impacting the type of the HVAC distribution system design, the HVAC equipment specified, and how the HVAC operates. HVAC systems are also required to provide suitable environmental conditions in addition to providing human comfort. In addition, energy use in buildings is becoming increasingly important and impacting the type of the HVAC distribution system design, the HVAC equipment specified, and how the HVAC operates. HVAC systems are also required to provide suitable environmental conditions for purposes other than human comfort.

## 1.3 HUMAN THERMAL COMFORT

### 1.3.1 Variables That Determine Human Thermal Comfort

Human thermal comfort is determined by the following four variables:

- Temperature
- Humidity
- Air Movement
- Air Quality

The objective of an HVAC system installed for human comfort is to control these four variables within an acceptable range for the occupants in the zone served by the HVAC system. The zone can be an entire building, an enclosed space within a building such as a room, or an area within a building. The HVAC system must be capable of controlling these four variables considering the activity taking place in the zone as well as changes in the outside environment, changes in the occupancy of the zone, and changes in the activity taking place in the zone. All of these changes take place continuously throughout the day and the HVAC system must be able to adjust and adapt to the dynamic nature of building thermal loads.

### 1.3.2 Establishing Parameters For Human Thermal Comfort

There are a number of industry standards and recommended practices that provide recommendations and guidance in establishing the parameters for achieving human thermal comfort for a given occupancy that take into account the activity being performed in the zone served by the HVAC system. Two important industry standards that establish the general parameters for human thermal comfort are published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) and are as follows:

- ASHRAE Standard 55-2004: *Thermal Environmental Conditions for Human Occupancy*
- ASHRAE Standard 62.1-2004: *Ventilation for Acceptable Indoor Air Quality*

Both of these standards are referenced in building codes, project technical specifications, and green building rating systems and their requirements may be mandatory on a building project. The following sections will discuss each of these industry standards.

#### 1.3.2.1 ASHRAE Standard 55

ASHRAE Standard 55 specifies the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80 percent of the occupants in a space. The environmental factors addressed are temperature,

