

2004
ASHRAE HANDBOOK

**HVAC Systems
and Equipment**

I-P Edition

Supported by ASHRAE Research

2004 ASHRAE® HANDBOOK

**Heating, Ventilating,
and
Air-Conditioning
SYSTEMS AND EQUIPMENT**

Inch-Pound Edition

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

1791 Tullie Circle, N.E., Atlanta, GA 30329

(404) 636-8400

<http://www.ashrae.org>

Copyright ©2004 by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. All rights reserved.

**DEDICATED TO THE ADVANCEMENT OF
THE PROFESSION AND ITS ALLIED INDUSTRIES**

No part of this book may be reproduced without permission in writing from ASHRAE, except by a reviewer who may quote brief passages or reproduce illustrations in a review with appropriate credit; nor may any part of this book be reproduced, stored in a retrieval system, or transmitted in any form or by any means—electronic, photocopying, recording, or other—without permission in writing from ASHRAE.

Volunteer members of ASHRAE Technical Committees and others compiled the information in this handbook, and it is generally reviewed and updated every four years. Comments, criticisms, and suggestions regarding the subject matter are invited. Any errors or omissions in the data should be brought to the attention of the Editor. Additions and corrections to Handbook volumes in print will be published in the Handbook published the year following their verification and, as soon as verified, on the ASHRAE Internet Web site.

DISCLAIMER

ASHRAE has compiled this publication with care, but ASHRAE has not investigated, and ASHRAE expressly disclaims any duty to investigate, any product, service, process, procedure, design, or the like that may be described herein. The appearance of any technical data or editorial material in this publication does not constitute endorsement, warranty, or guaranty by ASHRAE of any product, service, process, procedure, design, or the like. ASHRAE does not warrant that the information in this publication is free of errors. The entire risk of the use of any information in this publication is assumed by the user.

ISBN 1-931862-47-8

CONTENTS

Contributors

ASHRAE Technical Committees, Task Groups, and Technical Resource Groups

ASHRAE Research: Improving the Quality of Life

Preface

AIR-CONDITIONING AND HEATING SYSTEMS

- Chapter*
1. **HVAC System Analysis and Selection** (TC 9.1, Large Building Air-Conditioning Systems)
 2. **Building Air Distribution** (TC 9.1)
 3. **In-Room Terminal Systems** (TC 9.1)
 4. **Central Cooling and Heating** (TC 9.1)
 5. **Decentralized Cooling and Heating** (TC 9.1)
 6. **Panel Heating and Cooling** (TC 6.5, Radiant Space Heating and Cooling)
 7. **Cogeneration Systems and Engine and Turbine Drives** (TC 1.10, Cogeneration Systems)
 8. **Applied Heat Pump and Heat Recovery Systems**
(TC 9.4, Applied Heat Pump/Heat Recovery Systems)
 9. **Design of Small Forced-Air Heating and Cooling Systems**
(TC 6.3, Central Forced Air Heating and Cooling Systems)
 10. **Steam Systems** (TC 6.1, Hydronic and Steam Equipment and Systems)
 11. **District Heating and Cooling** (TC 6.2, District Energy)
 12. **Hydronic Heating and Cooling System Design** (TC 6.1)
 13. **Condenser Water Systems** (TC 6.1)
 14. **Medium- and High-Temperature Water Heating Systems** (TC 6.1)
 15. **Infrared Radiant Heating** (TC 6.5)

AIR-HANDLING EQUIPMENT

- Chapter*
16. **Duct Construction** (TC 5.2, Duct Design)
 17. **Room Air Distribution Equipment** (TC 5.3, Room Air Distribution)
 18. **Fans** (TC 5.1, Fans)
 19. **Evaporative Air-Cooling Equipment** (TC 5.7, Evaporative Cooling)
 20. **Humidifiers** (TC 5.11, Humidifying Equipment)
 21. **Air-Cooling and Dehumidifying Coils** (TC 8.4, Air-to-Refrigerant Heat Transfer Equipment)
 22. **Desiccant Dehumidification and Pressure Drying Equipment**
(TC 8.12, Desiccant and Sorption Technology)
 23. **Air-Heating Coils** (TC 8.4)
 24. **Air Cleaners for Particulate Contaminants** (TC 2.4, Particulate Air Contaminants and Particulate Contaminant Removal Equipment)
 25. **Industrial Gas Cleaning and Air Pollution Control**
[TC 5.4, Industrial Process Air Cleaning (Air Pollution Control)]

HEATING EQUIPMENT

- Chapter*
- 26. **Automatic Fuel-Burning Equipment** (TC 6.10, Fuels and Combustion)
 - 27. **Boilers** (TC 6.1)
 - 28. **Furnaces** (TC 6.3)
 - 29. **Residential In-Space Heating Equipment** (TC 6.4, In Space Convection Heating)
 - 30. **Chimney, Gas Vent, and Fireplace Systems** (TC 6.10)
 - 31. **Unit Ventilators, Unit Heaters, and Makeup Air Units**
(TC 6.1 and TC 5.8, Industrial Ventilation Systems)
 - 32. **Hydronic Heat-Distributing Units and Radiators** (TC 6.1)
 - 33. **Solar Energy Equipment** (TC 6.7, Solar Energy Utilization)

GENERAL COMPONENTS

- Chapter*
- 34. **Compressors** (TC 8.1, Positive Displacement Compressors, and TC 8.2, Centrifugal Machines)
 - 35. **Condensers** (TC 8.5, Liquid-to-Refrigerant Heat Exchangers, TC 8.4, and TC 8.6, Cooling Towers and Evaporative Condensers)
 - 36. **Cooling Towers** (TC 8.6)
 - 37. **Liquid Coolers** (TC 8.5)
 - 38. **Liquid-Chilling Systems** (TC 8.1 and TC 8.2)
 - 39. **Centrifugal Pumps** (TC 6.1)
 - 40. **Motors, Motor Controls, and Variable-Speed Drives**
(TC 1.11, Electric Motors and Motor Control)
 - 41. **Pipes, Tubes, and Fittings** (TC 6.1)
 - 42. **Valves** (TC 6.1)
 - 43. **Heat Exchangers** (TC 6.1)
 - 44. **Air-to-Air Energy Recovery** (TC 5.5, Air-to-Air Energy Recovery)

UNITARY EQUIPMENT

- Chapter*
- 45. **Unitary Air Conditioners and Heat Pumps** (TC 8.11, Unitary and Room Air Conditioners and Heat Pumps)
 - 46. **Room Air Conditioners and Packaged Terminal Air Conditioners** (TC 8.11)
 - 47. **Mechanical Dehumidifiers and Heat Pipes**
(TC 8.10, Mechanical Dehumidification Equipment and Heat Pipes)
 - 48. **Codes and Standards**

ADDITIONS AND CORRECTIONS

INDEX

Composite index to the 2001 Fundamentals, 2002 Refrigeration, 2003 HVAC Applications, and 2004 HVAC Systems and Equipment volumes

CONTRIBUTORS

In addition to the Technical Committees, the following individuals contributed significantly to this volume. The appropriate chapter numbers follow each contributor's name.

- | | | |
|--|--|---|
| Howard McKew (1, 4)
Richard D. Kimball Company, Inc. | Richard A. Hegberg (10, 31)
Hegberg & Associates | Eugene L. Valerio (24)
Technical Marketing Services |
| Gil Avery (2)
Kele Companies | Vernon P. Meyer (11)
U.S. Army Corps of Engineers
Missouri River Division | Derald G. Welles (24)
Steril-Aire, Inc. |
| Gene R. Strehlow (2)
Johnson Controls, Inc. | Victor L. Penar (11)
Perma-Pipe, Inc. | David J. Murphy (25)
Air Filter Testing Labs |
| David M. Elovitz (3)
Energy Economics, Inc. | Gary E. Phetteplace (11)
U.S. Army Cold Regions Research and
Engineering Laboratory | Jeanette M. Murphy (25)
Air Filter Testing Labs |
| Stephen Duda (4)
Ross and Baruzzini | Clinton W. Phillips (11) | Leonard J. O'Dell (25) |
| Mark W. Fly (4)
Gouvernaire Corporation | Kathleen M. Posteraro (11)
Pittsburgh Corning Corporation | Gregory R. Thiel (25)
Thiel Consulting, Inc. |
| Carl Lawson (5)
PWI Consulting Engineers | Kevin D. Rafferty (11)
Geo-Heat Center
Oregon Institute of Technology | Douglas W. Vanosdell (25)
Research Triangle Institute |
| Birol Kilkis (6, 15)
Watts Radiant | Steven M. Tredinnick (11)
Kattner/FVB | Douglas W. DeWerth (26, 30) |
| Ainul Abedin (7)
Ainul Abedin Consulting Engineers | William J. Coad (12, 13)
Coad Engineering Enterprises | Hall Virgil (26, 30)
Carrier Corporation |
| John S. Andrepont (7)
The Cool Solutions Company | Alexander H. Sleiman (14)
District Energy St. Paul, Inc. | Kevin J. Hoey (27)
EASCO Boiler Corporation |
| Ali Jalalzadeh-Azar (7)
National Renewable Energy Laboratory | Herman Behls (16)
Behls & Associates | Paul M. Haydock (28)
Carrier Corporation |
| Jay Jayaraman (7)
Enbridge Gas Distribution, Inc. | Patrick J. Brooks (16)
United McGill Corporation | Frank E. Jakob (28)
Battelle Columbus |
| Sriram Somasundaram (7)
Battelle-Pacific National Labs | John H. Stratton (16) | Wayne M. Lawton (31)
ARCADIS |
| Richard Sweetser (7)
EXERGY Partners Group | Brian Rock (17)
University of Kansas | Michael P. O'Rourke (32)
Mestek |
| James H. Watts (7)
Ingersoll-Rand Energy Systems | Walter R. Ziemann (18) | John I. Woodworth (32) |
| Abdi Zaltash (7)
Oak Ridge National Laboratory | John D. Guinn (19)
Bridges & Paxton | Mark Hertel (33)
SunEarth, Inc. |
| R.L. Douglas Cane (8)
Caneta Research, Inc. | Gursaran D. Mathur (19, 44)
Calsonic Kansei North America, Inc. | Albert Domingorena (34, 38)
Hussmann Corporation |
| John Andrews (9, 28)
Brookhaven National Laboratory | Leon Shaprio (19)
ADA Systems | Richard Hall (34, 38)
Battelle |
| Roger Hedrick (9)
Gard Analytics | Roger M. Pasch (20)
Research Products Corporation | Hermann Renz (34, 38)
Bitzer Kuhlmaschinenbau |
| Michael Lubliner (9)
Washington State University
Energy Program | Roland Ares (21, 23, 35) | John M. Edmonds (35, 36)
Edmonds Engineering Company |
| Roy C.E. Ahlgren (10, 39)
ITT Fluid Handling | Lew Harriman (22)
Mason-Grant Consulting | Daniel Kramer (35)
Kramer Engineering |
| | Larry C. Holcomb (24)
Holcomb Environmental Services | Paul Lindahl (35, 36)
Marley Cooling Tower Company |
-

Frank T. Morrison (35, 36)
Baltimore Aircoil Company

George R. Shriver (35, 36)
Evapco, Inc.

Ronald E. Woods (35, 36)
U.S. General Services Administration

James E. Bogart (37)
FlatPlate, Inc.

Louay M. Chamra (37)
Mississippi State University

John R. Thome (37)
Laboratory of Heat and Mass Transfer

Kenneth R. Luther (39)
ITT Fluid Handling

Joseph A. Thuman (39, 41)
Wallace Eannace Associates Inc.

Thomas F. Lowery (40)
Rockwell Automation-Reliance Electric

Sherri L. Peterson (40)
The Trane Company

Edward J. Swan (40)
Rockwell Automation

Richard E. Batherman (41)
VICO, Inc.

Paul A. Bourquin (41)

Randall J. Amerson (42)
Siemens Building Technologies, Inc.

Carl H. Jordan (42)

John C. Glunt (43)
Blackmore and Glunt

Prakash Damshala (44)
University of Tennessee-Chatanooga

Van D. Baxter (45, 46)
Lockheed Martin Energy Corporation

Piotr A. Domanski (45, 46)
National Institute of Standards
and Technology

Hugh I. Henderson (45)
CDH Energy Corporation

William Vance Payne II (45)
National Institute of Standards
and Technology

Gregory Rosenquist (45, 46)
Lawrence Berkeley National Laboratory

Don B. Shirey III (45)
Florida Solar Energy Center

Larry Wethje (46)
Association of Home Appliance
Manufacturers

Kenneth Cooper (47)
PoolPak International

Keith Coursin (47)
Desert Aire Corporation

Titu Doctor (47)
CENC, Inc.

Reinhold Kittler (47)
Dectron, Inc.

Harry Milliken (47)
Desert Aire Corporation

Dick Trent (47)
Carolina Heat Pipe, Inc.

ASHRAE HANDBOOK COMMITTEE

Kenneth W. Cooper, Chair

2004 HVAC Systems and Equipment Volume Subcommittee: **Lynn F. Werman**, Chair

Monica Y. Amalfitano **Prakash R. Damshala** **Ronald L. Davis** **Kevin J. Hoey** **J. Hal Lunsford** **Garry N. Myers**

ASHRAE HANDBOOK STAFF

Mark S. Owen, Editor

Heather E. Kennedy, Associate Editor

Nancy F. Thysell, Typographer/Page Designer

Barry Kurian, Manager and **Jayne E. Jackson**
Publishing Services

W. Stephen Comstock,
Director, Communications and Publications
Publisher

ASHRAE TECHNICAL COMMITTEES, TASK GROUPS, AND TECHNICAL RESOURCE GROUPS

SECTION 1.0—FUNDAMENTALS AND GENERAL

- 1.1 Thermodynamics and Psychrometrics
- 1.2 Instruments and Measurement
- 1.3 Heat Transfer and Fluid Flow
- 1.4 Control Theory and Application
- 1.5 Computer Applications
- 1.6 Terminology
- 1.7 Business, Management & General Legal Education
- 1.8 Mechanical Systems Insulation
- 1.9 Electrical Systems
- 1.10 Cogeneration Systems
- 1.11 Electric Motors and Motor Control
- 1.12 Moisture Management in Buildings

SECTION 2.0—ENVIRONMENTAL QUALITY

- 2.1 Physiology and Human Environment
- 2.2 Plant and Animal Environment
- 2.3 Gaseous Air Contaminants and Gas Contaminant Removal Equipment
- 2.4 Particulate Air Contaminants and Particulate Contaminant Removal Equipment
- 2.5 Global Climate Change
- 2.6 Sound and Vibration Control
- 2.7 Seismic and Wind Restraint Design
- 2.8 Building Environmental Impacts and Sustainability
- TRG Blast, Chemical and Biological Remediation

SECTION 3.0—MATERIALS AND PROCESSES

- 3.1 Refrigerants and Secondary Coolants
- 3.2 Refrigerant System Chemistry
- 3.3 Refrigerant Contaminant Control
- 3.4 Lubrication
- 3.5 Water Treatment
- 3.6 Refrigerant Containment

SECTION 4.0—LOAD CALCULATIONS AND ENERGY REQUIREMENTS

- 4.1 Load Calculation Data and Procedures
- 4.2 Weather Information
- 4.3 Building Materials and Building Envelope Performance
- 4.4 Fenestration
- 4.5 Energy Calculations
- 4.6 Indoor Environmental Modeling

SECTION 5.0—VENTILATION AND AIR DISTRIBUTION

- 5.1 Fans
- 5.2 Duct Design
- 5.3 Room Air Distribution
- 5.4 Industrial Process Air Cleaning (Air Pollution Control)
- 5.5 Air-to-Air Energy Recovery
- 5.6 Control of Fire and Smoke
- 5.7 Evaporative Cooling
- 5.8 Industrial Ventilation Systems
- 5.9 Enclosed Vehicular Facilities
- 5.10 Kitchen Ventilation
- 5.11 Humidifying Equipment
- 5.12 Ventilation Requirements and Infiltration

SECTION 6.0—HEATING EQUIPMENT, HEATING AND COOLING SYSTEMS AND APPLICATIONS

- 6.1 Hydronic and Steam Equipment and Systems
- 6.2 District Energy
- 6.3 Central Forced Air Heating and Cooling Systems
- 6.4 In Space Convection Heating
- 6.5 Radiant Space Heating and Cooling
- 6.6 Service Water Heating
- 6.7 Solar Energy Utilization
- 6.8 Geothermal Energy Utilization
- 6.9 Thermal Storage
- 6.10 Fuels and Combustion

SECTION 7.0—BUILDING PERFORMANCE

- 7.1 Integrated Building Design
- 7.2 Operation and Maintenance Management
- 7.3 Building Operation Dynamics
- 7.4 Smart Building Systems
- 7.5 Systems Energy Utilization
- 7.6 Testing and Balancing
- 7.7 Owning and Operating Costs
- 7.8 Building Commissioning

SECTION 8.0—AIR-CONDITIONING AND REFRIGERATION SYSTEM COMPONENTS

- 8.1 Positive Displacement Compressors
- 8.2 Centrifugal Machines
- 8.3 Absorption and Heat Operated Machines
- 8.4 Air-to-Refrigerant Heat Transfer Equipment
- 8.5 Liquid-to-Refrigerant Heat Exchangers
- 8.6 Cooling Towers and Evaporative Condensers
- 8.7 Combustion Gas Turbine Inlet Air Cooling Systems
- 8.8 Refrigerant System Controls and Accessories
- 8.9 Residential Refrigerators and Food Freezers
- 8.10 Mechanical Dehumidification Equipment and Heat Pipes
- 8.11 Unitary and Room Air Conditioners and Heat Pumps
- 8.12 Desiccant and Sorption Technology

SECTION 9.0—BUILDING APPLICATIONS

- 9.1 Large Building Air-Conditioning Systems
- 9.2 Industrial Air Conditioning
- 9.3 Transportation Air Conditioning
- 9.4 Applied Heat Pump/Heat Recovery Systems
- 9.5 Residential and Small Building Applications
- 9.6 Large Building Air-Conditioning Applications
- 9.7 Mission Critical Facilities, Technology Spaces and Electronic Equipment
- 9.8 Laboratory Systems
- 9.9 Clean Space
- 9.10 Tall Buildings

SECTION 10.0—REFRIGERATION SYSTEMS

- 10.1 Custom Engineered Refrigeration Systems
 - 10.2 Automatic Icemaking Plants and Skating Rinks
 - 10.3 Refrigerant Piping
 - 10.4 Ultra-Low Temperature Systems and Cryogenics
 - 10.5 Refrigerated Distribution and Storage Facilities
 - 10.6 Transport Refrigeration
 - 10.7 Commercial Food and Beverage Cooling Display and Storage
 - 10.8 Refrigeration Load Calculations
 - 10.9 Refrigeration Application for Foods and Beverages
 - TG10.MOC Immiscible Oil Refrigerant Systems
-

ASHRAE Research: Improving the Quality of Life

The American Society of Heating, Refrigerating and Air-Conditioning Engineers is the world's foremost technical society in the fields of heating, ventilation, air conditioning, and refrigeration. Its members worldwide are individuals who share ideas, identify needs, support research, and write the industry's standards for testing and practice. The result is that engineers are better able to keep indoor environments safe and productive while protecting and preserving the outdoors for generations to come.

One of the ways that ASHRAE supports its members' and industry's need for information is through ASHRAE Research. Thousands of individuals and companies support ASHRAE Research

annually, enabling ASHRAE to report new data about material properties and building physics and to promote the application of innovative technologies.

Chapters in the ASHRAE Handbook are updated through the experience of members of ASHRAE technical committees and through results of ASHRAE Research reported at ASHRAE meetings and published in ASHRAE special publications and in *ASHRAE Transactions*.

For information about ASHRAE Research or to become a member, contact ASHRAE, 1791 Tullie Circle, Atlanta, GA 30329; telephone: 404-636-8400; www.ashrae.org.

Preface

The 2004 *ASHRAE Handbook—HVAC Systems and Equipment* discusses various common systems and the equipment (components or assemblies) that comprise them, and describes features and differences. This information helps system designers and operators in selecting and using equipment. A new chapter (47), Mechanical Dehumidifiers and Heat Pipes, has been added. ASHRAE Technical Committees have updated chapters for current technology, clarified existing information, deleted obsolete material, and reorganized some chapters. Some of the revisions are as follows:

- Chapter 1, HVAC System Analysis and Selection, has expanded lists and discussion of system selection criteria.
- Chapter 2, Building Air Distribution, has added information on mixing plenums and static air mixers.
- Chapter 3, In-Room Terminal Systems, contains more information on both humidity control and fan-coils.
- Chapter 4, Central Cooling and Heating, has been rewritten to include more information on central systems' advantages and disadvantages; controls; and considerations for plant location, including noise and vibration.
- Chapter 5, Decentralized Cooling and Heating, has been updated throughout, with additional discussion on advantages and disadvantages of various systems.
- Chapter 6, Panel Heating and Cooling, extensively revised, now has panel performance rating equations and information on hybrid (load-sharing) systems using panels.
- Chapter 7, Cogeneration Systems and Engine and Turbine Drives, now contains content previously published in the 2000 volume's Chapter 47, Engine-Driven Heating and Cooling Equipment, plus new information on electrical system interface, fuel cells, and microturbines.
- Chapter 8, Applied Heat Pump and Heat Recovery Systems, has added the results of two ASHRAE research projects that (1) provided guidelines for evaluating the environmental benefits of using heat recovery heat pumps, and (2) evaluated computer models for water loop heat pumps and heat recovery chillers.
- Chapter 9, Design of Small Forced-Air Heating and Cooling Systems, has expanded discussions on commercial systems and on air distribution design considerations, especially duct location, leakage, and insulation.
- Chapter 16, Duct Construction, has been updated for research on sealing of duct/terminal connections, and has new sections on antimicrobial and fabric ducts.
- Chapter 17, Room Air Distribution Equipment, has been updated throughout and included new sections on supply nozzles and variable-geometry diffusers.
- Chapter 18, Fans, contains new sections on calculating the temperature rise across fans and on fan vibration concerns.

- Chapter 21, Air Cooling and Dehumidifying Coils, has expanded coil construction descriptions and new maintenance recommendations.
- Chapter 22, Desiccant Dehumidification and Pressure-Drying Equipment, updated for new technology, also has new material on ventilation air applications, plus a description of an interactive desiccant wheel performance estimator available on the TC 8.12 homepage via the ASHRAE Web site.
- Chapter 23, Air-Heating Coils, has updated sections on steam coils and coil maintenance.
- Chapter 35, Condensers, has added a comparison of water-cooled versus air-cooled condensers and information on biological control, brazed condensers, pony motors, and purging non-condensables.
- Chapter 36, Cooling Towers, has more information on closed-circuit towers, capacity control (including variable-frequency drives), critical speeds, biological control, wet/dry towers, plume, and cold-weather operation.
- Chapter 37, Liquid Coolers, has expanded descriptions of cooler types, including a new table listing feed devices, capacity ranges, and commonly used refrigerants for each.
- Chapter 44, Air-to-Air Energy Recovery, extensively revised, has added examples, figures, and calculation procedures, plus new material on air leakage, performance ratings, fan power requirements, pressure drop, and membrane plate heat exchangers.
- Chapter 46, Room Air Conditioners and Packaged Terminal Air Conditioners, no longer has dehumidifier information (see new Chapter 47) but has added tables on energy efficiency standards for room air conditioners.
- Chapter 47, Mechanical Dehumidifiers and Heat Pipes, a new chapter, includes basic construction and operating practices on this equipment for high-dew-point applications, plus discussion of heat pipes and their use with mechanical dehumidifiers.

This Handbook volume is published, both as a bound print volume and in electronic format on a CD-ROM, in two editions: one using inch-pound (I-P) units of measurement, the other using the International System of Units (SI).

Corrections to the 2001, 2002, and 2003 Handbook volumes are posted on the ASHRAE Web site at <http://www.ashrae.org>. Corrections for this volume will be reported in the 2005 *ASHRAE Handbook—Fundamentals* and on the ASHRAE Web site.

To make suggestions for improving a chapter or for information on how you can help revise a chapter, please comment using the form on the ASHRAE Web site; or e-mail mowen@ashrae.org; or write to Handbook Editor, ASHRAE, 1791 Tullie Circle, Atlanta, GA 30329; or fax 404-321-5478.

Mark S. Owen
ASHRAE Handbook Editor

CHAPTER 1

HVAC SYSTEM ANALYSIS AND SELECTION

<i>Selecting a System</i>	1.1
<i>HVAC Systems and Equipment</i>	1.3
<i>Space Requirements</i>	1.5
<i>Air Distribution</i>	1.6
<i>Piping</i>	1.7
<i>System Management</i>	1.7

AN HVAC system maintains desired environmental conditions in a space. In almost every application, many options are available to the design engineer to satisfy this basic goal. In the selection and combination of these options, the design engineer must consider all criteria defined here to achieve the functional requirements associated with the goal.

HVAC systems are categorized by the method used to control heating, ventilating, and air conditioning in the conditioned area. This chapter addresses procedures for selecting the appropriate system for a given application. It also describes and defines the design concepts and characteristics of basic HVAC systems. Chapters 2 through 5 describe specific systems and their attributes, based on their heating and cooling medium and commonly used variations.

This chapter applies to HVAC conversion, upgrades, retrofits, building renovations and expansion, and new construction. This analysis and selection process helps determine the optimum system(s) for any building. Regardless of facility type, analysis examines objective, subjective, short-term, and long-term goals.

SELECTING A SYSTEM

The design engineer is responsible for considering various systems and recommending one or two that will meet the goal and perform as desired. It is imperative that the design engineer and owner collaborate to identify and prioritize criteria associated with the design goal. Occupant comfort, process heating, and cooling or ventilation criteria may be considered, including the following:

- Temperature
- Humidity
- Air motion
- Air purity or quality
- Air changes per hour
- Air and/or water velocity requirements
- Local climate
- Mean radiant temperature (MRT)
- Space pressure requirements
- Capacity requirements, from a load calculation analysis
- Redundancy
- Spatial requirements
- First cost
- Operating cost, including energy and power costs
- Maintenance cost
- Reliability
- Flexibility
- Life cycle analysis
- Sustainability of design
- Acoustics and vibration
- Mold and mildew prevention

Because these factors are interrelated, the owner and design engineer must consider how these criteria affect each other. The relative importance of factors such as these varies with different owners and often changes from one project to another for the same owner. For example, typical owner concerns include first cost compared to operating cost, extent and frequency of maintenance and whether that maintenance requires entering the occupied space, expected frequency of system failure, effect of a failure, and time required to correct the failure. Each concern has a different priority, depending on the owner's goals.

Additional Goals

In addition to the primary goal of providing the desired environment, the design engineer must be aware of and account for other goals the owner may require. These goals may include the following:

- Supporting a process, such as operation of computer equipment
- Promoting a germ-free environment
- Increasing sales
- Increasing net rental income
- Increasing property salability

The owner can only make appropriate value judgments if the design engineer provides complete information on the advantages and disadvantages of each option. Just as the owner does not usually know the relative advantages and disadvantages of different systems, the design engineer rarely knows all the owner's financial and functional goals. Hence, the owner must be involved in system selection.

System Constraints

Once the goal criteria and additional goal options are listed, many constraints must be determined and documented. These constraints may include the following:

- Performance limitations (e.g., temperature, humidity, space pressure)
- Available capacity
- Available space
- Available utility source
- Building architecture
- Construction budget
- Construction schedule
- Equipment availability (i.e., delivery lead-times)

Few projects allow detailed quantitative evaluation of all alternatives. Common sense, historical data, and subjective experience can be used to narrow choices to one or two potential systems.

Heating and air-conditioning loads often contribute to constraints, narrowing the choice to systems that will fit in available space and be compatible with building architecture. Chapters 28 and 29 of the 2001 *ASHRAE Handbook—Fundamentals* describe methods to determine the size and characteristics of heating and air-conditioning loads. By establishing the capacity requirement, equipment size can be determined, and the choice may be narrowed to those systems that work well on projects within a size range.

The preparation of this chapter is assigned to TC 9.1, Large Building Air-Conditioning Systems.