

**PRINCIPLES
OF HEATING
VENTILATING
AND
AIR CONDITIONING**

ABOUT THE AUTHORS

Ronald H. Howell, PhD, PE, Fellow ASHRAE, retired as professor and chair of mechanical engineering at the University of South Florida and is also professor emeritus of the University of Missouri-Rolla. For 40 years he taught courses in refrigeration, heating and air conditioning, thermal analysis, and related areas. He has been the principal or co-principal investigator of 12 ASHRAE-funded research projects. His industrial and consulting engineering experience ranges from ventilation and condensation problems to the development and implementation of a complete air curtain test program.

Harry J. Sauer, Jr., PhD, PE, Fellow ASHRAE, is a professor of mechanical and aerospace engineering at the University of Missouri-Rolla. He has taught courses in air conditioning, refrigeration, environmental quality analysis and control, and related areas. His current research ranges from experimental boiling/condensing heat transfer and energy recovery equipment for HVAC systems to computer simulations of building energy use and actual monitoring of residential energy use. He has served as an advisor to the Missouri state government and has conducted energy auditor training programs for the US Department of Energy.

William J. Coad, PE, Fellow ASHRAE, was ASHRAE president in 2001-2002. He has been with McClure Engineering Associates, St. Louis, Mo., for 40 years and is currently a consulting principal. He is also president of Coad Engineering Enterprises. He has served as a consultant to the Missouri state government and was a lecturer in mechanical engineering for 12 years and an affiliate professor in the graduate program for 17 years at Washington University, St. Louis. He is the author of *Energy Engineering and Management for Building Systems* (Van Nostrand Reinhold).

PRINCIPLES OF HEATING VENTILATING AND AIR CONDITIONING

A Textbook with Design Data Based on the
2005 ASHRAE Handbook—Fundamentals

Ronald H. Howell

Harry J. Sauer, Jr.

William J. Coad



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

ISBN 1-931862-92-3

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and Air-Conditioning Engineers, Inc.
1791 Tullie Circle, N.E.
Atlanta, GA 30329
www.ashrae.org

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Printed in the United States of America

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CD-ROM: RTS Method Load Calculation Spreadsheet

(inside front cover)

PREFACE

Principles of Heating, Ventilating, and Air Conditioning, a textbook based on the 2005 ASHRAE Handbook—Fundamentals, should provide an attractive text for air-conditioning courses at engineering colleges and technical institutes. The text has been developed to give broad and current coverage of the heating, ventilation, and air-conditioning field when combined with the 2005 ASHRAE Handbook—Fundamentals.

The book should prove most suitable as a textbook and subsequent reference book for (a) undergraduate engineering courses in the general field of HVAC, (b) similar courses at technical institutes, (c) continuing education and refresher short courses for engineers, and (d) adult education courses for non-engineers. It contains more material than can normally be covered in a one-semester course. However, several different single-semester or shorter courses can be easily planned by merely eliminating the chapters and/or parts that are least applicable to the objectives of the particular course. This text will also readily aid in self-instruction of the 2005 ASHRAE Handbook—Fundamentals by engineers wishing to develop their competence in the HVAC&R field.

Although numerous references are made to the other ASHRAE Handbook volumes, sufficient material has been included from these to make this text complete enough for various courses in the HVAC&R field. The material covered for various audiences in regular university courses, technical institute courses, and short courses can, and will, vary greatly. The supplement needed to be complete to satisfy all of these anticipated uses and needs. Toward this end, the following major sections are included.

- Part I General Concepts, Chapters 1-10
- Part II Air-Conditioning Systems, Chapters 11-16
- Part III HVAC&R Equipment, Chapters 17-19

Although the 2005 ASHRAE Handbook—Fundamentals is published in an SI edition, which uses international units, and an inch-pound (I-P) edition, this single version of *Principles of Heating, Ventilating, and Air Conditioning* is designed to serve both the I-P and SI editions of *Fundamentals*. For the most part, the sample tables and figures are taken from the I-P edition, but illustrative and home problems are provided in both systems of units. A set of appropriate SI tables and figures follows each chapter.

There are four significant changes in this edition of *Principles of Heating, Ventilating, and Air Conditioning*. The first is the complete replacement of the CLTD/SCL/CLF method of design cooling load calculation with the new ASHRAE Radiant Time Series methodology with enhanced treatment of RTS procedures for nonresidential cooling and heating loads. The second is an essentially new chapter 6 on residential cooling and heating loads. The third change in this edition is the inclusion of discussions on sustainability and “green building” design. Finally, the fourth change is the inclusion of the new ventilation air procedure from ANSI/ASHRAE Standard 62.1-2004 in chapter 5.

A particular point of confusion must be pointed out. Because this book was developed to be used with the ASHRAE *Fundamentals* handbook volume, a number of tables and figures have been reproduced in the original form, complete with references to material elsewhere in *Fundamentals* (not in this book). Thus, if the subheading in the table or figure indicates that it is a *Fundamentals* table or figure, then all references to other locations, equations, tables, etc., refer to those in *Fundamentals*, not in *Principles*.

Chapter 1

BACKGROUND

This chapter provides a brief background on the heating, ventilating, air conditioning, and refrigeration (HVAC&R) field and industry, including the early history and some significant developments. An introduction to a few basic concepts is included along with suggestions for further reading.

1.1 Introduction

On the National Academy of Engineering's list of engineering achievements "that had the greatest impact on the quality of life in the 20th century," *air conditioning and refrigeration* came in tenth, indicating the great significance of this field in the world. With many people in the United States spending nearly 90% of their time indoors, it is hardly surprising that providing a comfortable and healthy indoor environment is a major factor in life today. In fact, over \$22 billion of air-conditioning equipment was sold in the US during the year 2004 alone.

Air-conditioning systems usually provide year-round control of several air *conditions*, namely, temperature, humidity, cleanliness, and air motion. These systems may also be referred to as *environmental control systems*, although today they are usually called heating, ventilating, and air-conditioning (HVAC) systems.

The primary function of an HVAC system is either (1) the generation and maintenance of comfort for occupants in a conditioned space; or (2) the supplying of a set of environmental conditions (high temperature and high humidity, low temperature and high humidity, etc.) for a process or product within a space. Human comfort design conditions are quite different from conditions required in textile mills or for grain storage and vary with factors such as time of year and the activity and clothing levels of the occupants.

If improperly sized equipment or the wrong type of equipment is used, the desired environmental conditions usually will not be met. Furthermore, improperly selected and/or sized equipment normally requires excess power and/or energy and may have a higher initial cost. The design of an HVAC system includes calculation of the maximum heating and cooling loads for the spaces to be served, selection of the type of system to be used, calculation of piping and/or duct sizes, selection of the type and size of equipment (heat exchangers, boilers, chillers, fans, etc.), and a layout of the system, with cost, indoor air quality, and energy conservation being considered along the way. Some criteria to be considered are

- Temperature, humidity, and space pressure requirements
- Capacity requirements
- Redundancy

- Spatial requirements
- First cost
- Operating cost
- Maintenance cost
- Reliability
- Flexibility
- Life-cycle analysis

The following details should be considered to properly design an air-conditioning system:

1. The location, elevation, and orientation of the structure so that the effects of the weather (wind, sun, and precipitation) on the building air-conditioning load can be anticipated.
2. The building size (wall area, roof area, glass area, floor area, and so forth).
3. The building shape (L-shaped, A-shaped, rectangular, etc.), which influences equipment location, type of heating and air conditioning system used, and duct or piping locations.
4. The space use characteristics. Will there be different users (office, bank, school, dance studios, etc.) of the space from year to year? Will there be different concurrent requirements from the tenants? Will there be night setback of the temperature controller or intermittent use of the building's facilities?
5. The type of material (wood, masonry, metal, and so forth) used in the construction of the building. What is the expected quality of the construction?
6. The type of fenestration (light transmitting partition) used, its location in the building, and how it might be shaded. Is glass heat absorbing, reflective, colored, etc.?
7. The types of doors (sliding, swinging, revolving) and windows (sealed, wood or metal frames, etc.) used. What is their expected use? This will affect the amount of infiltration air.
8. The expected occupancy for the space and the time schedule of this occupancy.
9. Type and location of lighting. Types of appliances and electrical machinery in the space and their expected use.
10. Location of electric, gas, and water services. These services should be integrated with the locations of the heating and air-conditioning duct, piping, and equipment.

11. Ventilation requirements for the structure. Does it require 100% outdoor air, a given number of cfm per person, or a given number of cfm per square foot of floor area?
12. Local and/or national codes relating to ventilation and gas, and/or electric piping.
13. Outside design temperatures and wind velocities for the location.
14. The environmental conditions that are maintained. Will fluctuations of these conditions with load be detrimental to the purpose served by the structure?
15. The heating and cooling loads (also consider the moisture load, air contaminants, and noise).
16. The type of heating and air-conditioning system to be used in the structure. Is it forced air, circulated water, or direct expansion? Will it be a multizone, single zone, reheat, variable air volume, or another type of system? What method of control will be used? Will a dedicated outdoor air system be considered?
17. The heating and cooling equipment size that will maintain the inside design conditions for the selected outside design condition. Electric heat or fossil fuel? Mechanical vapor compression or absorption chiller?
18. The advantages and disadvantages of oversizing and undersizing the equipment as applied to the structure. Survey any economic tradeoffs to be made. Should a different type of unit be installed in order to reduce operating costs? Should a more sophisticated control system be used to give more exact control of humidity and temperature or should an on-off cycle be used? Fuel economy as related to design will become an even more important factor in system selection and operation.
19. What is the estimated annual energy usage?

In general, no absolute rules dictate correct selections or specifications for each of the above items, so only engineering estimates or educated guesses can be made. However, estimates must be based on sound fundamental principles and concepts. This book presents a basic philosophy of environmental control as well as the basic concepts of design. These ideas relate directly to the *ASHRAE Handbook* series: *2002 Refrigeration*, *2003 HVAC Applications*, *2004 HVAC Systems and Equipment*, and most directly to the *2005 Fundamentals*.

1.2 Historical Notes

Knowing something of the past helps in understanding current design criteria and trends. As in other fields of technology, the accomplishments and failures of the past affect current and future design concepts. The following paragraphs consist mainly of edited excerpts from *ASHRAE Journal* articles: “A History of Heating” by John W. James, “The History of Refrigeration” by Willis R. Woolrich, and “Milestones in Air Conditioning” by Walter A. Grant, with additional information obtained from ASHRAE’s Historical Committee. These excerpts provide a synopsis of the history of environmental control.

Obviously, the earliest form of heating was the open fire. The addition of a chimney to carry away combustion byproducts was the first important step in the evolution of heating systems. By the time of the Romans, there was sufficient knowledge of ventilation to allow for the installation of ventilating and panel heating in baths. Leonardo da Vinci had invented a ventilating fan by the end of the 15th century. Robert Boyle’s law was established in 1659; John Dalton’s in 1800. In 1775, Dr. William Cullen made ice by pumping a vacuum in a vessel of water. A few years later, Benjamin Franklin wrote his treatise on Pennsylvania fireplaces, detailing their construction, installation, and operation.

Although warming and ventilating techniques had greatly improved by the 19th century, manufacturers were unable to exploit these techniques because

- Data available on such subjects as transmission coefficients, air and water friction in pipes, and brine and ammonia properties were sparse and unreliable.
- Neither set design conditions nor reliable psychrometric charts existed.
- A definitive rational theory that would permit performance calculation and prediction of results had not yet been developed.
- Little was known about physical, thermodynamic, and fluid dynamic properties of air, water, brines, and refrigerants.
- No authoritative information existed on heat transmission involving combustion, conduction, convection, radiation, evaporation, and condensation.
- No credible performance information for manufactured equipment was available.

Thanks to Thomas Edison, the first electric power plant opened in New York in 1882, making it possible for the first time to have an inexpensive source of energy for residential and commercial buildings.

Furnaces

By 1894, the year the American Society of Heating and Ventilating Engineers (ASH&VE) was born, central heating was fairly well developed. The basic heat sources were warm air furnaces and boilers. The combustion chambers of the first warm air furnaces were made of cast iron. Circulation in a gravity warm air furnace system is caused by the difference in air density in the many parts of the system. As the force of combustion is small, the system was designed to allow air to circulate freely. The addition of fans (circa 1899) to furnace systems provided a mechanical means of air circulation. Other additions to the modern furnace include cooling systems, humidification apparatuses, air distributors, and air filters. Another important step for the modern heating industry was the conversion of furnaces from coal to oil and gas, and from manual to automatic firing.