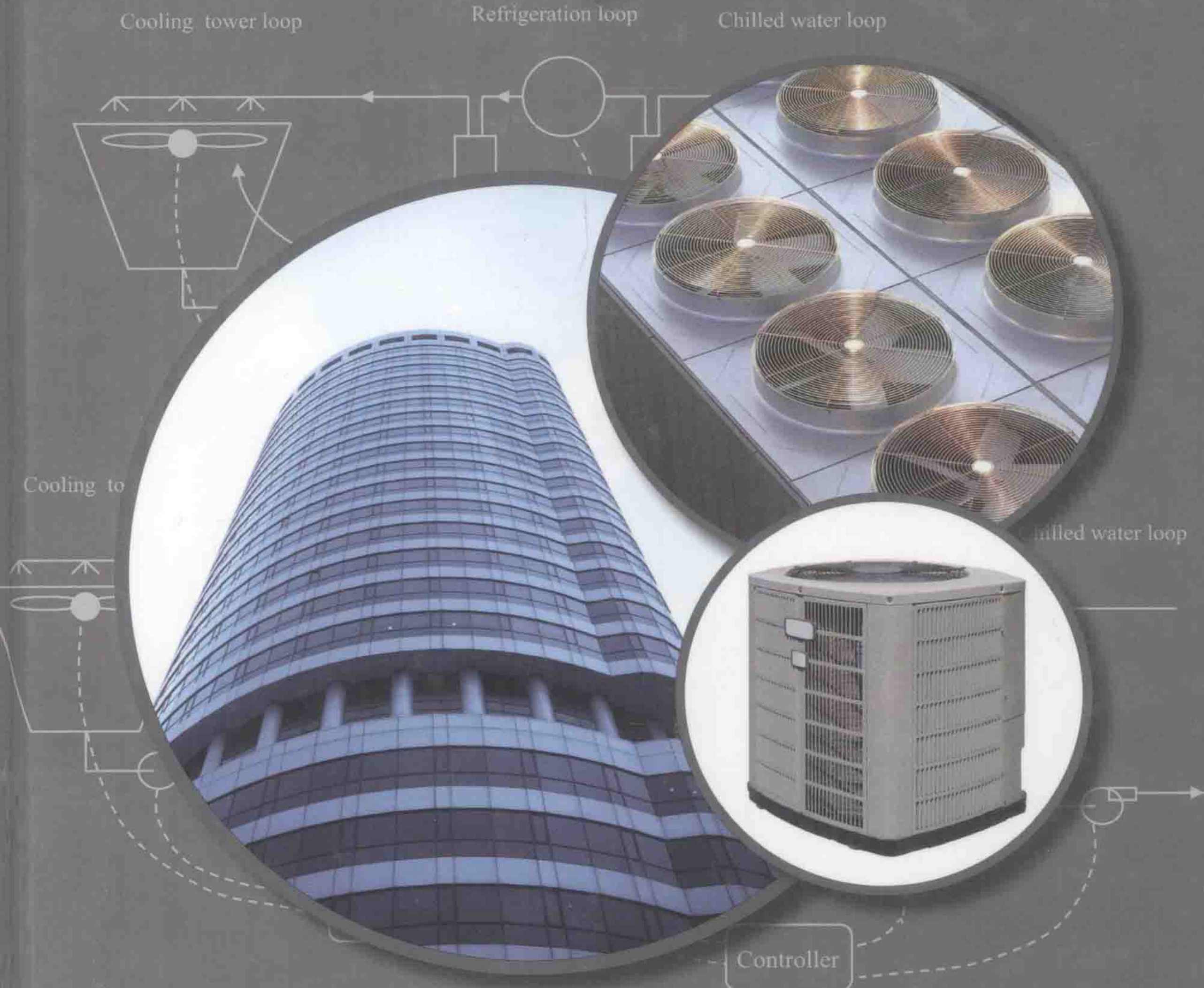
Principles of Heating, Ventilation, and Air Conditioning in Buildings



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Principles of Heating, Ventilation, and Air Conditioning in Buildings

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Principles of Heating, Ventilation, and Air Conditioning in Buildings

To Barbara
John W. Mitchell

To Julie, Liz, Emma, Tim, and Roger
James E. Braun

Online Material

Topics

Supplementary Material

Online Chapters

SM 2 Heat Exchangers for Cooling Applications

SM 3 Cooling Towers

SM 4 Heat and Mass Exchangers

SM 5 Thermal Storage Systems

SM 6 Compressors and Expansion Devices

SM 7 Evaporators and Condensers

SM 8 Absorption Air-conditioning Systems

SM 9 Combustion Heating Equipment

SM 10 Economic Evaluation of HVAC Systems

Preface

The career opportunities for engineering students and professionals in the HVAC field lie in many different areas: architectural and engineering (A&E) firms, equipment manufacturers, control companies, utilities, and government research institutions. The specific engineering applications and tools may be very different for each career path, but the fundamental principles associated with the heating, ventilating; and air conditioning (HVAC) equipment and systems are a common thread. It is the intent of this book to provide a fundamental basis for launching or enhancing careers in the HVAC field.

Our goal is to provide the foundational knowledge for the behavior and analysis of HVAC-related devices and processes. We believe that it is important for engineers to have a basic and quantitative understanding of the physical phenomena underlying the performance of the component or system with which they are concerned. The approach we have taken is to present the development of performance relations from fundamental thermodynamics, fluid dynamics, and heat transfer principles. Engineers will then be able to better understand why a device or system responds as it does and what its limits of performance are. This information will aid them in their design and equipment operation activities. The HVAC field is broad, and we have attempted, first, to cover most of the processes that an engineer might come in contact with, and second, to provide tools that allow the engineer to design or evaluate a new device, system, or process.

We believe that it is also important to state what this text is not intended to do. It does not prepare the student for immediate design practice. We do not cover the many "canned" programs and methodologies that are available and used in the profession for specialized design and evaluation tasks. Rather, we intend that our basic approach will prepare the student to understand what a software program or a hand calculation method is intended to do and be able to interpret results in a physically meaningful manner.

There are several features of this book not found in existing texts. The first is the tight integration of physical descriptions with a software program that allows performance to be directly calculated. The physical description of each device or system is developed from the basic engineering equations and carried through to performance. The examples in the text and the problems at the end of each chapter represent the type of situation that an engineer might face in practice. The problems are more than exercises and, while each problem is designed to emphasize the material in that chapter, it often includes basic material from other chapters. We believe these problems illustrate the complex and integrated nature of an HVAC system or piece of equipment.

Although many software programs are used throughout the industry, and some are available for class use, our approach is to have students formulate their own solutions rather than use existing design programs. In this manner they will learn the underlying physics. We have built the problems and examples around the program EES (Engineering Equation Solver), which is a general-purpose nonlinear equation solver. An important feature of EES is that thermodynamic and transport properties are directly integrated into EES, which facilitates the calculation of energy transfers that involve fluids such as moist air, water, and refrigerants. EES is an interpretive programming language and the program statements are essentially conventional mathematical statements, which reduces the problems of learning a new language. Powerful solution techniques are built into EES; this allows the engineer to focus on the physical description of the problem and not on how to obtain a numerical solution. By employing EES, much more realistic and complex problems can be formulated and solved than with hand calculations.

We have presented the examples in the text in terms of EES equations. This is a compact format that replicates the mathematical development in the text. The same nomenclature and symbols are used for both mathematical and EES formats. The descriptions of the examples are intended both to describe the situation in physical variables and to serve as a model for the student in developing the solution to an end-of-chapter problem.

We have found that the discipline required to formulate a program in EES, debug it, obtain a solution, and interpret the results carries over into the use of other programs. Although in practice an engineer may use a program designed for a specific design purpose, the same steps are present. The engineer still needs to understand the basic ideas and limits of the program being employed.

We have divided the book into four sections that cover the application of engineering principles to HVAC equipment and systems. The first section, entitled **Fundamentals**, comprises seven chapters that present the use of EES, review the relevant thermodynamics, fluid flow, and heat transfer principles, provide an in-depth study of psychrometrics, cover different types of HVAC systems and components, and present the criteria for comfort and air quality. The three chapters in the **Building Heating and Cooling Loads** section cover weather data processing and the procedures used to determine the design heating and cooling loads for a building. The section on **Equipment** covers systems that transfer energy: air and water distribution systems, heating and cooling coils, cooling towers, and equipment that supply heating or cooling. The last section on **Design and Control of HVAC Systems** covers the seasonal energy use of buildings and equipment, control techniques, and supervisory control of building operation. The last chapter in the book describes the HVAC design process and presents the rules of thumb often used in design. Several design problems typical of those that an engineer might face are included. Our experience is that this broad coverage coupled with detailed analysis provides a foundation for students entering the HVAC profession.

In addition to the text material, we have developed online chapters (termed Supplemental Material, SM) on a number of topics that relate to HVAC buildings and equipment but that are not central to the design of a typical HVAC system. This additional material includes the development of the basic heat and mass exchange relations as applicable to cooling coils, cooling towers, and similar equipment in which moisture is removed or added, mechanisms of ice formation in thermal stores, heat transfer relations for condenser and evaporators, models that yield insight into the performance of compressors and refrigeration systems, absorption systems, and combustion heating equipment. This material is included to allow an instructor or a student to explore in depth topics that are not covered in the text.

The book is intended first as the text for students in an HVAC or thermal systems course, and second as a reference book for practicing engineers who wish to extend or update their knowledge. To aid the instructor, we have developed a sample syllabus for a one-semester (14-week) course that provides the broad coverage of HVAC.

John W. Mitchell, Professor Emeritus, University of Wisconsin
James E. Braun, Professor, Purdue University

SAMPLE SYLLABUS

Chapter	Topic	No. of Weeks
1	Introduction to Air Conditioning Systems	2
2	System Analysis Techniques and the Use of EES	
3	Thermodynamics and Fluid Flow in HVAC Applications	
4	Heat Transfer in HVAC Applications	
5	Psychrometrics for HVAC Applications	1
6	Overview of HVAC Systems	2
7	Thermal Comfort and Air Quality	
8	Weather Data, Statistics, and Processing	3
9	Components of Building Heat Loss and Gain	
10	Heating and Cooling Loads	
11	Air Distribution Systems	1
12	Liquid Distribution Systems	
13	Heat Exchangers for Heating and Cooling Applications	1
14	Cooling Towers and Desiccant Dehumidification Systems	
15	Vapor-Compression Refrigeration and Air Conditioning Systems	2
16	Heat Pump Systems	
17	Thermal Storage	2
18	Building and HVAC Energy Use	
19	HVAC Control Principles	
20	Supervisory Control	

Acknowledgments

We are greatly indebted to our colleagues at the University of Wisconsin with whom we have discussed simulation and modeling both in general and as it relates to HVAC. The late Professor John (Jack) A. Duffie, Director of the Solar Energy Laboratory, University of Wisconsin, was a role model in how to approach problems and generate solutions. Professor William A. Beckman and Sanford A. Klein provided immeasurably valuable advice on modeling systems, and their development of EES has let students easily solve complicated problems. John Seem, Johnson Controls Inc., reviewed and provided valuable insight on HVAC controls.

ASHRAE has had a large influence on our careers, both through support of projects and providing us with a forum to present ideas and discuss them with colleagues. Our experience gained through ASHRAE has hopefully made this text a useful resource for others in the field.

Several colleagues have reviewed the manuscript and given valuable advice on orientation, style, and content. Agami Reddy, Arizona State University, and Leon Glicksman, MIT, have made many useful suggestions. Gregor Henze and Michael Brandmuehl, University of Colorado, William Bahnfleth, Pennsylvania State University, Gren Yuill, University of Nebraska—Lincoln, and Leslie Norford, MIT, have all provided encouragement for writing this text. Lastly, students in our classes over the years have provided constructive criticism of much of the material, which has helped us in the presentation of this important subject.

We would like to thank Linda Ratts, Executive Editor, for her support and encouragement, and Christopher Teja, Editorial Assistant, and Song Yee Lyn, Assistant Production Editor, for their diligent attention to production. Their contributions have been essential to bringing this project to completion.

Brief Contents

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