

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

- SM 1 Heat Exchangers for Heating Applications**
- 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**

Supplementary Material

EES Code for Text Chapter Examples

Text Problem Solutions

PowerPoint Slides for Text Chapter Material

EES Code for Online Chapter Examples

Online Problem Solutions

PowerPoint Slides for Online Chapter Material

Online Chapters

SM 1 Heat Exchangers for Heating Applications

- SM 1.1 Heat Exchanger Thermal Performance
- SM 1.2 Extended Surfaces
- SM 1.3 Single Phase Heat Transfer Coefficients and Pressure Drop
- SM 1.4 Extended Surface Heat Transfer Coefficients and Pressure Drop
- SM 1.5 Summary
- SM 1.6 Nomenclature
- SM 1.7 References
- SM 1.8 Problems

SM 2 Heat Exchangers for Cooling Applications

- SM 2.1 Heat and Mass Transfer Processes in a Cooling Coil
- SM 2.2 Cooling Coil Performance Using an Analogy to Heat Transfer
- SM 2.3 Heat and Mass Transfer Fin and Surface Efficiencies
- SM 2.4 Extension of Catalog Data
- SM 2.5 Summary
- SM 2.6 Nomenclature
- SM 2.7 References
- SM 2.8 Problems

SM 3 Cooling Towers

- SM 3.1 Heat and Mass Transfer Processes in a Cooling Tower
- SM 3.2 Cooling Tower Performance Using an Analogy to Heat Transfer
- SM 3.3 Extension of Catalog Information
- SM 3.4 Summary
- SM 3.5 Nomenclature
- SM 3.6 References
- SM 3.7 Problems

SM 4 Heat and Mass Exchangers

- SM 4.1 Introduction
- SM 4.2 Evaporative Coolers
- SM 4.3 Spray Dehumifiers
- SM 4.4 Evaporative Condensers
- SM 4.5 Enthalpy Exchangers
- SM 4.6 Summary
- SM 4.7 Nomenclature
- SM 4.8 References
- SM 4.9 Problems

SM 5 Thermal Storage Systems

- SM 5.1 Mechanisms for Freezing and Melting of Ice
- SM 5.2 Summary
- SM 5.3 Nomenclature
- SM 5.4 References
- SM 5.5 Problems

SM 6 Compressors and Expansion Devices

- SM 6.1 Performance Trends for Positive Displacement Compressors
- SM 6.2 Performance Correlations for Positive Displacement Compressors
- SM 6.3 Performance Trends for Centrifugal Compressors
- SM 6.4 Expansion Devices
- SM 6.5 System Component Integration
- SM 6.6 Summary
- SM 6.7 Nomenclature
- SM 6.8 References
- SM 6.9 Problems

SM 7 Evaporators and Condensers

- SM 7.1 Introduction
- SM 7.2 Thermal Performance of Shell-and-Tube Evaporators
- SM 7.3 Thermal Performance of Direct Expansion Cooling Coils
- SM 7.4 Heat Transfer Coefficients for Evaporators
- SM 7.5 Thermal Performance of Condensers
- SM 7.6 Heat Transfer Coefficients for Condensers
- SM 7.7 Pressure Drops in Two-Phase Flows
- SM 7.8 Summary
- SM 7.9 Nomenclature
- SM 7.10 References
- SM 7.11 Problems

SM 8 Absorption Air-conditioning Systems

- SM 8.1 Introduction
- SM 8.2 Fundamentals of Absorption
- SM 8.3 Performance of a Single Effect Absorption Cycle
- SM 8.4 Absorption Machine Configurations
- SM 8.5 Summary
- SM 8.6 Nomenclature
- SM 8.7 References
- SM 8.8 Problems

SM 9 Combustion Heating Equipment

- SM 9.1 Introduction
- SM 9.2 Combustion Processes
- SM 9.3 Combustion Reactions
- SM 9.4 Use of EES in Combustion Reactions
- SM 9.5 Combustion Reactions with Air
- SM 9.6 Simplified Model for Overall Furnace Performance
- SM 9.7 Seasonal Performance
- SM 9.8 Furnace Emissions
- SM 9.9 Summary
- SM 9.10 Nomenclature
- SM 9.11 References
- SM 9.12 Problems

SM 10 Economic Evaluation of HVAC Systems

- SM 10.1 Introduction
- SM 10.2 Costs and Interest Rates
- SM 10.3 Life-Cycle Cost Concepts
- SM 10.4 Present Worth Factors
- SM 10.5 Life-Cycle Cost Formulation
- SM 10.6 Costs and Savings Measures
- SM 10.7 Importance of Economic Factors
- SM 10.8 Summary
- SM 10.9 Nomenclature
- SM 10.10 References
- SM 10.11 Problems

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	

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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.

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Brief Contents

Fundamentals

1. Introduction to HVAC Systems 1
2. System Analysis Techniques and the Use of EES 15
3. Thermodynamics and Fluid Flow in HVAC Applications 39
4. Heat Transfer in HVAC Applications 61
5. Psychrometrics for HVAC Applications 95
6. Overview of HVAC Systems 137
7. Thermal Comfort and Air Quality 171

Building Heating and Cooling Loads

8. Weather Data, Statistics, and Processing 185
9. Components of Building Heat Loss and Gain 221
10. Heating and Cooling Loads 265

Equipment

11. Air Distribution Systems 289
12. Liquid Distribution Systems 329
13. Heat Exchangers for Heating and Cooling Applications 345
14. Cooling Towers and Desiccant Dehumidification Systems 379
15. Vapor Compression Refrigeration and Air-Conditioning Systems 401
16. Heat Pump Systems 433
17. Thermal Storage Systems 447

Design and Control of HVAC Systems

18. Building and HVAC Energy Use 475
19. HVAC Control Principles 497
20. Supervisory Control 523
21. Designing HVAC Systems 555

Table of Contents

Fundamentals

1 Introduction to HVAC Systems 1

- 1.1 Systems and Definitions 1
- 1.2 History of Air Conditioning 3
- 1.3 Trends in Energy Use and Impact 5
- 1.4 HVAC System Design and Operation 7
- 1.5 Energy Costs 11
- 1.6 Book Philosophy and Organization 11
- 1.7 Units 13
- 1.8 Summary 14
- Problems 14

2 System Analysis Techniques and the Use of EES 15

- 2.1 Introduction 15
- 2.2 Introduction to EES 19
- 2.3 Common Problems Encountered when Using EES 22
- 2.4 Curve Fitting Using EES 26
- 2.5 Optimization Using EES 29
- 2.6 Successful Problem Solving Using EES 31
- 2.7 Summary 34
- Problems 35

3 Thermodynamics and Fluid Flow in HVAC Applications 39

- 3.1 Introduction 39
- 3.2 Conservation of Mass 39
- 3.3 Conservation of Energy 41
- 3.4 Thermodynamic Properties of Pure Substances 43
- 3.5 Thermodynamic Limits on Performance 45
- 3.6 Thermodynamic Work Relations for Pure Substances 47
- 3.7 Thermodynamic Relations for Fluid Flow 48
- 3.8 Energy Loss Mechanisms in Fluid Flow 54
- 3.9 Summary 59
- Problems 59

4 Heat Transfer in HVAC Applications 61

- 4.1 Introduction 61
- 4.2 Conduction Heat Transfer 61
- 4.3 Convection Heat Transfer 67
- 4.4 Thermal Radiation Heat Transfer 76
- 4.5 Transient Heat Transfer 83
- 4.6 Combined-Mode Heat Transfer 87
- 4.7 Summary 92
- Problems 92

5 Psychrometrics for HVAC Applications 95

5.1	Introduction	95
5.2	Moist Air Properties	95
5.3	The Psychrometric Chart	102
5.4	The Standard Atmosphere	103
5.5	Determining Psychrometric Properties Using EES	105
5.6	Psychrometric Applications	109
5.7	Heat and Mass Transfer for Air–Water Vapor Mixtures	126
5.8	Summary	132
	Problems	133

6 Overview of HVAC Systems 137

6.1	Introduction	137
6.2	Overview of HVAC Systems and Components	137
6.3	Energy Comparison Between CAV and VAV Systems	144
6.4	HVAC System Performance Calculations	145
6.5	ASHRAE Load Calculation Equations	153
6.6	HVAC System Improvements and Alternatives	156
6.7	Summary	167
	Problems	167

7 Thermal Comfort and Air Quality 171

7.1	Introduction	171
7.2	Criteria for Occupant Comfort Inside Buildings	171
7.3	Criteria for Indoor Air Quality	179
7.4	Summary	182
	Problems	183

Building Heating and Cooling Loads

8 Weather Data, Statistics, and Processing 185

8.1	Introduction	185
8.2	Design Temperature Parameters for HVAC Systems	186
8.3	Ambient Temperature and Humidity Correlations	190
8.4	Degree-Day Data and Correlations	195
8.5	Bin Method Data	200
8.6	Ground Temperature Correlations	202
8.7	Solar Radiation Fundamentals	205
8.8	Clear-Sky Solar Radiation	213
8.9	Weather Records	216
8.10	Summary	219
	Problems	219

9 Components of Building Heat Loss and Gain 221

9.1	Introduction	221
9.2	Thermal Resistance and Conductance of Building Elements	222
9.3	Heat Flow Through Opaque Exterior Surfaces	225

9.4	Transient Heat Flow Through Building Elements	228
9.5	Heat Flow Through Building Elements—Transfer Function Approach	234
9.6	Heat Flow Through Building Elements—Thermal Network Approach	240
9.7	Heat Flow Through Glazing	244
9.8	Energy Flows Due to Ventilation and Infiltration	247
9.9	Internal Thermal Gains	256
9.10	Summary	258
	Problems	259

10 Heating and Cooling Loads 265

10.1	Introduction	265
10.2	Design Heating Load	266
10.3	Design Sensible Cooling Load Using the Heat Balance Method	268
10.4	The Heat Balance Method Using the Thermal Network Approach	273
10.5	Design Latent Cooling Load	276
10.6	Design Loads Using the Thermal Network Method	277
10.7	Summary	286
	Problems	287

Equipment

11 Air Distribution Systems 289

11.1	Introduction	289
11.2	Pressure Drops in Duct Systems	290
11.3	Design Methods for Air Distribution Systems	298
11.4	Fan Characteristics	311
11.5	Interaction Between Fan and Distribution System	315
11.6	Air Distribution in Zones	318
11.7	Heat Losses and Gains for Ducts	320
11.8	Air Leakage from Ducts	322
11.9	Summary	323
	Problems	324

12 Liquid Distribution Systems 329

12.1	Introduction	329
12.2	Head Loss and Pressure Drop in Liquid Distribution Systems	329
12.3	Water Distribution Systems	332
12.4	Steam Distribution Systems	335
12.5	Pump Characteristics	338
12.6	Heat Loss and Gain for Pipes	340
12.7	Summary	342
	Problems	342

13 Heat Exchangers for Heating and Cooling Applications 345

13.1	Introduction	345
13.2	Overall Heat Transfer Conductance	347
13.3	Heat Exchanger Thermal Performance	349

13.4	Heating Coil Selection Process	355
13.5	Cooling Coil Processes	361
13.6	Cooling Coil Performance Using a Heat Transfer Analogy	362
13.7	Cooling Coil Selection Procedure	368
13.8	Summary	376
	Problems	376
14	Cooling Towers and Desiccant Dehumidification Systems	379
14.1	Introduction	379
14.2	Cooling Towers	379
14.3	Cooling Tower Performance using an Analogy to Heat Transfer	381
14.4	Cooling Tower Selection Procedure	385
14.5	Desiccant Dehumidifiers	388
14.6	Desiccant Dehumidification Systems	393
14.7	Summary	397
	Problems	398
15	Vapor Compression Refrigeration and Air-Conditioning Systems	401
15.1	Introduction	401
15.2	Vapor Compression System	401
15.3	Refrigerants	407
15.4	Vapor Compression System Compressors	412
15.5	Vapor Compression System Performance	416
15.6	Alternative Vapor Compression System Concepts	421
15.7	Summary	429
	Problems	429
16	Heat Pump Systems	433
16.1	Introduction	433
16.2	Air Source Heat Pumps	435
16.3	Ground Source Heat Pumps	441
16.4	Water Loop Heat Pump Systems	443
16.5	Summary	444
	Problems	444
17	Thermal Storage Systems	447
17.1	Introduction	447
17.2	Ice Storage Systems	451
17.3	Chilled Water Storage Systems	452
17.4	Cold Air Distribution Systems	453
17.5	Building Thermal Storage	454
17.6	Thermal Storage Control Strategies	456
17.7	Performance Characteristics of Ice Storage Tanks	460
17.8	Selection of Ice Storage Capacity	466
17.9	Summary	471
	Problems	471