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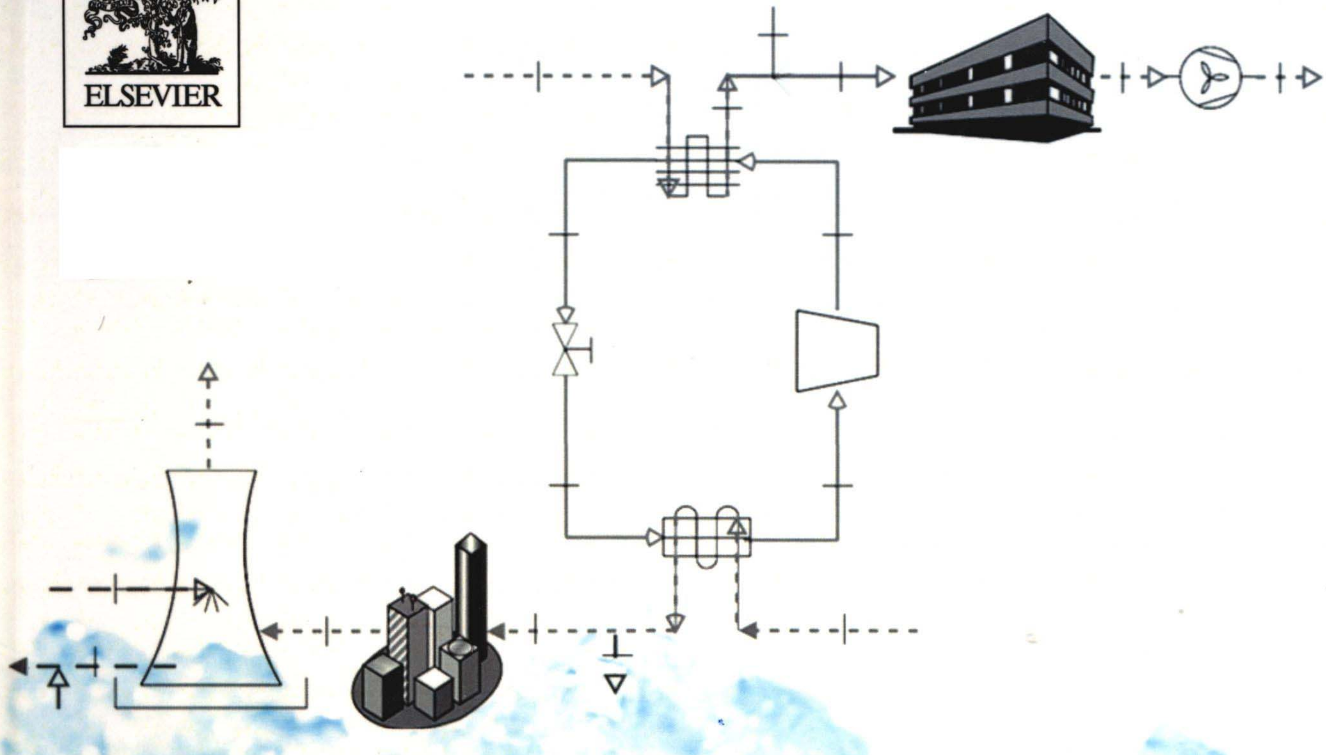

Exergy Analysis of Heating, Refrigerating, and Air Conditioning

Methods and Applications

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Ibrahim Dincer and Marc A. Rosen

July 2015

Preface

This book focuses on applications of exergy methods to the heating, refrigerating, and air conditioning industries and the primary technologies comprising them, with the aim of providing an enhanced understanding of the behaviors of such systems and better tools for their improvement. Heating, refrigeration, and air conditioning processes are very important energy technologies in most countries and are often responsible for a significant portion of their energy utilization. Thus, it is beneficial to consider all available tools in efforts to improve designs, in terms of efficiency, environmental performance, economics, and other factors.

Exergy analysis represents a relatively recent and exciting innovation in thermodynamics and energy systems. As a method that uses the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the analysis, exergy analysis helps in the design, optimization, and improvement of energy systems like HVAC. The exergy method is a useful tool for furthering the goal of more efficient energy resource use, for it enables the locations, types, and magnitudes of wastes and losses to be identified and meaningful efficiencies to be determined. Exergy methods have received notable attention only over the last few decades. Although that attention has grown during that period, it has remained somewhat limited and comprehensive applications of exergy analysis in the heating, refrigeration, and air conditioning industries remain needed.

The book seeks to describe comprehensively the application of exergy methods to heating, refrigerating, and air conditioning systems, so as to aid in their improvement. In doing so, the book contains eight chapters. The relations of the material to building energy systems and their management are stressed throughout.

Chapter 1 describes energy and exergy methods and how they are used to assess, design, and improve technologies and systems. Fundamental thermodynamic principles are explained and analysis methodologies based on exergy are covered in depth. In addition, extensions of these exergy-based methods to environmental, economic, and sustainability assessments are covered. To provide a broader context, the role of heating, refrigerating, and air conditioning in regional systems like countries is discussed, including relevant energy, and exergy perspectives.

In Chapter 2, energy and exergy analyses of basic heating, refrigeration, and air conditioning technologies and systems are presented. Included are applications of exergy analysis to the components comprising heating, refrigerating, and air conditioning, as well as psychrometric processes and overall systems.

Chapter 3, Chapter 4, Chapter 5, and Chapter 6 focus on a range of industrial systems and applications of heating, refrigeration, and air conditioning. Chapter 3 focuses on the use of exergy methods in industrial heating and cooling and the diverse range of processes that can be used for those activities. Heat pump systems are introduced but are examined in much greater depth in Chapter 4. Cogeneration, trigeneration, and multigeneration, as well as integrated energy systems and district heating and cooling, are covered in Chapter 5. Chapter 6 describes how exergy methods are applied to heat and cold storage systems, covering the range of such technologies that find applications in buildings.

In Chapter 7, building HVAC systems based on renewable energy are described and several case studies are considered for illustration. The utilization of renewable and sustainable energy in place of conventional energy resources like fossil fuels is an important extension of the material in the preceding chapters since we feel that renewable and sustainable energy systems represent the future of energy systems in general and for heating, refrigeration, and air conditioning in particular.

In Chapter 8, several illustrations are described of exergy-based methods for improving heating, refrigeration, and air conditioning systems. The methods covered include design for responsible energy and environment management, life cycle assessment, energy retrofits, and energy substitution, the strategic integration of energy systems, and the allocation of environmental emissions. These are linked to the material in Chapter 7 by linking them to the utilization of renewable and sustainable energy.

Incorporated throughout are many illustrative examples and case studies, which provide the reader with a substantial learning experience, especially in terms of practical applications.

The appendixes contain unit conversion factors and tables and charts of thermophysical properties of various materials in the International System of Units (SI). A glossary of exergy-related terminology is also provided.

References are included to direct the reader to sources where more details can be found and to assist the reader who is simply curious to learn more. The references can also help identify information on topics not covered comprehensively in the book.

As a research-oriented textbook, this volume includes theoretical and practical features often not included in solely academic textbooks. This book is mainly intended for use by advanced undergraduate or graduate students in several engineering and nonengineering disciplines and also as an essential tool for practitioners in HVAC disciplines. Theory and analysis are emphasized throughout this comprehensive book, reflecting new techniques, models, and applications, together with complementary materials and recent information. Coverage of the material is extensive, and the amount of information and data presented is sufficient for advanced courses related to heating, cooling, and air conditioning—and advanced technologies being applied in these areas—or as a supplement for courses on applied thermodynamics. We believe that this book will be of interest to students and practitioners and individuals and institutions who are interested in exergy and its applications to heating, cooling, and air conditioning as well as the various new technologies and methods that are increasingly finding use in these areas. This volume is also a valuable and readable reference for anyone who wishes to learn about exergy methods and/or advanced heating, cooling, and air conditioning.

We hope this book allows exergy methods to be more widely applied to heating, refrigerating, and air conditioning industries and both the traditional and new technologies being applied in them. The book thereby provides an enhanced understanding of the behaviors of heating, refrigerating, and air conditioning systems and enhanced tools for improving them. By exploiting the benefits of applying exergy methods to these systems, we believe they can be made more efficient, clean, and sustainable and help humanity address many of the challenges it faces.

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CHAPTER 1

Exergy and its Ties to the Environment, Economics, and Sustainability

1.1 INTRODUCTION

Heating, refrigeration, and air conditioning processes are treated as important energy technologies in most countries and are often responsible for a significant portion of their energy utilization. Applying exergy methods to technologies for the heating, refrigerating, and air conditioning can provide a better understanding of their behaviors and enhanced tools for improving them. This use of exergy analysis not only is advantageous but also is prudent, since it is useful to consider all available tools in efforts to improve designs, in terms of efficiency, environmental performance, economics, and other factors.

Exergy analysis represents a recently rediscovered and exciting innovation in thermodynamics and energy systems. Exergy methods, basic to enhanced and combined models, have received notable attention only over the last few decades. Although such attention has grown during that period, it has remained limited and applications of exergy analysis in the heating, refrigeration, and air conditioning industries, although they have increased notably, would benefit from an enhanced focus and a consolidation of the information.

The applications of exergy methods to heating, refrigerating, and air conditioning systems are described in a detailed and comprehensive manner in this book, with the intent of enhancing understanding and aiding in process assessments and improvements.

The book starts by describing energy and exergy methods and how they are used to assess, design, and improve technologies and systems. Fundamental thermodynamic principles are explained and analysis methodologies based on exergy are covered in depth. In addition, extensions of these exergy-based methods to environmental assessments and economic evaluations are covered. To provide a broader context, the role of heating, refrigerating, and air conditioning in regional systems like countries is discussed, including relevant energy and exergy perspectives.

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Next, energy and exergy analyses of basic heating, refrigeration, and air conditioning technologies and systems are presented. Included are applications of exergy analysis to the components comprising heating, refrigerating, and air conditioning, as well as overall systems. A diverse range of processes are considered, including industrial heating and cooling, drying, building energy management, cogeneration and trigeneration, district heating and cooling, and thermal storage. Measures for improving heating, refrigeration, and air conditioning systems are also described. Renewable and sustainable energy systems are covered throughout not only because of their expanding usage but also because they likely represent the future of energy systems.

The book closes by describing and assessing exergy-based methods for improving heating, refrigeration, and air conditioning systems. The methods covered include design for responsible energy and environment management, life cycle assessment, energy retrofits, and energy substitution. The latter is extended to the utilization of renewable and sustainable energy in place of conventional energy resources like fossil fuels.

1.2 WHY EXERGY?

Energy use is pervasive in life, and there is a strong relation between energy and prosperity. Throughout much of history, the emergence of civilizations has been characterized by the discovery and effective application of energy to help meet society's needs. The desire of people to sustain and improve their well-being is possibly the biggest driver of the growth in worldwide energy demand. Therefore, meeting the demand for energy services in a clean, efficient, secure, and reliable way is an important challenge.

Energy analysis is the traditional method of assessing the way energy is used in operations (e.g., physical or chemical processing of materials, heat transfer, and energy conversion). Energy analysis is based on the first law of thermodynamics (FLT) and usually entails performing energy balances and evaluating energy efficiencies. The FLT embodies the principle of conservation of energy, which states that, although energy can change form, it can be neither created nor destroyed. However, this law provides no information about the direction in which processes can spontaneously occur, that is, it does not explain reversibility aspects of thermodynamic processes. An energy balance also cannot explain the degradation of energy or resources during a process and does not quantify the usefulness or quality of energy and material quantities (e.g., input, product, and waste flows for a system). The FLT provides no information about the inability of any thermodynamic process to convert heat fully into mechanical work or any insight into why mixtures cannot