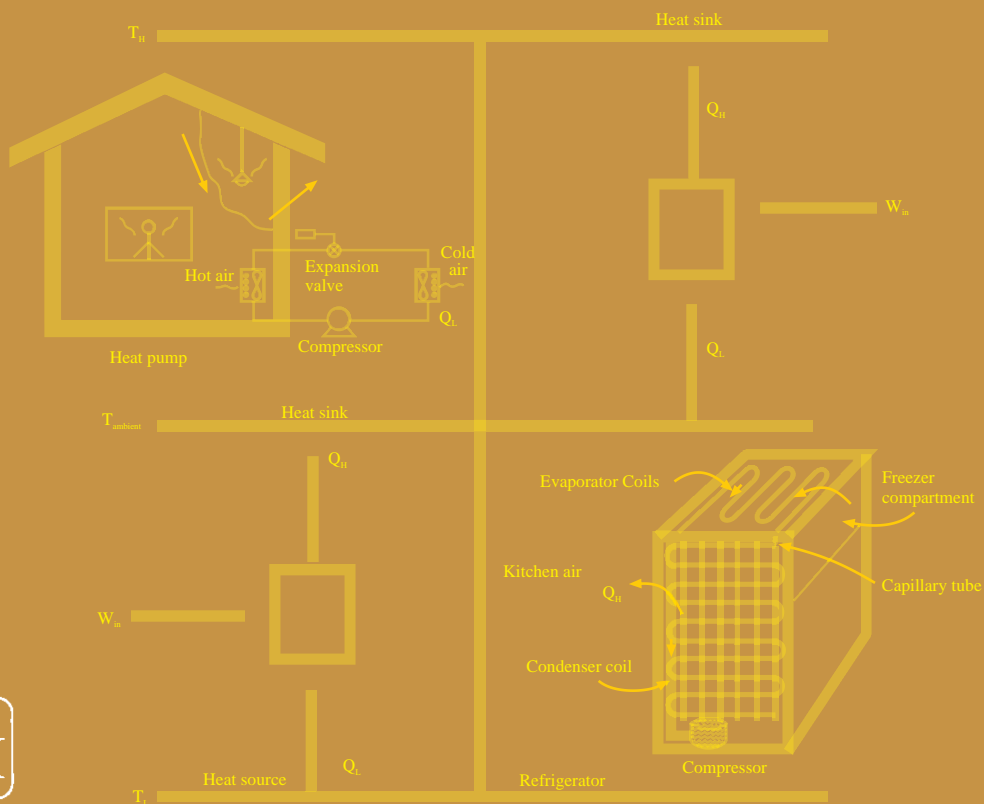


# Refrigeration and Air Conditioning

Ahmadul Ameen



# REFRIGERATION AND AIR CONDITIONING

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Ahmadul Ameen

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# Preface

This book has been conceived to serve a dual purpose: first, as a textbook for mechanical engineering students pursuing diploma and degree level courses at technical institutes and universities, and second as a ready guide and resource tool for practising engineers who need to keep themselves updated with the latest developments in design and applications of refrigeration and air-conditioning systems. As a text, the book has been designed for a comprehensive one-semester course in refrigeration and air conditioning. More emphasis has been placed on design problems and the essential features of hardware and controls in the context of refrigeration and air-conditioning practices in tropical and sub-tropical climates. Additionally, newer methods of air conditioning such as evaporative cooling, desiccant-based cooling, thermal storage air conditioning and chilled ceiling cooling that are breaking fresh ground, have also been included.

Since mechanical engineering students also pursue a course in thermodynamics and heat transfer, discussions on the related fundamentals have been limited. The SI units have been used throughout the text. Selected and abridged ASHRAE charts, tables and design data have been used extensively. Comprehensive illustrations provide an opportunity to understand the concepts and visualize the processes and factual details. It is hoped that by learning the simple illustrative examples provided in most of the chapters, the readers would be able to grasp the basic elements of refrigeration and air conditioning.

The chapters have been arranged under four distinct parts: Part I—General, Part II—Refrigeration Cycles and Refrigerants, Part III—Air Conditioning, and Part IV—Equipment, Accessories and Controls. Part I includes the introduction and the basic principles related to fundamental concepts of thermodynamics, heat transfer and fluid mechanics. Part II discusses the various refrigeration cycles and their applications including ultra-low temperature refrigeration, i.e. cryogenics. Part III deals extensively with the various aspects of air conditioning for human comfort with particular emphasis on the psychrometrics, air conditioning cooling load calculations, air distribution and duct designing. Practical examples of design problems have

been explained with copious illustrations to enable the students to grasp the design practices. In Part IV, equipment, accessories and controls of refrigeration and air-conditioning systems have been reviewed.

The first chapter of the book gives a survey of the broad area of the history, current state and the future trends in air conditioning. Chapter two briefly reviews the basic principles of thermodynamics, heat transfer and fluid mechanics. In-depth discussion of the same topics is not attempted because of the fact that students undergoing mechanical engineering courses would have studied those subjects as prerequisites.

Chapters three and five review the thermodynamic principles and features of vapour compression and vapour absorption cycles respectively, which are the most commonly used refrigeration cycles. Multistage vapour compression refrigeration systems and heat pumps have also been discussed in chapter three.

Chapter four describes the characteristics and properties of various refrigerants and their evolution. Chapter six describes the other less popular refrigeration cycles, followed by a discussion of the various applications of refrigeration in chapter seven. Particular emphasis has been laid on the food preservation application of refrigeration because of its enormous impact on global food chain and economies of the world. To that end, various facets of design and use of cold stores have been highlighted.

Chapter eight discusses the various aspects and applications of ultra-low temperature refrigeration, i.e. cryogenics. Chapter nine reviews the comfort criteria and its significance in air conditioning for human comfort. The need and importance of ventilation and indoor air quality and filtration have been discussed in chapter ten.

In chapter eleven the various types of air-conditioning systems, their salient features and applications have been described. The systems and the disposition of equipment, accessories and controls most appropriate for use in the tropics have been emphasized. Chapter twelve deals with psychrometrics and the use of the psychrometric chart as a tool of air-conditioning designers for analysing the various thermodynamic processes involved in air conditioning. Many worked-out examples with illustrations using skeleton psychrometric charts have been included for ease of comprehension by students.

Chapter thirteen explains the method of cooling load calculation. This has been preceded by a discussion of heat transmission in building structures and solar radiation. Although different methods of cooling load calculation have been mentioned, the illustrated problem has been solved by using the ASHRAE's Cooling Load Temperature Differential (CLTD) method.

Chapter fourteen discusses the room air distribution, and the choice of supply design condition and air outlets. Air duct design using the equal friction and static regain methods, has been covered in chapter fifteen. In chapter sixteen, refrigeration hardware comprising compressors, condensers, evaporators, expansion devices and accessories, has been discussed with ample pictorial illustrations.

In chapter seventeen the features, the characteristics and the selection criteria of air-conditioning plants including chillers, air handling units, water cooling equipment comprising evaporative condensers and cooling towers have been discussed. In the same chapter the performance characteristics of fans have also been dealt with.

Air-conditioning controls have been discussed in chapter eighteen, with emphasis on control applications in practical systems. In chapter nineteen the pumping and distribution systems of chilled water and condenser water circuit have been illustrated with examples. The suitability of evaporative, desiccant and radiant cooling for specific applications has been reviewed in chapter twenty. In the same chapter, thermal storage air conditioning has also been discussed.

The author gratefully thanks ASHRAE for granting permission to use many of their charts and tables. Without these tables and charts, the students and practitioners cannot gain exposure to the updated design methods and other valuable information.

The text was produced with the generous assistance of many persons.

I thank my wife Mahmooda for her patience and understanding and for making the task bearable. I also acknowledge the sustained encouragement received from my daughter Farial and son Faisal. My five-year old grandson, Farhan, also deserves appreciation for choosing the cover design.

Their efforts are much appreciated. In particular, I am deeply indebted to my research colleague and compatriot Khizir Mahmud without whose tireless and sustained support I would probably not have completed this book. I am also grateful to my colleague Prof. Aswatha Narayana for reviewing the manuscript.

I shall welcome constructive criticism, helpful suggestions and communication of errors leading to improvements of this textbook.

**AHMADUL AMEEN**

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# PART 1

## General

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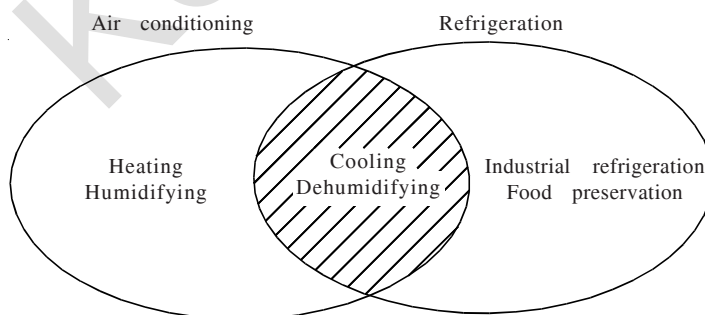
1. Introduction
2. Review of Basic Principles

# 1

## Introduction

Air conditioning deals with artificial tampering of the conditions of air that may involve cooling as well as heating coupled with ventilation, filtration, and air circulation. However, air conditioning is generally perceived as the process relating primarily to cooling of air. Control of environment through supply of heat, however, is generally treated as a process of heating.

Refrigeration, on the other hand, deals solely with cooling and one of its most important applications is air conditioning. Thus refrigeration and air conditioning are very closely interrelated as highlighted in Figure 1.1. For the same reason, very often the two subjects are treated in the same book. In the present book the discussion on air conditioning will focus more on providing a cool environment; the application of air conditioning to heating will be limited to that provided by a heat pump.



**FIGURE 1.1** Relationship of refrigeration and air conditioning.

Refrigeration has played an important role in the growth and attainment of the present-day standard of living. Because of refrigeration, bulk of the perishable foodstuffs wasted hitherto can

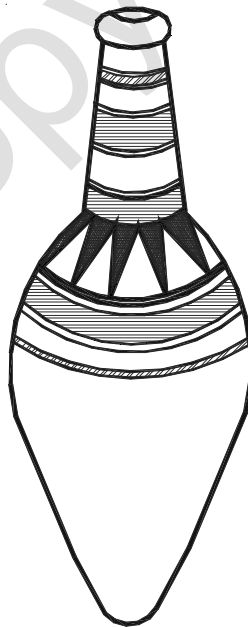
not only be preserved but also marketed to far flung corners of the world. Its application to air-conditioning enabled taming the natural climate into creating comfortable environment even in blistering summer. There has also been dramatic and continuous growth in the air-conditioning industry since the turn of the century. Air conditioning is no longer considered a luxury. The benefits of air conditioning are well established so much so that today it has become a necessity and a tool for higher productivity.

## 1.1 HISTORY OF REFRIGERATION

Refrigeration means the artificial withdrawal of heat, producing in a substance or within a space a temperature lower than that which would exist under the natural influence of the surroundings. Cooling effect created by a machine or mechanical device is classified as mechanical refrigeration.

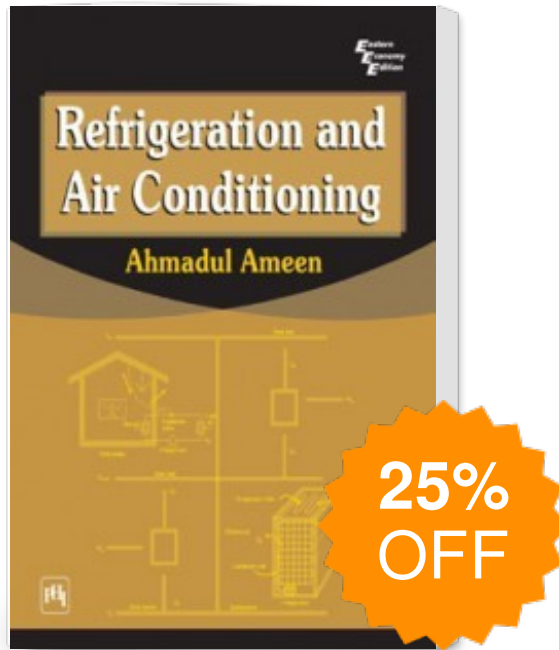
Since prehistoric times, artificial cooling has been recognized as desirable; food was kept in cold air in caves and wells to keep it fresh for longer periods.

Two physical phenomena were used in most remote times—without much understanding of the principles involved—*evaporation of water*, especially through vases of porous pottery (Figure 1.2) widely used in Egypt, India and China, and *terrestrial radiation* towards clear sky during the night. It is known that several centuries before the birth of Christ, Egyptians made ice by this means by putting porous earthen pots on the roof of the house during the night. Evaporation of water in cool dry air together with radiative heat transfer during a clear night caused ice formation even when the ambient temperature was above the freezing temperature.



**FIGURE 1.2** Earthen containers used by Egyptians for cooling water and making ice.

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