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Introduction to Bioenvironmental Engineering

Built Environment

Editor **Yuanhui Zhang**

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Preface

Built environment affects many aspects of our lives-quality of living, energy consumption and subsequent carbon emission to the atmosphere. In the United States, building sector, including residential and commercial, is the largest energy consumer using 40% of the total energy compared to 29% for transportation sector and 31% for industrial sector in the past decade. Built environment principles are indispensable elements in the body of knowledge of engineering students who are interested in areas of building, energy conservation, and indoor environment quality.

This book is an accumulation of the lecture notes during the past 16 years of teaching as an undergraduate introduction course at the University of Illinois. The objectives are, by completing this course, to enable the students to: (1) use a psychrometric chart, measure and calculate psychrometric properties such as temperatures, relative humidity, enthalpy, sensible heat and latent heat; (2) determine steady-state heat transfer rates in three modes: conduction, convection and radiation, through building envelopes, and calculate the heating/cooling loads; and (3) determine the ventilation requirements for the control of temperature, humidity and airborne pollutants, and select heating/ventilation equipment. This course has also been taught as a duel-language course at the College of Water Conservancy & Civil Engineering at China Agricultural University. Although this book is primarily written for engineering students, the principles and approach is suitable for students in related disciplines who are interested in building environment control and energy conservation.

As a textbook, it is suggested to be taught as a 2 to 3 hour credits course at sophomore or junior level. The twelve modules can be divided into three sections: (1) psychrometrics; (2) building heat transfer basics; and (3) mass transfer and ventilation requirement. First section includes Modules 1 to 4 that describes psychrometric chart for achieving Objective 1 of the course. Second section includes Modules 5, 6 and 7 that introduces heat transfer so the students can calculate the heating and cooling loads through a building envelope (Objective 2). The third section includes Modules 8 to 12 that discusses the ventilation requirement for an airspace to maintains energy and mass balances (Objective 3). There are homework assignments and laboratory exercises for each section. Several case studies in Module 12 are designed for classroom discussions or team studies.

Many graduate students have contributed to the lecture notes. I am in particular to acknowledge the co-authors of this book, Doug Barker, University of Illinois, Drs. Wei Cao and Chaoyuan Wang, China Agricultural University, for their comments, contributions to working problems and case studies.

Yuanhui Zhang
Urbana, IL
October 22, 2010

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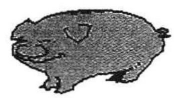
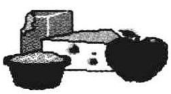
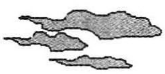
Module 1: Introduction

Air is a critical element to many living things. People, for example, may survive for two weeks without food and for two days without water. But without air, a person may only survive for two minutes! In daily life, an average person consumes approximately one kilogram of food, two kilograms of water and 20 kilograms of air! Furthermore, in developed countries, an average working person spends over 90% of their lifetime indoors.

Table 1-1. Daily intake of air of an average person and hog

Average Daily Intake		
		
	1 kg(2.2 lb)	2 kg(4.4 lb)
	2.0 kg(4.4 lb)	4 kg(8.8 lb)
	20 kg(44 lb)	40 kg(88 lb)

Most people are aware that outdoor air pollution can damage the environment and their health, but may not know that indoor air pollution can also have significant effects. Until the late 1960s, attention to air quality was primarily focused on outdoors because at that time, outdoor air pollution was considered to be responsible for many adverse health problems. In the early 1970s, scientists started to investigate the cause of complaints of indoor working environments. U. S. EPA studies of human exposure to air pollutants indicated that indoor air levels of many pollutants may be 2-5 times, and occasionally more than 100 times, higher than outdoor levels. Over the past several decades, our exposure to indoor air pollutants is believed to have increased due to a variety of factors, including the construction of more airtight buildings, reduced ventilation rates to conserve energy, the use of synthetic building materials and furnishings, and the use of chemically formulated personal care products, pesticides, printing inks, and household cleaners. In recent years, comparative risk studies performed by the U. S. EPA and its Science Advisory Board (SAB) have consistently ranked indoor air pollution among the top five environmental risks to public health. As a result of these studies, people began to realize that indoor air quality is important to the comfort and health of people. Additionally, improvement in the quality of outdoor air since the 1972 Clean Air Act enhances the relative importance of indoor air quality.

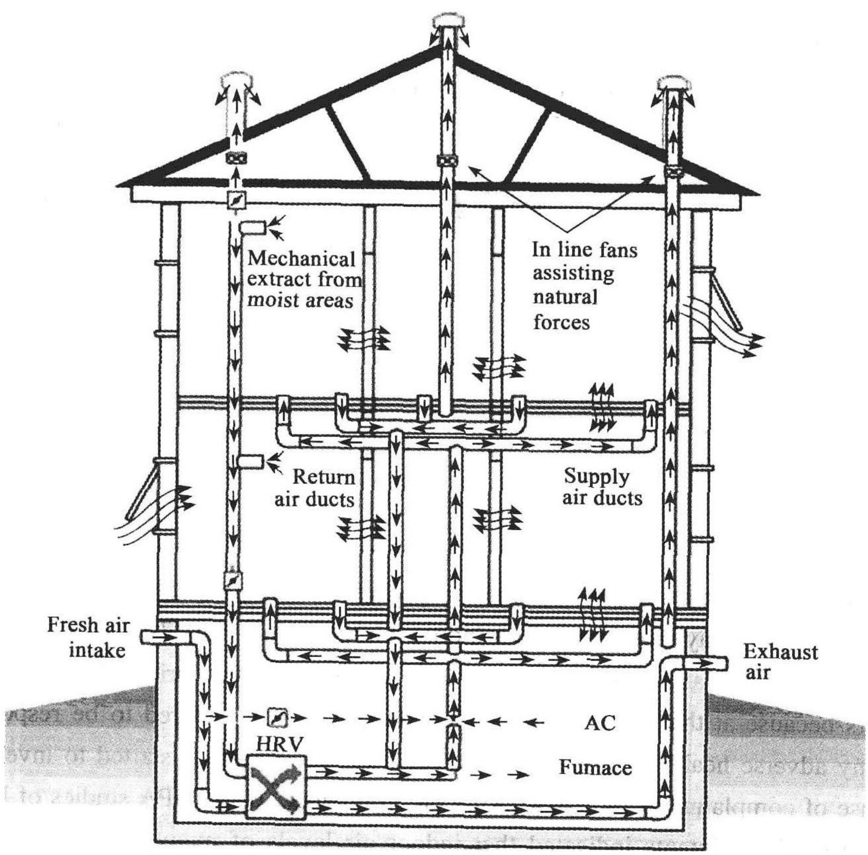


Figure 1-1. An example of air exchange in a residential house using hybrid (mechanical and natural) heating and ventilation scheme (NRC, 2006)

The importance of indoor air quality is also due to the sheer amount of time that people spend indoors. Traditionally, people spent more time outdoors than indoors. Today, people spend more than 90% of their lifetime indoors in industrialized countries. Take the United States for example, every day an average working person spends 22 hours and 15 minutes indoors and one hour in cars or other types of transportation mode-another type of indoor environment. Thus, the total time spent indoors for an average working person is 23 hours and 15 minutes per day, or 97.7% of his/her lifetime! Other types of people such as young children and seniors may spend more time indoors than employed individuals. Indeed, the quality of indoor air should be as high as possible.

1.1 Air Composition

In order to define air quality, a baseline reference to "clean air" or "standard air" should first be established. A typical clean air is the dry atmosphere air found in rural areas or over the ocean far from air pollution sources. The chemical composition of such clean dry atmospheric air is listed in Table 1-2. The atmospheric air also contains from 0.1% to 3% of water vapor by volume depending on temperature. The clean air defined in Table 1-2 is typical because in many instances, other traces of components are also found in the atmosphere that is considered clean. These other tracer components include ammonia, sulfur dioxide, formaldehyde, carbon monoxide, iodine, sodium chloride, and particulate matters such as dust and pollens.

Based on the definition of clean air, air quality refers to the degree of pollution of the clean air. In general, the lower the concentration of airborne pollutants, the better the air quality. *Airborne pollutant* is defined as the substances in the air that can harm the health and comfort of humans and animals, reduce performance and production of plants, or accelerate damage to equipment. Airborne pollutants can be in the form of solid (e.g., particulate matters), liquid (e.g., mists) and gaseous substances. Excessive high concentrations or depletion of substances listed in Table 1-2 can impose serious air quality problems. For example, it is suspected that excessive emissions of carbon dioxide and methane are responsible for greenhouse effects and global warming.

Table 1-2. Chemical composition and volumetric content of typical dry atmospheric air

Substances	Content (%[a])	Concentration (mg/L[a])
Nitrogen	78.084 ±0.004	780 840
Oxygen	20.946 ±0.002	209 460
Argon	0.934 ±0.001	9 340
Carbon dioxide	0.033 ±0.001	330
Neon		18
Helium		5.2
Methane		1.2
Krypton		0.5
Hydrogen		0.5
Xenon		0.08
Nitrogen dioxide		0.02
Ozone		0.01-0.04

Source: *The Handbook of Air Pollution*, PHS Publication, 1968.

[a] in volume.

1.2 Variables and Units

Throughout the text, the SI (International Systems) units-meter, kilogram and second (m-kg-s), will be used as the primary dimension system. However, due to the nature of particle size which is usually in the range of microns or sub-microns, centimeter, gram and second (c-g-s) are used as a secondary dimension system. Liters and milliliters are also used in very small volume or low flow rate. Those secondary units are easily derived from the m-kg-s system. It is important to pay special attention to the consistency of units before applying an equation.

1.3 Energy Use for Buildings

Heating, ventilation and air-conditioning constitute a large portion of the national energy consumption. The following summary data are from the U. S. Department of Energy Data Book (DOE, 2008). From Figure 1-2, energy used in buildings-residential and commercial combined-represents 39.84% of the total energy of the country. It is approximately the total petroleum energy (40.44% of total).

The United States consumed 1.2 billion tons of crude oil (57% imported) in 2007. To put it in perspective, on average, building energy used per person per year in the United States topped approximately four tons of crude oil equivalent. The U. S. Department of Energy summarizes and predicts building energy consumption annually at the website: http://buildingsdatabook.eren.doe.gov. Additional data on building energy use published in 2008 is in Appendix 1.

Table 1-3. Psychrometric variables and their symbols and dimension

Definition	Symbol	Dimension
Temperature:		
Dry bulb temperature	T	K or ℃
Wet bulb temperature	T_w	K or ℃
Dew point temperature	T_d	K or ℃
Humidity:		
Humidity ratio	W	kg_w/kg_a
Relative humidity	Φ	%
Degree of saturation	μ	%
Enthalpy:	h	kJ/kg
Sensible heat content	h_a	kJ/kg
Latent heat content	h_w	kJ/kg
Pressure:	P	kPa
Water vapor saturation partial pressure	P_{ws}	kPa
Water vapor partial pressure	P_w	kPa
Atmosphere pressure	P	kPa
Heat transfer:		
Heat transfer rate	q	J/s or W
Heat flux	q''	W/m^2
Mass transfer:		
Mass	M	kg
Mass flow rate	m	kg/s
Volumetric flow rate	Q	m^3/s
Specific volume	v	m^3/kg
Density	ρ	kg/m^3

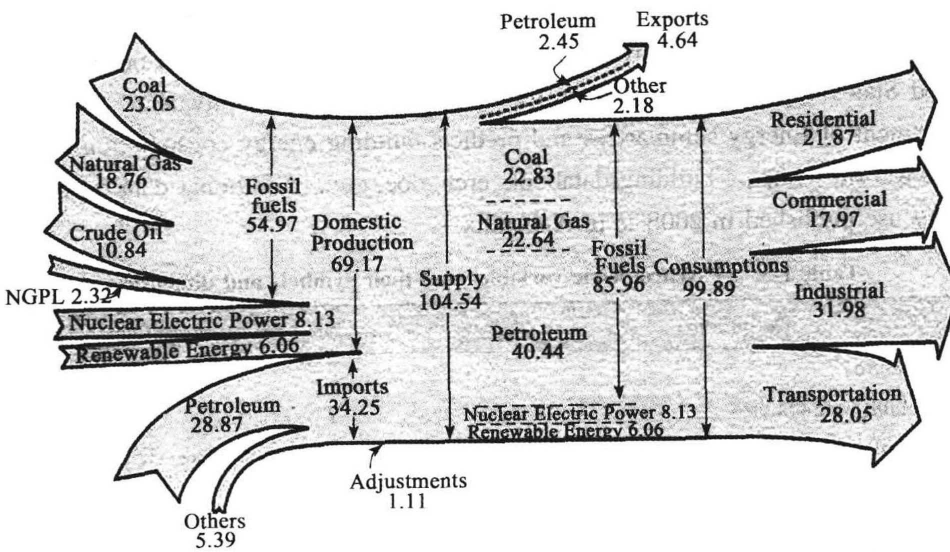


Figure 1-2. Energy flow through the United States in 2005 (EIA, 2005)

1.4 Course Objectives

By completing this course, you will have a basic understanding of psychrometric, heat transfer through a building shelter and ventilation. Specifically, you will be able to:

- Use a psychrometric chart, measure and calculate psychrometric properties, including temperature, relative humidity, enthalpy, sensible heat, and latent heat.
- Determine steady-state heat transfer rates in three modes: conduction, convection and radiation, through different building shelters.
- Calculate ventilation requirements for control of temperature, humidity and airborne contaminants, and properly size heating/ventilation equipment.

1.5 Laboratory Report Policies

Effective technical writing is an essential skill for engineers in all fields. Engineers who can communicate their work clearly, concisely and accurately to a wide range of audiences will be more successful in the long run.