Chapter 1

Introduction

The study of indoor air pollution has evolved into a unique discipline requiring knowledge in several areas. One must be adept at understanding fundamental principles of fluid mechanics, species transport, heat transfer, and systems engineering. Today, buildings have become complex entities with considerable electronic control features embedded within the structures. Of particular concern are issues involving contaminants that routinely enter or lie dormant within building interiors, and their effects upon human health. Articles can be commonly found in newspapers printed throughout the world describing groups of people becoming sick while staying in a hotel, cruising on a ship, or traveling in planes or buses.

Today, efforts to define and describe pollutant transport within buildings and interiors has become complex. Modeling pollutant transport within indoor environments now requires knowledge of computational tools and techniques that were utilized only in research laboratories a few years ago. Knowledge of fundamental principles of ventilation and building systems, including HVAC, must now be coupled with computational fluid dynamics techniques in order to accurately assess human health and predict contaminant exposure. We begin with a brief background in understanding exactly what is meant by indoor air pollution.

MODELING INDOOR AIR POLLUTION

http://www.worldscibooks.com/environsci/p612.html

1.1. What is Indoor Air Pollution

The study of indoor air pollution (IAP) involves dealing with the emission, accumulation, and assessment of pollutants generally attributed to poor ventilation and air exchange. Of particular concern are issues involving air quality and human comfort within buildings. Toxic fumes and airborne diseases are known to produce undesirable odors, eye and nose irritations, sickness, and occasionally death. Other products such as tobacco smoke and carbon monoxide can also have serious health effects on people exposed to a poorly ventilated environment; studies indicate that indirect or passive smoking can also lead to lung cancer. Recommendations for outdoor airflow rates to dilute indoor polluted air vary considerably.

1.2. Ventilation Systems

Ventilation systems are designed to either prevent contaminants from entering a room or remove contaminants from interior sources within the room. Since ventilation systems are integral to the study of indoor air pollution, it is prudent to at least identify them.

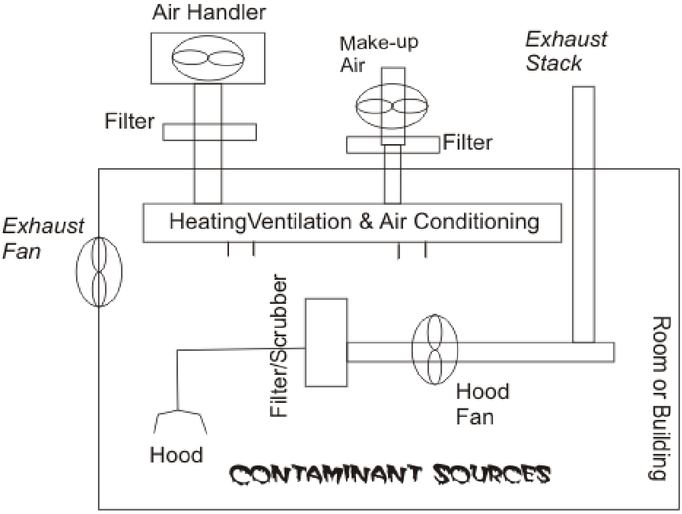

Fig. 1.1 Schematic of a typical ventilation system.

A ventilation system consists of several key components: (1) the contaminant source, (2) an exhaust hood, (3) an air mover, (4) ducts and fittings, (5) makeup air, (6) exhaust air, (7) a pollutant removal device, (8) a discharge stack, and (9) air recirculation. Variations of these components are typically found in most ventilation systems designed to deal with indoor air quality and pollutant removal. Figure 1.1 shows a schematic overview of a general ventilation system.

In particular, the contaminant source typically consists of particulates, gases, and vapors generated by various activities. An exhaust hood is used to contain contaminants emitted from a source, e.g., hoods are used to cover grills in kitchens, an air mover, or fan, is used to draw air into a hood ducts and fittings make up the piping network connecting the hood to the fan, makeup air is air that is brought into the room from the outside – this air is usually temperature and humidity controlled, exhaust air is the air discharged from the room, a pollutant removal device is a specific piece of equipment used to remove excess contaminant from the room (when environmental standards are exceeded), a discharge stack is a stack that exhausts air into the atmosphere, and air recirculation is air that is returned into the room (clean air).

These components are fairly common in rooms containing ventilation systems, especially industrial settings that deal with dirty environments. More detail describing these components and their proper selection can be found in the ASHRAE Handbook (1981) and the textbook by Heinshohn (1991).

1.3. Exposure Risks

The assessment of risk attributed to exposure from hazardous materials is a formal field of study. A great deal of effort was spent in developing risk limits during the early years of the nuclear industry, i.e., in the design and operation of nuclear reactors. A significant amount of mathematical development and theory exists on the subject (see Brain and Beck, 1985).

Assessing risk requires information dealing with the types and amounts of hazardous material and the percent discharged to the environment. It is essential that one have a good grasp of the materials and processes being undertaken before an accurate assessment of risk can be made. For example, there are over 56,000 manufactured or imported substances used in industrial operations (defined by the EPA in response to the Toxic Substances Control Act). The National Institute for Occupational Safety and Health (NIOSH) also lists a registry of toxic effects of chemical substances (RTECS). Likewise, the Occupational Safety and Health Administration (OSHA) maintains a list of toxic and hazardous materials. These registries are updated every few years and can be obtained from respective agency websites.

Risk is generally depicted in terms of events per year (usually a small number) and uncertainty (%). Exposure limits are usually depicted in parts per million or billion, denoted as PPM or PPB, or can be expressed in terms of milligrams per cubic meter (mg/m^3). For example, the risk of getting cancer due to smoking cigarettes (1 pack/day) is 3.6 x 10^{-3} (annual risk) or a factor of 3 (order of magnitude) in percent. The permissible exposure limit for acetone, for example, is 750 PPM; respirable dust from working with marble is around 5 mg/m^3. Table 1.1 shows a list of some common materials and activities and their permissible exposure limits.

Table 1.1 Permissible Exposure Limits of Several Materials and Activities

Material or Activity	**Annual Event**	%	**PPM**	**mg/m^3**
smoking	3.6 x 10^{-3}	10^{-3}		
chloroform in drinking water	6 x 10^{-7}	10^{-7}		
acetone			750	
chlorine			0.5	
fluorine			0.1	
ozone			0.1	
mercury vapor				0.05
marble dust (respirable)				5
grain dust (oat, wheat, barley)				10
wood dust				5

While one can envision various techniques used to establish risk, there is a simple technique to obtain a human exposure dose (Ames *et al.*, 1987). This Human Exposure Dose index is related to the Rodent

Potency Dose, or HERP, and relates the carcinogenicity of certain chemical agents to animal cancer tests. While one cannot use animal cancer tests to exactly predict human risk, the index does provide a good guide for establishing priorities and potential carcinogenic hazards. The HERP is defined as

$$\text{HERP} = \text{daily lifetime human dose (mg / kg) X rodent } TD_{50} \text{ (mg / kg)} , \quad (1.1)$$

where TD_{50} are values taken from a data base for 975 chemicals (Ames *et al.*, 1987). Table 1.2 lists several HERP values commonly encountered by humans.

Table 1.2 Risk Based on HERP Index (from Ames *et al.*, 1987)

Daily Human Exposure	**Dose (μg/70-kg person)**	**HERP (%)**
Chlorinated tap water	Chloroform	0.001
Swimming pool	Chloroform	0.008
Conventional home	Formaldehyde	0.6
Mobile home air	Formaldehyde	2.1
Beer (12 oz)	Ethyl alcohol	2.8
High exposure farm worker	Ethylene dibromide	140.0

1.4 Numerical Modeling of Indoor Air Flow

In recent years there has been extensive activity in the development and use of Computational Fluid Dynamics (CFD) software and special programs for room air movement and contaminant transport applications. These investigations range from the prediction of air jet diffusion, air velocity and temperature distribution in rooms, spread of contamination in enclosures, to fire and smoke spread inside buildings. In most cases the predicted results have been promising when compared to available experimental data. However, numerical modeling of ventilation and associated interior contaminant transport is still at an early stage of development and confidence level. A considerable amount of research and development work is still needed, particularly in the areas of more efficient computational schemes, irregular and adaptive grids, turbulence modeling and wall functions.

One of the earliest attempts to numerically simulate airflow in rooms was conducted by Nielsen (1974) using the stream function-vorticity approach for the dependent variables, along with a two-equation (k-ε) model for turbulence based on the numerical procedure developed by Gosman *et al.* (1969). The computations produced realistic room flows, but was limited to 2-D. Numerous papers have appeared over the years utilizing the stream function-vorticity approach for simulating 2-D flows within enclosures; however, the approach is *practically* limited to 2-D flows, and does not permit one to easily incorporate turbulence and 3-D effects inherent in actual ventilated enclosures. Efforts were later undertaken by Hjertager and Magnussen (1977) using the finite volume approach and the SIMPLE algorithm developed by Patankar and Spalding (1972) to solve the 3-D primitive equations of motion with the k-ε two-equation model for turbulence. They modeled the flow from an air jet exhausting into a rectangular room with two ceiling exits. While the point of jet separation from the ceiling was well predicted, the predicted velocity of the jet near the lower region of the room was higher than the measured value.

Gosman *et al.* (1980) extended their two-dimensional finite volume model to solve isothermal flows within 3-D enclosures with small ventilation openings. They achieved good correlations of velocity profiles and jet velocity decay with measurements. Sakamoto and Matsuo (1980) similarly predicted 3-D isothermal flow in a room using the marker and cell (MAC) technique (Harlow and Welch, 1965) and two turbulence models: the k-ε approach and the large eddy simulation (LES) technique (Deardorff, 1970). Results compared favorably with measured velocity profiles; they recommended that the k-ε approach for turbulence be used for room flow predictions over the LES model because it is simpler to use and requires less computing time for comparable accuracy. A computer program called CAFE, developed by Moult and Dean (1980), was used to solve the 3-D velocity components, temperature, concentration, and k-ε turbulence parameters for flow in industrial enclosures and clean rooms. Results were in good agreement with measurements in regions where velocities were large.

Murakami *et al.* (1987) investigated the three-dimensional airflow and contamination dispersion in six (rectangular) types of ceiling supply clean rooms both numerically and experimentally for isothermal flow. They used the MAC method coupled with a central difference approach for the velocity components, and a second-order upwind scheme for k, ε, and concentration, to solve the transient transport equations. Results showed good agreement between prediction and measurement, as well as some interesting flow phenomena regarding the spread of a jet exhaust as it reached the floor. Awbi (1989) numerically solved 2-D air flow and temperature distributions within rooms with diffusers and various vent locations in an effort to simulate 3-D effects; the 2-D non-isothermal predictions compared well to measured vertical velocity and temperature profiles in the room. An early historical discussion and descriptions of numerical methods for solving 2-D and 3-D ventilation and contaminant transport is given by Awbi (1991). A collection of chapters dealing with various issues regarding the modeling of indoor air quality and exposure was published by the ASTM (edited by Nagda, 1993). An overview of indoor climate and air quality issues is discussed by Hoppe and Martinac (1998). A detailed discussion of fire dynamics within enclosures, including modeling, is given by Karlsson and Quintiere (2000). More recent descriptions of modeling efforts can be found in such journals at *Numerical Heat Transfer*, the *ASHRAE Transactions*, *Indoor Air*, and other related technical journals. Today, one can simply log onto Google and do a search on indoor air quality to find numerous articles dealing with the many facets of IAQ.

1.5 Comments

The study of indoor air pollution and ways in which to assess and evaluate contaminant transport and exposure can quickly become overwhelming. There are numerous techniques and schemes now being used to examine IAQ issues, and new developments underway in many research facilities and universities.

While a solid background in engineering or science with familiarity in basic numerical methods is a plus, it is not critical that one be well trained or experienced in the intricacies or details of such fields. Much of the information and numerical schemes addressed in this text can be quickly digested and tried. Experience and confidence in dealing with indoor contaminant problems comes from repeated use and application of some of the tools addressed in this text.