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Residential Indoor Air Quality

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California's Indoor Air Quality Program

As a preface to my discussion of residential indoor air quality, a brief description of the California Program is in order. The California Indoor Air Quality Program is a formal, permanent state effort devoted to understanding the determinants of healthful indoor air quality (1). The staff consists of seven full-time scientists who initiate, design, and carry out research on important indoor air quality issues. Among the professional disciplines represented in the group are epidemiology, biostatistics, chemistry, environmental health sciences, psychology, engineering, and microbiology. A number of projects which focus on defining the nature and extent of indoor environmental problems have been completed, including a chamber study to characterize particle and vapor emissions from indoor combustion sources (2), determination of formaldehyde exposures inside mobile homes (3,4), a survey of private firms which measure indoor air contaminants on a fee-for-service basis (5), characterization of air quality in wood-burning houses (6), and an overview of the major policy and regulatory issues associated with safeguarding indoor air quality (7).

Introduction to Indoor Air Quality Issues

Historically, nonindustrial indoor environments (i.e., residences, offices, and commercial, institutional, and public buildings) have been considered to be relatively nonhazardous. During outdoor air pollution episodes, for example, sensitive individuals (e.g., those with asthma and emphysema, school children) are encouraged to stay indoors. While this may be good advice if the goal is to reduce exposures to photochemical oxidants, such as ozone, evidence continues to mount that concentrations of many air pollutants are routinely elevated in private and public buildings. Among the airborne contaminants commonly present at higher concentrations indoors than outdoors are passive tobacco smoke, formaldehyde, carbon monoxide, nitrogen dioxide, radon decay products, asbestos fibers, respirable particles, volatile organic compounds, microorganisms (e.g., bacteria, viruses, fungi), and aeroallergens (1). Information about indoor pollutants, important emission sources, and health effects is summarized in Table 1 (7).

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SUMMARY OF MAJOR INDOOR AIR CONTAMINANTS, IMPORTANT SOURCES, AND POTENTIAL HEALTH EFFECTS

CONTAMINANTS	INDOOR SOURCES	HEALTH EFFECTS
RESPIRABLE PARTICLES	tobacco smoke, cooking, unvented combustion appliances, aerosol sprays, condensation of vapors, resuspended house dust	depending on particle composition: mucous membrane irritation, respiratory infections, emphysema, heart disease, lung cancer
FORMALDEHYDE	particleboard, plywood, insulation, furnishings, adhesives, synthetic building materials, tobacco smoke	mucous membrant irrigation, skin rash, chemical sensitivity, lower respiratory irritation, pulmonary edema, central nervous system effects, possible human carcinogen
MICROORGANISMS (BACTERIA, VIRUSES, FUNGI)	air-cooling equipment, humidifiers, flush toilets, carpeting, people, pets, plants	acute respiratory infections (e.g., influenza, Legionnaire's disease, Pontiac Fever, Q Fever)
AEROALLERGENS (ALLERGIC AGENTS)	plant pollen, animal dander, insect parts, house dust, molds, mites, algae, detergents, chemical additives	allergic reaction, pneumonitis
COMBUSTIONS GASES (CO and NO_2)	unvented combustion appliances, attached garages, woodstoves, fireplaces, tobacco smoke	CO: oxygen deprivation due to COHb, impaired vision and brain function, fatal at high concentrations NO_2: increased respiratory infection rate, bronchoconstriction, pulmonary edema
RADON	underlying soil, building construction materials, well water	lung cancer
ORGANIC VAPORS	solvents, adhesives, synthetic building materials, aerosol sprays, pesticides, cooking, furnishings, paint, metabolic processes, tobacco smoke	mucous membrane irritation, narcotic at high concentrations, central nervous system effects, damage to heart, kidney, and liver, many documented or suspected human carcinogens
FIBERS (ASBESTOS, MINERAL, SYNTHETIC)	insulation, fire retardents, building construction materials, furnishings, texture paints	skin irritation, mucous membrane irritation, asbestos is associated with increased incidences of lung cancer, pleural and peritoneal mesotheliomas, and gastrointestinal tract cancer

Table 1

Importance of Safeguarding Indoor Air Quality

Realization that indoor air quality in nonindustrial environments is not uniformly healthful is a relatively recent development. Therefore, it is important to understand the basis for current concerns about potential adverse health effects from contaminated indoor air. In general, there are five major reasons why safeguarding indoor air quality is an essential component of strategies to reduce human exposures to air pollution.

- Most urban residents spend 80 - 90 percent of their time indoors, while some groups, such as the elderly, the infirm, and infants are inside almost all the time.

- Concentrations of many pollutants, such as tobacco smoke, volatile organic compounds, radon, asbestos, respirable and viable particles are commonly higher indoors than out.

- Monitoring studies have shown that personal exposure to many pollutants is not characterized adequately by outdoor measurements and that indoor (in-home) values are consistently the best estimator of individual exposure.

- Indoor air quality may be adversely affected by trends toward reduced ventilation in buildings, increased use of synthetic materials and increased reliance on unvented combustion appliances for space heating.

- Reports of inadequate indoor air quality and building-related illnesses from homeowners and office workers are a burgeoning problem for local, state, and federal health agencies.

Particles - Health Effects

Particles are an important category of indoor air pollution and are receiving increasing attention due to potential health consequences from indoor exposures.

The health effects of breathing airborne particles depend primarily on size and composition of inhaled aerosols. The penetration and region of ultimate deposition in the lung are mostly determined by particle size. Three distinctions commonly applied to particle sizes are fine fraction particles, respirable particles, and inhalable particles. Fine fraction particles are less than 2.5 microns in aerodynamic diameter, about 1/50th the width of a human hair. Respirable particles are those that are less than 3.5 microns in aerodynamic diameter. Particles smaller than 10 microns are referred to as inhalable. Very small particles, primarily those in the fine fraction and respirable size ranges, can penetrate deeply into the lung where residence time is on the order of months to years for insoluble particles. Particles that are soluble can actually enter the bloodstream within minutes when they penetrate into the alveolar region. Particles larger than 3.5 microns but smaller than about 10 microns are typically deposited in the upper respiratory tract where they are cleared in a matter of hours.

Although we often think of particles as small round spheres, they are obviously not spherical in many cases. In fact, fibers are a special class of particles. For instance, even though an asbestos fiber may be quite long, say longer than ten microns, as long as the aerodynamic diameter is less than about 3.5 microns, it can still penetrate deeply into the lung. There is evidence showing human lung tissue containing asbestos fibers that are as long as 200 microns.

The actual toxicity and associated health effects of individual particles are due to the composition of the particle as well as the size. There are three basic mechanisms by which particles can cause physiologic responses in the lung. In the first place, some substances are inherently toxic, such as sulfuric acid, lead, beryllium, asbestos, and silicon dioxide, and can cause damage in and of themselves. Secondly, though a particle itself may be chemically inert, it can interfere with the clearance of other toxic particles from the lung. And finally, particles may act as adsorbents for gaseous pollutants and thereby promote synergistic interactions.

A particle which is emitted directly from a source into the air is referred to as a primary particle emission. Primary particulate matter from combustion sources, for instance, typically contain carbon, usually in the form of soot, salts, metal oxides, and a variety of trace elements. Some examples of primary particles which are important health hazards are inorganic mineral fibers, dust, asbestos, and glass fibers. Secondary particles, in contrast, are formed by chemical and released into the air. Prime examples include the condensation of vapors to form secondary aerosols and the adsorption of organic material onto particle surfaces. Secondary aerosol formation plays an important role in the hazy conditions normally associated with photochemical smog and in the mechanism by which acid rain is formed in the atmosphere.

Indoor Air Quality Problems

Building occupants are increasingly reporting dissatisfaction with the quality of indoor air in their homes and offices. In addition, a significant number of individuals exhibit subjective symptoms which they believe are due to indoor air contaminants. Recognition of building-related illnesses as a widespread public health problem is just beginning and most state and local health agencies are ill-equipped to respond adequately to these types of complaints.

As it is commonly used, the term "building-related illness" refers to an illness outbreak among building occupants, with no secondary spread of the illness to others outside the building with whom affected individuals come into contact. Adverse reactions to indoor environments typically fall into two categories, feelings of discomfort (e.g., thermal discomfort, unpleasant odors, lack of air movement, inadequate lighting, excessive noise) and acute or short-term health effects (e.g., mucous membrane irritation, allergic reaction, skin rash, headaches, nausea, fatigue, persistent colds). Among the potential causes of building-related illness are infectious agents, allergic agents, physical parameters (e.g., temperature, ventilation), chemical contaminants, and psychosocial factors (e.g., job-related stress).

In addition to feelings of discomfort and short-term health effects, inadequate indoor air quality might also cause chronic or long-term health effects (e.g., upper respiratory disease, chemical sensitivity, repressed immune system response, malignancy). Because many diseases have latency periods of 10 years or more, building occupants could be suffering from irreversible health effects but exhibit no symptoms at the present time. Thus, much of the concern about unhealthful indoor air quality focuses on the long-term health implications of indoor pollution exposures, especially the possibility of adverse health consequences in the absence of acute symptoms.

Determinants of Indoor Air Quality

The building envelope forms the dividing line between indoors and outdoors. If outdoor pollutant concentrations are high, then the building envelope can provide some degree of protection from outdoor air pollution for the occupants. The extent to which pollutants of outdoor origin are able to penetrate into the interior of a particular building depends on factors such as the reactivity of the pollutant in question, the tightness of the structure, the amount and nature of natural and forced ventilation, and particle size (if applicable). On an annual average, for example, about 50 - 60 percent of respirable particles present in outdoor air penetrate inside a conventional residence. There are obviously significant diurnal and seasonal variations, however, due to changes in occupant activities, natural and forced ventilation, and ambient temperature.

If indoor sources are present, the building envelope can also act as a barrier which prevents indoor-generated pollutants from escaping. Recent trends toward energy conservation have fostered "tighter" buildings and reductions in ventilation rates. These changes can lead to a buildup indoors of airborne contaminants from synthetic material, tobacco smoking, unvented combustion appliances, underlying soil (i.e., radon), and other inside sources of air pollution.

Contaminant concentrations in a specific building depend on several parameters, including outdoor pollutant levels, air-exchange rates, inside mixing conditions, pollutant decay rates, and indoor source strengths. Specifying values for these parameters depends, in turn, on other factors. For example, outdoor pollutant concentrations are affected by proximity to pollution sources, meteorological variables, and local terrain, while air-exchange rates are influenced by indoor/outdoor temperature gradients, wind speed, and forced ventilation.

Mitigating Measures (from Reference 7)

Control methods for indoor air pollution can be grouped into five general categories: ventilation, source removal or substitution, source modification, air purification, and behavioral adjustments to reduce exposures (avoidance). The applicability of available controls to specific contaminants is summarized in Table 2.

SUMMARY OF MITIGATING MEASURES FOR INDOOR AIR CONTAMINANTS

CONTROL MEASURE DESCRIPTION	POLLUTANT	EXAMPLE
Ventilation: Dilution of indoor air with fresh outdoor air or recirculated filtered air, using mechanical or natural methods to promote localized, zonal, or general ventilation	Radon and radon progeny: combustion by-products; tobacco smoke: biological agents (particles)	Local exhaust of gas stove emissions; air-to-air heat exchangers; building ventilation codes; venting sub-slab area to remove radon gas or volatile organic compounds
Source removal or substitution: Removal of indoor emission sources or substitution of less hazardous materials or products	Organic substances; asbestiform minerals; tobacco smoke	Restrictions on smoking in public places; removal of asbestos
Source modification: Reduction of emission rates through changes in design or processes; containment of emissions by barriers or sealants	Radon and radon progeny: organic substances; asbestiform minerals; combustion by-products	Plastic barriers to reduce radon levels; containment of asbestos; design of buildings without basements to avoid radon; catalytic oxidation of CO to CO_2 in kerosene burners
Air cleaning: Purification of indoor air by gas adsorbers, air filters, and electrostatic precipitators	Particulate matter: combustion by-products; biological agents (particles)	Residential air cleaners to control tobacco smoke or wood smoke; ultraviolet irradiation to decontaminate ventilation air; formaldehyde-sorbant filters
Behavioral adjustment: Reduction in human exposure through modification of behavior patterns; facilitated by consumer education, product labeling, building design, warning devices, and legal liability	Organic substances: combustion by-products; tobacco smoke	Smoke-free zones; architectural design of interior space; certification of formaldehyde concentrations for home purchases

Table 2

Control classifications are not mutually exclusive and effectual strategies might use combinations to limit exposures resulting from indoor sources.

Historically, ventilation has been the primary means of providing adequate indoor air quality. Traditional forms of ventilation allow free exchange of indoor and outdoor air, but fail to conserve heat or humidity. Today, spiraling energy costs have launched a trend towards energy-efficient buildings with reduced air-exchange rates. The relatively recent development of improved air-to-air heat exchangers may allow for maintenance of both indoor air quality and energy conservation. Nevertheless, these devices are still in a relatively early stage of the development process.

Removing the source of a contaminant has obvious benefits. Prohibition of urea-formaldehyde foam insulation in residences and removal of asbestos products from school buildings are examples of source removal programs. Such strategies are most effective when substitute materials are readily available, and when affected parties agree on the necessity of action. Substitution of materials must be pursued cautiously to assure that new problems are not created in eliminating the old. Difficulties may also arise when programs require changes in behavior, conflict with consumer preferences, adversely affect specific groups, or involve an economic penalty.

Modifying the source of a contaminant to restrict emissions is often a practical alternative. For example, changes in process or design might be used effectively to limit release of combustion by-products from gas-fired appliances, woodstoves, kerosene heaters, and coal furnaces. Special sealants might be useful in limiting airborne releases from radon- and formaldehyde-emitting surfaces.

Purifying the air inside buildings is another option for improving air quality. Various kinds of small and relatively inexpensive air-cleaners are now on the market. Sales of these devices have expanded rapidly in the past few years and exceeded two million units in 1981. While there is clearly a demand for air-purifiers, their efficiency has not been tested adequately. Consumers, therefore, have no assurance that the air-cleaners they purchase are effective in reducing health risks.

Individuals can greatly influence their own exposures, particularly within residences, and less so in commercial, industrial, and institutional settings. Modifying behavior patterns can be a useful control technique, but this approach presupposes that individuals have sufficient information and motivation to take action. Strategies to promote individual action might include: public information programs to enhance consumer awareness, testing and labeling of products used in the home, development of simple contaminant sensing devices, and better definition of legal rights and liabilities. Fostering public awareness of the need to maintain healthful indoor air quality should be considered a critical element of any contaminant control strategy.

Designing workable and effective indoor control strategies requires an understanding of several pertinent factors. Contaminant characteristics need to be assessed, including such factors as concentrations, reactivity, physical state, and particle size, if applicable. Emission source configurations must also be taken into account. Are discharges continuous or intermittent, are they point or area releases, and do they originate primarily indoors or out? Another major consideration is the nature of exposure-response relationships. Are individuals to be protected from long-term exposures to relatively low concentrations or periodic short-term exposures to peak concentrations? Finally, the type of indoor enclosure is important. Some ameliorating measures are more suited to private residences than to public buildings, or to new, as opposed to older structures.

<u>Summary and Conclusions (from Reference 7)</u>

Evidence continues to mount that air pollution is a problem indoors as well as out. The current national trend towards energy-efficient buildings has raised concerns about possible adverse effects on human health. Unfortunately, insufficient data are currently available to assess public health risks associated with energy conservation measures, such as reducing air-exchange rates, fuel switching, and adding insulation. Nevertheless, it is clear that reducing forced and natural ventilation can cause a buildup indoors of toxic and carcinogenic emissions from passive tobacco smoke, building materials, unvented combustion appliances, furnishings, and underlying soil. Increasing reports of building-related illness among occupants of homes and offices provide evidence of the direct relationship between the quality of indoor air and acute or short-term health effects. While less well defined, the possibility of chronic, irreversible health consequences due to indoor exposures cannot be ignored.

Realization that indoor air quality in nonindustrial environments (e.g., residences, offices, schools, commercial and public buildings) is often less healthful than that outdoors presents policy-makers with a conundrum. National Ambient Air Quality Standards (NAAQS) have been promulgated for several outdoor air pollutants as a means to protect public health. As a result, billions of dollars have been spent to control atmospheric emissions from mobile and stationary sources. Yet even for those airborne contaminants which have both outdoor and indoor sources, such as respirable particles and nitrogen dioxide, the vast majority of exposures to concentrations above the standard occur indoors due to indoor combustion sources. Nevertheless, although the health effects of breathing respirable particles or nitrogen dioxide are the same indoors as out, all other factors being equal, existing NAAQS apply only to air which is external to buildings (7).

Still the fact remains that consideration of indoor exposures is essential for realistic assessment of air pollution health risks. Although outdoor air monitors continue to provide data about compliance with NAAQS, we now know that they are inappropriate for estimating human exposures. This leaves us with an anomalous situation, wherein NAAQS are set to protect public health, and outdoor air monitors are used to measure compliance with NAAQS, in spite of the fact that outdoor measurements provide little or no information concerning actual exposures. Thus, a substantial fraction of the population residing in an area which is nominally in compliance might still be exposed to concentrations in excess of existing outdoor standards. Yet because exposures occur inside buildings, they currently have no relevance for enforcement of air pollution laws (7).

If only the health implications of exposures are considered, then there is no obvious reason why air quality standards should not apply indoors as well as out. In actuality, however, the enforcing standards in tens of millions of buildings make application of the complex Clean Air Act regulations problematic. Furthermore, if NAAQS were extended indoors, every State in the Union would immediately be in noncompliance for carbon monoxide, nitrogen dioxide, and particulate matter, necessitating enactment of specified penalties (7).

Indoor air pollution raises complicated public policy questions about the role of government in safeguarding health and welfare inside buildings. Although differences between indoor and outdoor environments clearly have policy ramifications, little attention has been given to identifying and resolving important issues. The diversity of indoor environments, differences between public and private buildings, and distinctions between voluntary and nonvoluntary risks must be taken into account before effective and workable control strategies can be designed and implemented. Rules and regulations are not necessarily the most appropriate forms of government intervention for ameliorating indoor air quality problems. Moreover, if government insists on pursuing a regulatory approach, there is small likelihood that setting strict indoor air quality standards will prove to be effectual, especially in private residences (7).

If the discovery of indoor air pollution does nothing else, it illustrates that air pollution exposures are even more complex than initially supposed. It is unrealistic and counterproductive to think that air pollution health risks can be divided neatly into indoor and outdoor categories. Both exposure routes must be considered before health benefits of current and future control strategies can be assessed accurately (7).

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