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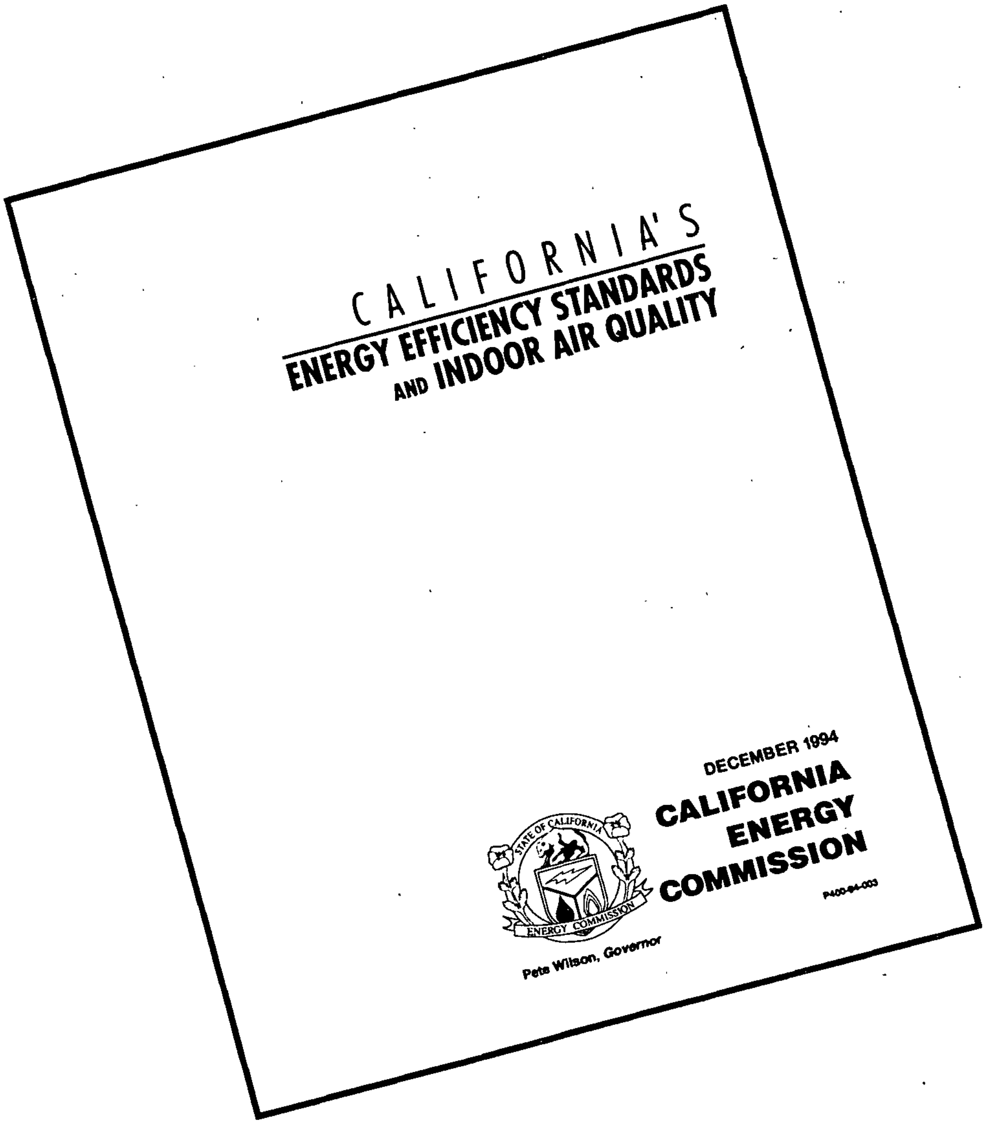
CALIFORNIA'S
ENERGY EFFICIENCY STANDARDS
AND INDOOR AIR QUALITY

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SPECIAL RECOGNITION

The California Energy Commission thanks Assembly Member Sally Tanner for her efforts in the areas of environment and public health protection. Now retired, Ms. Tanner served in the California Legislature from 1982 to 1992 and authored many important pieces of legislation related to toxics and air quality. Of particular significance to the California Energy Commission was AB 4655 which, in 1988, added Section 25402.8 to the Public Resources Code. This bill gave the Commission its specific authority and responsibility to consider regulations which would reduce the potential for indoor air pollution and has enabled the Commission to more completely consider the health impacts of indoor environments in its standards development process.

ACKNOWLEDGEMENTS

This draft report was prepared by an interdisciplinary team of California Energy Commission advisers and staff.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Public Resources Code (PRC), Section 25402, requires the California Energy Commission (Commission) to develop, implement, and periodically update energy efficiency standards for new buildings. AB 4655 (Tanner, 1988) added PRC Section 25402.8, requiring the Commission to examine the effects of the energy efficiency standards on indoor air quality. Specifically, this legislation requires the Commission to a) include in its deliberations while developing building standards the impact these standards could have on indoor air quality, and b) to complete, by December 31 1991, a review of current energy efficiency standards to determine whether modifications are needed to reduce the potential for indoor air pollution. This report is a summary of that review.

History of Concern Over Indoor Air Quality

Combined, the following factors have raised concern over the impact of indoor pollutants on human health:

- The discovery that high concentrations of the carcinogenic (cancer-causing) radon gas may be found in more homes than previously assumed
- Discovery of the possibility of high levels of carcinogenic asbestos fibers in some buildings with past applications of asbestos, a widely used insulating material
- Growing number of non-specific health symptoms which tend to occur when exposed to indoor pollutants
- Employment trends toward working indoors
- Building industry trends toward controlled indoor environments without occupant access to system controls or operable windows
- Building industry practices during the energy crises of restricting, if not eliminating, the use of outside air in heating and cooling systems
- Building energy standards' incorporation of infiltration control requirements to reduce uncontrolled building air leakage
- The growing number of volatile organic compounds found in typical homes and offices because of the use of manufactured products

Summary of Knowledge About Indoor Air Pollutants, Health Effects, Tight Building Syndrome and Building Related Illness

The main classes of pollutants (described along with related health effects) are:

- Biological contaminants
- Radon
- Combustion products
- Particulate matter
- Volatile organic compounds and semi volatile organic compounds

"Tight building syndrome" cannot be linked to specific exposure to specific pollutants. A building-related illness (such as Legionnaire's Disease) can. Multiple chemical sensitivity (MCS), also known as Environmental Illness (EI), affects a significant subset of the population, leading to heightened chemical sensitivity well beyond the normal sensitivity of the rest of the population.

Conceptual Approaches to Regulating Environmental Pollutants and their Applicability to Indoor Environments

Environmental pollutants are currently regulated according to their potential to cause cancer or health effects other than cancer. This potential is assessed through the health risk assessment process. This risk assessment process, however, is not useful for establishing energy-conserving ventilation requirements for buildings since there is no numerical correlation between ventilation rates and specific levels of risk.

The main factors that will affect the concentration of indoor air pollutants include:

- Effectiveness of any ventilation system in removing pollutants
- Care and maintenance of a building and its related systems
- Behavior of the building occupants
- Existence of entry pathways for pollutants
- Overall "air tightness" of the building
- Existence of significant indoor sources of pollution

Technological Approaches to Reducing Indoor Pollutants

The California Department of Health Services and Air Resources Board have identified source elimination as the most effective, economical and reliable method for reducing indoor concentrations of pollutants, with ventilation necessary for further reducing residual indoor pollutant levels. Ventilation is sometimes the most practical solution to immediate indoor air quality problems involving specific indoor pollutants from identifiable sources. In general, maintaining acceptable indoor air quality involves the approach of eliminating all known sources and providing adequate ventilation.

The concentration of a pollutant in a space is a function of the source strength and the dilution rate. The effects of the dilution rate on source strength is not easily quantifiable and is generally considered to be variable making it impossible to establish specific ventilation rates appropriate to all situations.

When formulating ventilation requirements for the purposes of reducing potential for pollutant accumulation, it is difficult to establish any one pollutant as an indicator of the absence of pollution-related health effects. Carbon dioxide levels have been identified from experience and limited studies as a roughly reliable indicator of acceptable indoor air quality. Total volatile organic compound concentration has been applied with some limited success as a general indicator of indoor pollutant levels. No other pollutants have been identified so far as capable of such an indicator role.

ASHRAE Standard 62-1989 bases its minimum ventilation rate on the same principle of minimizing levels of carbon dioxide as a way of maintaining indoor pollution within acceptable levels, as well as a general belief that higher levels of dilution reduce the potential for adverse health effects of indoor air pollution. The other components of the standard are based on committee consensus. Scientists have attempted to establish health-protective ventilation rates by using pollutants other than carbon dioxide as a surrogate for pollutant levels, but direct relationships between pollutant concentration and ventilation rates are difficult to establish because of the many factors that can affect the concentration of pollutants in any indoor environment.

Available ventilation technology and practices would be inadequate to guarantee against the effects of indoor pollutants in the individual with the multiple chemical sensitivity. The Americans with Disabilities Act may apply to these individuals by requiring they be provided reasonable access to buildings. This may mean additional measures to ensure such access. These measures may be technological, such as using point-source exhaust systems, or administrative, such as prohibiting smoking in buildings and near entrances to buildings.

The removal of pollutants from space can be accomplished in two ways: the pollutant-laden air can be exhausted from the space or treated to remove the pollutants of concern. At present, only limited confidence can be placed in the effectiveness of air treatment systems for protecting against health effects of indoor pollution due to the following factors: 1) air treatment is presently possible for only a small group of indoor pollutants, and 2) the safe levels of many of these pollutants have not been established.

California's Energy Efficiency Standards

The Commission is required to develop cost-effective energy efficiency standards that include both mandatory and performance requirements. The California Environmental Quality Act (CEQA) specifically requires the Commission to identify any potential negative environmental effects of compliance with these standards and to present alternatives which will mitigate these effects.

The efficiency standards have unique features that conceivably could lead to increased indoor concentrations of pollutants. These include infiltration control requirements and mandatory insulation levels. There are no specific requirements for mechanical ventilation of residential buildings. The Commission concludes that these requirements do not present a major risk of increased indoor pollutants and that residential buildings are adequately ventilated because of the universal application of operable windows.

The standards for nonresidential buildings have incorporated minimum ventilation requirements since their effective date in 1978. Two revisions of the standards reflect the following:

- Revision of ASHRAE Standard 62 in 1981 and 1989
- Further research pointing to the need for at least 15 cfm per person to help ensure that the concentrations of pollutants pose less risk of significant health effects
- The inappropriateness of distinguishing between smoking and non-smoking buildings given the large number of hazardous indoor pollutants
- Conclusion that demand controlled ventilation based on the levels of an acceptable indicator pollutant is the only reliable performance-based ventilation method

The 1992 nonresidential ventilation requirements can be met through natural or mechanical ventilation. The natural ventilation provisions limit this option to certain building geometrics. The mechanical ventilation requirements establish a minimum ventilation rate as the larger of a table value, in cfm per square foot, or 15 cfm per person. For office buildings, 0.15 cfm per square foot is required. This means that when an occupant density of 100 square feet per occupant is exceeded, the ventilation rate will be 15 cfm per person to reflect the increased need for carbon dioxide dilution.

The standards include provisions or requirements for the following:

- Demand controlled ventilation
- Supply of ventilation on a whole building basis
- Pre-occupancy purge requirements
- System control requirements
- Requirements for supply of air to zonal heat pumps and fan coils
- Completion and balancing requirements

The combined effects of higher ventilation rates and better efficiency requirements resulted in statewide energy savings. The Commission concluded the compliance with nonresidential standards would not lead to a significant increase in outdoor air pollution.

Commission's Strategy for Future Indoor Air Quality Research and Standards Development

Examination of the literature on indoor air quality issues shows substantial uncertainty about not only the best mechanisms for mitigating the problem in buildings, but also the essential elements of the problem being addressed in each situation. The Commission will continue examining these issues as part of the long term plan to assess and update its building efficiency standards as resources become available.

Based on the following key factors, the Commission is best equipped to establish ventilation rates for buildings covered by the energy efficiency standards.

- The need for ventilation, and the extent of ventilation, should be determined from knowledge of the state's energy needs, as well as the magnitude of the indoor pollution problem.
- Ventilation is not aimed at concentrations of single pollutants but at removing whole classes of pollutants.

- The existing health risk assessment process is of limited usefulness in formulating specific numerical requirements for ventilation.

- The Commission, since the first standards were established in 1978, has considered the impacts of its standards on indoor air quality in all of its revisions.

- The Commission is the only agency assigned the task of balancing the impacts of its standards on both indoor and outdoor environments.

- The Commission is able to assess the technological achievability, and cost-effectiveness of its energy conservation standards.

The Commission's work to date includes:

- Air leakage tests on pilot samples of homes built before and after the standards took effect.

- Investigation of potential building elements that can effect indoor air quality and ventilation rates.

- Participation of the Interagency Work Group on Indoor Air Quality, chaired by the Department of Health Services.

- Revision of the minimum ventilation requirements for nonresidential buildings to reflect the latest understanding of the nature of pollution-related health effects.

- Analysis of the potential environmental impacts of compliance with the Commission's standards.

In complying with the statutory requirements of the Warren-Alquist Act, the Commission conducted an assessment of its building standards and indoor air quality during its 1992 revisions to the standards. The Commission concluded that the combined effects of occupant behavior, emission from pollutant sources and heating, ventilating and air-conditioning systems design necessitated substantial revisions to the nonresidential ventilation requirements. The Commission chose not to develop mechanical ventilation requirements for single family homes due to universal use of operable windows in homes.

Future work of the Commission, assuming availability of resources, will include:

- Continued investigation and monitoring of both residential and nonresidential building air exchange rates
- Coordination with DHS, ARB, and federal agencies to develop a more reliable health risk assessment process for addressing indoor pollution problems
- Research, in cooperation with ARB and DHS of the effectiveness of interim pollution reduction measures such as building commissioning and bake-outs
- Further research of ventilation effectiveness in terms of air mixing and the ability to remove the pollutants of most concern
- Continued standards refinement and public education efforts to help building occupants understand the factors affecting indoor air quality

CHAPTER 1

INTRODUCTION

Public Resources Code (PRC), Section 25402, requires the California Energy Commission (Commission) to develop, implement, and periodically update energy efficiency standards for new buildings. AB 4655 (Tanner, 1988) added PRC Section 25402.8, requiring the Commission to examine the effects of the energy efficiency standards on indoor air quality (IAQ). Specifically, this legislation requires the commission to a) consider the potential IAQ impacts of these standards in its standards development process, and b) to complete, by December 31, 1991, a review of current energy efficiency standards to determine whether modifications are needed to reduce the potential for indoor air pollution.

AB 4655 is one of many bills relating to IAQ passed by the California legislature in recent years. Similar legislative requirements have been enacted regarding the efforts of other state agencies such as the California Department of Health Services (DHS) and the California Air Resources Board (ARB). All of these bills resulted from a growing concern among the general populace, the media and legislative bodies over addressing indoor air pollution in an effort to protect the public against the effects of environmental pollutants. These concerns reflect the following factors: 1) a growing number of documented cases of diagnoseable and undiagnoseable health complaints among building occupants, 2) the identification and measurement of significant indoor levels of hazardous air pollutants such as radon gas, asbestos, combustion products and biological contaminants, 3) introduction of an increasing number of potentially hazardous indoor pollutants (mainly organic compounds) into the indoor environment through the use of synthetic building materials, furniture and surface finishing products, and 4) changes in heating, ventilating and conditioning (HVAC) systems design and building operational practices.

This report:

- Summarizes the statutory requirements of the Commission for formulating the state's energy conservation standards

- Discusses indoor pollution in terms of the potential health effects of the most commonly encountered indoor pollutants

- Assesses their potential for health effects at their normal indoor levels

- Summarizes existing regulatory approaches to minimizing such effects

- Presents essential elements of the Commission's energy efficiency standards and assesses their potential to affect the quality of the indoor air

- Presents the Commission's ventilation requirements for buildings covered by the energy efficiency standards along with the history of, and rationale for, these requirements

- Discusses the Commission's plans for improving the existing knowledge on the cost-effectiveness of these standards

- Summarizes the Commission's plans for the future research necessary for more detailed consideration of the indoor pollution problem in future revisions to its standards

CHAPTER 2

THE EVOLUTION OF MODERN ENERGY EFFICIENT BUILDINGS

Modern buildings are designed and constructed according to building codes formulated by several professional organizations. The most widely known of these organizations include the International Conference of Building Officials (ICBO), the Council of American Building Officials International (CABO), and the Southern Building Codes Conference International (SBCCI). The provisions of these codes are intended to safeguard occupant health and safety, provide adequate access for the disabled, and ensure the efficient use of building energy. These codes or their modifications are adopted by regulatory agencies, industry, and design professionals to establish minimum requirements for product quality, building design, construction, maintenance and use.

A supply of fresh outdoor air is necessary in a building to eliminate indoor pollutants, provide needed oxygen, and ensure thermal comfort. This outdoor air can be provided by uncontrolled leakage through cracks, holes, and other passages in the building shell. Because of the variability and unreliability of such uncontrolled air flows, building designers developed mechanical ventilation for residential and commercial buildings. This allowed for evenly controlled building air exchanges, improved air mixing, and the desired degree of air conditioning.

During the 1950's and 60's, developments in the indoor climate control industry led to the introduction of many affordable technologies in the design of HVAC systems. Further sophistications in the technology, together with the abundance of inexpensive energy, afforded flexibility in designing what was considered the most appropriate comfort system for any specific building. The need for more effective building-wide climate controls led to the widespread use of centrally controlled systems to meet the varying thermal loads in the different parts of the building, and the trend towards non-operable windows. The low energy cost of building ventilation allowed for enough dilution air to minimize pollutant levels thereby assuring acceptable indoor air quality.

The energy crisis of the early 1970s led to sharp energy price increases and therefore the need for more efficient use of building energy. Because of the large energy cost of building air conditioning, operators of building climate control systems often minimized, and sometimes eliminated the introduction of outside air into buildings. Additionally, legislative bodies responded with mandates to reduce energy use, often these were implemented by increasing the "air tightness" of buildings to reduce air infiltration. Reduced air infiltration often meant a corresponding reduction in air exchange rate creating the potential for the accumulation of indoor pollution introduced from indoor or outdoor sources. In a parallel effort to reduce building energy use, designers increased the use of variable air volume (VAV) central fan systems for commercial buildings with complex energy requirements. Some of these systems reduced supply air along with ventilation air to zero for spaces that did not have an immediate demand for heating or cooling. This design and operation technique also created a potential for the accumulation of indoor pollution.

Residential buildings historically rely on infiltration air for ventilation. To reduce energy use, building codes minimized these infiltration rates mostly through increased air leakage control measures such as the use of more infiltration-resistant doors and windows and improved weather stripping.

In California, the Warren-Alquist State Energy Resources Conservation and Development Act of 1974 established the California Energy Commission as the central agency for developing and implementing the state's energy policy. With regard to energy conservation in buildings the Warren-Alquist Act requires the Commission to "prescribe by regulation" efficiency requirements that "reduce the wasteful, uneconomic, inefficient, or unnecessary consumption of energy." Specifically, the Commission must develop: 1) mandatory requirements for all new construction, 2) performance requirements for buildings, expressed in annual energy use per square foot, and 3) minimum operating efficiency levels for appliances. In all three cases these standards must be "cost effective, when taken in their entirety, and when amortized over the economic life of the structure when compared to historic practice."

The essential elements of these standards include mandatory and performance-based requirements for thermal performance of building envelopes, reduction in lighting loads, efficiency of building conditioning and water heating systems and ventilation. Some of these requirements could present a potential for affecting the accumulation of indoor pollutants. The most important of these measures are requirements to reduce uncontrolled air leakage and minimum ventilation rates.

CHAPTER 3

HISTORY OF CONCERN OVER INDOOR POLLUTION

Efforts to minimize public exposure to harmful levels of environmental pollutants have traditionally been focused on regulating their emission into the outdoor air. Under the provisions of the Clean Air Act of 1970, for example, enforceable limits were established as air quality standards, by the Environmental Protection Agency (EPA) on outdoor levels of some well known pollutants. These pollutants are called *criteria* pollutants and include sulfur dioxide, carbon monoxide, particulate matter, nitrogen dioxide, and lead. These criteria pollutants were emitted from well known – mostly industrial – outdoor sources. At the time of the Clean Air Act, buildings were mostly regarded as providing shelter from peak levels of outdoor pollution and little attention was paid to the need for specific regulations on indoor pollution. The lesser known pollutants for which no air quality standards have been established are called non-criteria pollutants. The most notable of such pollutants are the toxic trace metals and organic compounds associated with several well known industrial processes.

Based on human and animal studies, the EPA established air quality standards to protect humans from known biological effects of criteria pollutants. Since these pollutants were emitted in relatively larger amounts from well known sources, their environmental levels were viewed as amenable to control through uniform administrative and technological requirements. EPA limits the outdoor levels of non-criteria pollutants by establishing specific limits on their rates of emission from identifiable outdoor sources. This approach has proven successful in minimizing the most readily perceptible signs of the outdoor pollution associated with industrial development.

Since the low energy cost of building ventilation allowed for large air exchange before the energy crisis of the early 1970s, the indoor concentration of most common indoor pollutants were approximately the same as their relatively low outdoor levels. As a result, most indoor air pollution episodes of this period were due to the accumulation of individual pollutants from strong indoor or outdoor sources. The most important of these pollutants are the combustion-related pollutants with perceivable effects at relatively high concentrations – with the notable exception of the non-perceivable carbon monoxide – and the allergy-inducing biological pollutants from identifiable indoor and outdoor sources. Their potential for accumulation remains an important aspect of indoor air quality concern. Such accumulations are minimized through well established practices. As a result, pollutants in this group are normally encountered at low levels in most modern, energy-efficient buildings.

The 1970s energy crisis occurred at a time of increasing introduction of manufactured materials and products that created the potential for their constituent organic compounds to accumulate indoors. Pollutants in this group generally are more reactive than their mostly inorganic counterparts associated with most past indoor pollution episodes. They are more capable of health effects at lower concentrations than the pollutants regulated by health-protective air quality standards. Because of this capacity for effects at low concentrations, the amount of ventilation formerly considered adequate to protect against the biological effects of indoor pollution was found in some cases to be inadequate. In some sensitive individuals, effects could result from exposures too low to produce comparable effects in individuals with normal responses. For both normal responders and sensitive individuals, acute effects may result shortly after high-level exposures or following prolonged exposures at non-perceivable concentrations. These two types of effects are the target of all efforts at minimizing environmental pollution.

Biological Effects of Indoor Air Pollutants

The health and comfort effects of indoor pollutants can result from the biological effects of individual pollutants or the interactive effects of more than one pollutant. Such interactive effects may equal the sum of their individual effects; may be synergistic, in which case the interactive effects would be greater than the sum of the individual effects; or may be potentiating, whereby a pollutant which, though harmless by itself, may enhance the effects of other pollutants. Such interactions may lead to significant health symptoms at concentrations not normally associated with the effects of the individual pollutants. These interactions make it difficult to predict the potential for significant health effects from information about the indoor concentrations of such pollutants.

When exposure occurs at relatively high levels, the biological effects of most common organic and inorganic air pollutants would result from their direct action on the surface of the mucosa in the eyes, nose, throat, skin, and respiratory tract. In most such cases, the resulting symptoms end with the end of exposure and are usually reversible. In most commonly encountered situations, these effects manifest as unwanted sensory effects such as odor perception or sensory irritation. These can trigger other secondary symptoms which in some cases can be magnified in a way that could be life-threatening to the individual in question. While these immediate-onset effects can result from direct surface interactions, any systemic effects of such pollutants (such as liver, kidney, nervous, immune and reproductive system damage) will almost always be produced after their absorption into the body. While in the body, they are metabolized into toxic and non-toxic end products. The toxic end products are responsible for such systemic effects.

In the typical indoor environment, effects from such metabolism most commonly are associated with the reactive organic products from manufactured materials and products. For the most commonly encountered in this group, such effects have been established from animal experiments or human studies involving concentrations considerably higher than those commonly encountered indoors.

Those with the potential for genetic damage have the potential to induce cancer and other serious diseases.

In the case of biological indoor pollutants, such high exposures may produce biological effects through the direct action of their biological toxins, or through the growth and multiplication that constitutes infection. Depending on the exposure level, health symptoms may be produced in normally responding individuals or in individuals who may be sensitive to the effects of such pollutants. At much lower concentrations, exposures of little health consequences to the normal individual may pose a serious health threat to the sensitive individual. Such heightened response may be produced through either immunological (allergic) or non-immunological (non-allergic) sensitivity mechanisms. The allergic reactions are mediated through the immune response, while non-allergic sensitivity is associated with hyper-reactivity that results from increased tissue sensitivity to the pollutant or physical agent. Allergic reactions result from exposure through all common pathways while hyper-reactivity effects usually result from exposure through the respiratory tract and, to a lesser degree, the intestinal tract.

Available evidence shows most allergens as biological agents existing as viable or non-viable entities. Some chemical agents also are capable of eliciting allergic responses. The viable biological allergens include molds, protozoans, algae, and bacteria, while their non-viable counterparts include the fecal pellets of the house-dust mite, insect parts, microbial spores, animal excretions, and pollen. The most commonly encountered of their allergic diseases include allergic rhinitis, bronchial asthma and hypersensitivity pneumonitis. The number of hypersensitive individuals has increased substantially in recent years. Some authors point to indoor pollution as a factor in this increase.

Major Categories of Indoor Pollutants

For ease of mitigation, the main categories of indoor pollutants may be considered separately in the following categories, according to the nature of their major indoor or outdoor sources, as well as the conditions facilitating their indoor accumulation: 1) biological contaminants such as fungi, bacteria, pollen, and viruses, 2) combustion-related products, such as organic and inorganic gases and particulate matte,r 3) natural and man-made fibers, 4) radioactive pollutants, such as naturally occurring radon gas, and 5) the volatile and semi-volatile organic compounds from mostly man-made products.

Biological Contaminants

The indoor biological contaminants of most concern include a wide array of insects, mites, or their body parts and droppings, algae and algal spores, protozoans, molds and their spores and toxins, animal droppings or dander, pollen, bacteria and bacterial spores and toxins, and viruses. According to available information, indoor pollutants in this group are the leading cause of all human health effects in the indoor environment. For them, the potential for symptoms will depend on several factors including level and duration of exposure and individual susceptibility to their biological effects. Their main indoor and outdoor sources are well established along with conditions facilitating their growth and accumulation in the indoor environment.

In modern, energy-efficient buildings, most indoor episodes of biological contamination result from growth and multiplication occurring under conditions of high humidity, elevated temperatures and nutrient availability. Such conditions most commonly are within the air conditioning and humidifying systems in homes, public buildings and offices, food preparation areas and building furnishings. After multiplication, these agents may be spread through the ventilation system to other parts of the building where they may pose a health hazard to building occupants. In some of the cases of contemporary concern – such as those involving the causative agent of Pontiac Fever and Legionnaire's disease – such hazards may involve growth of potentially pathogenic organisms normally existing in the environment at relatively low levels. For infectious agents with human reservoirs, such as causative agents for influenza, chicken pox, measles, pulmonary tuberculosis, and small pox, any disease outbreaks typically not considered building related originate from infected individuals. This concept of building related indoor biological pollution applies to the effects of pathogens that can grow and multiply within the building environment.

As with chemical pollutants, disease outbreaks from such biological contamination are most readily recognized in large office buildings with enough occupants to allow for detection of above-normal cases of illness that establish specific episodes of indoor pollution. In the modern, energy efficient building, the accumulation of most biological contaminants is best minimized by adequate ventilation and adherence to established maintenance and hygienic practices. The lack of information on typical indoor levels of biological contaminants is due mainly to limitations in methods used in isolation and enumeration of the large number and variety of organisms involved. Most developments in this aspect of indoor pollution problems are related to the ability to more accurately associate disease outbreaks with exposure to specific causative agents.

Radon Gas

Radioactive radon (radon-222) is a colorless, odorless chemically inert gas that occurs naturally in rocks and soils from decay of radium-226. Radon is encountered in the outdoor air at levels two to 10 times lower than indoors. It is understood the least among common indoor pollutants because a) its presence cannot be perceived through the senses and can only be detected using complex detection techniques, b) it does not produce any immediate-onset biological effects at any exposure level and its effects would be difficult to associate with specific building occupancies, c) the interactive effects of the physical determinants of its indoor levels are not well understood, and d) the health consequences of long-term exposures at commonly encountered low indoor levels remain debatable although its cancer-causing potential is established for humans exposed at elevated levels.

Since the late 1960s and early 1970s, the probability for indoor accumulation of radon has been known in locations with uranium mill tailings or soils from phosphate mines. Not until the early 1980s were such accumulations considered possible in buildings in regions not having such obvious sources. This discovery served to focus national attention on the indoor radon issue. As a result, the Indoor Radon Abatement Act of 1988 was enacted by Congress establishing a national goal of reducing indoor radon levels to its outdoor levels or below. Biological effects are produced not by radon itself but by the direct effects of its relatively short-lived but biologically active decay products which can be inhaled directly or while attached to airborne particles. Cancer is the only health end-point established for such exposures in all animal and human studies. Smokers also are established to be most at risk from the effects of such exposures.

The primary sources of indoor radon are underlying soil, well water and in some isolated cases, building materials manufactured from radium-bearing rock and minerals. In most cases, accumulation results from migration through cracks and other opening in walls and floors, and is difficult to minimize through ventilation alone. Because of its mostly soil origin, radon may constitute more of an indoor air quality problem in low-rise buildings than multi-story buildings with relatively large building spaces per unit area of underlying soil. Its indoor levels are influenced primarily by amounts in the soil or other sources and by aspects of the building structure that influence its indoor migration rates. Since soil levels vary greatly in differing geologic regions, indoor radon levels vary from one area to the other. This variability points to the ineffectiveness of control through mandatory requirements. Since Radon's decay products exist for only a relatively short period – with a half-life of less than 30 minutes – concentrations of potential health significance cannot be maintained without a radon source.

Because it mainly originates from outside the building, radon accumulation is best minimized by preventing entry from outdoor sources and ensuring effective removal after entry. The EPA works cooperatively with the Department of Energy (DOE) and various state agencies in its continuing effort at identifying the extent of the radon problem and the most effective approaches to reducing the existing or potential health risks in the different geologic regions of the country. Present emphasis is on public education to facilitate the identification of problem buildings. Such identification would allow for control – according to building-specific conditions – to the extent presently practicable.

Between 1988 and 1989, a preliminary California radon survey was conducted by the Department of Health Services, funded primarily by the EPA and ARB, as part of their on-going effort to establish California's radon distribution pattern. Knowledge from such surveys may be used to establish the need for radon mitigation in California's different geologic regions.

Combustion Products

The combustion-related indoor pollutants result from fuel use or smoking and will accumulate when introduced faster than they can be removed from any building. The most important pollutants in this group include most of the criteria pollutants, – carbon monoxide, carbon dioxide, nitrogen dioxide, sulfur dioxide, particulate matter – the gas-phase organic compounds (such as gaseous formaldehyde), polycyclic aromatic hydrocarbons (PAH's), and the unique components of tobacco smoke. When they result from fuel use in such commonly implicated appliances as gas stoves, space heaters, wood stoves, and fireplaces, the potential for accumulation depends on the fuel type, combustion efficiency, usage pattern and most importantly, equipment installation and maintenance. Since such combustion sources are most commonly found in the residential environment, these fuel-related pollutants constitute more of a pollution problem in the home than in the typical office environment. In the absence of major indoor sources, their concentrations will be lower indoors than outdoors where they are emitted from several large industrial sources.

In the present regulatory practice, the accumulation of the fuel-related members of this group is minimized through known requirements for pollutant venting and combustion efficiency. Such accumulation is of relatively little importance in most indoor environments in terms of potential for readily perceivable health effects. For criteria pollutants in this group the present concern is over any perceivable effects of direct exposure in sensitive individuals or significant health effects from prolonged exposures at relatively low indoor levels. The potential for such health effects is not adequately established for such low-level exposures and is part of the information necessary for any future revisions to their outdoor air quality standards. The potential effects of low-level exposure to these pollutants are generally regarded, on mechanistic grounds, as less serious than the potential effects of similar types of exposure to the radioactive radon gas or the relatively reactive, product-related organic pollutants with the potential, in some cases, for the molecular damage that may lead to cancer and other serious diseases.

As noted, most cases of accumulation are associated with improper maintenance and operation. Recent research by state and federal agencies such as the Air Resources Board indicate a higher incidence of improper operation and inadequate maintenance of combustion appliances than previously assumed. ARB has monitored indoor levels of combustion pollutants in residences throughout California. The collected data show many cases where indoor levels of combustion pollutants are higher than levels generally associated with appropriate design, installation, operation and maintenance. ARB concluded that the risk of exposure to hazardous concentrations of combustion pollutants in residential buildings is greater than previously thought and that this risk is mainly due to improper operation and maintenance of combustion appliances.

When combustion pollutants originate from the complex tobacco smoke, they are emitted directly into the indoor environment and are encountered in both residential and office settings. As with other chemical pollutants, perceivable effects may result from the biological effects of direct high-level exposures or the cumulative effects of prolonged low-level exposures with related symptoms produced through biological mechanisms different from those underlying the acute effects of elevated exposures. As with radon, the current concern includes cancer. Some of the other effects are enhancement of microbial infections, sensory irritation, cardiovascular disease, and immune system and neurotoxic effects.

Non-Combustion Particulates

Asbestos, a known human carcinogen, is the non-combustion particle of most concern in the indoor environments of buildings built prior to 1978. For many years, asbestos was used in nearly all aspects of construction. The most common use was for sound proofing, fire proofing, floor coverings, roofing and thermal insulation. The existing hazard is inhaling asbestos fibers from past applications of the material. The main concern over exposure is the possibility of fibrosis or unique types of cancers that can result from the physical presence of asbestos fibers in the respiratory system. Respiration of asbestos fibers can occur if the fibers become airborne. Consequently, existing asbestos applications in original condition, when left intact, do not pose a significant risk of elevated airborne indoor asbestos levels. In cases where asbestos applications have been disturbed, established practices for abatement and/or removal are used. Since asbestos no longer is used in new building construction, releases from automobile clutches and brakes are remaining sources of asbestos fibers. Such releases could contribute to indoor levels of buildings near roadways.

The most widely used insulation and sound proofing materials in buildings today are man-made mineral fibers, principally fiber glass, rock wool and slag wool. High-fired refractory glass also may be found in some specialty applications. Unlike asbestos, airborne fiber glass, rock wool and slag wool have not been determined to cause cancer, mesothelioma or lung disease. While the same types of respiratory tract cancers are conceptually possible with any fiber of appropriate size and durability, they have not been established and on mechanistic grounds, are not likely to occur to any significant degree. The potential is there for skin and eye irritation from direct contact. This can be minimized by following the manufacturers' instructions for safe handling and installation. The potential for facilitating microbial growth may become an issue for any porous or fibrous insulating material if insulation materials become wet and dirty. Proper building and air conditioning system maintenance – cleaning of the coils and regular filter changes – reduce the potential for microbial growth by avoiding the dirt and moisture accumulation promoting such growth.

Organic Compounds from Synthetic Products

Product-related indoor organic pollutants of the most concern occur mainly as volatile or semi-volatile compounds in problem buildings. Their main sources are synthetic building materials, cleaning and maintenance products, furnishings, consumer products, commercial equipment, pesticides, and water – in cases of contaminated water supply. Establishing their typical indoor levels is difficult because each pollutant is encountered in any indoor environment according to the availability of its main sources. The full range is not yet established. However, surveys have identified certain groups most commonly associated with indoor pollution episodes involving the pollutants in this group. These include solvent-related compounds, pesticides, unavoidable by-products of water chlorination, and emissions from insulation materials, and building furnishings. Their acute and chronic effects are produced through different biological mechanisms in the exposed individual. This difference in mechanisms accounts for differences in the approaches for regulating against these two types of effects. As with radon and tobacco smoke, cancer is an important end point of concern regarding long-term exposures at typically low indoor concentrations. Other potential health end points include those associated with the systemic effects of their toxic metabolic end products. The number and variety continues to increase with the mounting array of manufactured products and will be better documented through methods capable of detection at ever decreasing levels.

For these product-related pollutants, indoor accumulation can best be minimized through the combined effects of source modification or elimination – in cases of product-related emissions within the direct control of the individual – and mechanical or natural ventilation. Source modification and elimination can be accomplished through education of users regarding pollutants that exist in various products and regulation of the use of potential pollutants in the product manufacturing process. This approach has reduced the involuntary indoor exposure applicable to some of the most reactive chemical pollutants in this group. The most notable is the sensitizing, highly irritant and potentially carcinogenic (cancer-causing) formaldehyde. In the case of product-related emissions, or emissions related to occupant behavior, accumulation is best minimized by eliminating the activity or following appropriate use directives.

Contemporary Indoor Air Quality Concerns: Manifestations of Indoor Air Quality Problems

Although the accumulation of most common indoor pollutants can best be minimized through specified procedures and practices in the modern, energy-efficient building, pollution episodes from such accumulation remain part of the continuing concern over indoor air quality. Death, for example, is continually possible from short-term exposures to some pollutants in this group. Carbon monoxide is the main culprit. The present concern is not necessarily over the potentially lethal effects of short-term exposure, always recognized by regulators, but related instead to four relatively recent developments: 1) the discovery that elevated radon exposures may be more wide spread in the indoor environment than previously assumed, 2) the discovery of relatively high levels of the cancer-causing asbestos fibers in some buildings with past applications, 3) realization of the large number and variety of toxic, product-related organic compounds that may be encountered in the modern energy-efficient environment, and 4) improved understanding of the potentially serious nature of their cumulative effects on building occupants.

In the case of radon, the potential risk of respiratory cancer has been estimated from human exposures at high concentrations. These study results extrapolated to the low-level exposures associated with the typical indoor environment, point to radon as posing a potentially significant cancer risk to occupants of the modern, energy efficient building. Its status as known human carcinogen heightens the concern over indoor air quality. As with radon, some of the reactive organic pollutants such as benzene and vinyl chloride, are established human carcinogens while others, such as formaldehyde, trichloroethylene, carbon tetrachloride, and chloroform, have been shown to be carcinogenic only in animals. They are therefore classified as suspected human carcinogens. To building occupants exposed over long periods of time, suspected human carcinogens constitute a potential cancer risk. The uniqueness of the cancer process makes it difficult to establish safe exposure levels to minimize concern about carcinogenic pollutants in the environment. Related cancers usually manifest long after the initiating exposures, making it difficult, in cases of indoor pollution, to associate with building occupancy in the precise manner necessary to formulate numerical ventilation requirements.

In addition to the potential for human cancers, the reactive indoor organic pollutants have the potential for non-cancer biological effects responsible for some non-specific feelings of discomfort or the medically established disease entities associated with the occupancy of problem buildings. Their immediate-onset effects which, as previously noted, are associated with high-level exposures in individuals with normal responses, or low-level exposures in hypersensitive individuals, are easier to associate with indoor pollution episodes than the effects resulting only after long-term exposures. In the typical non-industrial indoor environment of the home or office, these immediate-onset effects usually call for immediate mitigation. They presently are classified as building-related illnesses, or tight building syndrome, according to their underlying biological mechanisms. When such symptoms result from heightened chemical sensitivity the individual is said to exhibit the features of multiple chemical sensitivity. All these categories of symptoms contribute to the present indoor pollution problem and difficulty in assessing the health protectiveness of existing ventilation standards.

Building-Related Illness

Building-related illnesses are defined as those medically identifiable and attributable to the biological effects of specific pollutants or factors on specific organs or organ systems. They can be attributed to exposure to chemicals, biological contaminants, or allergens in the building in question. Depending on the causative agent, symptoms may manifest as those of allergic respiratory disease (sinusitis, tracheobronchitis, asthma, hypersensitivity pneumonitis, and humidifier fever), skin disease (irritant, allergic and photodermatitis), irritant syndromes such as those from formaldehyde and carpet shampoo exposure and infections (Legionnaire's disease, Pontiac fever and Q fever). Symptoms may be mild in some cases, but in others, such as those associated with Legionnaire's disease or in cases of chemical hypersensitivity, serious disability or death may result.

The most commonly implicated pollutants include molds, mites, carbon monoxide, oxides of nitrogen, pesticides, formaldehyde, and cigarette smoke. In the most common cases, the onset of health symptoms is associated with the occupancy of new, remodeled, or refurnished buildings with ventilation inadequate for the environmental conditions. Such ventilation inadequacies may be related to a) the introduction of unusually strong sources of the offending pollutant, b) inadequately maintained or operating HVAC systems, c) pollution generating occupant activities such as smoking or hobbies, and d) occupant densities beyond ventilation design assumptions. In general, symptoms end when the offending pollutant is removed. The potential for such symptoms can be minimized in the home or office by adhering to established hygienic, maintenance, ventilation and product use directives. Because symptoms can be induced in sensitive individuals when exposed to low levels of the offending pollutant, protection cannot presently be guaranteed for all building occupants by adhering to such pollution-minimizing practices. See similar discussion under Multiple Chemical Sensitivity.

Tight Building Syndrome

Tight building syndrome, often referred to as "sick building syndrome," represents the series of non-specific, immediate-onset health and comfort effects usually associated with occupancy in problem buildings. In contrast to building-related illnesses, symptoms of tight building syndrome are not those of specific disease entities, hence the designation of "syndrome." Symptoms commonly result from sensory irritation without the involvement of any specific organs or organ systems. The most common include eye, nose, throat, and skin irritation, weak but persistent perceptions of smell, symptoms of neurotoxicity such as mental fatigue, dizziness, headache, difficulty in sleeping, short-term memory loss, anxiety and depression and non-specific hypersensitivity which can manifest as runny nose, or asthma-like symptoms. Several of these types of symptoms may be experienced at the same time.

Unlike building-related illnesses, symptoms of the tight building syndrome typically result not from the action of any one agent or factor in the problem building, but instead are produced by the combined biological effects of physical factors, environmental pollutants and psycho-social stressors, none of which may exceed their generally accepted limits. This usually complicates any attempt at mitigation or predicting the possibility of effects from information on pollutant levels. Common contributing factors include inadequate control of building temperature, humidity, and noise; inadequate lighting; and exposure to volatile and semi-volatile organic compounds, microorganisms, tobacco smoke and emissions from motor vehicles and office machines.

Symptoms of tight building syndrome have been widely reported from case studies in schools, office buildings, apartments, condominiums, mobile homes, and conventional single-family homes. Only a few epidemiological studies have directly addressed the problem. Because such symptoms also are found in around 20 percent of the general population, the potential present extent of tight building syndrome cannot be determined with confidence. Its possible impact on worker productivity and health care costs can be estimated from similar symptoms existing in a similar percentage of office workers in the United States. Given the general difficulty in identifying the offending pollutant in each episode, the tight building syndrome can best be minimized through a) the elimination or reformulation of offending products, b) cessation of contributing occupant activities, and c) adherence to the administrative or maintenance steps necessary to ensure the effectiveness of existing ventilation requirements. Product avoidance or reformulation would best be prioritized using the results of indoor surveys designed to relate pollutant classes to main indoor or outdoor sources. Those related to occupant behavior are best minimized through education.

Multiple Chemical Sensitivity

In addition to building-related illnesses and tight building syndrome, increasing evidence suggests that illness symptoms could occur in some building occupants because of their abnormally high level of sensitivity to the effects of common environmental pollutants. This rather puzzling condition generally associated with tissue hyper-reactivity is referred to as "multiple chemical sensitivity." Its increasing incidence is suggested as accompanying the increasingly wide-spread use of products manufactured with potentially toxic chemical constituents. Available information points to this condition as an acquired disorder usually resulting from prior sensitization to chemicals in the environment. Such sensitization has been reported as possibly due to past high-level exposures or the cumulative effects of prolonged low-level exposures. Many have theorized the syndrome as resulting from varying degrees of damage to the detoxification, immune and nervous systems. The underlying mechanisms are not well understood and must await the results of further studies.

In contrast to tight building syndrome, which is not normally linked to the effects of any one pollutant, symptoms produced in the individual with multiple chemical sensitivity are normally triggered by exposure to specific chemicals. As with the normal allergic sensitivity occurring through well understood biological mechanisms, symptoms could result from exposures at levels generally unable to produce such symptoms in individuals with normal responsiveness to environmental pollutants. Unlike normal sensitivity, these immediate- or delayed-onset symptoms of low-level exposure may differ in the chemically sensitive individual from those that may manifest in the normal individual exposed to higher levels of the same offending chemical. This difference in response is thought by many investigators to be due to differences in the biological mechanisms responsible for both types of sensitivities. Also, unlike normal chemical sensitivity, the same types of symptoms may be induced by exposures to chemicals of differing structural classes and modes of action. Such response may manifest as different symptoms in different individuals. One of the most troubling aspects of the condition is that, after sensitization, symptoms may be triggered in the future by exposure to the same or an ever increasing variety of chemicals and at ever-decreasing levels. Such sensitivity enhancements would further add to the difficulty in protecting against such effects.

In contrast to the tight building syndrome, the biological effects produced in cases of multiple chemical sensitivity usually manifest as multiple symptoms which may be due to effects on one or several organs or organ systems. The most commonly reported symptoms may range from sensory irritation, headaches, mental fatigue, odor complaints, difficulty concentrating, and behavioral changes, to all levels of disability. Attempts to attribute such effects to indoor pollution are usually hampered by the difficulty in identifying the responsible agent as well as the lack of a generally acceptable diagnostic criteria. In spite of these difficulties, multiple chemical sensitivity is gaining increasing recognition as a valid medical condition estimated by some authors to exist, to varying degrees, in approximately 15 percent of the general population. An increase in the size of this sub-group is expected to parallel the continuing increase in the number and variety of synthetic products introduced into society.

Given the unusually low levels of the potentially triggering chemical exposure, and the wide variability in individual sensitivities, available ventilation technology and practices would be inadequate in a modern society to guarantee against the effects of indoor pollutants in the individual with the multiple chemical sensitivity syndrome. Public health agencies and scientific organizations world-wide continually attempt to identify airborne toxic materials, determine their main sources and human health effects and estimate concentrations of these pollutants typically found indoors. Legislation such as the Federal Americans with Disabilities Act (ADA) may apply to chemically sensitive individuals by requiring that people with disabilities be provided reasonable access to buildings. In the context of pollution-related disabilities, this may mean that additional measures would be needed to ensure such access. These measures may be technological, such as using point-source exhaust systems, or administrative, such as prohibiting smoking in buildings and near entrances to buildings.

CHAPTER 4

CONCEPTUAL APPROACHES TO REGULATING INDOOR POLLUTANTS

Environmental pollutants are currently regulated according to their ability to induce cancer or health effects other than cancer. The concepts behind such regulatory approaches can be discussed separately according to assumptions about the biological mechanisms underlying such effects.

Regulating Against Non-Cancer Effects

Since non-cancer health effects are assumed possible from exposures above established effects thresholds, the probability of non-cancer health symptoms can be minimized by limiting exposures below effects thresholds as established from studies in human and animal subjects. When non-carcinogenic pollutants are expected from any source, total exposure is expressed as the sum of background exposures and the potential contribution from the source in question. For criteria pollutants, such projected exposures are compared with established air quality limits to assess the potential for outdoor effects in the projected period of emissions. Without generally accepted methods for obtaining any quantitative estimates of potential for non-cancer health effects, only qualitative estimates can be made for the probability of such effects. When deemed likely from added emissions, more stringent control requirements may be needed. If further reductions are impracticable, corresponding reductions may be required for other sources with similar emissions in the area in question. This constitutes the principle of pollution reduction through offset requirements. This limit-based approach has proven successful in ensuring progressive improvements in outdoor air quality as envisaged at the time of the Clean Air Act.

Although this limit-based and technology-driven approach has been successful for regulating the outdoor levels of the familiar criteria pollutants from established outdoor sources, it is potentially ineffective in the indoor environment because 1) the pollution of concern may be due to occupant behavior not subject to regulation in a modern society, 2) pollutant levels are difficult to predict because they vary over time, and 3) the background levels of most pollutants have not been established for the indoor environment. Further difficulties could result from the lack of health effects information necessary to establish any health-protective limits for the large number of indoor pollutants involved. Even if such information were available for the individual indoor pollutants of the most concern, protection still could not be guaranteed against the poorly understood non-cancer effects of pollutant interactions.

As more is known about these individual and interactive effects, more concern will be expected regarding the health-protectiveness of existing control measures. The continuing challenge is to modify these measures, when deemed appropriate, to the extent commensurate with the magnitude of the non-cancer health risks of concern. This could be followed by educational programs needed to ensure compliance with requisite maintenance and ventilation practices.

Regulating Against Cancer-Inducing Effects

While the non-cancer effects of pollutants may result from chronic chemical exposures above effects thresholds, their cancer-inducing effects are assumed – according to present mechanistic understanding of the carcinogenic process – as possible from every level of exposure to the carcinogen in question. This non-threshold assumption implies that a definite cancer risk would be possible from every exposure to a carcinogen and accounts for the present role of cancer as the most sensitive end point for assessing the acceptability of total human exposure to the mix of carcinogenic and non-carcinogenic pollutants in any environment. When applied to the involuntary exposure associated with the future operation of an outdoor source of such pollutants, this cancer risk-based approach usually leads to stricter pollution control requirements.

The lifetime cancer risk of the average American is estimated as one in four, or 250,000 in a million, and includes the risks of avoidable cancers such as those associated with smoking. Environmental carcinogens are regulated, not by comparison with any established effects thresholds, as with non-carcinogens, but by limiting carcinogenic exposures below levels considered insignificant according to existing criteria. Such determinations are made by using results of the cancer risk assessment process. Because of experimental and iterative limitations in the process, however, the resulting numerical estimates of potential cancer risks are not regarded as the true estimates of the potential cancer risk. They more appropriately represented an upper bound on such potential risks. The true cancer risk would likely be lower or may even be zero. This relative lack of precision generally is recognized as limiting the usefulness of these risk estimates as accurate indicators of potential risk associated with the carcinogen exposure of concern and also points to the need for caution in interpreting results of such assessments or using them to establish numerical ventilation requirements to minimize indoor pollution.

As with outdoor pollution, numerical cancer risk estimates should best be used in the indoor context for 1) identifying and prioritizing pollutants for further studies or control, 2) assessing the relative merits of alternative control strategies, 3) determining the need for or potential extent of controls, and 4) evaluating success of any control efforts. The present heightened concern over environmentally caused cancer stems from the concept of cancer development established in the early cancer study and policy formulation period as a relatively simple process inducible by the finite number of environmental agents with unique capacity for requisite molecular damage. Emerging concepts on cancer causation point to the carcinogenic process as more complicated and also possible from the effects of a larger number and variety of compounds than previously assumed. Cancer-causing effects are recognized as possible from exposure to environmental agents with differing toxicological properties. These different classes of carcinogens also are recognized as capable of influencing the various stages of cancer development. How this influence occurs is not well understood. One important outcome of improved understanding of the carcinogenic process is the recognition of environmental pollution as responsible for a smaller percentage of human cancers than previously was assumed. Because of the generally high human background cancer risk, effective control of additional carcinogens is recognized as an important aspect of the attempt to safeguard human health from the all the effects of environmental pollution.

Numerous building surveys have identified a large number and variety of carcinogenic and potentially carcinogenic components of product-related chemical pollutants in their expected trace amounts. In the majority of cases, this carcinogenic potential was assumed from theoretical considerations without actual validation in animal or human studies. Some authors cite potential cancer risks from their cumulative effects, together with the potential cancer risk from exposure to the few known human carcinogens such as radon, cigarette smoke, and benzene in pointing to the modern, energy-efficient indoor environment as a potential cancer risk to human occupants. Such assumptions further focus the general public's attention on the indoor air quality problem. The continuing challenge is to regulate these environmental carcinogens in a way commensurate with the cancer risk they may pose in each circumstance of concern. This effort is hampered, in the indoor context, by relatively poor understanding of the magnitude of the true cancer risk and the factors influencing the indoor concentration of these and other classes of pollutants.

CHAPTER 5

TECHNOLOGICAL APPROACHES TO REDUCING INDOOR POLLUTION

Even with many factors affecting pollutant concentrations at any given time, the main determinants of their average concentrations remain the same: pollutant concentrations in spaces are determined by the relationship between the source strength and the dilution rate. If the source strength is greater than the dilution rate, pollutant concentration increases. Conversely, if the dilution rate is greater than the source strength, the pollutant concentration decreases. Strategies for effective indoor air pollution control must emphasize both source reduction and dilution through ventilation. Special, interim or situation specific measures such as building bake-outs, building commissioning or source-specific venting, when implemented appropriately, may serve to achieve acceptable indoor air quality.

The technological determinants of source reduction and elimination, dilution and special measures, are discussed separately. Individual measures implemented with respect to any one aspect of this pollution-reducing effort also will influence the others. For example, introduction of office partitions may affect pollutant sources in a space, but the partition's physical configuration may affect the ventilation system's efficiency as well. Point-specific venting of pollutants may compromise the effectiveness of ventilation in other areas in the building. Individual measures that address either source control, dilution or special measures interact with other aspects of the pollutant control effort to determine the pollution level.

Control of Pollutant Sources

Generally, source control strategies aim at limiting the number and type of sources of the pollutant or groups of pollutants in question. Both ARB and DHS generally recommend source control or pollutant removal as most cost-effective in reducing the potential for indoor pollutant accumulation in cases of readily identifiable sources. Such emission avoidance decreases the need for more costly dilution or other removal measures. Source control can be achieved through four main strategies: 1) Specifying building materials, surface finishes and furniture to minimize the potential for emissions, 2) modifying pollution-generating occupant behavior, 3) ensuring proper building system operation and maintenance, and 4) taking adequate precautions to minimize pollutant emissions during construction in occupied buildings. Each of these strategies is discussed further.

Building Materials, Surface Finishes and Furniture

Building materials, surface finishes and furniture are primary sources of potentially toxic organic pollutants. These pollutants are usually associated with adhesives and solvents used in the actual manufacturing of these products. Careful specification of all materials as to chemical composition and emission limits effectively minimizes the amount of point-source indoor pollution. The widespread use of proprietary processes and chemicals means that little information may be available on the chemical constituents of many of these products. Many voluntary emission standards such as the EPA's carpet emission guidelines are available, with increasing numbers of manufacturers electing to conform to these guidelines and publish emission specifications for their products. As more information about product emissions becomes available, designers will have more options for specifying low-emission products.

Occupant Activity

Tobacco smoke is the most notable source of indoor pollutants related to occupant behavior. Tobacco smoke consists of a large variety of pollutants from several classes of pollutants including particulates, combustion products, and organic and inorganic compounds. Potential human carcinogens such as formaldehyde and other compounds are also found in tobacco smoke. Residential and nonresidential buildings with smokers typically have higher levels of these tobacco-specific pollutants than other buildings without smokers. Consequently, the elimination of indoor smoking has been established as an effective way to reduce the indoor levels of this important group of pollutants.

Personal grooming products such as hair sprays, perfumes and deodorants also are a source of potentially toxic organic pollutants. Buildings with high occupant densities have a larger potential for accumulation of pollutants from personal grooming products than buildings of low occupant densities. Control measures for these types of pollutants generally should be implemented on a building-specific basis as deemed most appropriate by building management. Although banning obvious pollutant-generating indoor activities reduces the amount of indoor pollution, an effective policy for improving indoor air quality must accommodate the established fact that some level of indoor pollution always is associated with the presence of humans in the building.

Many occupant activities can affect the number and types of pollution sources within a building. The introduction of special processes such as copying, printing, cooking and manufacturing or office processes create emission sources unique to the processes themselves. Use and storage of cleaning and maintenance products also can provide sources of organic pollutants. The actual cleaning processes may also introduce biological contaminants and particulates to other parts of the building.

Although smoking cannot be regulated in homes of individual smokers, some city and county governments have sought to prevent involuntary exposures by prohibiting or severely limiting smoking in public buildings. If this trend continues, it would help further improve the quality of indoor air.

Building Operation and Maintenance

Even if the need for pollution control is properly considered during building design and periods of occupancy, problems with operations and maintenance of the building and its air handling system can develop and create a potential for pollutant accumulation. These problems usually develop over a period of time and may result in the onset of acute health effects. Careful and regular maintenance, is an important aspect of the effort necessary to ensure acceptable indoor air quality.

Maintenance practices such as generalized cleaning, HVAC duct and plenum servicing and ventilation system cleaning are essential for preventing the accumulation of most groups of indoor pollutants. Generalized cleaning, for example, usually helps prevent the build-up of biological contaminants and particulates. In the case of biological contaminants immediate repair and maintenance of broken plumbing fixtures and water leaks will help prevent the moisture buildup that fosters their rapid multiplication.

In many cases, the HVAC system can serve as a source of biological contaminants and particulates. Improperly maintained cooling towers and condensate drain systems can serve as reservoirs for biological contaminants including the causative agents of Legionnaire's disease and Pontiac Fever. Another significant cause of pollutant build up is infrequent replacement of filter systems or inadequate maintenance of air-treatment systems. Contaminant control is complicated by the fact that inadequate humidity control can promote microbial growth anywhere in the building particularly in inaccessible areas such as wall cavities and cracks. Recent studies have pointed to the link between indoor humidity levels, and occupant perception of acceptable indoor air quality. Humidity-related indoor air quality problems are most common in cold climates and regions with high outdoor humidity levels.

Section 5142 of the California Health and Safety Code requires annual maintenance and repair of building HVAC systems. Additionally, this section requires that any building's ventilation system be operated in accordance with the standards in effect at the time of construction. The California Occupational Safety and Health Standards Board and Department of Industrial Relations have the authority to enforce these requirements.

Construction in Occupied Buildings

Construction in occupied buildings presents a unique challenge to the effort to maintain acceptable indoor air quality because of its potential to compromise all other measures related to minimizing pollutant accumulation. Most of the accumulated pollutants usually originate from construction materials and the construction processes. Additionally, if the HVAC system in the affected area is not sealed off from potentially polluted areas, the pollutants generated from such construction may be distributed through the HVAC system to other parts of the building and pose a danger to occupant health. The California Department of Health Services is currently developing guidelines for pollutant reduction during construction in occupied buildings. Compliance with these guidelines should help minimize this aspect of the indoor pollution problem.

Dilution of Pollutants

The initial challenge in developing an adequate building ventilation system is to determine the amount of ventilation air required to dilute pollutants to acceptable levels. Once this ventilation rate is determined, the common assumption is that both ventilation air and building pollutants would be uniformly mixed throughout the building. If the ventilation rate is determined on a space-or room-specific basis, uniform mixing is assumed for the entire space or room. If ventilation is determined on a building wide basis, uniform mixing is assumed for the entire building. Uniform mixing is rarely if ever achieved, however, in residential or nonresidential buildings and is compromised by many building features.

The following sections individually discuss the existing approaches to determining ventilation rates adequate for the typical building as influenced by the physical features of the building and its air handling systems that may affect ventilation effectiveness. The final section provides a comparison of mechanical ventilation and air treatment as effective means of removing pollutants from the building.

Determining Adequate Ventilation Rates

Ideally, the building ventilation necessary to ensure acceptable indoor air quality should be established on the basis of rates required to dilute pollutants below their effects thresholds in all parts of the buildings. Thresholds for non-cancer health effects have been established for only a few of the large number of indoor pollutants. Their emission and dispersion depend on many factors. The most important of these factors include their chemical make-up, the physical characteristics of sources, and the physical features of the building that influence pollutant mixing rates. The influence of these factors on indoor air pollutant levels presently cannot be predicted for any specific building and differ from one building to the other. Until these issues are better understood, the health basis for establishing numerical ventilation requirements will remain unsatisfactory.

Because of the relative predictability of human respiration and metabolism rates, it is possible to roughly predict the production of carbon dioxide in a space if the number of occupants is known. By itself, carbon dioxide is not a hazardous pollutant at normally encountered levels. However, carbon dioxide is a direct by-product of metabolism and therefore an indicator of changing building occupant densities and levels of pollutants related to the presence of building occupants. If carbon dioxide is to be used as the basis for determining the needed level of ventilation air, it is best used in situations with humans as the main source of pollutants of most concern in the building space in question. The concentration of volatile organic compounds also is used in limited situations as an acceptable indicator of indoor pollutant levels. The control of total volatile organic compound concentration alone cannot assure protection against significant effects of other classes of indoor pollutants.

In practice, a carbon dioxide level of 1000 parts per million (1000 ppm) or less is regarded as a rough indicator of the levels of indoor pollution without significant risk to occupant health. To maintain this level, a ventilation requirement of 15 cubic feet per minute (cfm) per person must be maintained at all times the space is occupied. This ventilation rate assumes that the ambient concentration of carbon dioxide in the ventilation air is less than 300 ppm.

Although maintaining acceptable levels of carbon dioxide is useful for controlling pollutants related to metabolism, it is not reliable for controlling pollutants emitted from inanimate sources. Prior to its revision in 1989, earlier versions of Standard 62 of the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) required a minimum of 5 cfm of outdoor air per person. ASHRAE's new requirement of 15 cfm per person, not only increases the dilution rate of carbon dioxide, but also of all pollutants. At the current level of understanding, application of the dilution principle requires the assumption that all sources of pollutants have constant strengths. With this assumption, increasing the ventilation rate from 5 cfm per person to 15 cfm per person will reduce pollutant concentrations by 67 percent. The two main problems with this approach are 1) the relationship between source strength and dilution rate is not well understood, but is generally accepted as highly variable, and 2) the concept of tripling the ventilation rate on the basis of occupant density alone may not prove effective for spaces with low occupant densities and large numbers of pollutant sources. ASHRAE's change from a minimum of 5 cfm per person to 15 cfm per person reflects a general belief that higher dilution rates reduce the potential for the adverse health effects of indoor pollution.

Without an adequate health basis or knowledge of the nature of source strength/dilution rate interactions for establishing specific ventilation air requirements for any building space, building ventilation rates are established according to consensus on environmental acceptability as determined mainly by pollutant, odor and thermal comfort levels. In this context, acceptability is defined in terms of the readily perceivable health and comfort effects of indoor air pollutants from human and nonhuman sources. ASHRAE, in their Standard 62-1989 *Ventilation for Acceptable Indoor Air Quality,* simply specifies higher ventilation rates per person, as high as 70 cfm for some situations. Other national standards, such as those of Denmark, Sweden and The United Kingdom have established higher ventilation rates for buildings with the potential for more pollution from non-human sources of pollutants.

Regardless of the limitations in the current approaches to formulating ventilation requirements, an important consideration in assessing its potential for ensuring acceptable indoor air quality is a ventilation system's effectiveness in providing for uniform pollutant mixing. For any ventilation system which fails to ensure such uniform mixing, a designer should increase ventilation rates accordingly. Because of the difficulty in establishing a reliable measure of mixing effectiveness, the "design effectiveness" of a ventilation system is difficult to determine.

Physical Features of a Space that Affect Ventilation Effectiveness

Many physical features of a building contribute to the effectiveness of its ventilation system. Partitions and other office furnishings can create areas of little air mixing even if the ventilation effectiveness was high prior to installation of these furnishings. If natural ventilation is relied upon, ventilation effectiveness would be influenced by weather conditions as well as the usual physical space features that influence mixing rates. Open space planning may create many unknown mixing-related impacts difficult to factor into the design phase of a building. The indoor air quality impacts of changes in intended building use patterns is an issue of continuing study.

Physical and Operational Features of Ventilation Systems that Affect Ventilation Effectiveness

Ventilation system performance is affected by the type of air distribution system in the building. The two types of central fan-type air distribution systems in common use are constant-volume and variable-air-volume (VAV) systems. The practice throughout California is to use a single central fan-type system to supply air for heating, cooling and ventilation. Constant-volume systems distribute a fixed amount of air throughout the building. This type of system is common in houses and small-to medium-sized commercial buildings. The effectiveness of a constant volume air distribution system is usually influenced by the physical features of the building.

VAV systems varies the amount of air supplied to a space according to its heating or cooling demands. This system, popular in large nonresidential buildings with one central fan system, meets varying heating and cooling loads throughout a building. Spaces with low thermal loads, however, need small amounts of supply air often resulting in low amounts of ventilation air, leading to inadequate ventilation and mixing and the accumulation of "stale" air. In addition to the factors described, uniform mixing also is influenced by the constant changes in the amount of ventilation air. If poorly designed or installed, VAV systems can create inadequate mixing and inadequate dilution. These issues must be carefully considered during the design and construction phases.

Using central fan-type heating/cooling/ventilation systems may pose some mixing-related air quality problems in buildings with many spaces for different uses. In these cases, the required ventilation rate will differ between spaces with different uses. If the ventilation rate is met for the building as a whole, such non-uniform air flows could result in some spaces being ventilated below the standard while other spaces are ventilated more than required. This is especially problematic when strong sources of pollutants are located in under-ventilated spaces. These spaces would require high dilution rates to minimize the potential for pollutant accumulation. The lack of adequate dilution in these spaces may lead to accumulation to potentially hazardous levels.

Applications for Air Treatment Techniques

After pollutants are removed via a ventilation system from any point in a building, two options remain for ensuring their removal from the building. The first is to exhaust all or part of the pollutant-laden air and replace it with fresh, outdoor air. The rate at which this air is exhausted must be high enough to ensure that the new mixture of outside and recirculated air will contain pollutants at levels sufficiently low to ensure continued building-wide dilution. Another option is to treat the pollutant-laden air so that the concentration of pollutants are maintained within acceptable levels.

Air treatment is accomplished by installing filters, electrically driven precipitation equipment, or gaseous contaminant removal equipment in the return-air section of a building's ventilation system. These systems require regular maintenance to ensure long-term performance and reliability. Additionally, each system design must allow for the flexibility necessary to accommodate any changes in the building environment that may be related to the introduction of new types of pollutants or unusually strong sources of pollutants.

ASHRAE Standard 62-1989 specifies an "Indoor Air Quality Procedure" as an alternate means for supplying outside air for dilution. This procedure essentially requires a system of controls and air treatment equipment designed to limit the indoor concentrations of the six criteria pollutants below their federal outdoor air quality standards and to limit the indoor levels of four non-criteria pollutants below "acceptable" levels. Although this procedure establishes a limit-based approach to reducing indoor pollution, it ignores the many other pollutants suspected of contributing to the indoor air quality problem. Furthermore, the lack of accepted standards for assessing the performance of gas-phase contaminant removal equipment, does not allow for comparison of different building air treatment systems.

Special Measures

In addition to source control and dilution measures, some other measures for indoor pollutant reduction are discussed in this section.

Building Bake-Out

Building bake-out is a pollution-reducing procedure ideally performed prior to building occupancy and after completion of all construction, finishing and furniture installation. In this procedure, the building is heated to temperatures between 85 and 100 degrees Fahrenheit for a period of about 48 hours to enhance pollutant emissions from major sources. To ensure maximum flushing or dilution, the ventilation system is operated to supply as much outside air as possible while still maintaining the higher temperatures. Pollutant concentrations are monitored before, during and after the bake-out period. Some health investigators feel that this procedure is most useful for accelerating the emission of organic pollutants from such major indoor sources as building materials, finishes and furniture and would therefore reduce the levels of emissions expected during occupancy.

While conceptually useful for minimizing indoor pollution, results of numerous bake-outs throughout the world are presently inconclusive with regard to their effectiveness in minimizing the potential for future health complaints. These results show that pollutant concentrations may be higher or lower after bake-outs. Surveys of occupants before and after bake-outs indicated that occupants perceive indoor air quality as better after the bake-out. This issue should be further clarified by the results of further studies.

The California Department of Health Services recently began a controlled study of the effectiveness of building bake-outs which includes a number of newly constructed government buildings. This, and future studies should allow for the formulation of an appropriate state bake-out policy.

Building Commissioning

Building bake-out is only one of a series of measures associated with the process of building commissioning. Generally, building commissioning can be defined as a performance-based process in which buildings are designed, constructed and operated to meet specified and verifiable goals. Commissioning is an all-inclusive process that addresses energy savings as well as environmental performance. Environmental performance, assessed in terms of building indoor air quality and comfort, includes the acceptability of other physical determinants of occupant comfort such as lighting, space lay-out and access for people with physical disabilities.

Successful building commissioning in the context of indoor air quality and thermal comfort requires the following steps to be taken during the design phase:

- Specifying materials to identify and minimize pollutant emissions

- Designing ventilation and air treatment system to accomplish specific goals in terms of ventilation rates, pollutant removal capabilities, and thermal comfort

Pre-occupancy measures for building commissioning may include any of the following:

- Allowing for building materials and furniture to "air-out" outdoors prior to installation

- Operating ventilation systems during construction to ensure adequate pollutant removal with as high as 100 percent outside air in some applications

- Performing building bake-outs and subsequent pollutant monitoring to assess the success of the procedure

- Testing and balancing performance of the HVAC and air treatment systems to ensure performance as designed

- Training and educating building occupants, particularly operation and maintenance personnel about how best to minimize indoor pollution

ASHRAE has developed guidelines for HVAC commissioning and preparation of operation and maintenance documentation for building systems. The EPA and most trade and professional organizations such as ASHRAE, the Building Owners and Managers Association and the Association of California Energy Engineers, in their training stress the importance of building commissioning for reducing pollutant accumulation.

Exhaust Ventilation

Source-specific exhaust ventilation can be applied effectively to address any indoor pollution problem associated with the accumulation of pollutants from a specific source. This measure is addressed separately because it consists of both dilution and source control elements. High enough ventilation is necessary to remove or dilute, immediately upon emission, pollutants for an identified source, thereby controlling the contribution from the source to the overall building. The nature of the necessary ventilation system makes it a unique method of source control.

This type of source control/ventilation technology is required by most building codes and has been generally successful in minimizing the accumulation of pollutants from combustion sources. ASHRAE and the Sheet Metal and Air Conditioning Contractors National Association (SMACNA) have developed several standards and guidelines for exhaust ventilation that apply to various commercial and industrial processes.

CHAPTER 6

THE CALIFORNIA ENERGY COMMISSION'S BUILDING ENERGY EFFICIENCY STANDARDS

In accordance with provisions of the Warren-Alquist Act of 1974, the Commission's energy efficiency standards include mandatory measures that apply to both residential and nonresidential buildings. Specific to each group of buildings, residential or nonresidential, are a set of additional requirements based upon allowable energy budgets. The mandatory requirements applying to both types of buildings include air leakage control measures. Many requirements are specific to each type of building, however in terms of IAQ, the main distinction is the mandatory requirement for specific amounts of ventilation.

The Warren-Alquist Act requires the Commission to periodically update these standards to reflect changes in technological developments. Consistent with this requirement, the Commission has revised these standards every two to five years since 1975. For each set of requirements for residential and nonresidential buildings, staff from the Commission's Energy Efficiency Division solicited public opinion, technical guidance and industry recommendations regarding any revisions being considered. Representatives from the local building code enforcement agencies, various building and design trades and environmental interest groups contributed to the revision process.

The energy efficiency standards for residential buildings include measures pertaining to building envelope, HVAC systems, lighting and domestic water heating systems. Many of the mandatory features apply identically to residential and nonresidential buildings. Two features of the standards, related to indoor air quality, are unique to residential buildings and do not apply to nonresidential buildings. The standards for residential buildings do not include mandatory requirements for ventilation. Also, energy recovery ventilation devices are required whenever a continuous infiltration membrane, or wrapped construction, is utilized to meet the prescriptive or performance requirements.

As with residential buildings, the energy efficiency standards for nonresidential buildings contain requirements for insulation, lighting, and HVAC and water heating efficiency. They also include unique features related to indoor air quality. This feature is the requirement for minimum mechanical ventilation rates for all buildings covered by the standards. Also, these standards reference an ASHRAE standard for indoor HVAC design.

Energy Efficiency Standards and Indoor Air Quality

One of the effects of energy efficiency standards nationwide has been to generally increase the amount of thermal insulation used in buildings. Exposure to pollutants resulting directly from insulation is generally minimal since these materials usually are sealed within exterior walls, roofs and floors of buildings. Moisture in walls, roofs and floors does not automatically cause growth of molds and other biological agents in the fiberglass insulation. However, dirt and dust accumulated in the fiberglass will support growth of biological agents if moisture is present.

The energy efficiency standards also require measures intended to reduce uncontrolled air leakage in buildings. The most common method for controlling infiltration is the application of caulk or sealants at all potential points for leakage such as joints formed by wall sill and floors, window frames and studs, and holes associated with electrical wiring and plumbing. Weather stripping or weather seals are also applied at the junction of jambs or frames for doors or operable windows to further control infiltration. Rigid insulation in the walls, homogeneous wall construction without framing and complete building "wrapping" with plastic membranes also provide an excellent means of infiltration control. Buildings incorporating extensive infiltration controls of this nature often are referred to as "tight" buildings.

Materials used in air leakage controls can serve as sources of the organic indoor pollutants discussed previously. However, the main effect of infiltration controls is to reduce the overall outdoor air exchange rate in buildings and thus decrease the rate of dilution or flushing of indoor pollutants. Because of differences in ventilation requirements, the effects of measures to control air leakage are potentially different for residential and nonresidential buildings and are discussed in the following sections.

Residential Buildings

The energy efficiency requirements for residential buildings do not include requirements specifically addressing indoor air pollution. Consequently, the effects of the energy efficiency standards can only be assessed in light of the absence of any specific requirements. The residential standards essentially rely on controlled and uncontrolled passive ventilation to ensure adequate air exchange, and thus pollutant dilution or flushing, in residential buildings. This air exchange occurs by natural ventilation through intentional openings in the building shell such as doors, windows or vents, through air leakage (or infiltration) through holes and cracks in the building envelope, and through uncontrolled air leakage into the HVAC distribution systems. Each of these three passive air exchange phenomena is discussed separately.

The reliability of natural ventilation through openable windows and doors is highly dependent on the behavior of building occupants and weather-related conditions. Not only does adequate natural ventilation require that windows and doors be opened to provide ventilation air, but that building occupants be able to identify instances when the potential for indoor air pollution is elevated, and will therefore require the opening of windows or doors. The weather-related conditions of most significance in this regard include outdoor temperature and wind speed and indoor conditions such as temperature and physical characteristics of the space. Operation of HVAC systems will also contribute to the variability in the rates of natural ventilation.

The second means of passive air exchange in residential buildings is infiltration or air leakage through cracks and gaps in the building envelope. Such leakage most commonly occurs through cracks and openings in and around windows, doors, walls, roofs and floors. It also can occur through cracks and openings in the ducts of central fan-type space heating and cooling equipment. In general, uncontrolled air leakage can lead to considerable energy use in maintaining properly conditioned indoor air. There are many research reports on the effects of air leakage on energy use in residential buildings. According to these reports, energy consumption at a given air leakage rate depends on climatic conditions, the desired interior temperature and the building design.

The third means of air exchange in residential buildings is leakage through duct work in homes with central fan-type heating and air conditioning systems. Approximately 85 percent of California's newly constructed houses have central heating or air conditioning. For this reason, duct leakage is treated as a separate air leakage phenomenon, as the portion of houses without central air handling systems are not subject to this type of air leakage. Leakage through these central systems occurs via duct work fittings in attics and crawl spaces, connections between fan systems and main distribution ducts, connections to plenums and through the central fan equipment. The quality of construction and attention to duct sealing will contribute to the "tightness" of the house.

As with natural ventilation, infiltration is a highly variable means of introducing outside air into a house. The infiltration rate can vary greatly with changing outdoor conditions, the most important of which are temperature, wind speed and direction, and humidity. Also, there is no guarantee that this air will actually mix effectively with the indoor air and thereby assure adequate ventilation in all areas of the building.

The quality of the air in air-tight buildings depends on many factors that influence thermal comfort and pollutant levels. In general, the concentration of indoor pollutants depends mainly on source strength and dilution rate. In the typical residential building, where dilution occurs mostly by natural ventilation through openable windows, doors and duct work, many studies have been conducted to investigate the effects of increased air-tightness on indoor concentration of common pollutants. Generally, in cases of leakage-minimizing measures similar to California's, none of the studies revealed any direct correlation between infiltration controls and increased indoor concentrations of pollutants. Unusually high concentrations of pollutants, in most cases, were associated with emissions from identifiable sources. For example, elevated concentrations of combustion-related pollutants were usually associated with cigarette smoke, the use of unvented heating and cooking appliances, and the use of wood and coal burning stoves and fireplaces. In a few cases of unusual air tightness resulting from the use of a continuous infiltration membrane, the indoor levels of some pollutants were found to be higher than their outdoor levels. In such cases however, the strength of the indoor sources of such pollutants was more important than ventilation rates in determining their indoor levels.

Although increased ventilation is commonly associated with acceptable indoor air quality, such ventilation increases may worsen the quality of indoor air in cases of highly polluted outdoor air, or pollutants with mostly outdoor sources. For example, radon concentrations in homes located on geologic formations with high radon levels will be strongly related to the number, location and size of paths by which the gas can gain entry to the house. Leaky ducts in the vicinity of pollutant sources, such as household chemical stores or automobile garages, can cause potentially harmful pollutants to be pulled into the return air stream and distributed throughout the house.

Nonresidential Buildings

The energy efficiency standards always have included requirements for minimum ventilation requirements for nonresidential buildings. Consequently, the Commission has focused most of its efforts on determining the rates deemed adequate for reducing the potential for indoor pollutant accumulation when such buildings are ventilated as specified. In addition to the requirement for minimum ventilation on a building wide basis, the standards include prescriptive provisions which require the use of variable air volume capabilities in systems which serve multiple thermal zones in the building. These VAV systems, if poorly designed, can result in inadequate mixing of air in some spaces of a building. The factors that influence such multi-zone mixing are not well understood, but this does not mean that VAV systems typical in most large commercial office buildings should be regarded as incapable of maintaining good indoor air quality. These and other systems are designed to maintain ventilation at rates necessary to reduce levels of indoor pollutants to those not associated with their known adverse health effects. The precise ventilation and operational requirements necessary to achieve this goal, for all systems, under all exposure situations, are not well established and are a major focus of continuing research.

CHAPTER 7

THE COMMISSION'S PROCESS FOR DEVELOPING VENTILATION REQUIREMENTS

Essential Precautions in Assessing the Health-Based Need for Revisions to Existing Ventilation Standards

As noted, most indoor pollutants are found in trace amounts in buildings constructed and maintained according to the existing convention and at these levels, generally are difficult to reduce further, through ventilation alone. Any major revisions to existing ventilation standards should therefore be made from an adequate understanding of the magnitude of their true cancer and non-cancer health risks to building occupants. Although it could be argued that every building should be ventilated to the extent possible, without regard to cost, it also is important to recognize the need for a balance between potential health benefits of such increased ventilation and potential effects of outdoor pollution associated with the production of the needed energy. The need for such balance is the principle behind the Commission's approach to establishing its standards for building ventilation.

The Possible Extent of the Pollution-Related Indoor Cancer Problem

Since cancer usually manifests after long-term exposure to a carcinogenic agent, any cancer from indoor pollution likely will result from long-term exposure to indoor carcinogens at their usually low levels of occurrence. One important limitation of the present cancer-risk assessment process is the absence of provisions for differentiating between proven human carcinogens and animal carcinogens in establishing the numerical estimates of the potential cancer risk in question. This means that the potential risk from animal carcinogens is given the same weight as that from the few proven human carcinogens in obtaining their related risk estimates. According to present knowledge, the cancer-causing potential of environmental carcinogens varies widely among species and should be carefully considered in interpreting results of cancer studies. This level of variability further points to the need for caution in interpreting the results of traditional cancer risk assessments as being suitable for determining specific requirements for ventilation with the precision necessary to avoid wasteful use of building-related energy.

Because they are potentially toxic even at low concentrations, only the product-related organic compounds and the radioactive radon are considered capable of significant biological effects at their low levels of occurrence in the typical non-industrial indoor environment. Considering the differences in potential as true human carcinogens, environmental carcinogens should be regulated from a priority list according to the certainty of their establishment as human carcinogens. In the indoor context, priority should be given to the indoor control of such well established indoor carcinogens as radon, asbestos, vinyl chloride and benzene.

As with radon and the other established human carcinogens, cancer is conceptually possible from every exposure to carcinogenic members of toxic organic indoor pollutants that have not been shown to be human carcinogens. Present understanding of the carcinogenic process does not point to exposure to this group of pollutants as posing a significant cancer risk at commonly encountered indoor levels. Their potential cancer risk therefore is not considered sufficient to justify the present cancer-based concern over indoor air pollution. Even if someone wished to further reduce a specific carcinogen's normally low indoor levels, as a way of ensuring further protection against cancer risks, the current cancer risk assessment process is not sophisticated enough to provide an accurate estimate of the risk they pose in the typical indoor environment. Without accurate risk estimates, it is difficult to establish numerical ventilation requirements to control this group of indoor pollutants in a cost-effective manner. Their control should be based on the present principle of minimizing carcinogen exposure to avoid adding to the existing cancer burden, and after considering the broad range of issues that may be affected by selecting specific control strategies. In the indoor context, such minimizing would best be achieved through source control and effective ventilation. The Commission has considered these facts in formulating the most important elements of its ventilation requirements.

The Possible Extent of the Chronic Non-Cancer Effects of Indoor Pollution

As with carcinogenic effects, the systemic non-cancer effects of the toxic organic pollutants are established from long-term studies involving exposures higher than those encountered in the typical non-industrial indoor environment. Since many of these pollutants can produce their effects on the same target organ or tissue, the potential for effects is related to the cumulative action of the large variety and number of pollutants involved. Although such readily detectable effects are possible from high-level exposures, they generally are regarded unlikely on mechanistic and experimental grounds, at their usually low indoor levels of occurrence in the typical indoor environment. This points to the need for caution in citing the potential for chronic, low-level non-cancer effects as the basis for revisions to existing numerical requirements for ventilation. This lack of readily detectible effects should not be interpreted as evidence for a definite lack of the potential for health effects. When appropriate detection methods are established, such effects should be considered in the ventilation formulation process. In the meantime, most control efforts should focus on minimizing the immediate-onset effects readily associated with indoor pollution in the modern energy-efficient building. The need to protect against such perceivable, non-cancer effects is the guiding principle behind establishing existing requirements for ventilation.

Summary and Rationale for Ventilation Requirements as Part of Energy Efficiency Standards

The California Environmental Quality Act (CEQA) requires an Environmental Impact Report (EIR) to determine the potential environmental impacts of any proposed standards and reasonable alternatives. The Commission has prescribed minimum ventilation requirements as part of the building efficiency standards for nonresidential and high-rise residential buildings. The Commission's CEQA reviews of these standards are intended to assess the appropriateness of these requirements.

When developing minimum ventilation requirements, the Commission first examines similar requirements in other sections of the California State Building Code (CSBC) for the building types covered by the efficiency standards. The Commission then considers standards from ASHRAE and other states and nations for applicability along with their health based rationale, relative enforceability and potential impacts on statewide energy use. Resulting ventilation requirements reflect the practicable portions of all standards considered, and requirements reflecting only the Commission's conclusions rather than the requirements of the referenced standards.

The California State Building Code requires all residential buildings to be ventilated either by natural ventilation, through operable windows, doors or other openings in the building's envelope, or mechanical ventilation. The requirements of CSBC for residential ventilation have always exceeded the comparable requirements in all versions of ASHRAE Standard 62. At the time of adoption of the 1992 efficiency standards, these requirements also met or exceeded the requirements of other states.

ASHRAE has recently published an official version of Standard 90.2 "Energy Efficient Design of New Low-Rise Residential Buildings." This standard requires homes to be ventilated according to the requirements of Standard 62-1989. Additionally, this standard recommends installing air infiltration retarders in all climates. ASHRAE requirements exceed the comparable requirements set forth by the Commission in any versions of the California energy efficiency standards. ASHRAE Standard 90.1-1989, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings" is the applicable standard for high-rise residential buildings and contains requirements for ventilation and air leakage control that also refer to ASHRAE Standard 62-1989. The more stringent ventilation requirements of the CSBC, present the potential for public health benefits comparable to similar

ASHRAE requirements. The Commission therefore, is not planning to develop additional ventilation requirements for residential buildings.

The UBC as amended by California requires all nonresidential buildings to either have some means for natural ventilation or to have a mechanical ventilation system capable of supplying at least 5 cfm of outside air per occupant to all occupied spaces. Many scientific studies have demonstrated that at least 15 cfm per occupant is necessary to dilute the mix of indoor pollutants below hazardous levels – see discussion of ventilation standards. ASHRAE Standard 62-1989 reflects this development, setting its minimum mechanical ventilation rate at 15 cfm per occupant. Neither standard, however, addresses the potential for background levels of pollutants from sources that would exist regardless of the number of occupants in a building. Standards of other countries such as Denmark, Sweden and the United Kingdom address this phenomenon by requiring a minimum ventilation rate per unit area of floor space, to be overridden by the occupant-based requirement, if higher.

The ventilation component of the 1992 efficiency standards requires a minimum ventilation rate equal to the larger of 0.15 cfm per square foot of floor area (to account for any permanent sources of pollutants) or 15 cfm per occupant multiplied by the expected number of occupants. For some building types, higher minimum ventilation rates per square foot may be required in situations considered by the Commission to have the potential for more sources of pollutants than normal.

ASHRAE Standard 62-1989 allows an "Indoor Air Quality Procedure" as an alternate means of supplying outside air for dilution. This procedure requires a system of controls and air treatment equipment designed to limit indoor concentrations of the six criteria pollutants below their outdoor air quality standard levels and four non-criteria pollutants below "acceptable" levels. In the context of a building standard, the Indoor Air Quality Procedure requires building department personnel to verify: a) the adequacy of system design to meet the requirements, and b) that the system is installed as designed. The limitations of a system designed under the current ASHRAE indoor air quality procedure may make it inadequate for minimizing the levels of any pollutants that may be added in the future to the list of presently targeted pollutants. Additionally, there currently are no accepted standards for assessing the performance of gas-phase contaminant removal equipment. Without such standards, it would be difficult to compare the effectiveness of different air treatment systems.

Since specifying minimum ventilation rates alone would not guarantee acceptable indoor air quality for all indoor exposure situations, the Commission concluded that performance-based ventilation system designs should be accommodated in the 1992 efficiency standards. These standards allow performance-based systems that vary the amount of outside air, instead of treated recirculated air, to limit pollutants below certain levels. This system, known as a demand-controlled ventilation system, must be used with an indoor air quality sensor approved by the Commission.

ASHRAE Standard 62-1989 and many standards from other nations prescribe operation and maintenance requirements for mechanical ventilation systems. Although the Commission believes that these types of requirements are important, experience has shown that local building department personnel rarely return to conduct building inspections once the building is occupied. By requiring specific system controls together with commissioning, the 1992 efficiency standards should enable enforcement personnel to ensure that the building air handling system will have the capabilities to meet minimum ventilation requirements.

The History of Ventilation Requirements in the Energy Efficiency Standards

Since they first took effect in 1978, the energy efficiency standards have incorporated ventilation requirements for nonresidential buildings. The 1978 ventilation requirements referenced ASHRAE Standard 62-1973, *Natural and Mechanical Ventilation*. Standard 62-1973 provided a table of mechanical ventilation rates per occupant, for a list of important occupancy types. Provisions in both the energy efficiency standards and the referenced portions of Standard 62-1973 for the use of air economizers, air treatment practices, and prohibition of cigarette smoking, allowed for reductions in the required ventilation quantities to as low as 5 cfm per person. The Commission considered these three measures as providing adequate protection against indoor pollution. Research performed during revisions to the 1978 standards indicated that most designers claimed compliance with these provisions, causing most buildings to be ventilated at or near 5 cfm per person.

In 1980, the Commission began to revise its energy efficiency standards. At this time, indoor pollutant levels and personal exposures in office buildings and other occupancies remained poorly characterized. However, the number of documented cases of nonspecific health complaints in office buildings had grown substantially since the implementation of the 1978 nonresidential standards. Some preliminary investigations showed that concentrations of some types of airborne pollutants were much higher indoors than outdoors, even in locations where ambient outdoor air quality were frequently below federal standards. Other studies of nonspecific health complaints in buildings showed that many of the offending pollutants were not specifically targeted in ASHRAE's recommendations for maximum allowable contaminant concentrations for ventilation air and that concentrations of some pollutants were actually below their recommended levels. Additionally, ASHRAE adopted Standard 62-1981, *Ventilation for Acceptable Indoor Air Quality,* a revision to Standard 62-73, as part of their continuing effort to minimize indoor pollutant accumulation.

With such a large body of new information available, the Commission undertook a substantial critique and research project to revise ventilation requirements as part of the "second generation nonresidential standards development" project. The resulting revisions to the standards, phased in between 1985 and 1988, first applied to offices and then to retail and wholesale stores.

The minimum ventilation rates for second generation buildings were 20 cfm per person for offices and 5 cfm per person for stores. Commission staff assumed that stores were more intermittently occupied than offices and that the lower ventilation rates would be adequate. Through new language and specific references to ASHRAE Standard 62-1981 these new ventilation requirements included several provisions that were different from those of the first-generation standards, in addition to changes in the minimum ventilation rates. A summary of these provisions follows.

Systems and Equipment

The second-generation standards, through reference to ASHRAE Standard 62-1981 included: 1) requirements for airflow measurement strategies in mechanical ventilation systems, 2) uniform ventilation requirements throughout occupied spaces, 3) maintenance of acceptable indoor air quality when supply air is reduced, 4) location of outside air inlets and exhaust air outlets to avoid contamination of outside ventilation air with exhaust air, 5) collection of contaminants as close to the source as possible, with direct removal from the space, and 6) specific performance criteria for air cleaning equipment.

Ventilation Systems Capabilities

The second-generation standards reference the ventilation tables of ASHRAE Standard 62-1981 for the minimum required ventilation rates per person. The standards require that ventilation rates listed in the "smoking" column be used for offices and rates listed in the "non-smoking" column, for retail and wholesale stores. In either case, occupant density assumed in determining the total amount of outside air supplied to the space is the larger of the design occupant density and the occupant density listed in the ventilation tables. The second generation standards require load calculations for heating and cooling capacities performed under prescriptive standards, to use ventilation rates calculated according to these requirements. This requirement differs from its first generation equivalent by not setting different ventilation requirements for systems with economizers or systems serving non-smoking buildings.

Recirculation Air

The second-generation standards allow recirculated air to be substituted for all but the larger of 5 cfm per person and the minimum outside air supply determined from the ventilation tables of ASHRAE Standard 62-1981. Similar to ASHRAE Standard 62-1973, this recirculated air must meet specific requirements for acceptability of ventilation air. In instances where this exception is used, treatment of the recirculated air is almost always necessary.

Make-up Air for Local Exhaust

The second-generation standards allow exhaust air for bathrooms or kitchen hoods to be supplied with recirculated air, exhaust air from other spaces - also known as transfer air - or outside air. In any case the total amount of outside air to a building must be the larger of values calculated using the ventilation tables of ASHRAE Standard 62-1981 and the amount necessary to meet all exhaust requirements.

In 1988, the Commission began developing the 1992 energy efficiency standards. At the same time AB 4655 (Tanner) was signed into law, requiring the Commission to conduct a review of its current standards and to consider changes to the standards necessary to improve indoor air quality. Shortly after, in 1989, ASHRAE revised its ventilation standard and published Standard 62-1989 *Ventilation for Acceptable Indoor Air Quality*. Once again the Commission undertook an extensive research project for the purposes of revising the ventilation requirements.

The Commission identified several problems with the first and second generation requirements for ventilation. First, the large differences in the requirements for each occupancy meant that second generation occupancies were built to more stringent ventilation requirements. First generation occupancies potentially had greater risk of indoor pollutant accumulation since these buildings were allowed to use a lower minimum ventilation rate.

Second, both versions of ASHRAE Standard 62 (1973 and 1981), and consequently both first and second generation building standards established 5 cfm per person as the minimum ventilation rate necessary to maintain non-hazardous levels of indoor pollutants as suggested by carbon dioxide levels. Recent research has shown that 15 cfm per person is necessary to achieve this goal (See *Determining Adequate Ventilation Rates* for a discussion of the present role of carbon dioxide as an indicator of the potential for indoor pollution).

Another problem with the first-generation and second-generation standards is the distinction between smoking and non-smoking spaces. Tobacco smoke has been established as a human carcinogen. Cigarette smoke, however, constitutes a relatively small portion of the total concentration of pollutants in indoor environments. The Commission concluded that this smoking-related distinction was inappropriate given the limited knowledge of the single and combined health effects of indoor pollutants and the inability to predict whether or not smoking will be allowed in any given building in the future.

Finally, the combined complexity of two standards, each with different provision for smoking, air treatment and system design, created a difficult standard for local building department personnel to enforce. A building designed as a non-smoking building should ideally remain a non-smoking building, but building departments do not control the activities in a building once an occupancy permit is granted. Air treatment was allowed in place of outside air under both the first-generation and second-generation standards. In this case, standard performance descriptors do not exist for many air treatment technologies, therefore building department personnel cannot assess the adequacy of the air treatment system. In terms of system design, first-generation buildings could be ventilated at reduced rates if air economizers were used. This alternative, however, was not incorporated into the second-generation standards. The Commission concluded that simpler, universally applicable minimum ventilation requirements would accomplish more in terms of reducing the potential for accumulation of indoor pollutants.

The Commission's 1992 energy efficiency standards contain provisions which set specific requirements for outside air ventilation in nonresidential buildings. In keeping with the provisions of ASHRAE Standard 62-1989, the new standards require that all buildings have either natural ventilation meeting specific area and location requirements for outside air or mechanical ventilation meeting minimum quantities and control requirements.

Natural ventilation can only be used in spaces less than 20 feet from an openable wall or roof opening. Openable wall and roof openings must be readily accessible to occupants of the space and have an operable area of at least five percent of the floor space. Because of the nature of the specific language regarding natural ventilation, only a limited number of buildings can comply with the requirements for outside air using natural ventilation.

The provisions for mechanical ventilation require a minimum of 15 cfm per occupant or the value listed in a table, given in cfm per square foot of conditioned floor area. The Commission concluded that certain types of occupancies present a greater potential than others for possible sources of indoor pollutants. These occupancies are identified in Table 23-F of the standards, reproduced below:

Type of Occupancy	Cfm per Square Foot Of Conditioned Floor Area
Auto Repair Workshops	1.50
Barber Shops	0.40
Bars, Cocktail Lounges, and Casinos	1.50
Beauty Shops	0.40
Coin-Operated Dry Cleaning	0.30
Commercial Dry Cleaning	0.45
High-Rise Residential	Per CSBC Section 1205
Hotel Guest Rooms (less than 500 sq. ft.)	30 CFM/Guest Room

Type of Occupancy	Cfm per Square Foot Of Conditioned Floor Area
Hotel Guest Rooms (500 sq. ft. and greater)	0.15
Retail Stores	0.20
Smoking Lounges	1.50
All Others	0.15

The requirements for minimum outside air may be met for a building as a whole provided that 1) The air supply to each space, including both ventilation air, recirculated air and air transferred from other spaces, is at least equal to the minimum ventilation quantity calculated above for the occupancy in question, and 2) no unusual sources of indoor air contaminants (potential sources of harmful contaminants) are in the building or any space from which air is transferred. If condition 2) above is not met, then the actual amount of needed ventilation air must be supplied directly to each space.

These standards also contain provisions requiring ventilation systems to have controls that 1) supply ventilation air at all times a space is occupied, 2) operate the ventilation system at least one hour before the building is occupied, 3) prevent the interruption of supply air flow to any space when the space is occupied, and 4) allow the system to be reconfigured to use recirculated air should the ventilation needs of the space become less in the future. Provision 1) contains an exception for demand-controlled ventilation. In this case, an approved indoor air quality sensor may be used to reduce the ventilation rate to as low as 0.15 cfm per square foot of conditioned floor area, provided the pollutant concentration measured by the sensor does not exceed specified limits.

The last major provision for mechanical ventilation systems is the requirement for verifying the capability of any ventilation system to provide the required amount of outside air. This requirement may be met through a complete mechanical system air balance, an outside air measurement by the contractor installing the mechanical system, or the installation of air-flow measurement devices on all ventilation systems.

CHAPTER 8

THE COMMISSION'S STRATEGY FOR INDOOR AIR QUALITY RESEARCH AND STANDARDS DEVELOPMENT

Two specific bills have required the Commission to investigate the effects of the Commission's energy efficiency standards on indoor air quality. AB 191 (Bradley, 1987) required the Commission to conduct a pilot project of field testing of actual residential buildings in order to evaluate the impacts of the standards on energy savings, cost effectiveness and indoor air quality. AB 191 required the Commission to submit a final report of its findings to the Legislature by June 30, 1990. AB 4644 (Tanner, 1988) required the Commission to include in its deliberations regarding energy efficiency standards for all buildings, the potential impact of the standards on indoor air pollution problems. Additionally, AB 4644 required the Commission to review existing building standards and determine if modifications were needed to reduce the potential for indoor air pollution. In conducting this review the Commission was required to: 1) consult with the State Department of Health Services and the State Air Resources Board, and 2) consider the findings of reports completed by the Commission in accordance to AB 191 3) complete the review by December 31, 1991.

In response to AB 191, the Commission contracted with Berkeley Solar Group to study the relationship between occupancy patterns and energy use in California houses built between 1984 and 1988. To evaluate the effects of the energy efficiency standards on indoor air quality, the Commission performed two tasks: 1) conducted on-site monitoring of infiltration and air leakage of 40 houses, and 2) solicited subjective evaluations of indoor air quality from occupants of new California homes. Results of the infiltration tests showed that about one third of the houses monitored did not meet the minimum ventilation rate recommended in ASHRAE 62-1989. However this comparison has only limited value since ASHRAE's recommended ventilation rates apply only to buildings with mechanical ventilation. All the houses surveyed met ASHRAE 62-1989 since all houses were constructed with openable windows in all habitable rooms. (See discussion of energy efficiency standards and indoor air quality in residential buildings.) Results of the mail survey showed that, upon subjective evaluation, 87 percent of the occupants of new California houses consider the indoor air quality in their new houses to be equal or superior to that in their previous houses, while only 3 percent reported that it was worse.

AB 4644 gave the Commission specific statutory authority to consider the impacts of any changes to the standards on indoor air quality. Prior to this legislation, the Commission had performed this assessment as part of its obligation to meet the requirements of the California Environmental Quality Act (CEQA), which requires agencies to consider the environmental impacts of their discretionary activities and to consider alternative measures in cases of potentially significant environmental impacts. At the time of passage of AB 4644 in 1988, the Commission was just beginning its most recent periodic revision of the energy efficiency standards. This coincidence allowed the Commission to meet the statutory requirements for addressing indoor air quality impacts of compliance with its energy efficiency standards as part of the assessments for the environmental impact report for the 1992 revisions to the Commission's standards.

The Commission also completed its review of existing building standards along with their impacts on indoor pollution (required by December 31, 1991 as part of AB 4644) in conjunction with the development of the 1992 energy efficiency standards. Commission staff regularly participated in the activities of the California IAQ Interagency Working Group (IWG) and consulted regularly with staff from the Indoor Air Quality Program (IAQP) of the California Department of Health Services (DHS) and the Research Division of the California Air Resources Board (ARB). The Commission hired two contractors for a total amount of approximately $100,000 to research impacts of these standards on IAQ. The Commission held several public workshops to review research results and to solicit input on proposed revisions to the energy efficiency standards with respect to possible impacts on IAQ.

The Department of Health Services is responsible for assessing the effects of pollutants on public health as well as measures designed to protect public health from exposure to these pollutants. Various sections of the California Health and Safety Code (HSC) require DHS to coordinate all statewide programs with respect to indoor air pollution. DHS carries out these requirements through activities within its Indoor Air Quality Program (IAQP) and Air and Industrial Hygiene Laboratory (IAHL). DHS has no explicit authority for promulgating specific IAQ regulations, however the Health and Safety Code requires DHS to: 1) coordinate work toward assessing and improving IAQ, 2) conduct and coordinate research relating to the causes, effects, extent, prevention, and control of indoor pollution, and 3) make recommendations for regulations based on their research. Additionally, DHS chairs IWG, made up of state, federal and local agency representatives and private organizations involved with the various aspects of the indoor air quality issue. Representatives from these organizations meet at least quarterly to discuss indoor air quality issues, relevant work being performed by each organization and research and implementation needs with regard to IAQ.

The California Air Resources Board (ARB) has the authority to set standards for ambient outdoor air quality standards and motor vehicle emissions. The ARB also oversees implementation of non-vehicular source controls by local Air Pollution Control Districts (APCDs). When the ARB was first established, enabling legislation gave them no specific authority to research and assess indoor air pollutants, however the ARB interpreted its general mandate -to research air pollution, assess the effects of air pollution on human health and to identify areas needing research- as authority to conduct IAQ-related projects. Subsequent Assembly Bill 3343 (Tanner, 1988) required ARB to quantify the contributions of indoor and outdoor pollutant exposures to total human exposure to air pollutants.

AB 4644 requires the Commission to conduct its assessment of the effects of the standards on IAQ in consultation with DHS and ARB. Combined, DHS and ARB have worked co-operatively to identify the most common indoor pollutants and the nature and magnitude of their related health effects. Additionally, both ARB and DHS research mitigation technologies and methodologies for reducing concentrations of and exposures to indoor air pollutants. The Commission's decisions regarding the direction of research and revisions to the energy efficiency standards are made with consideration of the results of the research and studies conducted by these two agencies.

DHS and ARB identified a large number of pollutants commonly found in indoor environments. Although the individual and combined health effects of these pollutants remains poorly characterized, the ever-increasing number and types of these pollutants creates a greater risk of exposure to pollutants indoors. The Commission's energy efficiency standards contain mandatory requirements specifically oriented toward reducing uncontrolled outdoor air leakage in buildings while providing adequate ventilation. Their continued success in ensuring acceptable indoor air quality will depend on their consistent interpretation and effective implementation by local building department personnel.

In some cases, the combined efforts of DHS, ARB and the Commission have resulted in specific changes to the efficiency standards. The most notable example is the limitations on the use of urea formaldehyde foam insulation (UFFI). DHS identified formaldehyde as a hazardous pollutant while the Commission identified UFFI as a strong source of formaldehyde. The Commission then developed strict installation requirements to mitigate the risk of the related indoor concentrations of formaldehyde.

Consistent with the requirements of AB 4644 as well as its own conclusions, the Commission researches any potential links between the energy efficiency standards and indoor air pollution. An initial literature search, performed by ADM Associates, revealed growing incidences of IAQ problems for both residential and nonresidential buildings, but no clear causes or solutions common to all cases. Additional staff research has been oriented towards identifying the factors affecting indoor concentrations of pollutants.

Other research performed by contractors, as well as a large portion of Commission staff work, have targeted the effects of the building standards on the overall air exchange rates in both residential and nonresidential buildings. The Commission contracted with ADM Associates to perform a pilot air exchange study in 30 California houses built prior to 1978. The Commission compared the results of this pilot study with the results of the study performed in houses built between 1984 and 1988. Although the Commission did not conclude that the energy efficiency standards were responsible for reductions in air exchange rate in all cases, comparison of the two sets of results pointed to a potential for reduced air exchange in homes built to new building standards versus comparable older homes.

With respect to nonresidential buildings, the Commission has begun a multi-year Nonresidential Outdoor Air Exchange Project. The purpose of this study is to develop a repeatable protocol for measuring the overall air exchange rate in nonresidential buildings. The protocol established from these studies should be appropriate for further studies on buildings of all sizes and levels of complexity. The Commission plans to contract with private firms to perform air exchange measurements throughout California according to this protocol. The Commission plans to measure 48 buildings by December 1995. Like the two residential air exchange studies, the nonresidential air exchange study will contain equal portions of buildings built both before and after the energy conservation standards took effect.

The Commission's research into indoor air quality issues shows that the science is relatively new, that the issues and potential mitigation alternatives are complex and often poorly understood, and that there are no clear, easy and straightforward solutions to indoor pollution problems that would broadly apply to all classes of buildings. The potentially serious nature of the indoor air pollution problem demands a long-term commitment to information gathering and clarifying research.

The Commission, pending the availability of resources, intends to direct its future research and development efforts towards reducing the potential for the accumulation of indoor pollutants. The Commission also intends to complete its current research projects to more clearly assess the impacts of its standards on air exchange rates in both residential and nonresidential buildings. To continue the work started with the two pilot residential air infiltration studies, further outdoor air exchange measurements will be performed in residential buildings built before and after the effective date of the Commission's standards. The pilot nonresidential outdoor air exchange study should be completed by 1996.

The Commission, pending availability of resources, will continue its standards refinement and public education efforts emphasizing not only ventilation requirements but additional methods and technologies outside the scope of the standards that can reduce the potential for indoor pollution. These efforts should emphasize, but not be limited to, system operation and maintenance, building commissioning, source reduction, occupant activities and innovative design.

Potential avenues for these efforts include, but are not limited to:

- Amendments to the standards to encourage energy efficient air treatment systems, demand controlled ventilation, energy recovery ventilation and direct ventilation of spaces with unusually strong sources of pollutants

- Inclusion of indoor air quality chapters in the Commission's standards compliance manuals for residential and nonresidential buildings

- Facilitating the implementation of California's electricity and natural gas utilities' incentive programs designed to encourage those pollution minimizing procedures and technologies that may not be directly influenced by the Commission's energy efficiency standards

- Institution of outreach programs, such as training and speaking engagements in cooperation with trade and professional organizations involved with design, construction and operation of buildings covered by the Commission's standards

- Providing other publicly available documents dealing with the basic principles for reducing the health risks of exposure to indoor pollutants

The Commission plans to continue working in cooperation with DHS and ARB to better assess IAQ problems as a way of identifying the most cost-effective solutions. Although DHS and ARB have the responsibility for identifying pollutants and their health effects, the three agencies combined should be able to continue identifying sources of those pollutants, prioritize them for reduction and establish the most effective and cost-effective mitigation measures. Through this cooperative effort, the state can help ensure that buildings in California will continue to be constructed in a way that minimizes the health effects of indoor pollution in an energy-efficient manner. Ideally, this will result in continued reductions in the rate of increases in statewide energy use.